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Causes of powerful earthquakes in the rapids of the South Caspian basin and Absheron-Balkhan sill and their geotectonic identification

Geology

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Researches showed, that formation of the hotbeds of tension is the cause of earthquakes. The Absheron-Balkhan threshold or anticlinal structure is an intermediate structure that links the continuation of the Main Caucasus chain in the south-east to the Gubadag-Bigbalkhany meganticlinorium on the east coast. The northern border of the western threshold is at an acute angle, morphogenetically associated with the south-eastern extension of the Main Caucasus and Siyazan deep fault limits on its northern borders. In terms of seismicity the threshold of stronger earthquakes is Sengechal Okurdzha.

Key words: South Caspian basin, megabasin, earthquakes, sediments, Absheron-Balkhan sill.

Introduction

The Caspian Sea is a large enclosed sea located to the east of the Black Sea in western Asia that covers over 371,000 km^2 and its adjacent areas form the Caspian oil/gas-bearing megabasin, one of the largest in the world, that make up part of the Barents-Caspian oil and gas belt. The N-S-trending megabasin consists of three sedimentary basins, separated by latitudinal sills: North Caspian, Middle Caspian, and South Caspian basins.

The foundation of the Caspian basin includes typical large tectonic units, therefore, morphological structure of the seabed is characterized by diversity. So, most of the northern and central part of Caspian basin belongs to the old Kaleidon Epichersin platforms; the South Caspian basin, the Absheron anticline Balkhanian area and the north-western part of its intrageosynclinal depression belong to the Alpine fold system.

The South Caspian basin is a tertiary basin lying in Azerbaijan between the Greater and Lesser Caucasus and Talysh Mountains, and in Iran and Turkmenistan, respectively, the Elburz and Kopet Dagh Mountains. The basin underwent intensive subsidence during the Pliocene. The sedimentary column is one of the world's thickest known and reaching 22 km. Hydrocarbons were first identified in the South Caspian basin through the numerous active oil and gas seps of the region, many of which are associated with mud volcanoes and diapirs.

Statement of the problem

The South Caspian basin includes a unique set of geological parameters, which make it one of the world's most prolific hydrocarbon regions. The basin has accumulated up to 25 km of sediment surrounded by compressional orogens, with more than 10 km of this fill deposited in the last 6 m.y. This recent, rapid burial has resulted in such low gradients of temperature that hydrocarbons are still being actively generated at depths between 8 and 12 km. The basin's anticlinal structures are large and interpreted as buckle folds that overlap a regional detachment based on regional 2-D seismic data analysis. The combination of a prolific hydrocarbon system, large undrilled structures, and a favorable foreign investment political climate has focused considerable attention on the potential of this basin.

