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Archaeoseismological Studies for the Northern Bulgarian Black Sea Coast

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Abstract
New data and information about the ancient seismic events affected the archaeological sites on the Northern Bulgarian Black Sea coast are observed, collected and interpreted. Almost all seismic effects to the investigated archaeological sites, structures (excavated or surface), or rocks are expressed as fallen stones or bricks or cracks, or different deformations to the possible epicenter. The calibration curve derived from the macroseismic map of the M7.2 seismic event of 31st March, 1901 is used for the investigated objects to transform observed seismic effects to the intensities. The variations in distances and respective intensities cover the observed effects and give the possibility of eventual reconstruction of the acting forces, their directions and correct interpretation of the observations. The proved of the suggested interpretations confirmed the seismic effects to the investigated objects. In total eight historical and archaeological sites on the Northern Bulgarian Black Sea coast have been investigated.
Key words:*historical earthquakes**,** seismic effects**,** archaeological data, archaeoloseismological studies, Black Sea coast*

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I. INTRODUCTION

The paper deals with the new data collected during the summer expedition to the northern part of the Bulgarian Black sea coast. The archaeseismological studies are based on the developed methodology for the identification of the seismic effects to the archaeological objects.

The methodology in this study is limited due to the specifics of:

- Earthquake source location in the sea
- The multihazards chains of disastrous events (earthquakes, landslides, water level changes, tsunamis, surge storms, etc.) frequently affected the ancient inhabited areas repeatedly [Ranguelov et al., 2008, Ranguelov and Nikolov, 2008]
- Archaeological excavations and disclosures of the preserved sediments, destructions and disturbances to the structures of the investigated objects limited in space and time.
- Lack of the possibility to organize expected archaeoseismology research and excavations when necessary mostly due to the financial reasons.
- Removal of the deposits during the excavations (this is a common archaeological practice, which frequently eliminated many signs of disaster affection to the historical and archaeological sites)
- Seismic source formalization, based on known past earthquakes and seismic zoning maps of Bulgaria
- New interpretation of the seismic source formalization targeted to this study
- Use of the referent seismic event (M 7.2, 31st March, 1901) relatively well documented with an extended macroseismic map.
- Construction of the Table with distances, azimuths and intensities related to the investigated archaeological sites and created for the interpretation's purposes.
- Dating – based on seismology and historical descriptions, archaeology data, information, artifacts, etc. for the time assessment of the observed seismic effects.
- In total eight archeological sites have been investigated for observed seismic and similar effects, intensities assessed, possible seismic sources identified and uncertainties outlined.

Short historical summary to the seismicity of the region

There are a lot of studies related to the northern Bulgarian Black Sea coast earthquakes. [Ranguelov, Gospodinov, 1994; Ranguelov, 1996; Ranguelov, 2011; Ranguelov, 2013, etc.] The seismogenic area Shabla-Kaliakra is the main source of the strongest earthquakes occurred during the historical times. Several events with the magnitude 7 and above occurred in this area creating a lot of destructions, victims and many secondary effects accompanying such high energy seismic events – Table 1.

Table 1. Earthquakes in Shabla-Kaliakra seismic zone with M>5 since ancient times to the present days (according to the Balkan Catalogue, 1972 with some modifications)

Year	Month/Day	Time	Lat(E)	Long(N)	Depth	M
46-45 c.BC			(43,5?)	(28,3?)	20(?)	7.6 (?)
3rd c. BC			43,4	28,4	20	7,0
543			43,5	28,3	20	7,6
1444	XI		43,2	28,1	20	7,5
1832			43,4	28,7	14	6,5
1858	I / 8	01:15	43,4	28,7	20	5,2
1869	I / 10		43,6	28,7		6,5
1901	III /31	07:10:24	43,4	28,6	14	7,2
1901	III /31	11:30	43,6	28,8	25	5,0
2009	VIII/5	7:49:27	43,38	28,77	8	5,0

Despite the relatively well documented catalogue data about the local seismicity, a lot of unknown and not proved facts exist, especially related to the ancient seismic events. This area is famous with the development of multihazard natural disasters such as:earthquakes, landslides, tsunamis, floods, storm surges etc., frequently generating each other and thus creating so called domino effects [Ranguelov, 2011; Ranguelov, Dimitrova, 2004; Ranguelov et al 2006, Avramova-Tacheva, Dobrev. 2007, Dobrev et al., 2017, Berov et al., 2011]. Because of its location on the Black Sea shore the area was inhabited since very ancient times. Due to this a lot of historical descriptions exist about different hazardous events observed since a long time ago. Such situation combined with the earthquake source located in the aquatory of the sea creates still a lot of interest especially among the specialists in seismology, geodynamics, geomorphology, seismostratigraphy and archaeology.

So, the combination of the multidisciplinary approach is absolutely necessary to solve a lot of complicated problems related to the better documentation of occurred events, their consequences to the society and the prognosis of the possible future disasters, which can affect this highly populated area with developed infrastructure, tourism and marine and industrial activities.[Ranguelov, 2015; Radiches et al., 2015].

II. METHODOLOGY

To combine the natural hazards approach with the archaeology, the previously developed methodology was used [for examp.:Ranguelov, and Bojkova., 2008; Ranguelov, 2008, Ranguelov, and Nikolov, 2009; Paneva, and Ranguelov., 2011].

