ESONET NoE - Black Sea Observatory

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With anoxic conditions in the deep, problems with invasive species and high sediment loads delivered to the system, this area has unique problems requiring long term stations.

The Black Sea is one of the largest regional seas of the Eurasian continent and unique in many of its geographical, geological, biological, hydrographical and socio-political characteristics. Its total shoreline is 4340 km, and it is bordered by Romania, Bulgaria, Turkey, Georgia, Russia and Ukraine, with more than 160 million people inhabiting the greater Black Sea basin. The coastal zone of the Black Sea region has maritime temperate climate. The Black Sea is the world's most isolated sea, connected to the world's oceans only via the Bosporus to the Mediterranean Sea, and with the Sea of Azov in the northeast through the Kerch Strait. It has a surface area of 432000 square kilometers and contains 550000 cubic kilometers of water. Through the Bosporus Strait about 300 cubic kilometers of seawater flows from the Mediterranean to the Black Sea along the bottom, returning a mixture of seawater and freshwater of about 600 cubic kilometers. The Black Sea is highly impacted by riverine discharge of some of the largest European rivers, the Danube, Dniepr and Don. Its salinity ranges between 18-22‰. It receives the drainage from a 2 million square kilometer basin, covering about one third of the area of continental Europe and delivering about 350 cubic kilometers of river water. The shelf occupies a large area in the north-western part of the Black Sea, where it is over 200 km wide and has depths of 150 meters. In eastern and southern parts of the sea the shelf has a depth of less than 100 m and a width of only 2.2 to 15 km. The smallest stretches of shelf are found near the Caucasian and Anatolian coasts. The Black Sea also comprises deep-water habitats, reaching > 2200 meters in the central area. A unique characteristic of the Black Sea Basin is its anoxia below 150 m water depth, and the consequent effect on biological and biogeochemical processes, including a limited zone populated by animal life defined by oxygen availability, a distinct chemocline, an extensive sulfidic zone, high methanogenesis rates and a high microbial diversity. The most unique type of life in the Black Sea are the reef- and crust-forming methanotrophic archaea (Michaelis et al. 2002). The total methane inventory in Black Sea waters has been estimated as $6x10^{12}$ mmol (Reeburgh et al., 1991). Furthermore, because of its hydrological isolation, the Black Sea has experienced extreme variations of salinity in the past 2 million years. Different from most marine sediments those of the Black Sea were formed under changes between limnic, marine and hypersaline settings, and oxic/anoxic phases in the water column. This has made the Black Sea one of the most fascinating areas to study sedimentary deposits and geological as well as hydrographical and climatic history of the region.

