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Geophysical characteristics, natural hazards and resources of the Bulgarian Black Sea and coastal land according integrated information

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ABSTRACT: *An integrated approach to the new and interpreted geophysical data, natural hazards expressions and local natural resources is applied to reveal the relationships, dependencies and possible interactions between the potential geophysical fields, DEM and bathymetry, natural hazards developed in the regional geodynamic context and the natural resources explored and exploited since historical times up to the present days. The main aim of this study is to reveal the relationships in depth, when they exist and to present the areas where such dependencies are not adequate. Such approach is newly performed and is targeted to the scientists, decision makers and local and regional administrations to inform them about possible sustainable deployment of the natural resources and their effective exploitation in case if a strong multihazards natural phenomenon affects the study area and brings*

The side effect of this research is the deeper view to the possibilities of the recent geophysics to help the extended knowledge and mitigation measures in case if the strong disaster occurred.

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I. INTRODUCTION

This is a fundamental study revealing the relationships between geophysical fields, natural hazards and some natural resources located on the Bulgarian sector of the Black Sea and coastal land. It summarized the known and newly obtained geophysical data according several research projects targeted to different tasks – from geophysical characteristics of the regional geophysical fields, trough historical and observed natural disasters to the recently discovered natural resources some of them explored and exploited during the ancient times, up to the present days. During the last several years new geophysical data was produced and collected giving a new deeper inside view about the geophysical characteristics and stronger dependencies between observed geophysical fields, natural hazards, natural resources and deposits and into the new geodynamic context of the costal area – on land, in the sea and their relationships from deeper horizons to the surface layers.

The data collected and used in this study is as follows:
New data about the low velocity layers interpreted as asthenosphere as inferred from 3D attenuation by MMS [Dimcho Josifov, Boyko Ranguelov, Emil Oynakov, 2018.], [Йосифов, Д., Б.Рангелов, Е.Ойнаков.,2018]
New map of the gravity free air and Bouguer anomalies [Radu Dimitriu ., Gheorghe Oaie., Boyko Ranguelov., Radi Radichev 2016]
New map of the total vector of the magnetic field [B.K. Ranguelov, M.S. Bayraktutan, R.S. Radichev, A. S. Kisyov ., 2015.], [Radu Dimitriu ., Gheorghe Oaie., Boyko Ranguelov., Radi Radichev 2016]
New map of high resolution bathymetry [B.K. Ranguelov, M.S. Bayraktutan, R.S. Radichev, A. S. Kisyov ., 2015.]
New coastal profile of Bouguer, magnetic and radioactivity anomalies [Radichev, R, Dimovski, St., Ranguelov, B., Kostyanev, S., Trapov, A., Tzankov, Ch., Mihailov, Em., Kisyov, At., Stoyanov, V., Kirilov, N., 2014.]

New Black Sea catalogue of earthquakes and seismicity map [G. A. Papadopoulos, G. Diakogianni, A. Fokaefs, and B. Ranguelov., 2011.], [Muco B., G. Alexiev, S. Aliaj, Z. Elezi, B. Grecu , N. Mandrescu, Z. Milutinovic, M. Radulian, B. Ranguelov, D. Shkupi., 2012.] [Рангелов Б., 2010.]

New data about the active faults inferred by seismostratigraphy and filed observations [Orlin Dimitrov , I. Genov., 2004.]
Map of the Earth's crust thickness [Д. Йосифов, Р. Радичев., 2013.]
Map of the gas hydrates depositions [Orlin Dimitrov, Atanas Vassilev., 2016]
Map of the Geological hazards [Бручев И.,и др.,1994], [Ranguelov B., 2013,],
Map of the natural resources [https://search.yahoo.com/search?ei=utf-8&fr=tightropetb&p=Map+of+the+natural+resources+of+Bulgaria&type=11455_062615]

The largest volume of the new materials, data and interpretation views, supported by the previous background of geology, geotectonic and natural hazards processes of the study region [42-44N, 27.5-29E] provides a possibility to establish all geophysical characteristics and the relationships between them. This is a solid base for structural and deeper understanding of the lateral and vertical peculiarities from upper mantle up to the surface recent depositions.