The methodology in this study was limited due to the specifics of:

- Earthquake source location in the sea.
- The multihazards chains of disastrous events (earthquakes, landslides, water level changes, tsunamis, surge storms, etc.) frequently affected the ancient inhabited areas [Ranguelov et al., 2008;Ranguelov and Nikolov, 2008].
- Archaeological excavations and disclosures of the preserved sediments, destructions and disturbances limited in space and time, due to the lack of funds for extended arhaeoseismology research when necessary.
- Removal of the deposits during the excavations, which almost always eliminated all signs of disaster affection to the historical and archaeological sites.

According to the developed archaeoseismological studies in Bulgaria the following methodological topics were applied in depths to support this study:

- Data collection by fieldobservations, measurements, documentation, interpretation and seismic intensity assessment
- Seismic sources formalization, based on known past earthquakes and seismic zoning map of Bulgaria – fig.1. and fig.2. [Bonchev et al., 1982]
- New interpretation of the seismic source formalization – fig.3.A) and B)
- Use of the referent seismic event (M7.2 31stMarch, 1901) relatively well documented with an extended macroseismic map – fig. 4, good description of the effects of this strong event (secondary effects generated by it – subsidence, rockfalls, landslides, tsunami, etc.- and their influence to the environment) to create the calibration curve – intensity vs. distance [Ranguelov, 2011, Ranguelov and Nikolov, 2009].
- Creation of the calibration curve itself, considering the sea location of the epicenter, the azimuth distribution of the intensities, intensity attenuation, destructions and disturbances, etc. – fig.5.
- Selection of the most affected part of the coastal area with the investigated objects– fig. 6.
- Construction of the Table 2. with distances, azimuths and intensities related to the investigated sites and created for the interpretation's purposes.

Table 2. The distance to the boundary points of the idealized seismic sources, azimuths and the observed intensities with possible dispersion according to the calibration curve.

Site	Distance to 1(Azimuth)	Distance to 2(Azimuth)	Distance to 3(Azimuth)	Distance to 4(Azimuth)	Distance to 5(Azimuth)	Imax (+/-I)
Durankulak	40 (125)	47 (215)	43 (170)	70 (193)	55 (143)	IX(+X, -VIII)
Kamen Bryag	32 (90)	33 (243)	19 (165)	40 (203)	37 (124)	X (+X, -X)
Kaliakra	40 (75)	22 (256)	14 (124)	36 (200)	40 (104)	X (+X, -X)
Kavarna	49 (85)	16 (225)	26 (125)	42 (183)	51 (110)	IX(+X, -IX)
Balchik	64 (86)	10 (163)	39 (112)	44 (163)	66 (105)	IX (+IX, -IX)
Kastrici	82 (70)	20 (53)	50 (80)	32 (121)	70 (85)	VII (+VIII, -VII)
Varna	88 (72)	25 (65)	57 (82)	38 (121)	83 (86)	VII (+VII, -VII)
Provadia	125 (75)	63 (75)	95 (82)	71 (100)	121 (85)	VII (+VII, -VII)

- Dating – based on seismology and historical descriptions, archaeology data, information, artifacts, etc. for the time assessment of the observed seismic effects.

The created methodology gives the possibility to an objective assessment of the existing information, the extraction of the most valuable data, the correct interpretation of the observed facts and maximum elimination of the subjective considerations [Ranguelov, 1998; Glavcheva, Dimova et al., 2006]. Using such methodology and applying the established relationships the following results and discussion are concluded.

Results and discussion

The following archaeological sites have been visited, observations made and interpretations done according to the described methodology

1.Durankulak

A Neolithic site excavated many years ago [Берчу, 1963; Димов, 1992]. A lot of artifacts are discovered and well dating is performed.

Most of the structures are renovated and some seismic effects on the structures are eliminated by the reconstructions and are not recognizable. There are few stones broken from the rocks and fallen down to SE direction – Pic.1.1. The only remarkable stone block is almost underwater to the S-SE and seems like a Cyclops' structure [remains of the Cybele temple] – Pic.1.2. and Pic. 1.3.

The average distance from the idealized seismic source is about 40-45 km with dispersion between 40 and 70 km.

According our interpretation and the calibrating curve, the intensity affected the site was at least 10-9 EMS. Thus this site is considered probably affected by the earthquake of 4600-4500 years BC – the event which destructed the Provadia-Solnicata site [Ranguelov, Nikolov 2009]

2. KamenBryag (Yailata)

One of the closest to the sea located Shabla-Kaliakra source is this natural phenomena consisting of a bunch of stone falls geologically related to the Sarmatianlimestones. The average distance is about 20 km with dispersion between 30 and 40 km. This means that the site is potentially very strong affected by any strong seismic event in the past attributed to the established seismic source (Shabla-Kaliakra) and its segments.

The seismic effects are expressed by huge stone falls to different directions mostly to the East. Pic. 2.1. The archaeological excavations [Торбатов, 2002] are recently reconstructed and very few effects are visible – Pic.2.2

As this is one of the closest to the source site, the observed intensities are frequently about 10 EMS, but the dating of the seismic effects is extremely difficult. Most probably the site is affected by a number of earthquakes accumulating destructive effects and disturbing the unstable rocks around.

