

Modern tectonic events in near-bottom sediments of the Middle Caspian Sea

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ABSTRACT

The Central Caspian western border is a seismically active region with contrasting combinations of mountain clinoforms and troughs. Intense troughing started here at the end of the Pliocene and remained uncompensated by sediments. Using high resolution seismoacoustic profiles associated with earthquake catalogs and also some additional data, this study investigated the correlation between modern seismic events and deformation structures in the seabed sediments of the Derbent Basin in the western part of the Middle Caspian Sea. The results showed that the seismic activity and the sediment disruption vary across the basin, and can be classified into four areas: single deformations, western slope, deep basin north-east area, and deep basin south area. The study revealed that the Caspian Sea is a tectonically active region, and that the seismic events can trigger high pressure and hot fluid to seep through the weak zones in the sediments. This paper also presents some interesting observation on seismoacoustic profiles including tens of disruptions in sediment structure and disjunctions in seafloor relief, fault groups, gas pipes, and horizontal zones of non-correlation.

1. Introduction

Caspian Sea is a hydrocarbon basin of great value. But there is a great variety of exploration problems as well. One of the problems is microseismicity and shallow tectonic movements. Every natural process is responsible for some geological forms, which could be seen on seismic sections. North and Central Caspian Sea shows distinct zones of different geological environments, which are connected with different geohazards [1, 2]. Assessment of the stability of the Quaternary sediments on continental slopes in the Central Caspian Basin has high practical value in light of intense hydrocarbon surveys and exploration. In the Central Caspian with medium water depths around 400 m, mainly the pipeline projects are facing with the problems caused by natural geohazards in compare to the construction projects. The fields are in the center of the Sea with a relatively calm environment but pipelines have to be stretched long routs along seabed with different sediments, geological features and various natural processes which usually associated with hazardous conditions. For a pipeline project, it is very important to investigate slopes stabilities and sediment transport pattern along pathways of the pipe [3].

Modern tectonic movements lead to deformation both in sediment cover as a whole and in local near-bottom layers. In addition to powerful earthquakes which is well known that can trigger submarine huge mass movements, mud volcanoes and etc., repeatedly occurring earthquakes with low magnitude (<6) may activate different types of landslides and mudflows in seabed [4]. The Central Caspian area is considered as seismically active area with powerful earthquakes reported in the western border in Caucasus mountains, but most of the earthquakes occurred in the Derbent basin have magnitude less than 6 on the Richter scale [5, 6] The aim of this paper is to establish connection between already-known sediment forms and geohazardous processes of microseismicity and modern active tectonics in the central Caspian Basin.

2. Physical Setting

The Caspian Sea has the Caucasus mountain system on the west, the vast steppe of Central Asia on the east, the Russian platform on the north and the Alborz Mountains on the south. The sea has no connection with World Ocean, but is too large (1200km x 300km) to be called a lake. The present water surface is 28 m

below the world ocean level. Geomorphologically, the Caspian Sea can be divided into three regions (fig. 1).