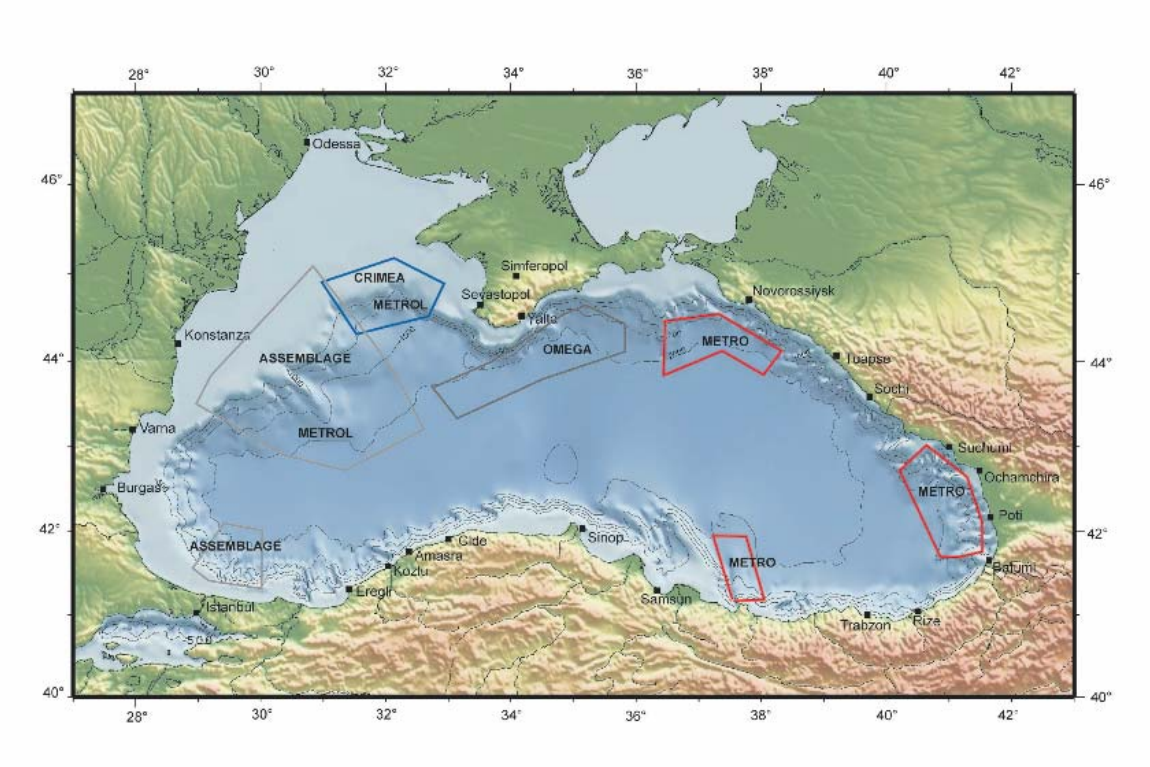

Figure 1 : ***Map of the Black Sea with investigation areas of recent European research programs.***

The eutrophication of the Black Sea due to the excessive loads of nutrients via the rivers and directly from the coastal countries has led to radical changes in the ecosystem since the 1960es. This had a major impact on biological diversity and human use of the sea, including fisheries and recreation. One of the regions of intensive radioactive precipitation during the Chernobyl disaster was the northwestern Black Sea region. To release environmental pressure from the Black Sea, a variety of political and non-governmental actions have been taken. A co-operation for the protection of the Black Sea environment takes place in the framework of the Convention on the Protection of the Black Sea against Pollution (Black Sea Convention), to which the European Union has been granted official observer status. Other partnerships include the Black Sea - Danube Strategic Partnership (BSDSP). One of its main partners, the Black Sea Ecosystem Recovery Project (BSERP) has been developed under the auspices of the Global Environmental Facility (GEF) International Waters (IW) Program, and is implemented by the United Nations Development Program (UNDP). Main efforts in ecosystem recovery started in 2002 and included the Black Sea Nutrient Reduction Facility (World Bank) amongst a variety of activities. The BSERP ensures the provision of a suite of harmonized legal and policy instruments for tackling the problem of eutrophication, and release of certain hazardous substances, and to facilitate. Other important activities include the Danube Regional Project harmonized with the EU Water Framework Directive and GEF requirements, the EU-Russia-Ukraine GMES net-working on pipeline and oil spill monitoring and the DABLAS Task Force with the aim of providing a platform for co-operation for the protection of water and water related ecosystems of the wider Black Sea region, including the Danube basin. A summary of environmental projects concerned with the Black Sea region is given on http://www.blackseaweb.net. A first Black Sea Global Ocean Observing System (GOOS) sponsored by the IOC implemented basic elements of an operational network for observation, oceanographic data exchange, assimilation, forecasting, and issues of products for marine ecological applications

(http://www.ims.metu.edu.tr/black_sea_goos/). Major topics of Black Sea GOOS are coastal observations, sea level measurements, remote sensing, buoy measurements of basin circulation, regional weather forecasting and improved ecosystem modelling. The first EU funded Black Sea GOOS Project ARENA has been launched in 2003. ARENA is a regional capacity building and networking program to upgrade monitoring and forecasting activity in the Black Sea basin. ARENA aims a networking and capacity building for the development of the regional GOOS.