3. Kaliakra Cape

This is the most impressive geomorphology structure in the region. Very high cliffs elongated to the South (sometime reaching 50-60 meters) are surrounded by the sea. The very ancient archaeological site [Лазаров 1976; Бонев, 2003] with a medieval bastion are strongly excavated and renovated.

Unfortunately almost all seismic effects and evidences are eliminated and very few remained - Pic 3.1. But due to its morphological position of the slopes, the stone and rock falls indicated a lot of strong seismic forces acted over there –.Pic 3.2. The average distance to the seismic source is less than 15 km (this is the reason to call the source as Shabla-Kaliakra) with dispersion between 20 and 40 km. The most frequent seismic intensity according the observations in the past is 10-11degree EMS. There are the only well expressed geologically seismogenic faults structures visible clearly to the slopes and the flanks of the almost vertical rock walls. – Pic 3.3. The seismic effects are integrated and it is almost impossible to date the time of affection. The witnesses' descriptions of the secondary effects of the M7.2 earthquake on 31 March, 1901 expressed rock and stone falls, huge subsidence around Bulgarevo village and tsunami effects.

4. Kavarna

One of the best preserved morphological evidences about the chained complex destructive events and domino effects registered by the chroniclers is the Chirakmana plateau [Мирчев, 1962].

The reconstructed chain of the destructive events could be found in the descriptions of Strabo and other ancient chroniclers (Demetrius Calatius). They said that the whole old Greek colony of "Bisone (present Kavarna town) sank in the waters of the Black Sea". The dating of this event is still questionable, but the most recent historical investigations show the approximate time of about 3rd century BC. The recent reconstruction of these hazardous events is that a shallow earthquake 3rd c.BC triggered a huge landslide (clearly visible at present days – Pic 4.1.) which dragged the whole ancient port facilities under the sea level. Present days divers can discover the remains of these facilities to the depths of 7-8 meters. The morphology of the slide masses shows the link with the Chirakmana exposed to the sea rocks. This is one of the most destructive ancient events, also triggered tsunamis [Papadopoulos et al, 2011].

5. Balchik

An ancient town Dionisopolis is well known from the descriptions of the old chronicles – Strabo, Demetrius Kalatius, Plinius, etc [Мирчев, 1962]..

The town is famous with the largely spread huge landslides, most of them reaching the sea. The archaeological site – Cybele temple is the best example of the chain of destructive events occurred in 543-545. Some of them (a tsunami and an earthquake occurred that time) have been mentioned in several publications ([Guidoboni et al, 1994, Ranguelov, 2008, Papadopulos et al, 2011)].

The multihazard events triggered each other or occurred in the very narrow time interval are as follows (according the Cybele temple destruction and buried ruins [Ranguelov, 2008]. Initially the fire burned the roof of the temple (most probable wood construction), then an earthquake (approximate magnitude 7.5?) cracked the walls (visible cracks and displacements to the excavated walls) and put down some of the stellas inside the temple (broken stella found on the floor of temple together with others). The tsunami approached the temple and deposited a tsunami deposits (disturbed sand and shells of the sea mollusks with almost constant thickness over the floor). The temple was almost ruined and then very fast covered by a landslide, preserving in this way the remaining parts of the structure, as well as all artifacts discovered after the excavations. The scenario of these multihazrdous events is presented on Pic. 5.1. All data about these events have been collected during 2007 archaeological excavations of the temple. Most probably the temple was used from the 3rdcentury BC to the 5-6thcentury AD and we considered the time interval with the relatively calm seismicity (regarding strong (M>6.0) local earthquakes produced by the local seismic source Shabla-Kaliakra. According the calibration curve the average epicentral distance is about 40 km and the dispersion from 10 to 65-66 km. The observed intensity of the 543 AD event is about IX and from 1901 (M7.2) event – also IX.

6. Aladja Monastery

There are two hypotheses about the foundation of the rock carved monastery. The first is that the monastery is established during IX-X century. The second one more supported by different artifacts and historical descriptions is that the establishment was considered as of XII-XIII century. The analogy of the different structures of the monastery with well known and well dated similar objects supported this hypothesis [Гръцки…1965; Попконстантинов et al, 2005] .

The ascetic cells are located about 8-12 meters above the available heights and probably the supply to the monks have been provided by ropes.

Unfortunately all archives of the Monastery are not preserved. The visual examination of the possible seismic effects to the walls of the cells and chapels do not provide clear information about significant seismic influences. This is probably due to the solid and massive rocks and the fact that structures are in the rocks, where the seismic influence is usually reduced. This was confirmed after the 1901 seismic event, when no significant effects have been observed. The average epicentral distance is about 40-45 km and expected intensities from the closest seismic sources is about IX EMS.

7. Kastrici (Evxinograd)

This castle has been established in V-VI century AD as Byzantium military point. It was destructed in 614 by barbarians. At the end of XII-XIII century the castle was renovated and extensively developed due to the Venetian invasion. The first map (1321) mentioned the town named Kastrici. The town was well developed military and trade center [Плетньов et al 2009, Плетньов et al, 2010].

The recent archaeological excavations are targeted to the medieval town, bastions and castle walls [Плетньов, 2006].