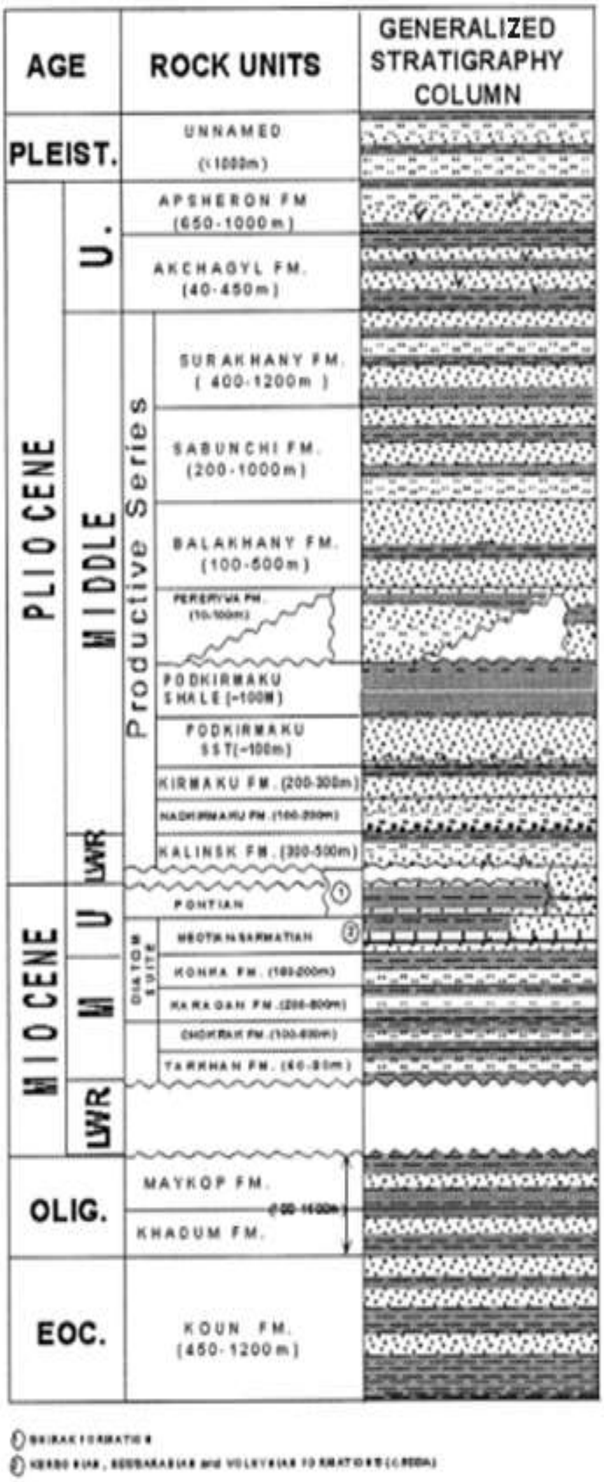

Fig.1. Generalized stratigraphic column

The granite-metamorphic basement of the basins is younger from north to south, from the north of Early Precambrian to the south of Early Cimmerian. It was formed from the southern edge of the East European Craton (Paleozoic continent Baltica) to the Tethys oceanic basin in the transitional zone. Accordingly, the Caspian megabasin is superimposed on the East European ancient platform, Scythian-Turanian young platform, and Alpine-Himalayan mobile belt. Each tectonic province comprises structural zones of a subordinate character: the North Caspian depression within the first province; Karpinsky Ridge, Kuma zone, North Ustyurt block, Buzachi uplift, Mangyshlak-Central Ustyurt and South Mangyshlak zones, as well as Karabogaz arch, and Middle Caspian basin within the second province; the Greater Caucasus, Kopet Dagh, Kura and South Caspian depression, West Turkmenian trough, and Alborz range within the third province. The age of the sedimentary cover embraces the entire Phanerozoic and, probably, upper parts of the Proterozoic in the North Caspian region; the Jurassic, Cretaceous, and the Cenozoic in the Middle Caspian; and the Oligocene-Holocene in the South Caspian. The Permian and Triassic deposits in the Middle Caspian; the Jurassic, Cretaceous, and lower Paleogene deposits in the South Caspian occupy partly both the folded basement of the basin and its sedimentary cover. The stratigraphic range of oil and gas occurrence varies accordingly: from the Devonian to Paleogene in the North Caspian, from the Triassic to Miocene in the Middle Caspian, and from the Cretaceous to Eopleistocene in the South Caspian (Fig.1).

The South Caspian depression occupies a southern part of the N-S trending Caspian Sea megabasin, but is characterized by the approximately latitudinal orientation of the major elements of the whole structure. This observation emphasizes its active involvement in tectogenesis in the Alps. In the north, it is bordered by the Greater Caucasus structures, which dip eastward under the Caspian Sea and continue further into the Transcaspian region as the Greater Balkhan-Kopet Dagh mountain system. The south-eastern and eastern parts of the depression are enveloped by the Alborz structures (including the Talysh zone).

The South Caspian depression is an autonomous tectonic unit that consists of: the southern part of the Caspian Sea; the West Turkmen depression adjacent to the latter; the northern lowland periphery of the Alborz system; the Lower Kura trough; and the Absheron – Gobustan trough.

The crust beneath the South Caspian depression is two-layered and consists of the sedimentary cover up to 25 km thick and a “basaltic layer” 15–20 km thick (V_p = 6.6–6.7 km/s) (Fig.4).