An important topic for the wider Black Sea area is potential impacts from earthquakes, landslides and floods. There is still controversial evidence for the biblical Black Sea flooding event 7000 years ago, but certainly did floods play an important role in the history of human settlements around the Black Sea. Northern Turkey lies on the Anatolian Fault, where earthquakes have been reshaping the land for millions of years. Other regions of seismotectonic concern are the Kaliakra or Shabla seismic zones. The seismic and differentiating character of earthquakes in this region is closely related to the deep fracture and the block construction of the crust. Some of the coastal mountains rise to over 3000 m attitude within 50 km from the sea. Steep slopes, agricultural land use and heavy rainfalls contribute to an increasing risk of landslides in the coastal areas of the Black Sea. The role of seafloor instabilities in the Black Sea is not well known. It hosts steep canyon systems, where bottom sediments of the shelf zone are removed to the continental slope region and finally to the abyssal part of the sea. Benthic turbidity storms due to bottom erosion, landslides and local submarine earthquakes have been observed occasionally. Furthermore, the recently recognized widespread occurrence of subsurface fluid flow, gas seeps, mud volcanism and gas hydrate deposits indicates an important role of these phenomena in seafloor stability, and a potential for catastrophic interactions between gas release and earthquakes and landslides.

Many of the important discoveries regarding gas seepage and mud volcanism in the Black Sea were made during the Training-through-Research (TTR) program of UNESCO in operation since 1990 based on a major initiative of Moscow State University (MSU), which puts together the advantages of the formal training of undergraduate and postgraduate students and young scientists with the experiences gained in advanced research. Its main operational field is marine geology and geophysics combined in with studies in benthic biology and physical oceanography, studying processes of geosphere-biosphere coupling in high-seas (http://ioc.unesco.org/ttr/geninfo.html). In the period 1991-2004, fourteen major TTR cruises were conducted in the Mediterranean and Black Seas and in the northeastern Atlantic.

In the 5th and 6th EC framework programs several major research projects have been funded within the OMARC (Ocean Margin Research Deep Water Consortium) to further increase knowledge on the Black Sea deep-water areas especially with regard to gas seepage. A brief summary of the results and study areas of interest is given in the next paragraphs. Several of the members of these OMARC projects in the Black Sea are also participants in ESONET and will help integrating previous knowledge into the planning of seafloor observatories.

The 5th FP project ASSEMBLAGE (http://www.ifremer.fr/assemblage/) has focused on the assessment of the Black Sea sedimentary system since the last glacial extreme. Main questions were the history of the connection between Mediterranean and Black Sea area, the growth of the sedimentary system in the Northwestern Black Sea, including the Danube and Dniepr-Dniestr deep-sea fans, the sedimentary records of the past global climate and sea

level changes as well as the distribution of gas seeps and gas hydrates (Popescu et al. 2003). The fieldwork within ASSEMBLAGE has provided long sediments cores for the study of climatic proxies and age determination, and bottom-simulating reflectors were investigated as potential indicators of paleo-environmental conditions. Heat flow measurements were made on specific target points on the BSRs, and 3D high-resolution seismic mapping was carried out in an area bearing gas hydrates. ASSEMBLAGE has concentrated on the area 43-44°N and 30-31°E and could provide high-resolution information of sedimentary environments, hydrate settings, and BSRs.