At the beginning of XV c. the intensive life in the town is surprisingly ended. We explore possible reason for the end of life due to the earthquake destruction, followed by an epidemic event. A lot of reconstructions have been performed – visible on the Scheme of the excavations - Pic.6.1 and it is very difficult to find signs of past seismic effects generated by past earthquakes.

During the filed expedition a lot of fallen stones, walls and bricks from the houses and other facilities have been observed in situ – Pic 6.2. The direction is to the E-NE, i.e. to the seismic source. From historical description is derived the information about 1444 strong seismic event, most probably affected the town and reflected by these disturbances. Moreover – some cracks, destructions and displacements on the castle walls are also observed. Pic.6.3.

The average epicentral distance is about 50 km with dispersion from 20 to 80 km. The observed intensity is between VII and VIII EMS. The interpreted data coincide with the fieldobservations and can be considered reliable.

8. Varna (Monastery St. Bogorodica– Karaachteke)

A large monastery complex is located to North of Varna on a plane in the footnotes of an active landslide: length about 260m, width -170m and area coverage about 3 ha located at the hypsometric levels between 185 and 230 m. The landslide is probably formed before the building of the monastery complex. - Pic 7.1. The observed archeological data (discovered structures, walls, fundaments, columns, etc. did not give a possibility to consider them affected by the landslide during the active life of the complex. Local small slope activity is presented even today. The described landslide is probably a part of the larger unit, located at the mountain slope between Kamenar village and Vozrajdane quarter of Varna. There are some indications (old chronics) about seismic influence with E-W direction. The possible source could be considered as Shabla-Kaliakra zone or alternatively by the active fault 23 established by seismostratigraphy methods and described in the Seismotectonic model of the Bulgarians sector of Black Sea coast [Dimitrov et al 2005].

The massive walls look not disturbed by the seismic effects and no displacements on the row of walls can be observed – Pic. 7.2.

Some fallen stones can be attributed to the seismic effects but very uncertain. – Pic.7.3

The average distance to the seismic source is 55-60 km with dispersion from 25 to 90 km. Most probably the nearest segment of the seismic source had not been activated during the last times, because there are no significant seismic effects to the city of Varna, which are established there since centuries. The expected maximum intensity is about VII EMS.

9. Provadia

Provadia – Solnicata archaeological site does not belong to the coastal sites, but can serve as well documented and investigated area with observations supporting the applied approach. Data and results obtained show the possibility to reconstruct the source direction, to assess the observed intensity (respective epicentral distance and magnitude) and to date reliable the time of occurrence of the affecting seismic event [Ranguelov, Nikolov, 2009]. Well reconstructed effects, time dating and azimuth confirmation of an ancient earthquake, also helps to consider effects to the Durankulak site as well documented and reliable assessed to the seismic source from another side of the affected area. The Solnicata is located to the S-SW direction (95 km) and the Durankulak to N-NW (40-45 km). Both have approximately one and the same age of affection. This means that probably a single seismic event affected both sites during 46-45 century BC.

As a general result summarizing the new observations and the known earlier data about the documented strong earthquakes and their effects, intensities and generated secondary effects in the area of the Northern Black Sea Bulgarian coast, a Table was created considering the new data and previous knowledge and interpretations.

Table 3. The known earthquakes of the north Bulgarian Black Sea coast and confirmations of their effects by the last (2018) investigations to the archaeological sites.

Year	Month/Day	Time	Lat(E)	Long(N)	Depth	M	Confirmation	Site
46-45							Confirmed	Durankulak, Provadia
c.BC			(43,5?)	(28,3?)	20(?)	7.6 (?)		
3rd c. BC							Confirmed	Kavarna
			43,4	28,4	20	7,0		
543			43,5	28,3	20	7,6	Confirmed	Balchik
							Uncertain	Kastrici,Varna
1444	XI		43,2	28,1	20	7,5		
							Uncertain	Kaliakra, KamenBriag
							(Integral effect?)	
1832			43,4	28,7	14	6,5		
1858	I / 8	01:15	43,4	28,7	20	5,2	No	
							Uncertain (Integral effect?)	Kaliakra, KamenBriag
1869	I / 10		43,6	28,7		6,5		
							Confirmed	Kavarna, Balchik
1901	III /31	07:10:24	43,4	28,6	14	7,2		
1901	III /31	11:30	43,6	28,8	25	5,0	Uncertain	Balchik
							Confirmed	Kavarna, Balchik
2009	VIII/5	7:49:27	43,38	28,77	8	5,0		

III. Conclusions

- There are a lot of effects observed and proved on the archeological sites, paleoseismic and recently active faults and their activated segments, which could be considered as sources of the seismic effects to the investigated archaeological sites and objects.
- The most difficult to assess parameter is the time of the seismic event, affected the respective site and structures. The timing could be improved by larger cooperation between seismologists and archaeologists.
- Frequently integrated effects of several seismic events are impossible to separate, because of the lack of written descriptions.
- These uncertainties need wider cooperation between seismologists, archaeologists and other specialists to solve the existing problems.

