TSUNAMI HAZARD AND RISK IN THE MEDITERRANEAN AND IN THE BLACK SEA

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In the Euro-Mediterranean area, including the Marmara Sea and the Black Sea, there is a potential for the occurrence of large tsunamis, as is testified by historical data and is supported by the today's knowledge of the seismotectonic setting of the area. The major sources of the Mediterranean tsunamis are submarine and coastal earthquakes, but also landslides and volcanic activity may generate tsunamis (see Tinti et al., 2001), and further there are recognized instances of tsunami-like perturbations excited by travelling air pressure pulses that are known as meteotsunamis (Montserrat et al., 2006).

The main scope of the paper is to present the state-of- the-art of today's research in tsunamis in the Euro-Mediterranean region, and to delineate future perspectives both in terms of knowledge improvement and in terms of the implementation of measures to mitigate the tsunami effects and to protect the coastal communities. It is noted that after the big tsunami disaster in the Indian Ocean in 2004, populations and governments in the Euro-Mediterranean area have suddenly realized that the region resulted unprotected from tsunamis since no Tsunami Warning System (TWS) was in place at that time. In the following years the TWS in the Pacific was strengthened, and TWS's were created in the Indian Ocean and in the Caribbean Sea. In the same years, the basis was posed for the creation of a TWS also in the Euro-Mediterranean region, which, according to the TWS implementation plan adopted by the ICG/NEAMTWS (IOC-UNESCO), should be fully operational in 2011(se the ICG/NEAMTWS IV Report, 2008). This goal requires joint efforts from the science community and from all the institutional organizations, such as services and agencies and administrators, that are responsible for emergency management and post-disaster resilience policies and in the long-term for setting up integrated strategies of coastal zone management.

This paper outlines the main known sources of tsunamis in the region, the today's state of the monitoring network, the recent progress in numerical modeling of tsunami propagation and of tsunami impact against the coast, the efforts that are being made in the field of vulnerability evaluation and of tsunami risk assessment. But it also stresses the main deficiencies that may hamper the planned implementation of an efficient protection against tsunami attacks. These are mainly related to the difficulties in identifying tsunamigenic seismic faults offshore, to the incomplete knowledge of the tsunami generation mechanism from sources other than earthquakes, to the unsatisfactorily slow progress of the sea-level monitoring network to meet tsunami quick detection requirements, to the lack of organic national and international plans to provide coastal communities of the needed basic tools for their protections, such as tsunami scenarios and tsunami inundation maps. As to the last point, it is emphasized that the efforts to assess tsunami vulnerability and risk are really limited to a few, though very important, spots in the Euro-Mediterranean region, and with different degree of details (e.g. the Messina Straits in Italy, the western Hellenic Arc and Rhodes in Greece, Istanbul and Fethiye in Turkey, Alexandria in Egypt, the Bulgarian Black Sea coast, etc). The merit of having at least enlightened such spots has to be recognized to specific projects that, at national and European level, have been focused on the mitigation of tsunami consequences. The demerit for a not systematic coverage of all the coastal communities at risk is to be ascribed to the lack of sufficient resources and more substantially to the lack of a clearly defined political vision of the problem. Indeed we know that the relevant advancement of the numerical modeling technology along with the continuous enhancement of computing and archiving facilities make it feasible today the creation of large databases of pre-run tsunami propagation and impact scenarios that can be exploited in the frame of the TWS's s in order to assess the effect of a tsunami while is still travelling in the open ocean and before it arrives at the coast with destructive power. This goes together with the great progress made in the algorithms for quick detection of earthquakes and tsunamis. Therefore the big challenge for the next years is to provide the coastal communities and the national and regional TWS's of monitoring systems adequate for the timely detection of the tsunami, and of the databases suitable for the quick evaluation of the tsunami impact.

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THE BLACK SEA: GEOLOGY, ENVIRONMENT AND NATURAL HAZARDS

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Geomorphological characteristics

The Black Sea is one of the largest enclosed seas in the world (4.2x10^5 km^2, the maximum water depth - 2.212 m, the total water volume of 534,000 km^3, drainage basin - 2 million km^2) and 423,000 km^3 volume of anoxic deep water, contaminated with H_2S, below the depth of 150-200 m.
From the physiographic point of view the basin of the Black Sea can be divided into four provinces: shelf (about 29.9% of the total area of the sea), basin slope (27.3%), basin apron (30.6%), and abyssal plain (12.2%) (Fig.1).

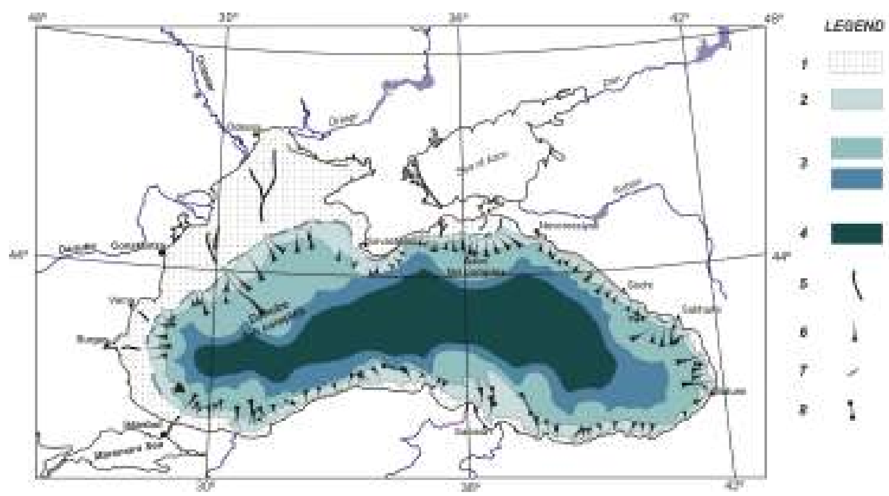

Fig. 1 - Geomorphologic zoning of the Black Sea
Legend; 1, continental shelf; 2, continental slope; 3, basin apron: 3 a - deep sea fan complexes; 3 b - lower apron; 4, deep sea (abyssal) plain; 5, paleo-channels on the continental shelf filled up with Holocene and recent fine grained sediments; 6, main submarine valleys - canyons; 7, paleo-cliffs near the shelf break; 8, fracture zones expressed in the bottom morphology.

For the northwestern Black Sea area one of the most prominent physiographic features is the very large shallow continental shelf (about 25 % of the total area of the sea; less than 200 m water deep).

Geological evolution

Of geological point of view, the Black Sea is located within a complex of high folded mountain chains of the Alpine system, only in the north-west, there are low-standing plateaux and the Danube Delta lowland. Geologists consider the Black Sea a back-arc marginal extensional basin, which originated from the northward subduction of the Neo-Tethys along the southern margin of the Eurasian plate under a Cretaceous-Early Tertiary volcanic arc (Letouzey et al., 1977; Dercourt et al., 1986; Zonenshain and Le Pichon, 1986), as a result of the northward movement of the Arabic plate.

Since about 120 million years ago, the area has been a sea basin, with extremely dynamic development and huge sediment accumulation (up to 13 km thickness of bottom sediment in the central part of the basin).

In the Black Sea, there are two extensional sub-basins with different geological history: the Western Black Sea Basin, which was opened by the rifting of the Moesian Platform some 110 Ma ago (Late Barremian), followed by major subsidence and probable oceanic crust formation about 90 Ma ago (Cenomanian) (Finetti et al., 1988; Görür, 1988), and the Eastern Black Sea Basin, with rifting beginning, probably, in the Late Palaeocene (about 55 Ma ago), and extension and oceanic crust generation in the Middle Eocene (ca.45 Ma ago)(Robinson et al., 1995).

Environmental problematics

Large-scale sea level changes and consequently drastic reshaping of land morphology, large accumulation of sediments in the deep part of the sea and modifications of environmental settings occurred all along the Black Sea geologic history. The Quaternary was especially characterized by very spectacular changes, which have been driven by the global glaciations and deglaciations.

During these changes the Black Sea level behavior was influenced by the restricted connection with the Mediterranean Sea by the Bosphorous – Dardanelles straits. When the general sea level lowered bellow the Bosphorous sill, the further variations of the Black Sea level followed specific regional conditions. One of the main consequences of the lowstands was the interruption of the Mediterranean water into the Black Sea, which became an almost freshwater giant lake.

The main glacial periods of the Quaternary period in Europe (Danube, Günz, Mindel, Riss and Würm) corresponded to the regressive phases of the Black Sea, with lowstands of the water level down to – 120 m. As mentioned above, the regressions represent phases of isolation of the Black Sea from the Mediterranean Sea and the World Ocean. Only the connection with the Caspian Sea could sometimes continue through Manytch valley. During regressions, under fresh water conditions, the particularities of fauna assemblages had a pronounced Caspian character. During interglacial periods, the water level rose to the present level, the sea was reconnected to the Mediterranean Sea, and the environmental conditions, as well as the fauna characteristics, underwent marine Mediterranean influences.