II. METHODOLOGY

The methodology is based on the collection, analysis and interpretation of all available recently obtained geophysical data and the comparison of the revealed characteristics. Then the data and integrated information of the natural hazards, developed in the study area are extracted and summarized, discovering their destructive potential. The information has been overlapped, the relationships and correlation between them revealed and then have been integrated into a comparative table. The local natural resources known up to now are added to assess the sustainability of the economic stability and the possibility of the studied region for resilience and mitigation of affection by largely developed natural hazards in the investigated area.
Analysis and obtained relationships
Geophysical data and interpretation

The deepest part of the investigated area [42-44N, 27.5-29E] is characterized by the low seismic velocity thick layer interpreted as asthenosphere with fan shape located from approximately the latitude of town of Byala up to the most northern area. Fig.1 a) and b) The average depth starts at about 100-120 km and then goes deeper to the east under the Black Sea bottom. The thickness probably reaches 400-600 km
To the south a higher seismic velocity body is outlined between Byala and Sozopol.

To the south again very thick low seismic velocity layer is observed with the same characteristics as the northern one. Probably more massive layer is extended to the east to deeper aquatory of the sea. The observed peculiarities are just like tendencies because of the lack of data, impossible to be collected in the sea. (Josifov, Ranguelov, Oynakov, 2018)

The depths to the Mohorovicic boundary have low variability – between -33 to -27 km, but only from the land to the east up to the continental shelf. The deeper Black sea Moho depth shows sharp decrease and very thin Earth's crust due to the lack of "granite" layer.

It is well known that the gravity field of the deeper part of the Black sea is relatively positive – Josifov, Radichev…The last higher accuracy gravimetric mapping performed by the "Mare Nigrum" geophysical vessel shows well correlated link between the sea and coastal peculiarities of the gravity field (Bouguer anomaly onshore, Free Air gravity offshore). The simultaneously performed high resolution bathymetry mapping, gives the possibility to consider the bathymetry changes to the behavior of the regional geophysical fields (gravity and magnetic). As a reflector of the deep structure of the geological strata, the gravity anomalies map shows large and calm gravity field – [Radu at al…] to the north – from Byala to the Bulgarian-Romanian boundary oscillating around 0 mGal. From the continental slope to the east – the negative gravity field is separated by an intensive gradient reaching – 100 mGal. Much more interesting is the behavior of the gravity to the south of Byala. Intensive positive anomaly (up to 60 mGal) is located in the sea and on the land along the coast between Bourgas and Ahtopol. To the east in a deeper sea another positive anomaly (about 30 mGal) is located, before transforming to the east in a negative one trough larger gradient.

Much more variable is the magnetic field – fig.2. The total vector mapped with an increased accuracy of about 10 nT on shore and in the sea (the composition needs special technique), gives the possibility of isolines step at about 25 nT. Again the space interval between Byala and the Bulgarian-Romanian boundary shows calm magnetic field with an exception of a positive anomaly (about 300 nT) located between cape Kaliakra and cape Shabla). The origin of this anomaly is still disputable.

To the south – from cape Emine to the town of Ahtopol, very variable intensive positive anomalies (reaching 300-400 nT) form a mosaic structure. In the geology context the most probable origin of these anomalies are the volcanic bodies discovered along the coastline on land and in the sea – fig.3.

Very clear positive correlation (CC reaches about 0.9) can be observed between the positive gravity and magnetic fields – fig.4..

The high accuracy measurements profile for the magnetic, gravity and radioactivity fields has been executed to fit the correct correlation between sea and on land data – fig.5. The results obtained confirmed

positive correlation between gravity magnetic fields as well as the variation of the gamma radioactivity to the south part (up to cape Emine) and much less changes of these fields to the north part of the coastline (from Byala to the Bulgarian-Romanian boundary). For better interpretation of the gravity and magnetic filed calculations the physical properties of the rocks along the profile have been measured in situ and in the laboratory of MGU. The density of the rocks varied between 2.3-2.35 g/cm3 (for limestone) to 2.6-2.65 (for the volcanic rocks). The measured in situ magnetic susceptibility is between 4-10 x10-3 SI (for the limestone and other sedimentary rocks) to 60-80 x10-3 SI (for the vulcanite rocks).