Another 5th FP project fully dedicated to methane seepage was CRIMEA ("Contribution of high-intensity gas seeps in the Black Sea to methane emission to the atmosphere"). This project focused on the transfer of methane from the seafloor through the water column and into the atmosphere from submarine high-intensity methane seeps and outbursts in the Black Sea (http://www.crimea-info.org) using a combination of modern geophysical, geological and biogeochemical methods. An important finding was that some shelf areas release large amounts of methane to the seawater, where it is partly oxidized and consumed by bacterial activity. CRIMEA concentrated mainly on the Dnepr paleo-delta area (water depth 100-700 m) and Sorokin Trough. Intense seepage areas have been identified particularly on the western and northwestern shelf and slope, as well as on the northern and north-eastern slope (Klerkx 2002, Klaucke et al. 2005). Moreover, high-intensity seeps were detected that vigorously eject methane into the water column and also to the atmosphere (Schmale et al. 2005). Sediments, which underlay the shelf and slope of the Western Black Sea, contain source rocks with significant oil and gas potential of several million tons of hydrocarbons km-3. For the Bulgarian continental shelf, the gas flux at the seabed is estimated at 147,000,000 to 737,000,000 m3 / year (Dimitrov, 2002). High estimates were also obtained for the north-western shelf, and the coast of Georgia. Furthermore, the annual gas flux from mud volcanoes in the Black Sea is inferred at 0.5 - 3Tg. Gas hydrates have been recovered in submarine fans, in fractured zones and within mud volcanoes. Theoretically, methane hydrates can form in the Black Sea at water depths exceeding 580 to 700 meters. Hence, the area of the Black Sea that is suitable for gas hydrate formation is evaluated at 288 100 km2, representing about 68% of the total Black Sea. So far, the volume of gas hydrates in the Black Sea has been estimated at 4.8 km3 corresponding to 0.1-1x 1012 m3 of methane gas.

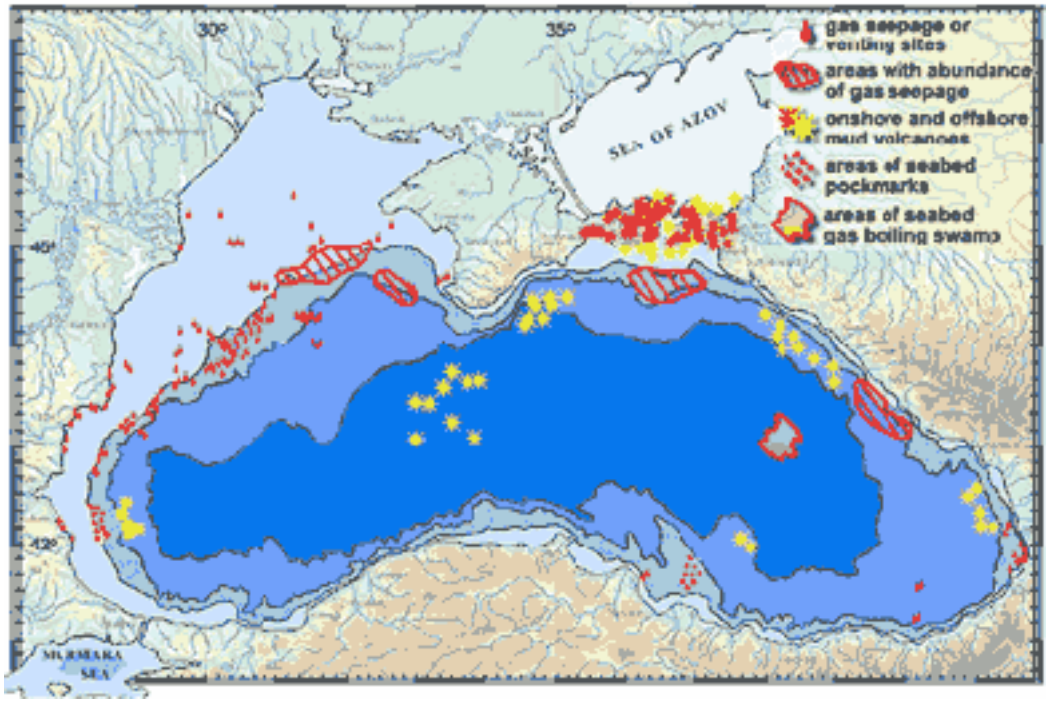

Figure 2 : ***Distribution of seabed structures related to gas seepage (***http://www.crimea-info.org***).***