During the Karangatian phase (since 125 ka BP to ~ 65 ka BP) of the Black Sea, which corresponds to the warm Riss-Würm (Mikulinian) interglacial period, the water level exceeded the present-day level by 8 to 12 m. The saline Mediterranean water penetrated through the Bosphorous, and the Black Sea became saline (30 to 37 ‰), with a steno- and euri-haline Mediterranean type fauna (Nevesskaya, 1970). The sea covered the lowlands in the coastal zone. The last Upper Würmian glaciation (Late Valdai, Ostashkovian) corresponds to a very low-stand phase, down to -110 ÷ -130 m. The shoreline moved far away from the present-day position, especially in the north-western part of the Black Sea, and large areas of the continental shelf were exposed. The hydrographic network, especially the large rivers as Palaeo-Danube and Palaeo-Dniepr, incised up to 90 m the exposed areas.

The Neoeuxinian basin, during the glacial maximum (~19 ÷ ~16 ka BP) was completely isolated from the Mediterranean Sea, and, correspondingly, the water became brackish and even fresh (3÷7 ‰ and even less), well oxygenated, without H_2S contamination. The fauna was brackish to fresh water type with Caspian influence.

At about 16 ÷ 15 ka BP the postglacial warming and the ice caps melting started. As the supply of the melting water from the glaciers through the Dniepr and the Dniestr rivers, as well as the Danube river to the Black Sea was very direct and important, the Neoeuxinian sea-level rose very quickly, reaching and overpassing at ~ 12 ka BP the Bosphorous sill altitude. The majority of scientists, who studied the Black Sea, believe that in this phase it was a large fresh-water outflow through the Bosphorous-Dardanelles straits towards the Mediterranean (Aegean) Sea. Kvasov (1975) calculated that the fresh water outflow discharge was of about 190 km^3/year.

At the beginning of the Holocene, some 9-7.5 ka BP, when the Mediterranean and the Black Seas have reached the same level (close to the present day one), the two-way water exchange was established, and the process of transformation of the Black Sea in an anoxic brackish sea started. During the last 3 ka BP, a number of smaller oscillations of the water level have been recorded ("Phanagorian regression", "Nymphaean" transgression, a lowering of 1÷2 m in the X century AD, a slow rising continuing even today).

The northwestern Black Sea receives the discharge of the largest rivers in Black Sea drainage area – the Danube River, with a mean water discharge of about 200 km^3/yr, and the Ukrainian rivers Dniepr, Southern Bug and Dniestr contributing with about 65 km^3/yr.

Presently the Danube influence is predominant for the sedimentation on the northwestern Black Sea shelf area (30-40 million t/yr, of which 10-12 % is sandy material). The other three tributaries of the north-western Black Sea (Dniestr, Dniepr and Southern Bug) are time not significant suppliers of sediments presently because they are discharging their sedimentary load into lagoonal systems.

Marine natural hazards in the Black Sea

The Black Sea coastal zone can be divided in 17 main zones characterized by different geological and morphological characteristics. In a more general approach the Black Sea coast zone could be subdivided into three main morphodynamic categories, with very specific characteristics and behaviour: (1) low, accumulative coasts mostly related to the main rivers mouth zones; (2) erosive coasts within lowstanding plateaux and plains; (3) mountainous coasts, with cliffs, certain number of marine terraces, land slides, sometimes with sandy or gravely beaches.

The coastal erosion will depend on synergetic effect of factors controlling the littoral processes (meteorological regime, wave energy regime, water circulation, sediment supply and drift etc.), global changes and the consequent modification of the energetic level of the coastal sea, general sea level rise and regional characteristics as shoreline morphology, elevation and geologic constitution, subsidence or/ and neotectonic regime, including the anthropogenic factors (littoral structures as breakwaters, dykes, harbours etc.). The low, accumulative coasts are influenced by the global changes, specifically by the sea level changes and by the changes in the river sediment inputs. The decreasing of sediment supply and changes in littoral sediment drift due to anthropic activities (river damming, hydrotechnical regularization, littoral structures etc.), especially when the sandy beaches are low, added to the rising of the sea level and the increasing of littoral sea energy could determine, in certain conditions, a very active and almost continuous recession of the beach line up to 20-30 m/y, as it happens in some sections within the Danube Delta littoral.

Located in the **north-western** of the **continental slope** of the Black Sea the submarine landslides can be challenge by the gas-hydrates dissociation or the collapse of the unconsolidated sediment accumulations. The submarine landslide phenomena and gas hydrates dissociation could be considered an auto-feedback process. As geological hazards, produced by gas hydrates, we mention the decomposition of clatrates or possible violent releases of methane in the water column, downwards 600 m water depth.

Considering that the shelf area of the Northwestern Black Sea basin is very large and bordered by orogenic areas with high tectonic mobility, the water depth are below 20 0 m and the sediment accumulation rates are important, it is obvious that this area is typical for formation of tsunami waves. Recent studies revealed existence of multiple evidence of passage of remarkable waves along the coastal area. Evidences comprise historical documents, instrumental measurements, records on visual observations and geological studies.

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DATA PROCESSING, MODELING AND ASSESSMENT OF TSUNAMIS BETWEEN SOURCE AND TARGET REGIONS; MEDITERRANEAN AND BLACK SEA EXAMPLES

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Earthquakes or earthquake triggered submarine ground failures are main reasons of tsunamis and those are also existent in the Mediterranean, Aegean, Marmara and Black sea in Turkey. The historical records show numerous large earthquakes and some of them have also generated tsunamis.

The most important characteristics of tsunamis are: i) generation mechanisms ii) split and evolution of the wave iii) propagation iv) near field impact v) long distance propagation and far field impact vi) arrival time of the first and maximum wave, vii) shape of the wave front, viii) coastal amplification, inundation, and runup ix) different implications on several types of coastal and marine structures and hydrodynamic conditions x) preparedness and mitigation.

In order to assess the generation, propagation and coastal amplifications of tsunamis, modeling is one of the most essential tools and it is necessary to assess, examine, discuss and develop proper tsunami mitigation measures for the better preparedness against future events.

Tsunami modeling covers i) mathematical description of the problem and initial/boundary conditions with proper approximations and assumptions, ii) solutions of the governing equations with different techniques, iii) simulation, iv) visualization. Beyond these, v) analysis of the results, vi) interpretation of the results and tsunami parameters, vii) understanding of their effects in the inundation zone, and viii) developing the mitigation measures accordingly and viii) using them for educational and public awareness purposes.

The bathymetric and topographic data in digital form available from navigational charts, conventional and multi beam bathymetric measurements, digital elevation models, satellite images must be collected. The digital form of the bathymetry/topography data, obtained from the analysis and conversion of the collected data for the region, are main data sources for tsunami modeling. The database must also be in sufficient resolution, especially nearshore and shallow regions, with sufficient accuracy in horizontal and vertical dimensions.

The distribution of land, coastal and marine structures in the study coastal area must be located in the land use plans and basement maps. Parallel to land use plans the fault maps, possible characteristics of each nearshore or submarine fault or the segments of each fault, submarine/subaerial landslide features must be identified and located on the maps. These maps guide the modeler to determine the boundaries of the study areas to be covered in the tsunami numerical modeling.

It is recommended that the shoreline data used in the model, must fit quite well with the real shoreline. In order to satisfy this requirement, intensive shoreline measurements must be performed and the digital bathy top data must be adjusted accordingly.

The borders of the nested study domains covering nearfield and far field sources in largest domain, and also the coastal area in smallest domain must be selected and the spatial grid size of each domain must be determined. It is suggested that the grid size of largest domain can be maximum 2 arc minute (~3700m) and smallest domain (at the coastal site) can be around 20 m. (suggested) but maximum 50 m is recommended.