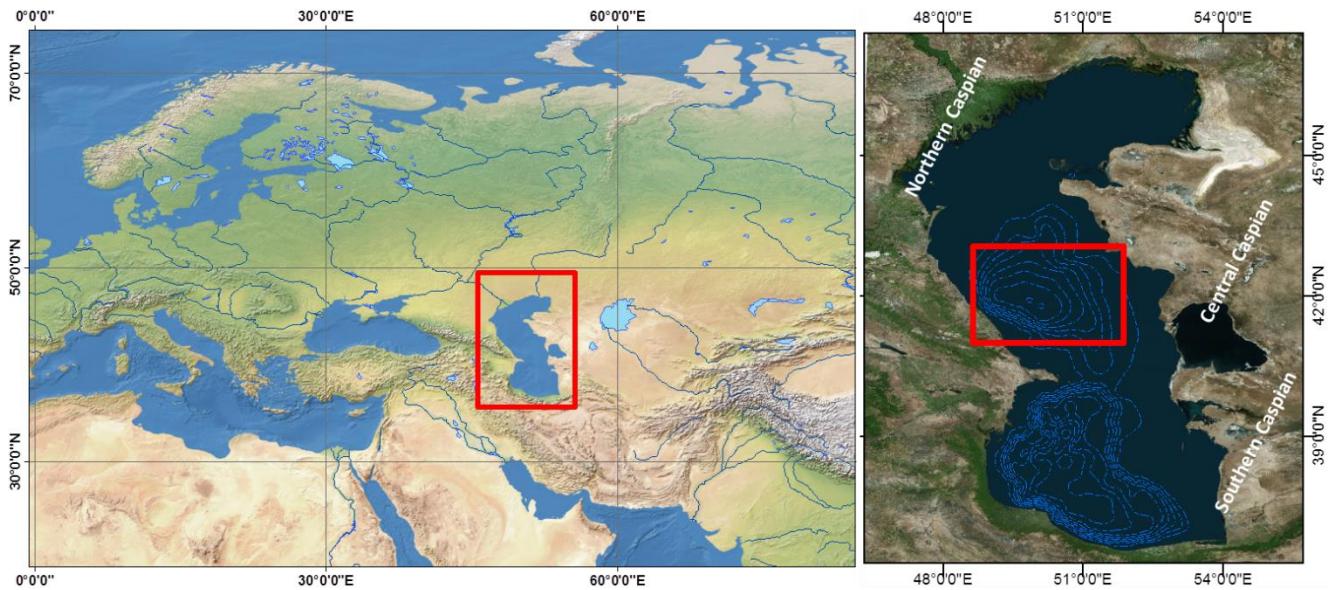


Figure 1. The position of the study area in the Caspian Sea.

The boundary between the northern and central parts is the Mangyshlak Threshold (a large sediment body) and between the central and southern parts is the Apsheron threshold (a tectonic sill).

The Middle Caspian Depression that has been considered in the present study is quasi-oval shape, extending in a NNW direction over a distance of 450 km with wide of 100-200 km. It is characterized by a slightly steeper near-Caucasian slope, with the deepest part also shifted towards the Caucasus Mountains. The depression is filled with Jurassic-Quaternary sediments up to 8–10 km thick with a maximum thickness registered in the band adjacent to the Dagestan coast. The sedimentary cover is underlain by a partly deformed Permo-Triassic rock complex and metamorphosed basement of Paleozoic and, probably, older age. The crust beneath the Middle Caspian Basin is approximately 40 km thick, whereas the thickness of the lithosphere is 150 km [7, 8].

The Caspian depression crosses structural elements of different origins. The seismogenic zone distribution correlates well with fields of modern tension in the Caucasus region and with the most likely directions of lithospheric mass movement (mostly northwest) [9]. The Central Caspian has relatively high seismicity because its western border is the seismically active Caucasus mountain system. The earthquake magnitude on the western slope can reach 6-7 on the Richter scale [5].

Based on the pattern of earthquakes below the borders of modern structures, Ivanova and Trifonov [10] distinguished several seismotectonic areas on the Caspian Sea (fig. 2). According to this classification, the area of the present research is situated in

seismotectonic area I. This is an area with contrasting combinations of mountain clinofolds and troughs. Intense tectonizing was started here at the end of the Pliocene and remained uncompensated by sediments .