The high resolution (up to 20 cm) bathymetry map covered the isobaths of 20 meters to the deep sea shelf – fig.6. Very clear ancient rivers' beds are visible and the old terraces before flooding the entire basin about 10 000 years ago, when the fresh water closed lake has been transformed in the low salinity sea after the intrusion of the Mediterranean salt waters.

The seismicity map (fig.7.) shows another geophysical characteristic of the recent geodynamics of the region. In contrast of the gravity and magnetic field the northern part of the western Black sea coastal region, is much more seismically active then the southern part. In general during the last 50-60 years the maximum observed magnitudes of the seismic events in the investigated area reach no more then 5.0-5.5, as more then 90% of the seismic events are located to the north. The great exception is the well known Shabla-Kaliakra seismic source which can produce seismic events with magnitudes 7.5 even 8.0. The origin of the seismic activity of this source is not yet clear. Some investigators link it to the local faults and fault knots. According to the historical data the mentioned seismic source can generate rare, but very strong earthquakes. The last manifestation is the earthquake of 1901 with a magnitude 7.1 and observed epicentral intensity X EMS. The data about local tsunami generated by such events related to this source are frequently discussed (papad et.al.). In the general context the low seismicity to the south is limited unexpectedly to the south boundary of Bulgaria. The southern coastline south of Bourgas is practically asesimic. In Turkey northern territory the seismicity on land and in the sea increases especially to the area of Istanbul and extends to the North Anatolian fault and its branches to the west.

Active faults, seismostraigraphy and parameters obtained.

There are several sources of data about the active faults on the coast and in the sea – fig.8.

For the northern part surface observations and geophysical data interpretation are the main sources of active faults identification. The high seismic activity in the area Shabla-Kaliakra suggests huge active faults, fault's crossings and fault's knots. (Fig)

For the deep sea zone the seismostratigraphy is the source of the information about faults and their activity – fig.9.

To the south surface observations on the cliffs and outcrops show high density of recently active faults which do not produce significant even low magnitude registered earthquakes.

Natural hazards and natural resources – reflections to the geophysical characteristics

Natural Hazadrds And Assesment

- Collapsibility of loess. The hazard spreads to the north part of the Black sea coast. It is mixed with some karsts activities. The negative influence could be expected to the buildings constructions, underground mining and collapse of the agricultural land. The level of the destructive potential is low, because simple geology and geophysical prospecting can define clearly the areas of potential threat.
- Rock falls and cracked deposits. The hazard is located to the rocks near to the sea and can be localized easy. Low destructive potential.
- Active faults and mud flows. These are surface geodynamic factors with low destructive potential.
- Active faults and earthquakes. The typical representative seismic source is so called Shabla-Kaliakra source. According to the maps of the seismic hazard this is one of the most dangerous seismic active sources. Typical example is the earthquake from 1901 – magnitude 7.1, I max (intensity) X EMS. The location of the epicenter is in the sea about 10-15 km from the coast. The earthquake triggered big block subsidence (about 3 km2), large rock falls and landslides and even clear tsunami effects (about 3 meters local sea inundation in Balchik). The source has no clear origin. Some theories suspect the activation of the faults cross-section, another the fault's knot, but the observations did not confirm any of it. The source is characterized by very strong seismic events which occur irregularly, but there are a lot of historical descriptions about ancient strong earthquakes with very high magnitudes, strong destructive effects and triggering other destructive hazards like landslides, stone falls, tsunamis, etc. The destructive potential is very high and preventive, protective and safety measures are essential. The seismic source is one of the most active and hazardous all over the Black Sea coast [Gheorghe OAIE , Antoneta SEGHEDI, Vlad RĂDULESCU., 2016]