The present study has been conducted in connection with the implementation of two projects:

1. "Research of the Consequences of Strong Earthquakes in the Coastal Areas of Bulgaria and the Taman Peninsula - West Caucasus, Aiming a New Assessment of the Seismic Risk in these Regions" under the program for bilateral cooperation between Bulgaria and Russian Federation. Funded by the Research Fund (Contract №DNTS / Russia 02/20 of 25.06.2018. and RFBR18-55-18014Болг_а)

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The authors - declarations of interest: none.

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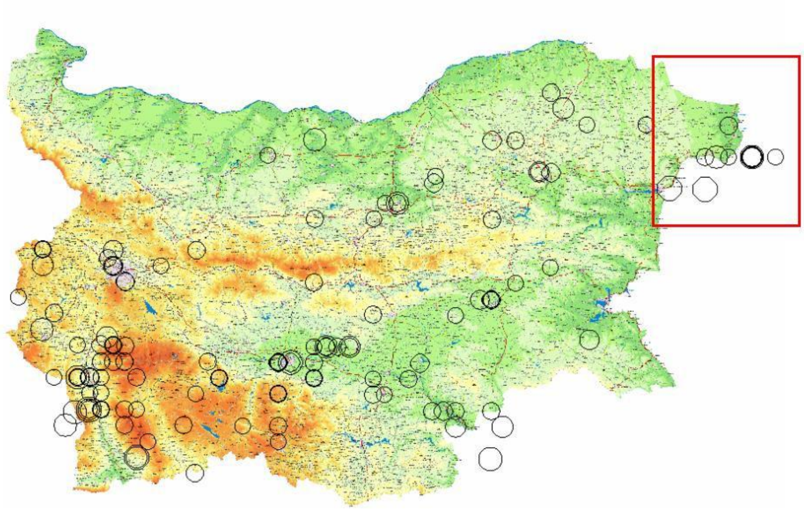


Fig. 1. Studied area(redquadrangle) and epicenter of allearthquakes withmagnitudeM>5 known in Bulgariasinceancient times[Bonchevet al., 1982]

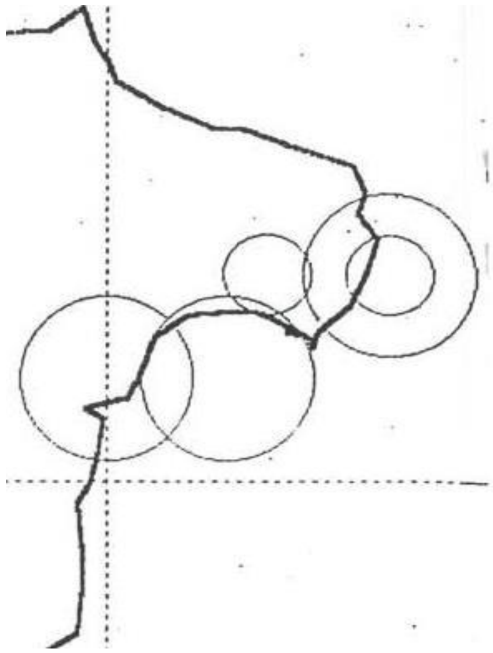
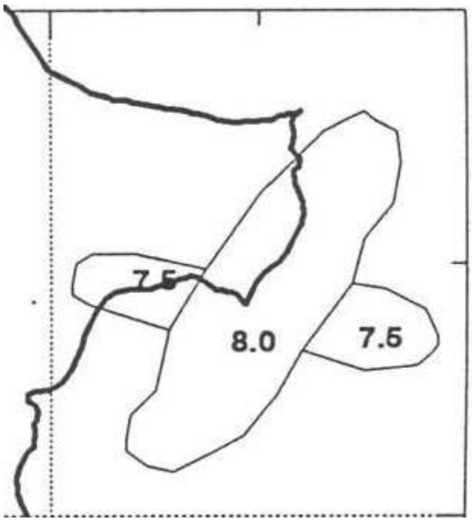


Fig.2.Historical earthquake epicenters accordingseismic zoningmap ofBulgaria[Bonchevet al., 1982]



A)

B)

Fig.3.Formalized seismicsourcesaccordingseismiczoningmapof Bulgaria [Bonchevet al., 1982]-A), and the edgepoints of theformalized seismic sourceShabla-Kaliakra accordingour interpretation-B)