Another EC 5th FP project was METROL "Methane flux control in ocean margin sediments" which dealt with gas distribution in shelf sediments and microbial processes controlling gas fluxes. Methane seeps were mapped through extensive acoustic surveys by the partners GeoEcoMar and IBSS. Anaerobic methane oxidation as the main sink for methane in the ocean was found to take place in the subsurface and at the seafloor at gas vents. Within METROL three working areas were chosen according to existing information on gas seeps distribution, accumulations of free gas in the sediment, and sediment geochemistry. The Danube Canyon (also known as Viteaz Canyon) is a large shelf-indenting canyon that has developed seaward of the late Pleistocene paleo–Danube Valley. It is located on the outer northwestern Black Sea shelf and stretches for 26 km from ca. 44°05'N, 30°10'E to the shelf break at ca. 43°55'N, 30°20'E. The canyon is up to 110 m deep and represents the proximal end of the paleo-Danube delta system. Aggregations of methane seeps have been mapped along the canyon slope and adjacent areas, especially along the shelf break edge to both sides of the canyon and along the landward prolongation of the paleo-Danube system. Subsurface gas plumes have been mapped in sediments in the canyon and along its prolongation (Popescu et al. 2004); further information on subsurface gas distribution is available by sub-bottom profiles from METROL project partner GeoEcoMar. A number of gas seeps have been mapped in water depths between 100 and 300 m along the entire north western shelf break between the Danube Canyon and the paleo-Dniepr delta area (Egorov et al. 1998). Dense accumulations of seep positions are known from the area around 44°35'N 31°10'E. This area mainly served for the search for gas seeps and associated carbonate precipitating microbial mats. Also, the paleo-Dniepr area has been intensively mapped by METROL for gas seep positions (Egorov et al. 2003). Data on the distribution of shallow gas have been made available by the METROL project partner GeoEcoMar and by the EU project CRIMEA.

Additional information about deep water gas seeps becomes available through the German national Geotechnologies program METRO (http://www.rcom-bremen.de/Page1908.html)

supported by DFG and BMBF as well as by the national research programs of the riparian countries. Highly active deep-water mud volcanoes were detected in the western basin and especially in the Sorokin Trough southeast of the Krim peninsula in water depths of 800-2000 m (Greinert et al. in press). The Sorokin Trough has been investigated in detail by METEOR-expedition M52/1 (Bohrmann et al., 2003; Krastel et al. 2003), focusing on gas hydrate structure, composition and distribution as well as association with fluid migration.