- Induced seismicity – some data about man-made earthquakes with magnitude up to 4.5 are observed due to the exploitation of the huge salt body near Devnia. The method of solution extraction is supposed to be a trigger of stress redistribution and small earthquakes generation. The subsidence is also observed.
- Tsunamis. As it was mentioned some local earthquakes can trigger tsunami. The far field tsunamis of seismic origin have been also observed – sources from Crimea, North Anatolian fault, Vrancea, etc. There are data about tsunamis generated by other phenomena – like underwater slides (turbidities), atmospheric disturbances as well as of not known origin. A typical representative event is this one from 7 May, 2007. It created local disturbances of the sea level with amplitude of about three meters. The models calculated on the basis of underwater landslide (because the seismic activity was not detected) as well as of atmospheric origin, does not confirm certainly the source of this tsunami generation mechanism. There are some hypotheses that large gas emissions and mud volcanoes can also trigger tsunamis. The model calculations for some typical cases show that the tsunami height can not go over 3 meters. But other calculations show very specific effect of some local peculiarities of the bottom and coastal geometry, which can focus the tsunami energy to some local places. This could be very dangerous and needs special investigations and modeling. For now the destructive potential is assessed as middle.
- Landslides. Almost the whole area of the Bulgarian northern Black Sea coast consists of large active landslides which are active due to the rainfalls, underground waters' levels changes, triggered by earthquakes, etc. The destructive potential is very high and many roads, buildings and other facilities have been destructed during the historical times (Kavarna case - III c. BC) as well as recent constructions. To the south the Sarmatian lime stones (the main geological reason of the landslide process) are rarer and around Cape Emine the spreading of the active landslides is decreasing. The south part of the sea coast only rare cases can be observed. [Ranguelov B., Radichev R., Dimovsky S., Oaie G., Dimitriu R., Diaconescu M., Palazov A., Dimitrov O., Shanov S., Dobrev N., 2011]
- Erosion on land and on the costal rocks (abrasion) – widely spread all over the coast. Very clear expressed and could be avoided. Low destructive potential.
- Salt waters intrusion and silanization – widely spread and some salty lands are out of exploitation. Low destructive potential
- Floods. Flash floods are frequent event usually related to storms. The can affect the low lands and river estuaries and deltas. High destructive potential.
- Storms. The whole black Sea coast is vulnerable to storms. Surge storms and high sea water levels are frequently observed. Sometimes the sea level increased up to several meters. Wind storms are also frequent. High destructive potential due to the needs to close ports during the wind storms. Hail and snow storms are usual during the winter time. In general - high destructive potential.
- Icing. The northern part of the coast is frequently affected by icing during the winter times. Sometimes even the sea is freezing.
- Natural and artificial (due to the flotation ore processes) radioactivity. Observed on some beaches (for example "Vromos") and waste deposits (for example near Rosen cooper mine)

Nathural Resources (General View From North To South And From The Land To The Sea)

The natural resources (mineral deposit, oil and gas, cool mining, etc.) are extracted from the general map of Bulgaria and show relative high concentration of different deposits in the coastal area – fig.2.

- The Shabla (Kamen briag-Tulenovo) oil deposit. Small block structured deposit which produces still very small quantities of heavy oil.
- Dobrudja cool basin. Deep (~4000 m.) anthracite deposit with significant quantities, but due to the deep location and underground waters wait for innovative approach of exploitation.
- Manganese deposit. Huge deposit near Obrochishte. Mine exploitation. Potential for local people employment.
- Salt deposit near Devnya – base for chemical industry and potential of human employment.
- Gas seeps in the sea, related to the shallow depositions of methane. Predominantly located in the sea and near to the north coast. No industrial quantities are expected.
- The gas deposit Galata. Still produces gas. Some difficulties for the exploitation due to the high content of the abrasive material in the gas substrate.
- Healthy mud. High medically elective mud deposits near Balchik (Tuzlata) and Pomorie. High potential for health tourism.
- Hot mineral waters – wide spread to the north. Due to the Valangine water aquifer of lime stones. High potential for health tourism.
- Sapropel deposits due to the sea plants deposition. Considered as a resource with multiple application to the agriculture, pharmaceutics, etc.
- Sea salt production – open exploitation and production near Bourgas and Pomorie.