The data of initial conditions of tsunami source (i.e., initial fluid displacements and velocity fields) are obtained by using proper computational model(s). These data sets are used in tsunami numerical modeling of propagation and coastal amplification of tsunamis, from the source to the target (shoreline and run-up location). The modeling phase must briefly cover i) tsunami scenarios ii) use of validated and verified tsunami propagation and inundation model(s) iii) simulation and analysis of relevant historical tsunamis, iv) simulation of predefined tsunami scenarios and their analysis, v) tsunami impact micro zoning, vi) inundation mapping for selected coastal regions.
The main deliverables of tsunami simulations are:

- i) Tsunami propagation maps for selected scenarios
- ii) Time histories of water level fluctuations at selected locations near NPP
- iii) Arrival time distributions of first wave along shoreline
- iv) Arrival time distributions of maximum wave along shoreline
- v) Distributions of magnitude and direction of maximum currents
- vi) Distributions of maximum positive amplitudes
- vii) Distributions of maximum negative amplitudes
- viii) Distribution of inundation distances
- ix) Distributions of relative impact forces

The inundation maps providing the information of the estimated hazard zone parameters, such as design flow elevation (DFE) and maximum velocity, related to deterministic and probabilistic tsunami scenarios must be prepared according to the numerical outputs of tsunami modeling. These maps give comparisons of these estimates with one another and with the available manuals and guidelines and also show estimated borders of inundation.
In order to define the probable effects of tsunamis along the inundation areas, the coastal topography with land use plans, showing sensitive and vulnerable regions and structures must be taken into account. Using the probabilistic and/or deterministic approaches and their results on arrival time, maximum positive amplitudes near shoreline, shoreline velocities and estimated run-up and inundation distances, hydrodynamic loads and the potential effects of probable tsunamis must be estimated for the preparedness issues.
By using advanced numerical modeling for visualization, awareness, preparedness and dissemination of the results and making them to be wider applicable, there must be the series of audio-visual products and educational/training materials showing the behavior and possible effects of tsunamis in the region. The main deliverables are:

- i) the database of all processed and produced data,
- ii) illustrative maps,
- iii) visual materials 2 and/or 3D still images and video animations
- iv) Report on the computed maximum positive and negative amplitudes, run-up values, coastal and overland velocities, flow depths, tsunami forces and their estimated frequencies of occurrences and their possible effects.

These effects are 1)impact, 2)erosion, 3)deposition, 4)water level uplift (positive amplitude), 5)subsidence (negative amplitude), 6)flow velocities, 7)duration of water level subsidence 8)approach direction of tsunami.
In this paper, the specific interpretation and physical descriptions of each of the above effects will be described with the examples from the Mediterranean Sea and Black Sea region.
The above procedure is based on deterministic analysis. The probability of occurrence of each tsunami scenario can also be used to describe the modeling results in probabilistic terms.

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SHALLOW GEOPHYSICS ON ROMANIAN BLACK SEA COASTAL AREAS

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Objective: The main objective of the study was the inland geophysical detection of shallow sedimentary deposits that are exposed on the southern half of Romanian Black Sea shore and are supposed to represent traces of past tsunami type marine waves. These formations consist either of shells, especially close to the Romanian-Bulgarian border, or of sand, mainly at the Corbu Bay, north of the town Navodari. The interpretation of such geological evidence, whether they represent storm waves or tsunami waves deposits, might depend on their inland development.
Methods: Magnetics was considered as an appropriate geophysical method for this study, considering the magnetic contrasts that may exist between shells layers and the covering sedimentary deposits (palaeosoil, loess) or between sand layers and intercalations of palaeosoils. Magnetic field and magnetic vertical gradient were measured with 0.1 nT accuracy employing EDA OMNI IV magnetometers on a 5 m interval grids or profiles. A special methodology was tested in the Corbu Bay area, magnetic vertical gradient measurements being taken at different heights, ranging from 0.7 to 3.0 m. The geophysical data were represented as magnetic maps or vertical diagrams of magnetic gradient.
Conclusions: In this stage of the study, the inland development of the Vama Veche buried shells layer was not precisely detected using magnetics. However, the inland location up to 100 m from the shoreline of a sandy deposit, situated immediately beneath the surface, is evident on the magnetic maps. The succession of magnetic highs and lows, parallel to the seashore (Fig. 1), shows that the sand was carried inland by sea water, during strong storms or tsunami type events. The variation of the magnetic vertical gradient with the altitude, observed on several sequences of shallow sedimentary layers proved that this geophysical methodology may be used to detect the inland development of tsunamites, as it is supposed to be the case in the Corbu Bay area (Fig. 2).

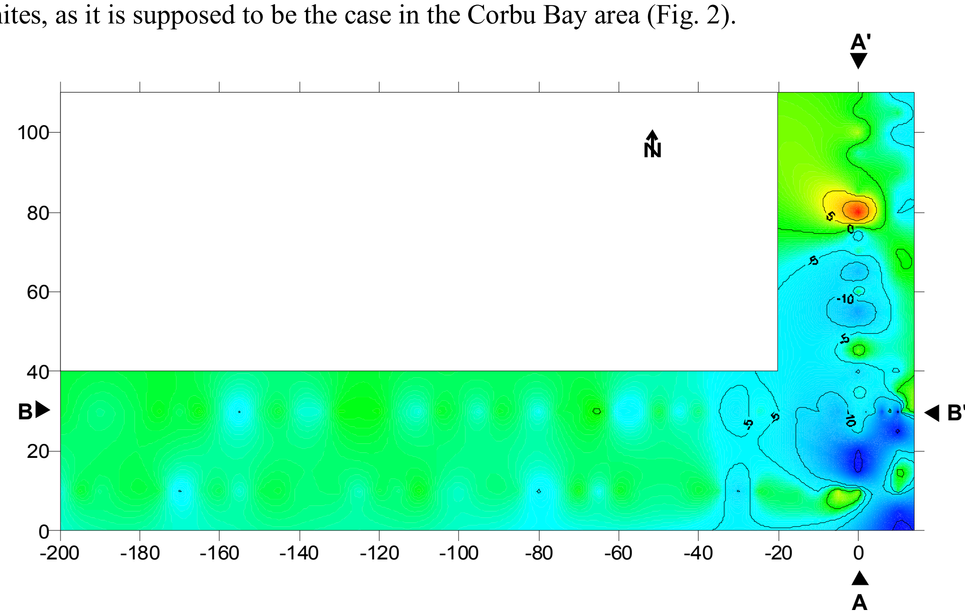

Fig. 1 – Map of magnetic vertical gradient (Vama Veche area)

Fig. 2 – Sand and palaeosoil layers

(Corbu Bay area)

CHARACTERIZATION OF THE TSUNAMIGENIC POTENTIAL OF THE SEISMIC SOURCES LOCATED AROUND THE BLACK SEA AREA

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One of the main objectives of the paper is to characterize the seismicity of the Black Sea area with tsunamigenic potential.
In order to characterize the seismic sources the following elements have been taken into account:
- depth of the earthquakes foci, that allow separation of two major categories: intermediate subcrustal (60-200km) and crustal, normal, (less than 60 km deep);
- development of the earthquakes epicenters in the orogen zone or in platform regions in zones with active tectonics (fault systems);
-establishment of the areas of active faults along which the earthquakes epicenters are aligned;
In absence of a recent tectonic activity the epicenters recorded in the stable zones are considered as the result of a diffuse, accidental seismicity.
The studies on active tectonics have clearly shown the position of the seismic sources (connected to well defined active fault), which do not interfere and do not result in alternatives of other seismotectonic model constructions.
According to the distribution map of earthquakes as well as to the map of the areas with active tectonics, ten seismic sources were established (Fig.1): North Dobrogea (S1), Central and South Dobrogea (S2), Shabla (S3), Istanbul (S4), North Anatolian Fault (S5), Georgia (S6), Novorossjsk (S7), Crimea (S8), West Black Sea Fault (S9) and Mid Black Sea Ridge (S10). The maximum possible magnitude of a seismic source was evaluated according to international practice and IAEA recommendation, either from data of seismotectonics and geological database (the length of the faults, possible apparition on surface, geomorphology, etc), or by applying the method of maxim observed magnitude (intensity).
From the analyses of the fault plain solutions for each seismic source mentioned above, some main conclusions can be drawn:

- the **North Dobrogea** seismic source is characterized by reverse and strike slip fault plain solution in concordance with the known tectonics;
- for the **Central and South Dobrogea** seismic source, we have no information concerning the focal mechanism;
- the **Shabla** seismic source, although it has a tsunamigenic potential; it is poorly documented and we have no seismological information concerning the character of the faults from this area. From the geological and tectonical point of view, the Shabla area is positioned on the intersection between the faults parallel to the Black sea coast (which have a strike slip character with a predominant oblique slip type) and the Intramoesian normal fault;
- the **Istanbu**l seismic source is situated along the intersection between the southern part of the West Black Sea fault and faults associated to the North Anatolian fault. The fault plain solutions highlight a strike slip character of the faults;
- the **North Anatolian Fault** is characterized by a strike slip movement and less than a reverse or oblique character of the faults;
- for the **Georgia** seismic source, there is no seismological information concerning the character of the faults which generate the earthquakes from this area;

- the **Novorossjsk** seismic source**,** is characterized by reverse character of the faults;
- the **Crimea** seismic source, have two distinguished zones, one on the continental part which has a reverse character of the fault and a marine one with a strike slip character;
- For the **West Black Sea Fault** seismic source, we only have two fault plain solutions, which highlight a left lateral strike slip of the fault;
- the **Mid Black Sea Ridge** seismic source has a right lateral strike slip character of this tectonic accident.