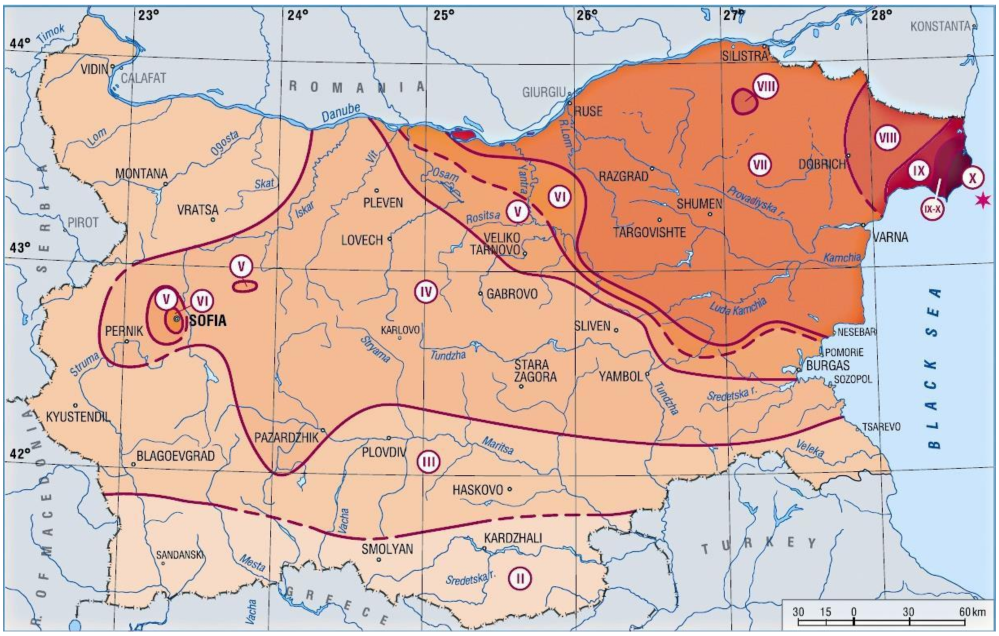


Fig.4. Macroseismic mapof the31stMarch, 1901 referent seismic event (M7.2) [Ranguelov, 2011]

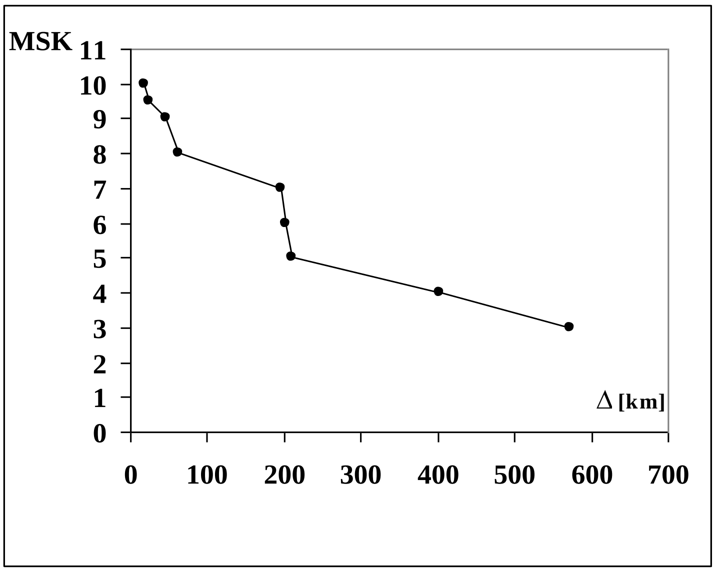


Fig.5. Calibration curve Intensity (MSK) vs Distance (km) for the real earthquake of the 31st March, 1901 (M7.2)

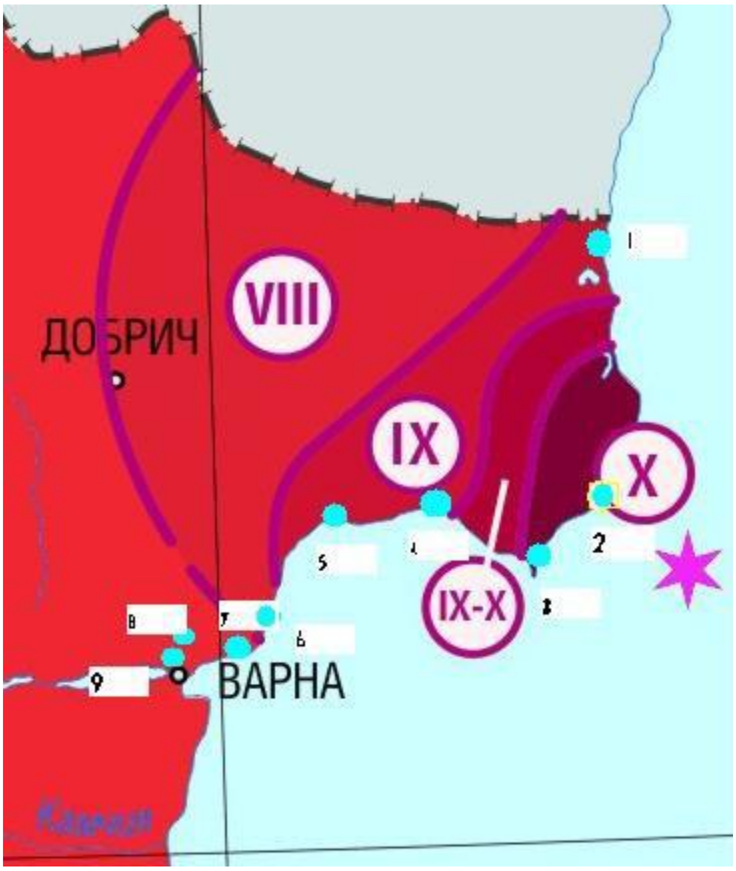
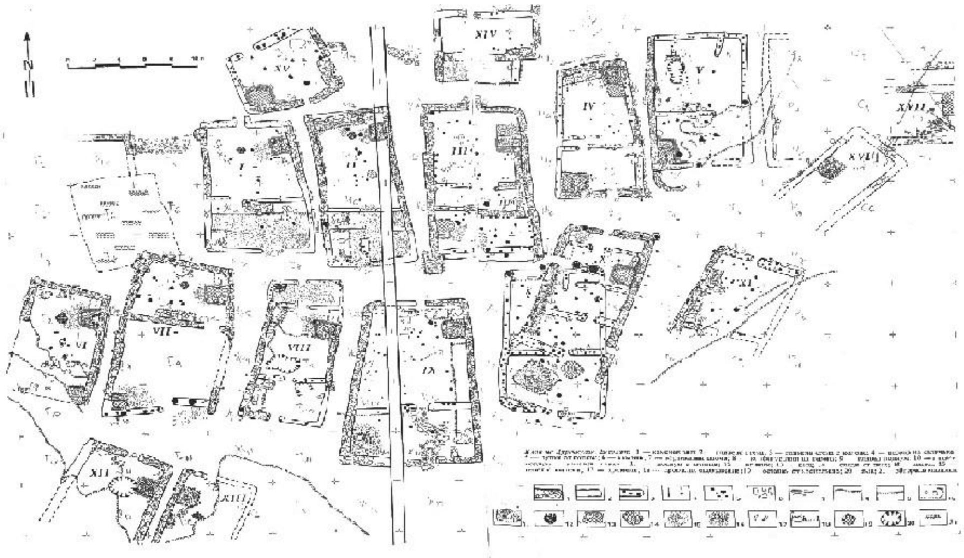