- Black Sea cool basin north of Bourgas. Mining activity and exploitation.
- Cooper and multi metal ore deposits south of Bourgas (mines Rossen, Varli briag and Gramatikovo deposits). Ore exploitation since ancient times up to the present days.
- H2S – the sea water contains solution of H2S especially for the depths deeper then 150-200 meters. There are expectations about industrial processing of this resource.
- Gas hydrates. Huge deposits in the sea around the cost. Considered as a huge source of energy. Expectations about industrial exploitation. Needs innovative approach

The main and very large income factor is considered the tourism with all facilities and services. This is a very vulnerable sector of the natural hazards and strongly depends on the natural resources

A comparative table about the natural hazards, natural resources and their relationships and dependencies with the geophysical characteristics

Object	Location (source)	Level of danger	Geophysical characteristics	Indicators (geology & geophysics)
Natural hazard				
a) Earthquakes	Shabla-Kaliakra seismic source (SS) (in the sea)	Very high	Generator of irregular very strong earthquakes (up to M8) with long lasted aftershocks	Historical and recent seismic catalogues and descriptions
b) Earthquakes	Sparse distribution in the sea north and east of Bourgas city	Middle	Magnitude up to 5.5 (Richter scale)	Recent active faults
c) Earthquakes	On land around Devnya town	Middle	Magnitude up to 5.0 (Richter)	Tectonic and anthropogenic origin
Tsunamis	Threaten the whole coastal areas by local or far field tsunamis	Middle	Conservative models calculated up to 3 meters height and hundreds of meters inundation. Local anomalies due to the costal and bottom geometry.	Local SS (Shabla-Kaliakra) Regional SS (Crimea, Caucasus and Turkish coasts) Sometimes atmospheric or turbidities origin
Landslides	Northern (largely distributed along the coast) and southern (much rare) coastal zone	High	Huge volumes, deep layers of sliding - geological origin and gravitational processes	Frequent activated areas up to several hundred square acres. Can be triggered by earthquakes and surface waters
Rock falls	Cliffs areas all over the coast	Low	Single huge rocks and/or avalanche type of gravitational process	Triggered by erosion, abrasion and possibly earthquakes
Turbidities	Underwater avalanche type deposition flows on the continental slope	Low	Mudflows sometimes with huge dimensions developed on the sea shelf	Mainly triggered by earthquakes or other destabilization processes
Salt waters intrusion and silanization	Lowlands on the costal areas, river beds	Low	Changed electrical conductivity	Stalinization of surface layers (sometimes on the land)
Floods	On land (low lands and river beds are more vulnerable)	Very high	Water masses intruded to the land and flash floods in lowlands and river beds	Generated by sea storms (sea waters intrusion) or rain and/or snow melting
Storms.	The whole costal line	High	High wind speeds, sea waters level increase, huge rain and snow	Wind sea storms, storm surges, rain and snow storms on the land and sea.
Icing.	Winter hazard mainly to the north coastal area	Middle	Low temperatures, wind and snow	Freezing areas, disconnection of electricity, sometimes even the sea is freezing
Radioactivity	Areas around the cooper mining waste deposits	Low	Radioactivity over the natural background	Higher radioactivity over ancient mines and recent waste deposits.
Mineral recourses (deposits)				
The Shabla oil deposit	Kamen briag-Tulenovo	Very low	Relatively low reflection to the gravity and magnetic fields	Low reflections to the seismic exploration data
Dobrudja cool basin.	Central Dobrudja	No	Low reflection to the gravity and magnetic	Low reflections to the seismic exploration data

			fields	
Manganese deposit	Near Obrochishte village	Low	Low reflection to the gravity and magnetic fields	Geology evidences about deposits
Salt deposit	Near Devnya town	High due to the induced seismicity	Very high reflection to the gravity field. Low reflection to the magnetic field.	High reflection to the seismic exploration data
Gas seeps	Near and/or deeper to the sea costal area	Middle due to the possibility of inflaming	Bubbles and visible emissions	High relationships with the bottom underwater active faults
The gas deposit "Galata".	In the sea near to the Galata cape	Low	Low refection to the gravity and magnetic fields	High reflection to the seismic exploration
Healthy mud	Tuzlata (near Balchik) and Pomorie	No	No refection to the gravity and magnetic fields	No refection to the seismic exploration data. Visible deposits.
Hot mineral waters	Developed mainly to the north coast (so called Valangian layer)	No	No refection to the gravity and magnetic fields. The Valangian layer is detected by seismic exploration and electro conductivity (VES) methods.	Higher temperature. High electro conductivity and reflectivity to the seismic exploration of the Valangian.
Sapropel deposits	In the sea	No	No refection to the gravity and magnetic fields	Underwater exploration
Sea salt production	Near Pomorie and Bourgas	No	No refection to the gravity and magnetic fields	Visible deposits during the exploitation
Black Sea cool basin	North of Bourgas	Middle	Normal magnetic and gravity fields	Mining activity
Cooper and multi metal ore deposits	Around Bourgas	Middle	Intensive mosaic magnetic field. Positive gravity anomaly. Radioactivity.	Mining activity, waste deposits, ore exploitation high magnetic susceptibility
H_2S	Everywhere in the sea water	High due to the possibility of poisoned environment	Solution in the water, high chemical reduction potential	No life, conservation of objects due to the low O2 content
Gas hydrates	Depositions to the deeper parts of the sea	Low	Anomalous low temperatures and higher pressure	Frozen methane, easy vaporizing to the surface