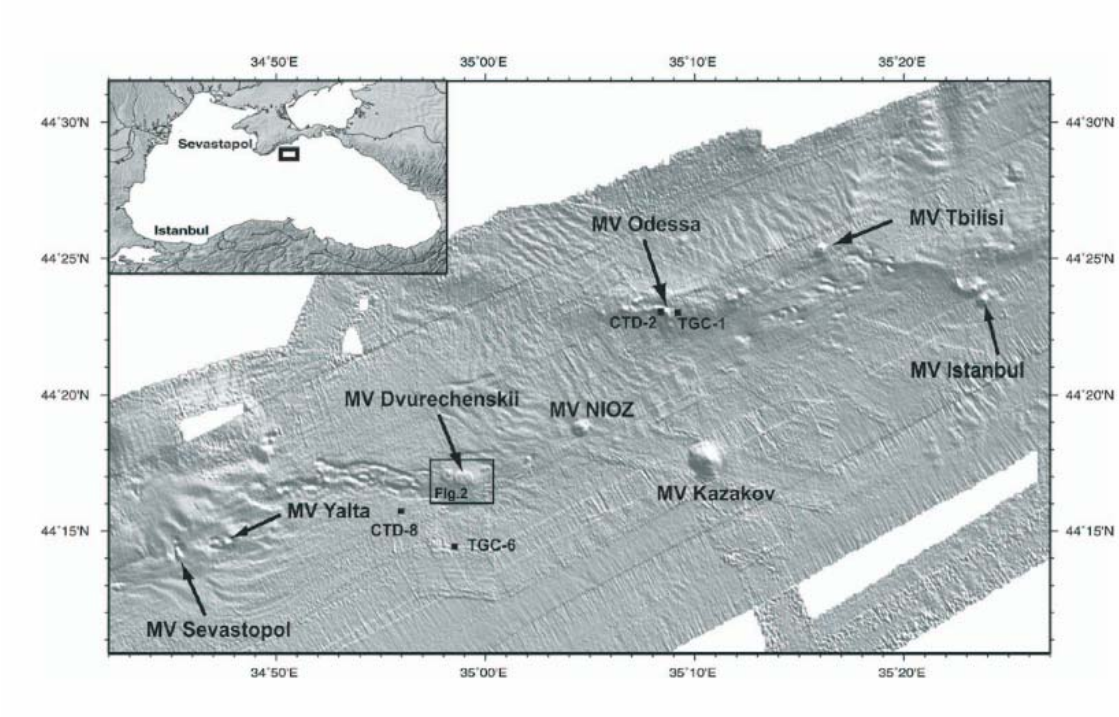

Figure 3 : ***Map of the central Sorokin Trough and the most important active mud volcanoes***

Another main focus of current EC research projects in the Black Sea is on deep-water hot spot ecosystems. The 6th EC FP project HERMES "Hot spot ecosystem research on margins of European seas" operates one of its regional work packages in the Black Sea, which is concerned with the biodiversity of microorganisms in slope and fluid flow impacted systems (http://www.eu-hermes.net/). Several European research cruises are planned together with riparian partner countries between 2007 and 2009 with a focus on in situ geophysical, geological, biogeochemical and biological measurements, and use of state of the art equipment for non-stationary benthic observation tools (including swath bathymetry, deep towed side scan sonars, ROVs, AUVs, benthic lander systems, in situ chemical sensors, camera deployments, colonization experiments etc). This work will provide a good baseline for selection of deep-water sites of interest for long-term observation, and will considerably improve the use of in situ analytical technology. All information collected during HERMES Black Sea activities will become available in the PANGAEA database for long term data storage. The WebGIS portals of the HERMES GIS (http://gis-web.iu-bremen.de/website/hermes/) will continue to provide facilities for online data analysis and visualisation. Close co-operation and collaboration with MARUM will insure direct access to the Pangaea database and maintenance of data standards. The HERMES partners will support ESONET by providing access to this information for accurate planning of activities in the Black Sea. The GIS tool will be available to ESONET and it is planned to develop an integration of observatory data into a GIS scheme.

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ESONET plans to prepare and establish networks for the establishment of benthic observatories targeted to several objectives of the Global Change and Ecosystems sub-Priority, which could be realized in the Black Sea. Deep water long term observatories in areas of particle entrainment from the Danube and/or other discharging rivers could help detecting patterns related to global change, physical oceanography and anthropogenic impact. Furthermore, knowledge is available to plan observatories detecting geohazards including submarine earthquakes, slope instabilities, tsunamis, as well as fluid flow and gas seepage. This will also contribute to the knowledge on non-living resources especially with regard to hydrocarbons and CO2 sequestration. Last but not least, the deep water systems represent unique marine ecosystems with highly interesting biogeography, and biodiversity. Major objectives addressed by the Black Sea regional team are to prepare and plan long-term systematic observations of marine abiotic and biotic processes and key parameters such as:

- physical processes (e.g. tidal waves, eddies)
- river discharge
- changes in the quantity and composition of surface and deep water masses (salinity, temperature, current speed & direction)
- changes in atmospheric forcing
- distribution and high resolution analysis of the chemocline
- slope stabilities and failures
- sediment transport
- canyons as conduits between the deep-sea and the upper slope
- occurrence and distribution of pollutants
- productivity changes
- biodiversity and habitat changes

Today no concrete technology plans are available to install glass fiber cables or other types of submarine infrastructure. The main task for ESONET will be to help structuring the resources of the participating institutes to create the necessary critical mass, remove barriers and fragmentation of ideas, technologies and infrastructure, improve teaching, education and outreach, and - through joint program of activities – to arrive at durable solutions for the future organization of benthic observatories.