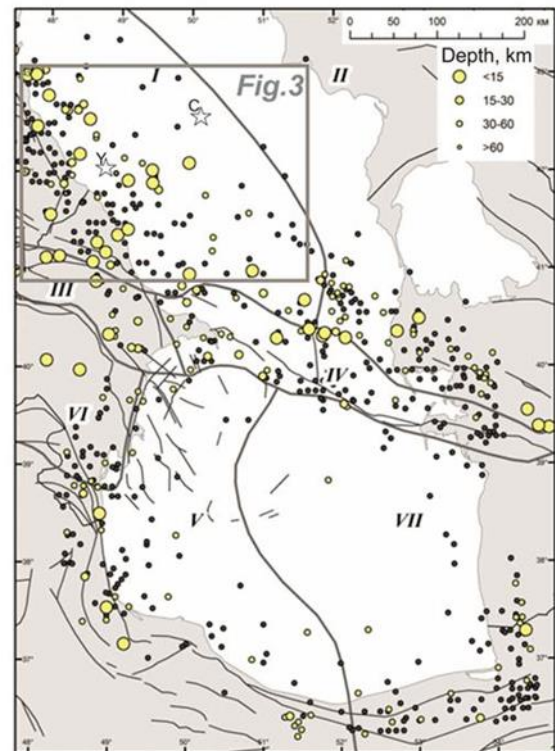


Figure 2. Seismotectonic provinces I-VII (by Ivanova and Trifonov [10]) and distribution of earthquake epicenters: black for earthquakes before 1998, yellow for 1998-2017. Thin black lines are for main tectonic faults.

3. Material and Methods

Seismoacoustic method used in this study to survey seabed sediments and features is a branch of “shallow” seismic applications which sometimes called sub-bottom profiler. It uses acoustic waves of much higher frequency (kHz) than “big” seismic waves, which are tens and hundreds of Hz [11]. “Shallow” means that the seismic profile provides information about the upper parts of the sediment cover, e.g. 150 m below sea bottom only, but the resolution can reach tens of centimeters (some SES data). The profiles used in this study were obtained by Shirshov Institute of Oceanology in 2004-2013, by single-channel seismic profiling system GEONT with multielectrode sparker and parametric echo-sounding SES-2000-standard (Tab. 1). The position of the profiles were used in this study are presented in figure 3. The collected seismic

reflection data were processed using the RadExPro seismic processing program with standard algorithm (muting, filtration, sometimes deconvolution). Interpretation was performed using Kingdom software.

Deep drilling log data for two hydrocarbon sites including Centralnaya and Yalama were used here to confirm the observation where it is necessary but unfortunately we are not allowed to publish these log data (fig. 3).

The earthquake catalogues from the last 150 years [12,13,6] were used to evaluate the modern tectonic activity. All recorded and reported seismic events during the period of 1998-2017 including more than 500 earthquakes with magnitude more than 3 on the Richter scale were selected and analyzed to achieve the goal of this study.

Table 1. Specifications of the seismic instruments used for geophysical surveys

| Instrument type | Function | Frequency range, kHz | Penetration (depend on sediments), m | Vertical resolution, m |
|-------------------|---------------------------------|----------------------|--------------------------------------|------------------------|
| Sparker | Seismic profiler | 0.2-0.7 | 50 – 300 | 2-3 |
| SES–2000 standard | Echo-sounder + Seismic profiler | 100 4-12 | 10 – 50 | 0.05-0.15 |

4. Results

The study concerns western part of tectonic province I (fig. 2, 3), where the sediment cover has maximum thickness of 14 km with Pliocene-Quaternary part of 5 km. In general, most of the earthquake epicenters are concentrated in western side of the Middle Caspian Sea (fig. 3) and all have depth no more than 75 km. The most of the earthquakes in selected area have focus depth about 5-15 km and magnitude of 3.5-4 on the Richter scale which could be interpreted as signs of a technically active zone in the rigid basement. However, there are several events in the “calm” area of deep basin with focus depth of 0-5 km and magnitude about 3.5.