From the **seismological** theoretical point of view the earthquakes which are responsible for tsunami are the thrust fault (associated to subduction zones), normal and inverse faults and less strike slip fault (only if the oblique-slip and deep slip components are predominant). So, as a result the possible areas with tsunami-genetic potential are as follows:

A. From perspective of **type of fault plain** solutions:
- **Shabla** seismic source,
- faults associated to **North Anatolian fault** (in western part where are more reverse and normal fault type), and
- **Crimea** seismic source.

B. From the perspective of the **magnitude** of the earthquakes (that is an important criteria in defining tsunamogenic areas: major tsunamis are generated by earthquakes with magnitude more 7.5 on Richter scale, also earthquakes with magnitude between 6.9 and 7.5 could generate tsunami but a small one, with local effects), potential areas are:
- **Shabla** seismic source, with observed magnitude of 7.2 on Richter scale, and possible maximum magnitude of 7.3 on Richter scale, but the limited length of the active faults (of only 25 km) indicate a limited effect of a potential tsunami.
- the **Crimea** seismic source, where even if the length of the faults are relatively higher compared to the Shabla area, the maximum magnitude observed was of 6.5 which indicate a potential tsunami genetic area but with local effects.

C. The third criteria to describe a tsunami genetic area is the depth of the earthquakes. The seismic events with a shallow depth (less than 20 km) are most likely to generate tsunamis then crustal earthquakes located less then 40 km deep. The defined areas are:
- **Shabla** seismic source, where the average focal depth is around 14 km
- **Crimea s**eismic source, where the average focal depth is around 17 km

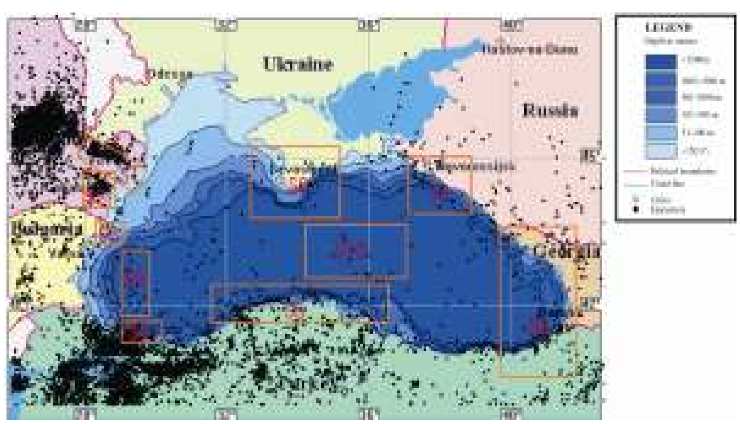

Fig.1. Distribution of the earthquakes with magnitude more than 2 on Richter scale, along the Black Sea area.

POSSIBLE TSUNAGEMIC SEDIMENTARY DEPOSITS REVEALED BY GEOELECTRICAL METHODS

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Keywords: instrumental measurements, geoelectrical sections, vertical electrical sounding

The presence around the Black Sea basin of important seismic activities, the existence of documented gas-hydrates deposits and submarine landslides represent certain tsunami - triggering mechanisms.
Holocene geological formations, located along the western Black Sea coast, support the idea that the mentioned coastal area could have been affected by possible tsunami events during the last centuries (Ranguelov, 2003; Oaie et al, 2007).
Recent outcrop geological investigations, based on visual descriptions, laboratory analyses and instrumental measurements, showed irregular sandy and/or shelly layers, rich in pebbles elements, poor sorted, with a microfauna mixture originated from marine, brackish and lacustrine species (Oaie et al., 2006).
The presence of the various layers, including the possibly tsunami generated ones, was well underlined by the obvious resistivity contrasts detected by the use of continuous current geoelectrical methods.
Vertical electrical sounding (VES) was performed in two geoelectrical profiles in the Vama Veche area, close to the Romanian – Bulgarian border, by using a Schlumberger array with following parameters: AB/2 max = 23m, MN = 0,5m , step AB/2 of 0,5-1m. A numerical procedure was applied for inversion of obtained data.
Five geological strata were identified on the geoelectrical sections on the basis of net resistivity contrasts. The superficial layer is formed by a 2 m thick soil, with resistivity of 7 – 35 Ohmm. The following one, which is interpreted as a possible tsunami - generated layer, has a thickness of about 1.00 m (associated resistivity being of 25 Ohmm). Downwards, the following layer consists of 1 m thick clay (resistivity of de 10 Ohmm), while the bottom one being represented by compact limestone about 5 m thick (150 Ohmm). The uppermost part of the limestone is saturated with saline water, the resistivity varying between 30 – 40 Ohmm.
Vertical electrical sounding (VES) results, cumulated with field geological observations, pointed out the continuity of a sedimentary layer, interpreted as a result of a possible tsunami marine events, which extends inland on more than 100 m.
The use of geoelectrical methods, as presented in the present paper, proved their usefulness to geological studies, specifically in determination of flag layer continuity.

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DUAL-ENERGY COMPUTED TOMOGRAPHY AND DIGITAL RADIOGRAPHY: VALUABLE METHODS IN INVESTIGATING UNCONSOLIDATED SEDIMENTS

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Keywords: X-ray, computed tomography, digital radiography, sediments, dual-energy

Among the methods used for a noninvasive study of different specimens of geological interest, the techniques based upon the differential attenuation of X or gamma rays are of special significance as they usually permit to characterize the internal structure of investigated samples with a spatial resolution up to fractions of mm. As the interaction of high energy electromagnetic radiation such as X or gamma rays with matter are described only by means of the Linear Attenuation Coefficient (LAC), the resulted information furnished by these methods are related to the LAC distribution throughout the considered object. As the LAC depends in a rather complex manner on X or gamma ray energy as well as on both density and effective atomic number of sample, to extract quantitative information concerning internal structure and composition of an object is almost impossible by using monoenergetic X or gamma rays.

Sediments, which continuously accumulate on the river beds, lakes as well as on sea and ocean floors, represents a living archive of past geological events and climate as well as of the complex processes related with the water circulation. With very few exceptions, all category of both actual and up to tens of Ma old sediments are unconsolidated that needs special methods of collecting and study. As an important amount of information is contained in sediments stratigraphy, investigation of undisturbed sediments is of major importance and from this point of view, nondestructive methods such as classical and digital radiography or computed tomography are some the most suitable.

For this reason, as a result of a fruitful partnership between Accent Pro 2000 ltd Company, National Institute of Geoecology and Marine Geology and the Department of Atomic and Nuclear Physics of the University of Bucharest, a dedicate on-board dual energy computer tomograph able to generate both tomographic and digital radiographic images of unconsolidated sediments cores with a diameter up to 12 cm and a height up to 1 ma was designed, built and commissioned. In order to obtain simultaneously not only digital radiographs or computed tomographic images but also numerical values of local density and effective atomic number values of unconsolidated sediment cores, the instrument can work in both single and dual-energy mode. Moreover, to obtain digital radiographies of tomographic images in real time, the instrument can be used an-board of the R/V Mare Nigrum, of any oceanographic research vessel with minimum adaptations as well on stationary laboratory, provided with an adequate protection against hard X-rays.

The tomograph is provided with a single X-ray tube with maximum anodic potential of 160 kV and two set of 200 in-line X-ray detectors separated by a copper shield which allowed obtaining tomographic as well as digital radiographic images depicting the distribution of both density and effective atomic number within investigated objects. In tomographic mode, the spatial resolution of reconstructed images of LAC is about 0.5 mm while in dual-energy mode, when reconstructed images depict the distribution of densities and effective atomic numbers, the spatial resolution is about 1 to 1.5 mm. The same spatial resolution was obtained also in digital radiographic mode.

By using a set of standard samples with well known values of densities and effective atomic numbers we have estimated the precision in calculating the local values of these parameters to 8.7 % for density and 2% for the effective atomic number.

To check the instrument performances, we have investigated in this way a significant number co cores contained unconsolidated sediments collected from Danube Delta (Sulina Channel Mouth) as well as from the Black Sea Continental Shelf (above and inside the anoxic zone). At the same time, in the case of unconsolidated sediments which are collected by coring, the majority of primary information concerning sediments stratigraphy can be obtained by digital radiography and only in special cases when in is imperiously necessary to obtain more details concerning a 3D structure of core, tomographic method in its variant single or dual can be used.