One of the main structural elements of the Alp geosynclinal system in the middle of the Caspian waters is the Terek-Caspian bend, considered the Ciscaucasian trough in the south-east. One of the features of the Terek-Caspian basin is that its threshold is sharp slopes and in the east and north-east as a result of anthropogenic Pliocene precipitation curves become more intense, the trend line of the axis is directed to Makhachkala, Krasnovodsk. It is because of this slice of the Caspian Sea, its second deepest part (788m) - falls into the cavity of Derbent.

Throughout the eastern gentle lines of the Middle Caspian in bathymetry 50-100 m from Derbent to Makhachkala, at a distance of 30-40 km from the shore of the sea reef, curving at a more acute angle suddenly reaches 600 meters in the latitudinal range of Derbent (Fig.2). This geomorphological imbalance should be in the south-west 100-150 km. Configurations of the north and south-eastern parts of the deep trough Derbent also follow in this direction. All these, and other information obtained by the detection of anomalous geophysical fields in the transformations of gravimetric and magnetometric fields show the presence of deep faults related to the neotectonic period, Makhachkala, Krasnovodsk direction.

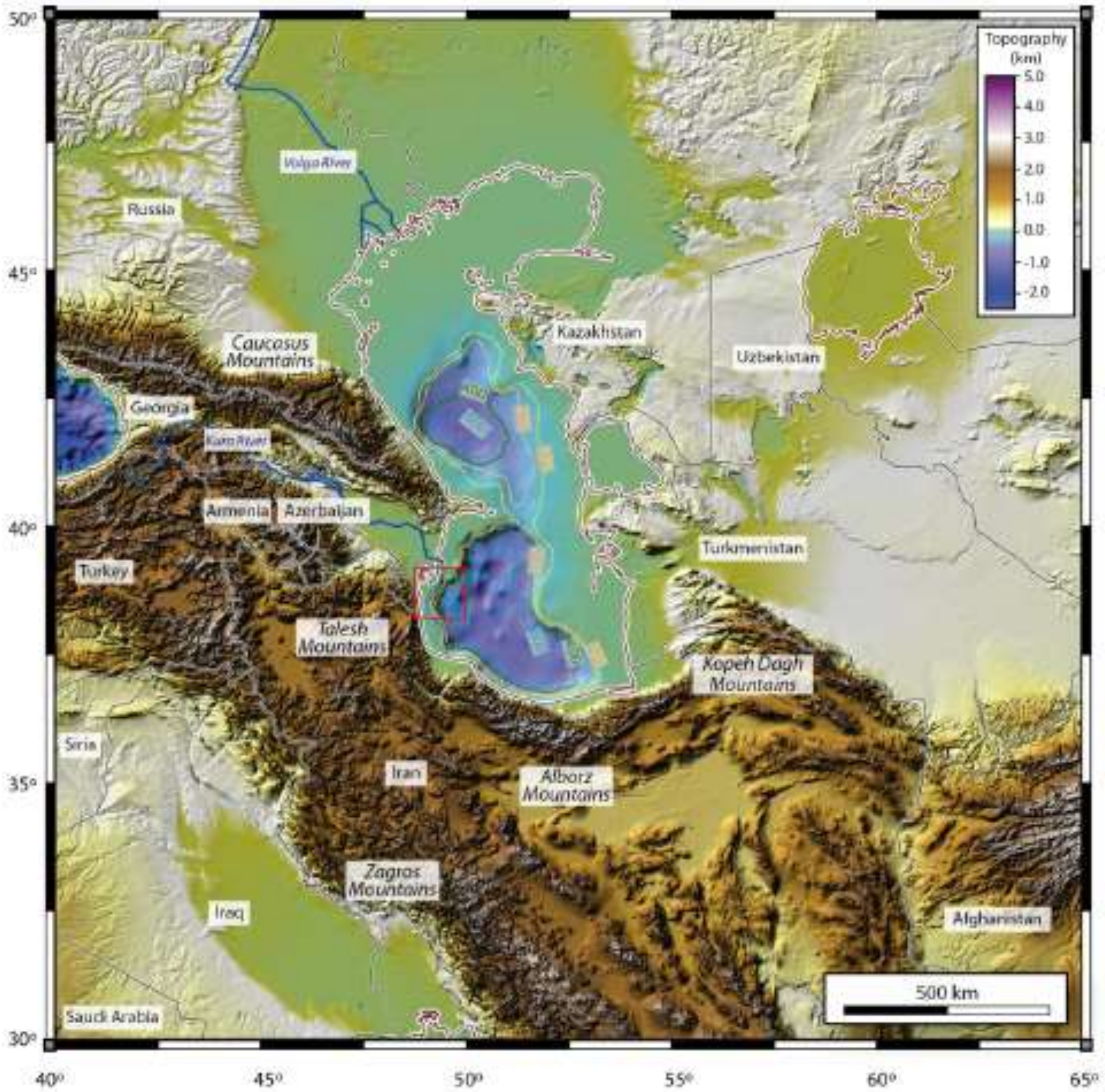

Fig.2. Topographic-bathymetric map of Caspian Sea

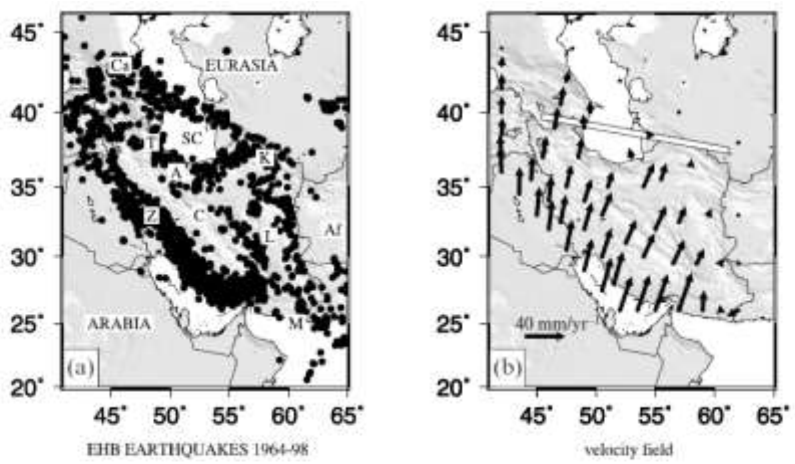

Fig.3. (a) Seismicity of Iran 1964–98, from the catalogue of Engdahl et al. (1998).
The Zagros is marked by Z, the Alborz by A, the Kopet Dagh by K, the relatively seismic central Iran block by C, the Lut block by L, the Greater Caucasus by Ca, the Talysh by T, the Makran by M and Afghanistan by Af. (b) A velocity field showing how the NNE motion of Arabia relative to Asia is absorbed in Iran. The distribution of velocities within Iran is estimated from the spatial variation in the style of strain rates indicated by earthquakes (from Jackson et al. 1995). The white bar shows the line of the cross-section in Fig.4

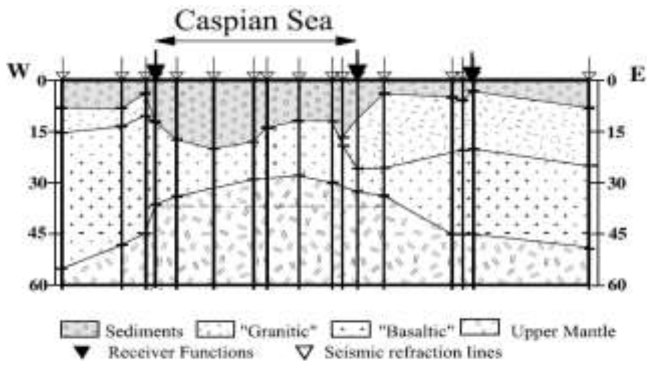

Fig.4. Crust and uppermost mantle cross-section between the Kura basin to the west of the South Caspian basin (y39.5N, 46.0E) and the Turkmenian lowlands and the Kopet dagh mountains to the east (y37.5N, 61.5E): see Fig. 2(b) for location