III. CONCLUSIONS

An integrated research based on the new and interpreted geophysical data and information is performed and reveals the typical geophysical characteristics of the potential geophysical fields on land and in the sea on the Bulgarian Black Sea sector.

The essence of the natural hazards at the same area is extracted and shows high destructive potential, possibilities of multihazards effects and disastrous threats to the area of the coastal communities on the Bulgarian Black Sea coast.

A comparative table created and investigated in depth shows the reflections of the natural hazards to the geophysical fields and discovers systematic peculiarities of positive and sometimes negative correlations. [Ranguelov B., 2011.]

All summarized information seems to be rather useful to the decision makers, local and regional administrations and the scientific community giving the tool for mitigation and sustainable development of the study region.

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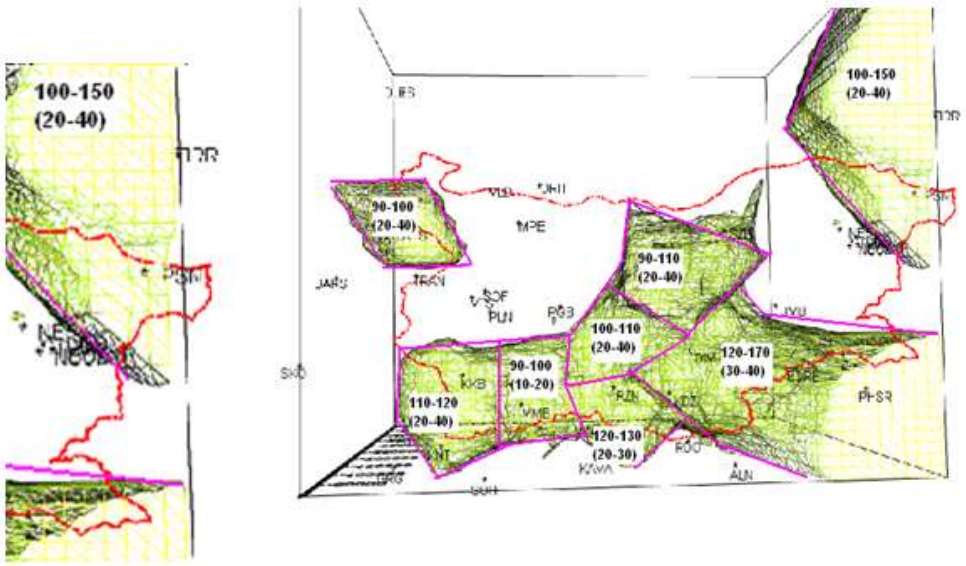

Fig.1 The coast sector – a), and the view of asthenosphere in Bulgaria – b), used in this study.