Fig.6.Theisoseismals (Roman numbers)of thedestructive earthquake(M7.2, 31st March 1901)with the archaeological sites on the coast (black Arabicnumbers) (Варна – Varna; Добрич – Dobrich)

Pic. 1.1 Durankulak fallen stones

Pic. 1.2 Durankulak – remaining of the Cybele temple

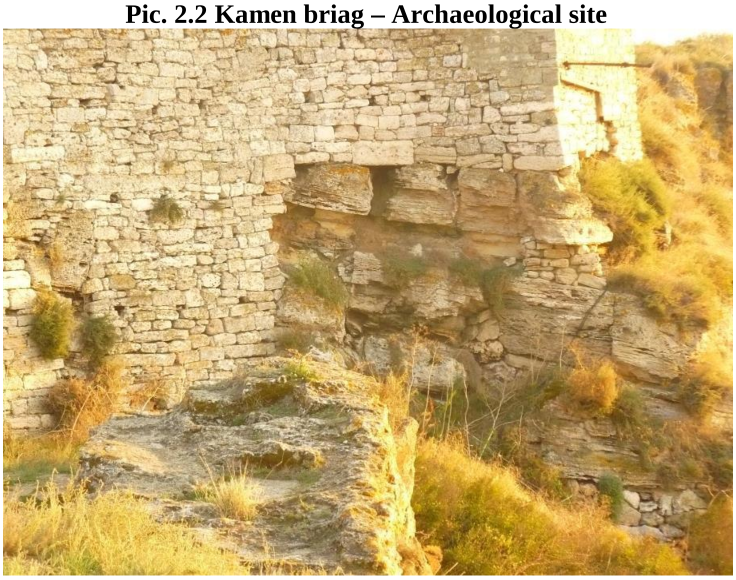
Pic.1.3. Droneviewof the archaeologysite– the block is marked withyellow and the areaof fallenrocks byred ellipse



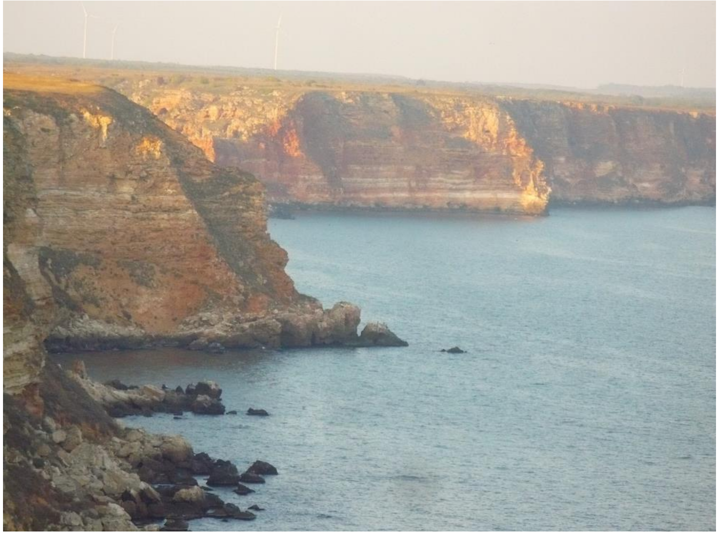
Pic. 1.4. Archaeologysketch ofthe initial excavations.