Solution of the problem

The almost complete absence of severe earthquakes in the South Caspian basin itself shows that it acts as a rigid block in the collision zone between Eurasia, Iran and Arabia. This conclusion is reached despite the abundant folding of the offshore sedimentary cover, which we do not believe indicates the defect of its underlying basement. The surface folding is instead likely to be completely decoupled and spatially separated from any shortening of the basement by the overpressured mud. Thus the N–S folds in offshore Azerbaijan are probably a response to deeper basement shortening that occurs 100 km further west beneath the Talysh, and the WNW–ESE surface folds near the Absheron–Balkhan sill are probably a response to deeper thrusting of the southern Caspian beneath the northern Caspian. The lack of shallow earthquakes on the Absheron–Balkhan sill indicates that this shortening is largely aseismic, which is known in other places, such as the Hellenic Trench, where thick sediments choke the subduction zone. Other folds in the centre of the South Caspian basin could also be a response to any of these factors, aided by mud diapirism. If the South Caspian basin is rigid, its movement relative to Iran and Eurasia results in the deformation of the belts surrounding it. This is most clearly established in its eastern part, where a right-lateral component in the western Kopet dagh and a left-lateral component in the eastern Alborz indicate that the motion of the SE Caspian lowlands must have a westward component relative to Eurasia and Iran , in a geometry that resembles the expulsion of central Anatolia from the collision zone in eastern Turkey. This westward component of motion enhances the underthrusting of the south Caspian basement beneath the Talysh. Although left-lateral strike-slip is seen along the whole curved arc of the Alborz from 49uE to 56uE, we cannot use the shape of the arc to establish a pole of rotation for the South Caspian basin because the overall motion is not pure strike-slip (unlike that of the North Anatolian fault in Turkey).

Both the earthquake mechanisms and the geology indicate that the strike slip in the Alborz and western Kopet dagh is accompanied by considerable shortening, and since we do not know the relative importance of these two components, we cannot determine the overall slip vectors or how they change during the strike (Fig.3). However, it is possible to make some crude estimates of likely rates. The overall Arabia–Eurasia convergence is known from a combination of Africa–Eurasia and Arabia–Africa motions to be approximately N–S at about 30–33 mm yrx1 at the longitude of the Caspian suggest that about 10–15 mm yrx1 of this motion is accommodated in the Zagros mountains: an estimate that is very dependent on the assumptions they made, but which is roughly compatible with the 50 km of shortening thought to have occurred in the Simple Folded Belt of the Zagros over the last 5 Myr. 15–20 mm yrx1 remains to be taken up across the Alborz and Absheron–Balkhan sill, we can construct a velocity triangle. First, we observe that the left-lateral motion in the Alborz appears to die out in the west at about 49uE, where the regional trend and the strike of the left-lateral Rudbar–Tarom earthquake fault is about 300u. This suggests that the motion of the South Caspian relative to Iran is in the direction y210u, or that angle the EIC is y30u. If the angle EIC>30u we would expect the left-lateral motion to continue further west as the arc of the Alborz swings into the Talysh; if EIC<30u the left-lateral motion would not extend as far west as it does. These considerations are compatible with the strike-slip faulting being clearer and in lower topography east of 53E, where the strike-slip component should be greater than in the western Alborz, where the strike-slip faulting is less obvious in the morphology is associated with higher mountains, and where thrust faulting should predominate.