As main objective will be the planning of the investigation of long-term patterns in fluid flow and gas seepage through sediments and gas hydrates. This is of high interest to society because structures such as gas chimney's acoustic blanking effects, subsurface sediment mobilization, and landslides close to the outcrop of the gas hydrate stability zone may indicate the episodic release of fluids from the gas hydrate reservoir to the seabed and into the water column (Kessler et al. 2006, Naudts et al. 2006, Schmale et al. 2005, Greinert et al. in press). Currently an initiative from various members of European programs, including partners of ESONET, proposes a new deep drilling program in the Black Sea to investigate both climatic and hydrological change in the basin as well as fluid and gas migration and hydrate distribution. A collaboration regarding site choices and possible linkage to benthic observatories is foreseen. To understand hydrocarbon release from gas hydrates in times of bottom water warming, when pressure and temperature dependent gas hydrate stability field conditions are changing, and in relation to seismic activities is of high importance. Previous observations in the Black Sea suggest that the geosphere can release large amounts of carbon during short time spans, bypassing the biological buffers and offsetting ocean atmosphere carbon equilibrium. It is important to quantify the involved carbon and methane

fluxes, to establish their relationship with biodiversity hotspot and ecosystem development and to implement them into climate models. Measuring fluid flow through sediments and subtle carbon flux variation in fluid and gaseous phases from the seabed requires long-term cabled observatories.

One first proposal for a long-term observatory to combine gas flux analysis with earthquake warnings has been put forward to ESONET (Dimitrov P.S., Institute of Oceanology – Varna, Bulgarian Academy of Sciences). This project for constructing a geodynamic polygon in the immediate vicinity of the Black Sea region has been developed in relation to rapidly increased seismic activities during last years. The main objective for this polygon is the registration of changes in gas-methane rates in permanently active gas springs related to tectonic infractions, to allow for warnings several hours before the occurrence of an earthquake. The idea for such a construction is based on previously described phenomenas of increased gas emission from the bottom several hours before an earthquake. An example is the Crimea earthquake on 12.09.1927: In front of terrestrial observing points in Lukuk, Eupatoria and Sevastopol fires were watched. The reason for the observed "fires" in the sea may be explained with release of gas (methane) from the seafloor, which could have ignited spontaneously and locally in the atmosphere. The main element of the geodynamic polygon is an installation for the capturing of gas expelled from natural seepage, to measure gas fluxes. It is proposed to exploit the emitted gas.

An ideal region for the construction of the polygon is the "Zelenka" area because the region is in the center of the Kaliakra earthquake zone, because gas emission occurs along predictable patterns (faults) and because the gas sources are very close to the coast, which allows for cheaper construction and service costs. The installation would consist of a semi-sphere fitted to the underwater gas sources, as well as a built-in pipe equipped with a line pipe with a valve, and a hermetic cable-pipe with a muffle and branch box for the cable. The muffle is connected with valve and outlet tube. Seismic sensors on the sphere and in the center, as well as the sensors for pressure, sea-water temperature and salinity are to be included in the branch box by hermetic couplings. Gas sources connected to deep faults exist in the Black Sea near Georgia, the Ukraine, and in other areas. Therefore, similar polygons could be constructed on the margins of all Black Sea countries. It would be a favourable long-term goal to achieve a complete regional observation of seismic and gas flux activities by connecting the data flow from the separate polygons. Today, only one such gas flux observation and collection construction has been installed at the famous Coal Oil Point Seep Field close to Santa Barbara, California (http://www.bubbleology.com/). Since the late 1990s, scientists have mapped the seeps in the area using sonar and quantified seepage flux from sonar and direct gas capture using a flux buoy (Washburn et al., 2001). In this area, most seepage is also located along linear trends above faults or fractured anticlines (Hornafius et al. 1999). The availability of such a submarine observatory and gas collection site has been very important for understanding ling term changes in gas emission in relation to geological processes.

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