The digital radiographic images obtained in this way revealed a multitude of details such as the presence of massive muddy layer affected by biotic activity, as burrows (tubes) in vertical position (Fig. 1. I), mud/fine sand (silt) parallel and cross fine laminations affected by biotic activity to the upper part of the core (Fig. 1.II) or sandy to silty layers with unclear limits, affected by biotic activity, and some cracks from the coring process (Fig. 1.III), lithofacieses characteristic for a dynamic interaction between the Danube River water saturated with sediments and sea water that determine a nonstationary deposition.

On contrary, the Black sea sediments present millimetric horizontal laminae of coccolithic ooze and coccolithic mud, undisturbed by biotic activity, typical for an anoxic environment (Figure 1.IV) or an alternation of layers containing *Mytilus galloprovincialis* shell fragments or even entire shells and fine sand (silt) intercalations, with unclear limits, characteristic for the mussel-rich facies, currently found on the Black Sea Shelf at depth between 35 and 60 m (Fig. 1.V).

As digital radiography is based upon digital acquisition of images followed by her digital processing, a supplementary digital filtering in the *k*-space of spatial frequencies can further improve the image quality, by reducing the rounded aspect of core image (Fig. 2). It is worth mentioning that the dual-energy technique was used in both tomographic and digital radiography mode, which, in the last case represents a significant improvement by respect to single energy procedure (Figure 2). In this way it was possible to obtain the effective atomic number histogram which is very helpful in understanding the mineralogy and petrology of investigated sediments (Fig. 2).

In this way, by its performances and by its ability to work on-board, the tomograph could be very useful not only for oceanographic researches but also for any exploratory works performed on open sea.

Acknowledgment

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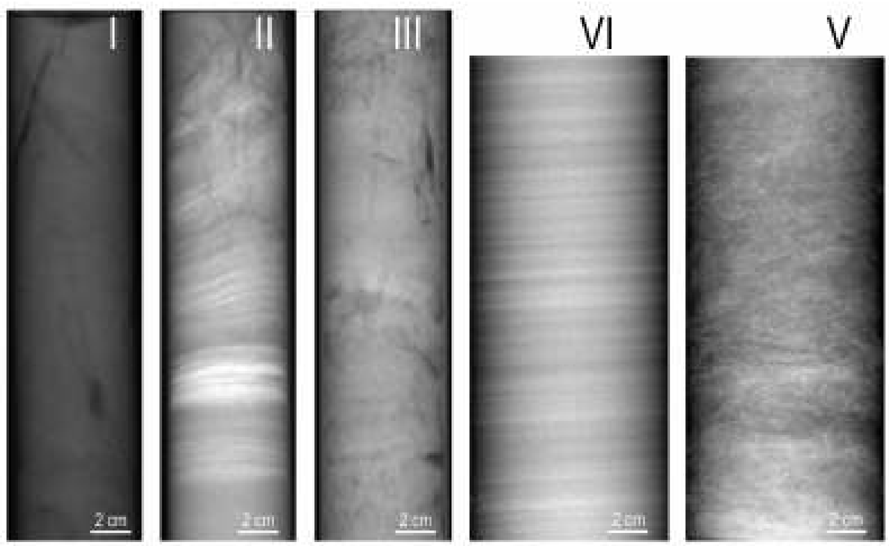

Fig. 1 Five digital radiographs of unconsolidated sediments collected from the Danube Delta Sulina Canal mouth (I to III) and from the Black Sea Continental Shelf (IV and V). The IVth images illustrates with clarity a rhythmic succession of almost horizontal fine laminae, without any trace of bioturbation, specific for the anoxic zone of the Black Sea. The Vth radiograph shows the presence of mussel (*Mytilus galloprovincialis* L.) shells debris alternating with horizontal bedded sand, typical for the *Mytillus* facies which exists between 20 and 40 m depth.

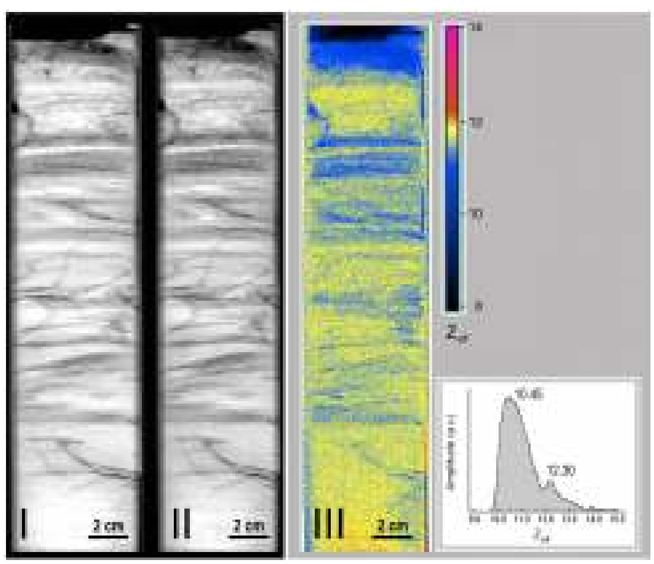

Fig. 2 Three digital radiographs of the same core collected from the Black Sea shelf breack. The left-side picture illustrates the result of high pas filtering in the *K* space such that the final image looks more flat, without the cylindrical characteristic aspect of unfiltered imaged as appeared in previous figure. The right-side picture represents the distribution of effective atomic numbers within the core that indicates the presence of two mineral fractions

TSUNAMIS IN THE BLACK SEA AND SOME RECENT INVESTIGATIONS

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Keywords: tsunamis, Black Sea, recent investigations

The tsunamis in the Black Sea have been observed, described and some of them recorded in more than 25 cases. They are not very well known and popular phenomena. This does not mean that this threat could be neglected. That's why the investigations, data collection, modeling and risk assessment are important topics about this phenomenon. During the last 2-3 decades some progress has been achieved. A lot of data have been collected, many new and sophisticated investigations have been preformed, significant results obtained. Several EU projects have been dedicated to the study of the tsunami hazard and risk to the European coasts. GITEC I and II, TRANFER and SCHEMA – the last two still in development – focused on the tsunami influence in all aspects to the European coasts, including as well as the Black Sea. Several important results have been obtained.

A Black Sea tsunami catalogue has been compiled from all available sources. All events have been assessed in a standard form (GITEC II) including not only the parameters of the main tsunamigenic events, but also reliability of the data collected. A specific point to the Black Sea is that some of the tsunamis have been triggered by the far field earthquakes (for example from Vrancea source and from the North Anatolian fault earthquake in 1939 (M~8.0).

The Black Sea was studied from a point of view of the tsunami energy dissipation/concentration due to the bathymetry and costal geometry. These investigations could explain why all tsunamis observed in the Black Sea had mostly a local influence and most powerful expression to the nearest coast lines.

Some results related to the vulnerability of selected sites have been assessed. This vulnerability refers not only to the man-made structures (port facilities, beaches, tourist infrastructure and cultural heritage, etc.), but also to the natural vulnerable objects – such as steep bays, estuaries, deltas, low lands, lagoons, etc.

The special focus is dedicated to the Bulgarian Black Sea tsunami cases (as most powerful expression of this phenomenon in comparison to all coasts of the Sea). The following cases have been better documented:

- I-st (III?) century BC- multihazards event; earthquake, slides and regional inundation reported by ancient chronicle by Strabo; Tsunami intensity IX-X degree of the Papadopoulos - Imamura (P-I) scale. Paleotsunami deposits discovered 20-30 km to the southwest (near Golden sands resort)
- 543AD-multihazards event; earthquake, slides, local inundation reconstructed using the data of the Cybele temple diggings (2007-2008); Tsunami intensity - VII (P-I) scale
- 31st March, 1901 – multihazard event earthquake, slides, rockfalls, subsidence, local inundation observed; Tsunami intensity - V-VI (P-I) scale
- 7th May, 2007 - event by nonseismic origin, only frequent water level oscillations and some damages observed, a lot of visual data collected; Tsunami intensity - V (P-I) scale

Two important events related to tsunami occurred during 2007:

- The tsunami case of 7th May, 2007 and
- The discovery of the Cybele temple in Balchik (in late April), bringing some new and confirming data about the tsunami of 543 AD event.