Using the seismoacoustic profiles from the selected area (fig.3), many disruptions were revealed in sediment structure and in seafloor relief. In general, it is possible to distinguish three disruption types: first, faults and fault groups (fig.5, 6, 7) that are mainly situated in near- bottom layers, second, horizontal zones of non-correlation (fig. 4, 7) that are disturbed acoustic horizons on the two-way time (TWT) depth from 0.8 to 1.3 ms, and third, “gas pipes” (fig.7) that are vertical structures with roots in disturbance layers. For all these objects, there is a clear geographical pattern of three areas: 1) the western slope of the Derbent basin, 2) deep part of the Basin near the southern slope, and 3) eastern part of the Basin. There

are also single objects of interest (six). Some profiles represent one object from different sides, but mostly there are single crossings (see the position of profiles on fig.3).

Field measurement of water column properties in the Central Caspian basin showed anomalous values of temperature salinity and sound velocity close to seabed which can help our understanding of the characteristics of the fluids that come out of the seabed (fig. 4).

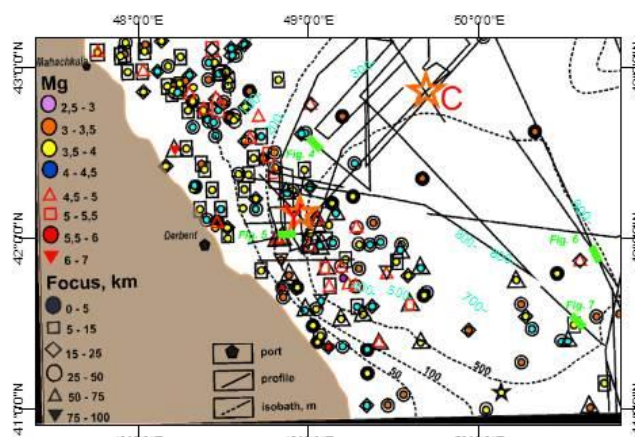


Figure 3. Position and characteristics of the earthquakes and location of seismoacoustic profiles in the area of interest. Stars show two hydrocarbon drilling sites with deep stratigraphic and geophysical data called: Centralnaya (C) and Yalama (Y).

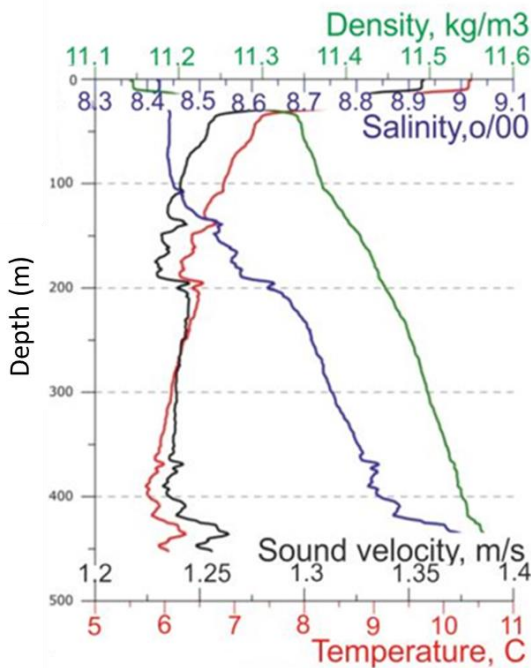


Figure 4. Physical properties of water column measured in the Central Caspian Basin (After [14]).

5. Discussion

Distribution maps of modern seismic events and disruptions in seabed sediment structure were evaluated and showed significant correlation between modern tectonically activities and prominent seismic events with deformation and features observed in seabed sediments. The characteristics of the observed phenomena are different around the basin and can be classified as discussed in the following.

5.1. Single deformations

Nearly all single deformations in sediments have nearby earthquake events with focus depths on 0-5 km (fig.3). The most spectacular deformation is located in northwest of the Mangyshlak Threshold and appears to indicate long lived fault (red lines in fig.5) with several stages. In addition to this fault, seismic data shows groups of minor sub vertical disruptions (however that could be slumping) and horizontal zones of non-correlation (disturbed layer on TWT 0.8 to 0.9 ms). The nearest earthquake is double (Mg 4-4.5 events) and situated several kilometers to the northwest (fig.3). We interpret the objects as evidences of modern on-going tectonic events, occurring due to repeatedly throwing and re-compensation processes in sediment cover.