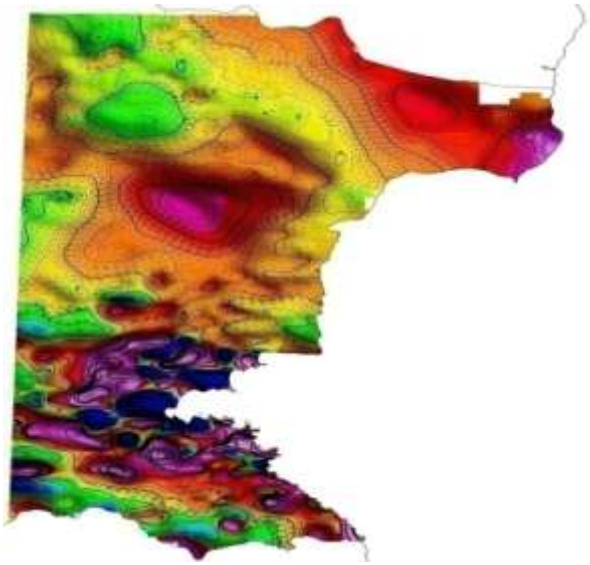

Fig.2. Total vector magnetic field map on land for Bulgarian coastal area

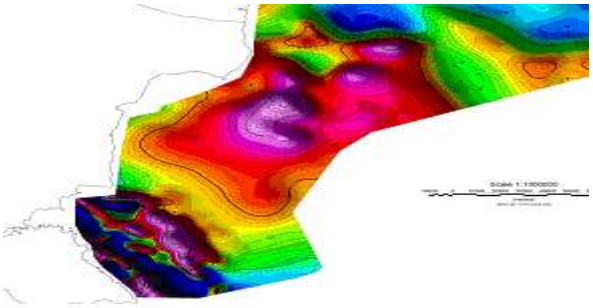

Fig.3. Total vector magnetic field map measured in the sea for Bulgarian coastal area

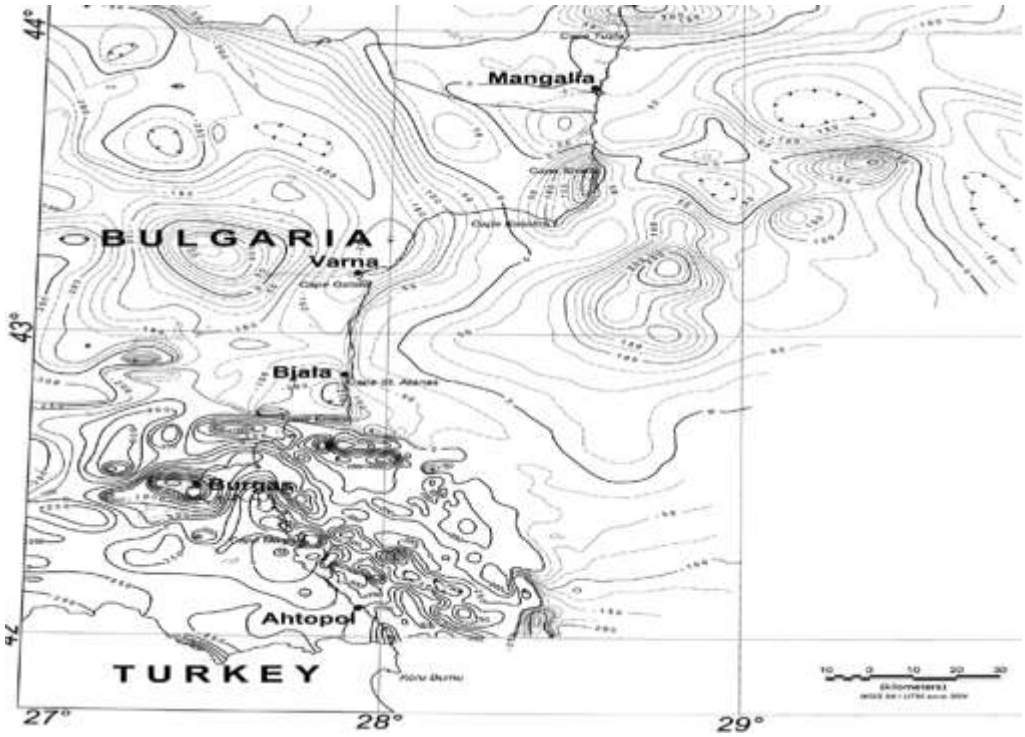

Fig.4. Integrated magnetic filed map. (Radu et al...)