Special attention is paid to the multihazard threats to the North Bulgarian Black Sea coast. Earthquakes that can trigger tsunami, landslides, subsidence, soil liquefaction and other secondary effects appear as complex phenomena, which can affect the coastal areas. The simultaneous action of

such events (which can occur in case of a strong earthquake) can complicate extremely the emergency actions and population safety.
The recent investigations include some models (together with the team of the University of Bologna) of the tsunami sources, wave propagation and virtual tide gauge records. They help in the modern approach of solving the problem of the tsunami energy dissipation/concentration in different direction of the sea. Landslide models have been developed to explain the last case of the observed tsunami in the sea – 7th May, 2007. Several other sources have been modeled and wave propagation studied.
The last EU projects (TRANSFER and SCHEMA) are both focused on the data base creation of the main tsunamigenic sources of the sea (of seismic and non seismic origin) as well as the vulnerability elements and population. The preliminary tsunami zonation of the Black Sea is in the near future tasks. The data collection about the vulnerable elements on the shore line is under execution. The measures of protection of the infrastructure and people lives will be next steps of decreasing the tsunami risk in the region. The establishment of the evacuation roads, the Early Warning System effectiveness assessment, the different physical and virtual (planning, education, etc.) protective measures are in progress.

THE GEOLOGICAL STRUCTURE OF IN THE NORTH-WESTERN BLACK SEA AREA

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Key words: Dobrogea, Scythian Platform, Moesian Platform, North Dobrogea orogen

The structural units in the circum Black Sea area are represented by largely E-W oriented orogenic belts and platforms separated by major faults. The major structural units of the north-western Black Sea area, lying in front of the East Carpathians bend zone, include: the Predobrogea Depression superimposed on the Scythian Platform, the North Dobrogea Orogen and the Moesian Platform, all separated by major faults trending WNW-ESE. The main faults in the area of Dobrogea, as well as the seismic activity in historical times along them is presented, based on a review of the geological, structural and seismological data.

The Sf. Gheorghe Fault separates the Paleozoic Scythian Platform from the Cimmerian belt of North Dobrogea, a narrow, short lived Early Alpine belt with Hercynian deformed basement and Triassic – Jurassic sedimentation and deformation.

The Peceneaga-Camena Fault, separating the North Dobrogea Orogen from the Moesian Platform to the south, is a major crustal scale fault affecting both Conrad and Moho discontinuities. With a complex and protracted tectonic activity in the Mesozoic and Cenozoic as indicated by paleostress and geological evidence, the Peceneaga-Camena Fault is still active in Dobrogea as indicated by seismological data. The Capidava-Ovidiu Fault is a major discontinuity within the East Moesian Platform, separating between two main tectonic blocks, Central and South Dobrogea. A system of WNW-ESE faults parallels the Capidava-Ovidiu Fault in both tectonic blocks of East Moesian Platform. The Intramoesian Fault represents the separation between the East Moesian and West Moesian parts of the platform, with distinct Paleozoic basement history.

The main seismogenic zones from the southern part of Romania are represented by the Predobrogea Depression and the Intramoesian Fault (active in extensional regime) and the Vrancea zone (active in compressional regime). Seismological data indicate that several types of earthquakes occurred in the area of Dobrogea, mentioned in historical documents with the following local names (Radulian et al., 2000): the Pontic earthquakes, with their focus along the Black Sea shore, in the area Constanța-Mangalia-Cavarna-Balcic-Shabla; prebalkanic earthquakes, with focus in Dulovo area (along Kemanlar-Ruslar line) (south Dobrogea); Cimmerian earthquakes, with focus along the Topolog – Cogealac seismic line. Several other lines of seismic instability are active largely during earthquakes occurring in the eastern part of Romania: the Tulcea-Isaccea line (an eastward prolongation of the Galați-Pechea line), the Brăila-Măcin-Cerna line (also active during the Pontic earthquakes), the Babadag line, the Cernavodă-Medgidia line (sensitive during the prebalcanic earthquakes).

According to the measurements within the seismic network of the National Institute of Earth Physics, the distribution of epicenters of local earthquakes (occurring during 1900-2002 in the area of the Moesian Platform) concentrate along the Peceneaga-Camena and Capidava-Ovidiu Faults and along some faults parallel to the latter.

Investigations in the area between the Peceneaga-Camena and Intramoesian Fault suggested that the convergent NW movement of the Black Sea microplate is still active (Airinei, 1977; Constantinescu & Enescu, 1984; Enescu & Enescu, 1993), being accommodated by slip along the Peceneaga-Camena and Intramoesian Faults. Recent investigations (Radulian et al., 2000) partly confirm this hypothesis.

Consequently, these major faults, as well as the seismic instability lines presented above represent a tectonic hazard for the NW Black Sea area.

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MARINE NATURAL HAZARD: NEW DATA ABOUT TSUNAMI PHENOMENA ALONG THE ROMANIAN BLACK SEA COAST

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Keywords: marine hazard, tsunami, coquina bed, microfossils

Limited by active fault systems and showing a high regional seismicity, the Black Sea basin represents a suitable area for the occurrence of natural hazards, including the tsunami-type waves. A very large shelf area (150 – 190 km), with low water depths (< 200 m) and low seashore topography make the coastal area, highly vulnerable to possible tsunami phenomena.

The circum-Black Sea countries, as Turkey, Bulgaria, Ukraine, benefit from a large amount of historical evidence and have performed studies focused on the tsunami-type natural hazard. The same data (recordings of extreme natural events) in Romania, as well as the tsunami phenomenon, has been poorly documented. The present paper is bringing important information that covers the lacks in this area.

The largest part of the Quaternary sediments, along the Romanian Black Sea shore, belongs to the Danube Delta complex. This complex is superimposed on three main tectonic units, represented, from north to south, by: the Scythian Platform (overlain by the Danube Delta fluvial and lacustrine sediments), the North Dobrogea Cimmerian Orogen and the Moesian Platform (on top of which the Razelm – Sinoe lacustrine complex of the Danube Delta has accumulated).

Three main tectonic units are separated by major faults, some of them crustal-scale faults (like the Peceneaga Camena Fault, separating North Dobrogea Cimmerian Orogen from the Moesian Platform), and geological and geophysical evidence indicates the existence of important faults within the Moesian Platform (Seghedi, 2007). Some of these faults, including the Peceneaga-Camena Fault, prolongate eastward into the Black Sea offshore and show evidence for active seismicity at least along some segments, therefore creating a potential for triggering submarine landslides, as other potential tsunami-type waves mechanism.

The first historical information related to tsunami type anomalous waves in the Black Sea belong to the Byzantine historian Theophanes – in 544/545 AD. The Armenian historian Mowses Khorenatsi (410-491 AD) has mentioned a similar event on the Black Sea southern shore (Altynok, 1999). For the Romanian Black Sea coast the oldest tsunami mention is from the year 104, when the Callatis citadel was affected by high sea waves (Marmureanu, 2005).

Using recent documented information, along the Romanian coast anomalous hydrodynamic events occurred, usually described by eye-witnesses and rarely measured by instruments or mentioned in written documents. In several cases, subsequently to their occurrence, such events are documented by visual or instrumental measurements, but their causes are difficult to interpret.

A summary of these observations (Oaie et al., 2006) is presented in the following:

- instrumental observation: 1957/high waves to the entrance in the Sulina canal; August, 1993/floods on the Sulina canal jetties;
- visual observations: May 1958/ floods on jetties situated along the Sulina canal and in the eastern part of the town; December 1960/complete flooding of the canal jetties and of the

meteorological station platform, displacements of jetties rock blocks, sudden and violent displacement of ships anchored in Sulina harbor; August, 1993/floods on the Sulina canal jetties; March and May, 1995/ total flooding of Sahalin Island and floods on the Sulina canal jetties and of the nearby beach.

In all the above mentioned situations, the uprising of water level occurred as solitary waves (?) propagating from south toward north, with heights varying between 1.50 – 2.00 m. The water level increased rapidly and decreased much slower, during several hours.

Recent investigations, along the Romanian Black Sea shoreline, reveal discontinuous occurrences of geological formations with features recorded in "tsunamites".

Geophysical studies (seismology, magnetometry) identified active faults and earthquakes hypocenters in the vicinity of the Black Sea basin, high magnitude seismic events being considered as triggering the tsunami type waves. Since 1826, based on historical written evidence on the Black Sea seismicity, a number of 1435 earthquakes have been recorded. Starting with 1945, the earthquakes were instrumentally recorded, the interpreted hypocenters depths ranging between 10 and 60 km. Most of these events occurred in the northern and northeastern parts of the Black Sea basin.

Geological investigations in the southern part of the Romanian shore (Vama Veche area) revealed a lithological succession consisting, from bottom to top, of compact red clay, with irregular top; 0 - 15 cm – poorly sorted, medium to coarse grained sand, discontinuous on strike; 30 - 50 cm – coquina bed, with matrix almost absent, with irregular base and flat top; 4 m – grey, slightly sandy soil, with vegetal fragments and plant roots. The sand bed and the coquina layer within the succession, both with erosive base, suggest deposition related to an unusual marine environment, which took place before the deposition of the thick loess or loessoid layer. The great thickness of the two beds (together) suggests a significant development landward on more then 100 m (unpublished data).