5.2. Western Slope

Deformation structures in the sediments of the western slope of Derbent Basin correlate with earthquake events with magnitudes from 3.5 to 5. Alongside with sediment waves and reworking zones, seismoacoustic sections show mainly disjunctions of different

amplitudes, several unclear “pipes” and some “non-correlated” zones (fig. 6). Object diversity is caused by peculiarities in the western slope relief and the proximity of Caucasus mountain system. In the north-western part of the Derbent slope most focuses have depth about 20 km, magnitudes of 3.5-4 (fig.3) and disjunctions are slight, but to the southeast, magnitudes reach to 4.5-5 with a single event of 6.1. On seismic profiles, there are some vertical zones that seem very similar to “pipes” and also faults that become more prominent and look more like grabens (fig. 6). Focus depths here are from 50 to 75 km. In spite of nearby presence of Caucasus Mountains, it seems that the tectono-stratigraphic processes in this area can be connected with observation on the deep well-log data of Yalama hydrocarbon site.

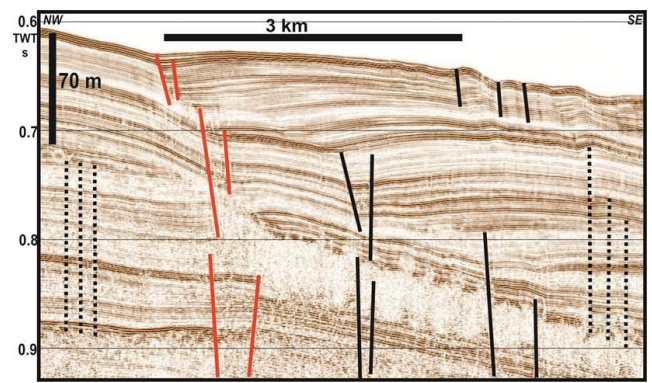


Figure 5. Seismoacoustic profile on Mangyshlak threshold. Red lines indicate long live fault zone.

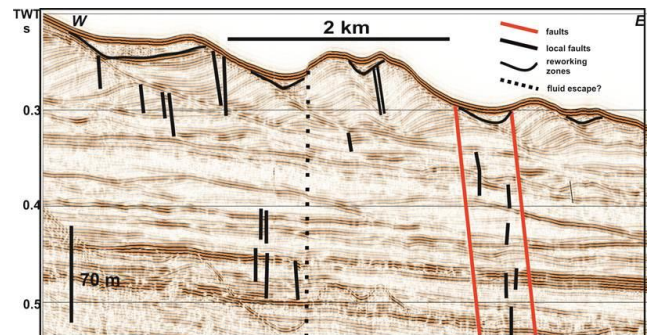


Figure 6. Seismoacoustic profile recorded on the Western Derbent slope

5.3. Deep basin: north-east area

In this area earthquake events are rare, with an average magnitude of 4 and a single event of 5.3 (fig.3). The depths of most focuses are approximately 5 km, but some are 50 km. Seismoacoustic sections show several vertical zones of disturbance with “transparent” wave field which could be interpreted as “gas pipes” and associated with slight vertical disruptions in some places which can be local faults. The sediment strata are undisturbed and well-stratified, with consistent horizontal reflectors (fig. 7). The Caspian Sea has high hydrocarbon potential, thus,

degasation processes are inevitable. It seems that earthquakes even of low magnitude can generate new faults and re-activate existing ones, and via these disruptions high pressure fluids resulted from, degasation processes can be unloaded.