Pic. 2.1 Kamen briag - stone falls

Pic. 2.2 Kamen briag – Archaeological site



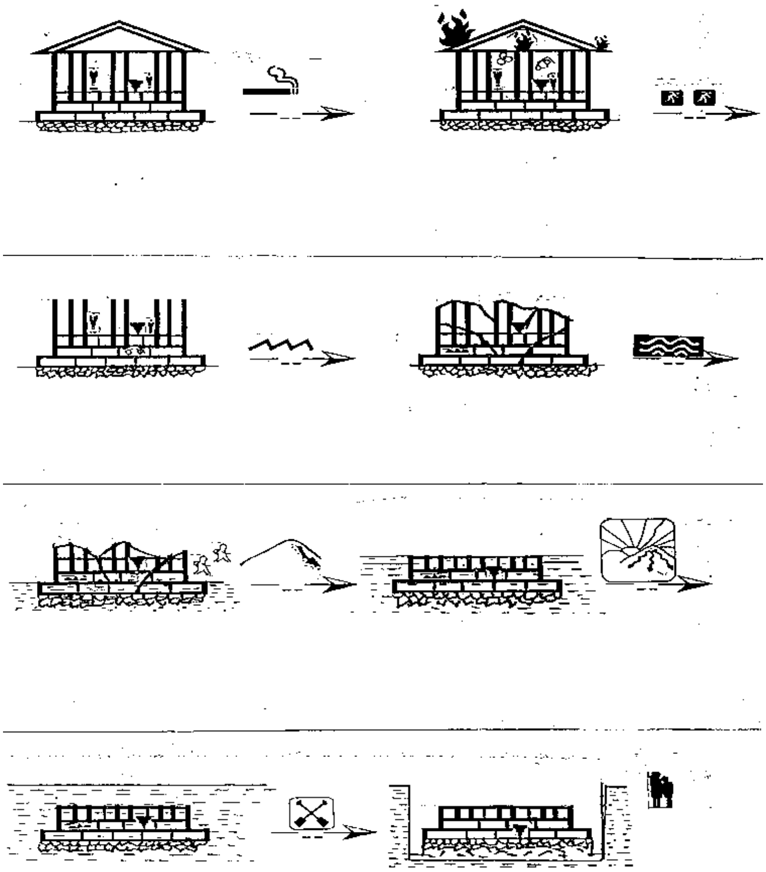
Pic. 3.1 Kaliakra – ancient and reconstructed walls



Pic. 3.2Kaliakra - morphostructures

Pic. 3.3Kaliakra – visible faults

Pic. 4.1 Chirakmana plateau near Kavarna and traces of the huge landslide.

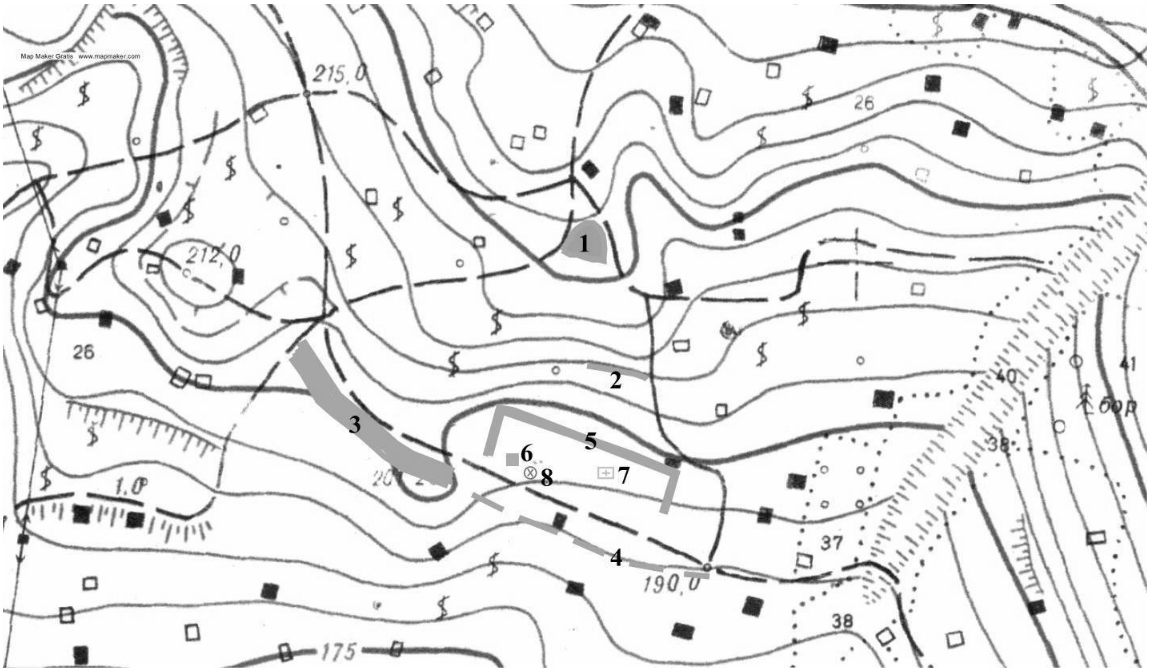


Pic. 5.1 Scenario of the Cybele temple (in Balchik) destruction and preservation.

Pic. 6.1Late Antiquity and MedievalFortress "Kastritsi" – Varna
Общ план - General plan

Pic. 6.2 Kastrici – fallen stones

Pic. 6.3 Kastrici – ancient displacements



Pic. 7.1.
Markings: 1 - Head of the landslide, 2 - Sand slope, 3 - The preserved part of the sliding shaft, 4 – Asupposed existed in the past extension of the landslide embankment, 5 - The eastern, northern and western walls of the monastery complex, 6 – The monastery water source, 7- A monastery church, 8 – Contemporary catchment.

Pic. 7.2 Monastery (Karaachteke) – view to the lanslide

Pic. 7.3 Monastery (Karaachteke) – ancient displacements

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