According to the criteria which discriminate the storm deposits from tsunami type beds, the described strata seem to be the result of tsunami type waves. The evidences for a tsunami-wave deposition are: erosional contacts, limestone clasts imbedded in the bed, weakly sorted sand, chaotic distribution of mollusk valves mixed with large limestone clasts and the presence of clay layers toward the top. In the same area, several lithological successions have been reported, with questionable origin:

- North Vama Veche beach – at the upper part of the escarpment a discontinuous, 10 cm thick layer is exposed, with flat base and top, consisting dominantly of mollusk shells, mainly crushed, unsorted, with very little sandy matrix; the bed is situated several meters above modern sea level;
- along the base of the cliff between Vama Veche and 2 Mai, the red clay layer is overlain by another layer with maximum thickness of about 40 cm, weakly sorted, discontinuous on strike, with erosive base; this layer consists of mixed boulders and organogenic matrix and it is overlain by Holocene loess deposits.

Outcrop observations in the area of Golful Corbului (north of Midia Harbor) revealed lithological successions consisting of various types of interbeds, like soil/sand or soil/sand/clay/sand/boulder beds. The successions show unsorted, coarse sand interbeds, with abundant faunal debris, with clearly erosive bases and various sedimentary structures like massive beds, tabular cross-beds and normal grading. The discriminator criteria between storm beds and tsunami beds point again to the second.

Sedimentological studies on the sediment cores from the Razelm – Sinoe lagoonal complex show that the basement of the lacustrine basin is formed by a loess layer, on top of which several sets of fossil beach-ridges of the Sf. Gheorghe I and II, Cosna and Sinoe deltas accumulated (Panin, 1998). The fossil beach-ridges, dominantly sandy, are overlain by fine sediments (muds and silts) specific for the lacustrine sedimentary processes. The thickness of lacustrine sediments varies from lake to lake. Within the lacustrine deposits, poorly sorted, coarse sandy beds occur, with whole or fragmented shells, irregularly disseminated or disposed in non-uniform coquina beds rich in vegetal debris. These

strata, - composed of underlain and overlain by fine sediments (muds, silts) -, have been investigated in order to reveal their sedimentological significance.
Analysis of radiographs, performed on cores from the Razelm – Sinoe lagoonal complex (Oaie, 1983), revealed several sedimentological features: layers with coarse sand and current cross-bedding; cross-beds in sandy layers and presence of a coarse sandy layer, with horizontal to trough and cross-bedding indicating various transport directions. The analysis of facies, shown by cores sampled from the Razelm – Sinoe lagoonal complex, shows that a series of major hydrodynamic events (tsunami waves?) have perturbed the lacustrine depositional environment, resulting in the formation of different types of strata both as internal sedimentary structures and grain sizes. The existence of a succession structures, from horizontal to cross-lamination and oblique laminations shows that a major current has changed its flow direction within the same hydrodynamic event.
The presence of coarse intercalations within fine-grained strata deposited in a lacustrine environment, as well as the various transport directions (marked by internal laminations), indicate possible accumulations related to tsunami-type waves which have crossed the beach-ridge located between the sea and the Razelm – Sinoe lagoonal complex.
Geological strata, suspected to be results of tsunami phenomena, contain a mixture of fossils showing different geological ages, derived from marine, brackish and lacustrine environments (Opreanu in Oaie et al., 2008). Micropaleontological analyses were made on the sediment cores collected from the Black Sea onshore and offshore areas, at water depths of maximum 10 – 12 m. In the collected sediment cores the ostracodes association appear as a mixture of marine (*Leptocythere devexa, Xestoleberis decipiens),* brackish (*Leptocythere histriana, Cyprideis littorali*) and freshwater (*Darvinula stevensoni*) species. Within this mixture, the predominant species are typical marine. Sporadic appearance of the freshwater species *Darwinula stevensoni* was observed. Fauna association can be considered as *in situ*, excepting the freshwater species *Ilyocypris bradyi, Paracandona albicans, Limnocythere inopinata, Darwinula stevensoni* and *Cypria* sp.
The collected cores were also analyzed for calcareous nannofossil assemblages (Melinte in Oaie et al., 2008). Smear-slides were prepared directly from untreated samples, in order to retain the original composition. The samples yielded nannofloral assemblages, with a moderate diversity and abundance, entirely reworked from older Cretaceous, Paleogene and Neogene deposits. Several samples do not contain any nanofloras, either *in situ* or reworked. The presence of the huge nannofloral reworking (more then 600-700 specimens/sample) could suggest an important marine phenomenon, possible a tsunami event, in front of the Danube Delta area.
From the classical triggering mechanisms of the tsunami-type natural hazard, the most known in the Black Sea are earthquakes, which usually accompany areas with active tectonic activity (e.g. the North Anatolian Fault, Shabla Fault, etc). The submarine landslides have been well constrained, especially in the NW part of the basin (Ion et al., 2008). We cannot completely preclude the rare or exceptional events, like large-scale gas-hydrates seeps and even falling of meteorites.
Many earthquakes, with magnitudes of 6.5 or more, have their epicenters on the Black Sea coasts (Oaie et al., 2006) being potential sources for future tsunamis. Although some areas, like the northern coast of Turkey, the Crimean coast (Ukraine) or the western Black Sea coast are subject to a higher risk than other localities, researchers have suggested that the entire Black Sea coast should be considered as a possible tsunami target.
We should emphasize that there is the possibility that submarine landslides and /or escarpment slides to play a much more important part in the formation of the Black Sea tsunamis. Currently, the correlation of existing data with superficial wave manifestations is still insufficiently studied.
The micropaleontological studies showed that the sediment samples from the shelf area are relatively rich in micro- and macrofauna when compared with those from the coastal dunes area. The sediment cores contains mixtures of marine and brackish ostracoda (plus one freshwater species), as well as

foraminifera and mollusks of strictly marine origin. The marine fauna is clearly *in situ,* while the freshwater species are clearly allochtonous, proving thus the possible existence of some extreme marine events in the area.

Based on the tsunami-type events that occurred in the Black Sea during the last 120 years (1868-1997), the recurrence time for a tsunami was estimated at 20 years (Pelinovski, 1999). From the 22 major events known in the Black Sea, 9 were produced in the XX century (Yalciner et al., 2004). Considering only on these events, the authors concluded that the recurrence period for the tsunamis in the Black Sea seems to be of only 11 years.

The complexity of the subject and lack of systematic data at national level require collecting new data, updating the existing information and increasing the data base with information from the circum-Black Sea countries. The appearance of such an event anywhere in the Black Sea basin would have significant effects on the coastal area, so a system of real time warning could be a necessity.

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SEDIMENTARY RELATIONSHIPS BETWEEN THE DACIAN BASIN AND THE BLACK SEA DEPRESSION DURING THE LATE NEOGENE

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Keywords: Black Sea, Dacian Basin, Euxinian Basin, detrital fluxes

The detrital exchanges reflect the sedimentary affiliation of two basins. This type of relationship between the Dacian Basin and the Black Sea Depression have been evaluated on the basis of sedimentological and paleogeographical information.

The Dacian Basin and the Euxinian Basin (which includes the Black Sea Depression) have been neighbouring water bodies within the Paratethys Domain. Both basins displayed brackish water environment, during the Middle Sarmatian (s.l.) to Middle Dacian period of time. (approximately 11 to 4.5 Ma). The two basins have also been in direct communication during all this time, as witnessed by similarities of their faunal associations. However, it appears that no significant detrital fluxes existed between the brackish Dacian and Euxinian basins.

Paleogeographic maps (Saulea et al., 1969; Hamor et al., 1988; Popov et al., 2004) reveal that the sediment accumulations at the contact zone between the eastern Dacian Basin and the western Euxinian Basin (shallow shelf zone) show contrasting characters. The eastern Dacian sediments are sandy – clayey, while on the western Euxinian shelf there are dominantly clayey sediments and coquina limestones. In addition, the two sediment accumulations display quite different sedimentation rates: for the same period of time hundreds of meters of sediment thickness in the eastern Dacian Basin and only meters or tens of meters of sediments on the western Euxinian shelf.

The above presented dissimilitude of the sedimentary features reflects the different physiographic characters of the two areas under discussion. During the approximately 11 to 4.5 Ma time period the Dacian Basin was active as a sedimentary trough, receiving a large amount of detrital material from the Carpathian source-area. The Carpathian-derived clastics have been conveyed toward the southern and southwestern areas of the Dacian Basin. No significant influx of Carpathian clastics, coming through the Dacian Basin. reached the Black Sea Depression during this Late Neogene time.