5.4. Deep basin: south area (Apsheon Threshold base)

In the southernmost area of Derbent Basin, earthquake events are rare with average magnitudes of approximately 4 which mostly have depths of 0-75 km (fig.3) and located mainly to the south-east nearby tectonic-originated Apsheon Sill. On seismoacoustic sections, there are plentiful “gas pipes”, series or vertical disruptions, and acoustically heterogeneous layers with chaotic packages below (fig.8). Also seismoacoustic sections show that stratified sediment cover underwent post-sediment deformations. Field measurements of physical properties of water column showed temperature and salinity anomaly close to seabed over the area of study (fig. 4). We interpret these post-sediment structures as paths for high pressure, hot and saline.

6. Conclusions

This paper examined the relationship between modern seismic events and deformation structures in the seabed sediments of the Derbent Basin in the western part of the Middle Caspian Sea, using high resolution seismoacoustic profiles, earthquake catalogs, and some other data. The findings indicated that the basin has different levels of seismic activity and sediment disruption, which can be divided into four areas: single deformations, western slope, deep basin north-east area, and deep basin south area. The paper showed that the seismic events can cause seepage of high pressure fluid through the weak zones in the sediments. The paper also reported some interesting features on seismoacoustic profiles, such as numerous disruptions in sediment structure and seafloor relief, fault groups, gas pipes, and horizontal zones of non-correlation.

The Caspian Sea has high hydrocarbon potential; thus, degasation processes are very possible. Strong earthquakes can generate new faults and re-activate existing ones, and via these disruptions fluids are fluid seeps that had occurred during periods of high seismic activity. After that even slight seismic events (of magnitude <6) can provoke high pressure fluids to pass through the weak zones mainly including faults and “gas pipes” [14].

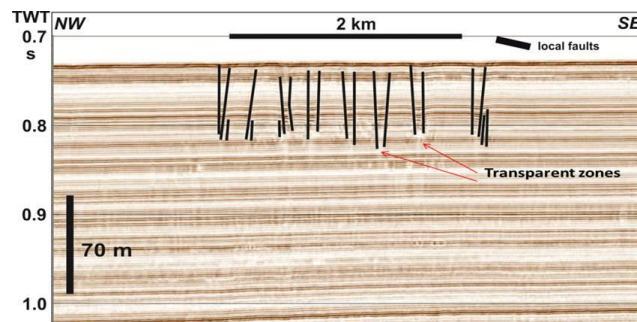


Figure 7. Observation on seismoacoustic profiles in the north-eastern area of Deep basin.

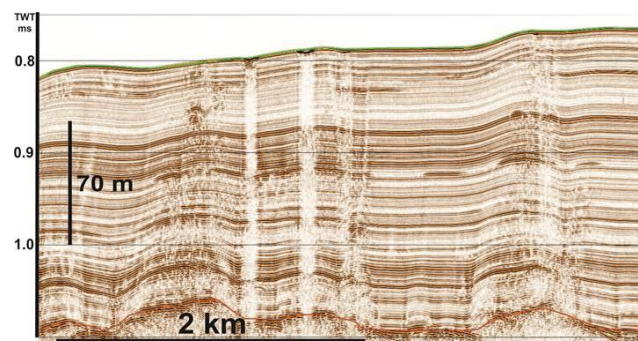


Figure 8. Seismoacoustic profiles in the southern slope of the Central basin (Apsheon Sill).

the deformation effects of modern seismic processes [15, 16]. In the case of Central Caspian, weak (average magnitude 4) and shallow (average depth 20 km, rare 75 km) earthquakes cause disruptions in the upper part of sediment strata.

In most cases, disruptions are coupled with signs of fluid activity such as non-correlation zones. These zones follow faults and/or “acoustically weak zones”, and on acoustic sections these zones appear as disrupted areas. Most likely, earthquake displacements and shakings which caused by unloading of stress in deep horizons, generate series of local faults through all strata near to seabed where high pressure fluids can escape from sediments. If fluid migrates by lateral migration, non-correlation zones may occur hundreds kilometers from the seismic activity point.

At the end it should be noted that the results of such basic researches can be useful for many different field of studies [17, 18].

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