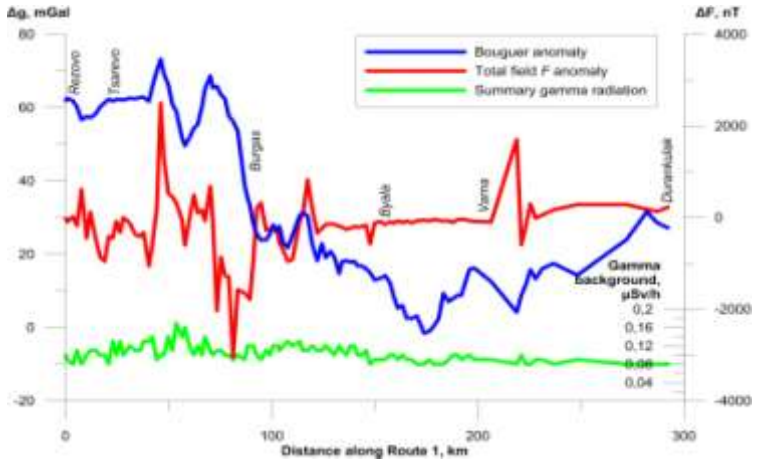

Fig.5. High accuracy measurements profile for Bouguer anomaly, anomalous geomagnetic field ΔF and background gamma radiation along the Bulgarian Black Sea coastline (from Rezovo to Durankulak)

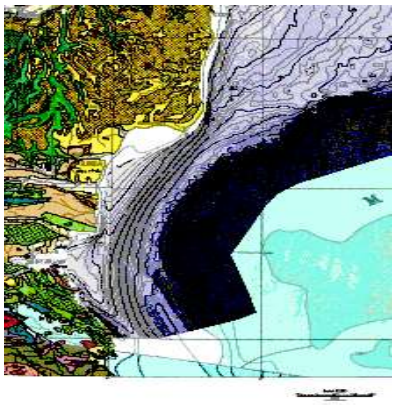

Fig.6. The high resolution bathymetry map (Bulgarian coast) of the deeper then 20 meters bottom of the sea (Black Sea cruise (2013) of the geophysical equipped vessel "Mare Nigrum")

Fig.7. Seismicity map (1965-2018) as from USGS files.

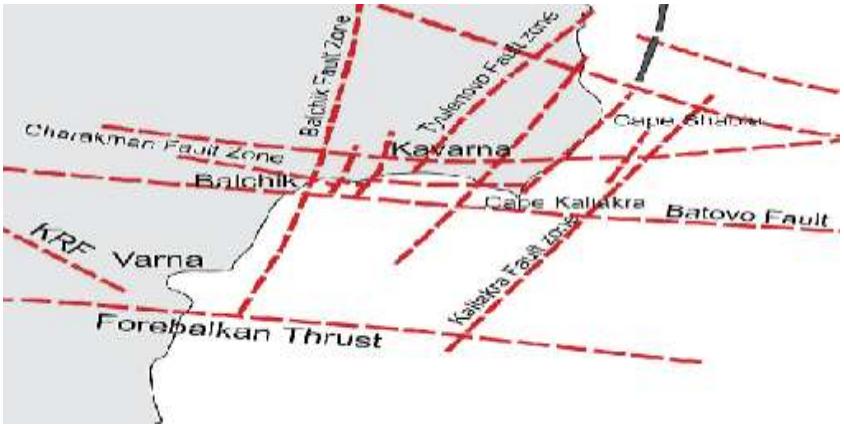

Fig.8. Recognized faults, fault crossings and faults knots.

Fig.9. Survey area, seismic-acoustic profiles, faults, recognized by sesimostratigraphy interpretations (Dimitrov O., A. Vasilev 2016)

Legend: 1 – epicentre of an earthquake and a number showing the magnitude of the earthquake (showing the known earthquakes over the period 1900–2010); 2 – single gas vents with high capacity (gas flares); 3 – polygons, white-line outline of areas with BSR (areas with gas hydrates – project BLASON); 4 – diamonds - groups of gas vents found in expeditions RV "Academic" in the period 2010–2015; 5 – geothermal stations and values of the heat flow [mW/m2]; 6 – thin and thick black lines – faults lines; 7 – thick gray lines — inner fault zone; 8 – vents; 9 – negative numbers along contour lines – depths and isobaths; 10 – red lines – tracks of the seismo-acoustic profiles; 11 – yellow square – groups of gas vents with data from (Egorov V.N. et al 2011)

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