Starting from the Middle Dacian time (approximately 4.5 Ma) the Dacian Basin dried out and became a fluvial sedimentation area. This evolution trend induced an essential environmental differentiation between the continental-fluvial Dacian Basin and the brackish-marine Euxinian Basin. During the Dacian – Romanian time (approximately 4.5 to 1.8 Ma), as well as afterward, the Dacian Basin acted as the agent which canalized the Carpathian detrital supply toward the Black Sea depression. This process was made possible by the appearance (not earlier than 4.5 Ma time) of the Lower Danube Paleo River.

During the Romanian time, the continental area of the Dacian Basin was intermittently flooded by Euxinian brackish - marine water. The presence of brackish Euxinian sediments in the Dacian area, with fluvial Romanian sedimentation, was documented by Andreescu (1972; 1983). These data represent the argument for another scenario concerning the sedimentary relationships between Dacian and Euxinian basins. The occurrence of the brackish – marine deposits within a fluvial Dacian area, can be explained as a result of the rising level of the Euxinian sea, which produced the invasion of the brackish Euxinian waters over the eastern Dacian territory (Fig. 2B).

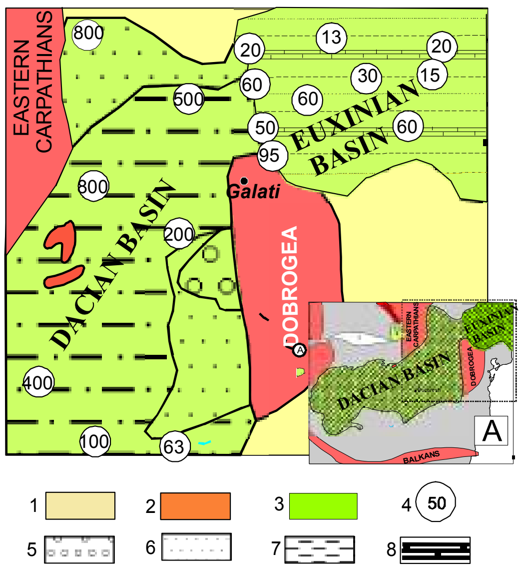

Fig. 1. Lithofacies and sediment thickness at the Dacian/Euxinian boundary during the Pontian time (6.6 - 5.8 Ma). This is an example of the contrasting sedimentary feature at the contact between the Dacian and Euxinian basins. Simplified, from Hamor et al., 1988. Legend: 1.Dry land. 2.High relief land. 3. Brackish sedimentary basins. 4.Sediment thickness (m). 5.Gravel. 6.Sand. 7.Clay. 8. Limestones

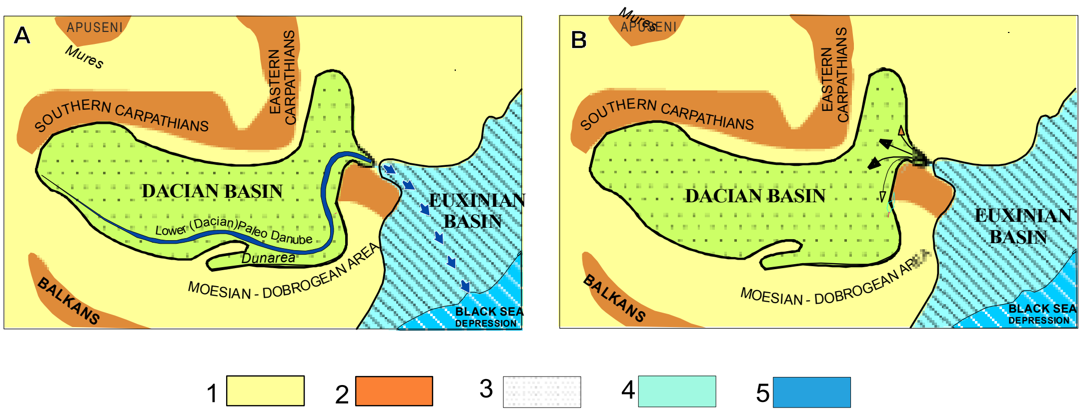

Fig. 2. Sediment fluxes between the Dacian Basin and the Euxinian Basin during the Romanian time (3.4 - 1.8 Ma). A. Detrital flux from Carpathians to Black Sea, through the Dacian Basin. B. Detrital flux through Euxinian water inflow into the eastern Dacian Basin. Paleogeographic sketches simplified, after Khondkarian et al. (In Popov et al, 2004). Legend: 1.Dry land. 2.High relief land. 3. Fluvial sedimentary basin. 4.Brackish shelf. 5.Brackish deep basin

LES DIATOMITES MARINES DU MESSINIEN, UNE EXPRESSSION DE CHANGEMENTS CLIMATIQUES GLOBAUX ?

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Mots clés: Messinien, bloom biogénique, dominance, diatomée, productivité biologique

Le Messinien est une période qui continue à susciter des amples débats scientifiques sur l'histoire de la Méditerranée, en considérant surtout le schéma d'une Méditerrané asséchée qui impliquerait une crise biologique de grande ampleur. Plusieurs modèles proposés intègrent les dépôts diatomitiques, bien développés à cette époque, mais aucun ne prend en compte réellement le message biologique délivré par les diatomées à l'origine de ces dépôts.

L'étude de la biosédimentation siliceuse dans différents provinces océaniques a mis en évidence plusieurs événements majeurs, biologiques, climatiques et tectoniques au cours des derniers 15 Ma (Cortese *et al.*, 2004). Un de ces événements biologiques a été enregistré sous le nom de "Bloom biogénique siliceux du Miocène supérieur-Pliocène inférieur (7-4.5 Ma)". Remarqué au départ dans l'océan Pacifique équatorial (Farrel *et al.*, 1995), cet événement a été reconnu par la suite dans l'océan Nord Pacifique, l'océan Indien, l'océan Atlantique, la mer de Chine. Deux hypothèses sont envisagées pour expliquer cet événement d'exception: 1) une réorganisation des masses océaniques entre le Pacifique et l'Atlantique et 2) un bloom biogénique provoqué par une augmentation globale des nutriments dans les océans (Cortese *et al.*, 2004). En Californie, les importants sédiments diatomitiques (en affleurements) connus sous le nom de Formation de Monterey et Formation de Sisquoq indiquent une croissance de "diatom mass accumulation" entre 7 et 4 Ma. Barron (1998) explique le bloom biogénique siliceux en Californie à 6,5 Ma comme résultant du refroidissement climatique enregistré dans les hautes latitudes et qui a stimulé le fonctionnement des upwellings et donc une croissance de la paléoproductivité des diatomées. On voit que la sédimentation diatomitique en Méditerranée se situe exactement dans la même tranche de temps, entre 7 et 6,1 Ma. Plusieurs sections diatomitiques étudiées au Maroc (Bassin de Mellila, Bassin de Boudinar), en Sicile (bassin de Caltanissetta) et en Espagne (Bassin de Sorbas) montrent la dominance des taxons d'eaux froides (*Coscinodiscus marginatus*) avant 6.5 Ma. Après 6.5 Ma, on constate une augmentation de la diversité des diatomées et la dominance à certains niveaux de l'espèce *Thalassionema nitzschioides* qui indique généralement la manifestation du phénomène d'upwelling.

De manière générale, les apparitions/disparitions des espèces de diatomées marines coïncident avec les périodes de refroidissements majeurs et rapides dans les hautes latitudes (Barron & Baldauf, 1995). En océan Pacifique équatorial la plupart des apparitions des nouvelles espèces de diatomées sont entre 6,5 Ma et 6,0 Ma. A ce titre, un fait extrêmement intéressant et inexploité jusqu'à présent concerne la présence dans la série de diatomites du Messinien de certaines espèces, marqueurs biostratigraphiques caractéristiques du Miocène supérieur de la Province Pacifique équatoriale (*Thalassiosira* *praeconvexa*: 6,7-6,2 Ma, *Thalassiosira miocenica* 7,3-6,1 Ma, *Thalassiosira convexa* var. *aspinosa*: 6,6-2,43 Ma), espèces identifiées dans les coupes de Falconara (Sicile), Messadit (bassin de Mellila, Maroc) et Sidi Hadj Youssef (bassin de Boudinar, Maroc) postérieurement à 6,5 Ma.

Ainsi, on observe dans les dépôts diatomitiques marins de Méditerranée, l'apparition de nouveaux taxons à partir de 6,7 Ma et l'enregistrement de probables phénomènes d'upwellings à partir de 6,5 Ma, événements également connus dans l'ensemble du domaine océanique à la même époque. Finalement, la sédimentation diatomitique messinienne en Méditerranée pourrait simplement être une réponse d'un phénomène global, au Néogène supérieur, de croissance de la productivité biologique marine. On peut donc envisager une nouvelle approche des événements biogéniques siliceux en Méditerranée occultée jusqu'à présent probablement par une polarisation naturelle sur le thème de la crise de salinité.

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