Secondly, the motion of the South Caspian relative to Eurasia must have a shortening component and therefore an azimuth which exceeds the 300 trend of the Kopet dagh west of 56W; in other words, the IEC angle must be less than 60. These simple considerations suggest that the Caspian–Eurasia motion is at least 7–10 mm yrx1 in a direction somewhat north of 300u, and that the Caspian–Iran motion is no more than 13–17 mm yrx1 in the directiony210u. However, we emphasize that these rates are very uncertain. We can now compare these postulated rates and motions with the geological evidence. Shortening in the central Kopet dagh since the Miocene is evidently compatible with y15 mm yrx1 convergence between Iran and Eurasia. We suspect that the earthquakes at 80–100 km beneath the Absheron–Balkhan sill imply some subduction of the 'oceanic' South Caspian basement into the mantle, but it is not clear how much shortening this represents between the South Caspian basin and Eurasia, as we do not know the age or duration of the motion responsible. However, two observations suggest that the South Caspian–Eurasia shortening is both recent and relatively small in magnitude. First of all, there is no sign of recent volcanism north of the Absheron–Balkhan sill, which might be expected if the deep earthquakes represent the declining activity in a subduction zone that has been active for some time. Second of all, the Greater Caucasus, Absheron–Balkhan sill and the Kopet dagh are all roughly collinear, yet the polarity of the underthrusting on the sill is opposite to that on either side: both the Greater Caucasus and the Kopehdag are overriding shields to the north, whereas the earthquakes and the bathymetry indicate that the central Caspian overrides the South Caspian Basin to the south. If this configuration persisted for a long time, it would soon develop into a non-collinear geometry. Much of the deformation in the sediments of the South Caspian basin is younger than approximately 3.4 Myr, with sediments older than this showing no changes in thickness over the folds, while younger sediments are thinner than the fold crests. It is possible that some re-arrangement in the motions happened at this time, with shortening switching from the Alborz to the Absheron–Balkhan sill. Prior to the Pliocene we know the Alborz was elevated from the coarse Neogene clastic sediments on both of its margins. If at that time most of the Iran–Eurasia convergence was concentrated in the Alborz, the South Caspian basin would have been a deep, heavily sedimentloaded, elongated tongue of material protruding into Iran 300 km in front of the Greater Caucasus and Kopet dagh. It would perhaps be no surprise if it later broke along the narrow gap following the Absheron–Balkhan sill, and if the lower South Caspian basin then started to underthrust the higher and thicker crust on the northern side. Thus the entire present-day geometry of the deformation in the Southern Caspian basin and its surroundings may date from about 3.4 Ma. The trigger for this postulated reorganization could be the initiation of shortening in the Simple Folded Belt of the Zagros (Falcon 1969, 1974), which perhaps heralded the final accretion into the collision zone of the various tectonic blocks within Iran, and the start of truly intracontinental shortening. If it is true that shortening has been concentrated in the Caucasus–Talysh–Alborz–Kopet dagh arc, then we would also expect evidence for a N–S right lateral shear between the Caspian and NW Iran in the Talysh, of which there is no sign in the earthquake mechanisms. N–S right-lateral strike-slip faults linking the eastern Caucasus with the Talesh are shown on various maps of Russian origin, but it is not clear on what evidence their existence is postulated. Right-stepping en echelon folds and right-lateral strike-slip faults splaying NW–SE away from the thrusts west of Baku and entering the northern side of the Kura basin. We are unaware of any convincing evidence that such faulting crosses the Kura basin or enters the Talysh as N–S right-lateral strike-slip, those interprets an apparent right-lateral offset of the Kura river as evidence that such a N–S fault zone is active. At low levels, the strong curvature of the Talysh folding axes, from E-W in the north to N-S along the coast, could be linked to a shear that rotated the originally E-W folds in the direction of the clock to parallel the coast as the western (Iranian) side moves north past the Caspian. In this case, it may be that shear is distributed in the wedge of relatively weak sediment above the low-angle thrusts at 15–25 km rather than concentrated on to a strike-slip fault, while the E–W shortening component (related to the westward component of the Caspian's motion) is taken up by N–S thrusts. This is again a form of 'slippartitioning', but without requiring a discrete strike-slip fault at the surface. It does not, however, explain the lack of any seismological evidence for N–S right-lateral shear at deeper levels. The E–W folds and thrusts in the northern Talysh are an important indication that on the west side of the Caspian some of the Iran–Eurasia shortening is taken up south of the Kura basin, accounting for the relatively minor shortening in the eastern Greater Caucasus, represented by the decreasing elevation of that range as it approaches the Apsheron–Balkhan sill. The folds in the Kura basin and offshore imitate this connection between the Caucasus and the Talysh, curving from E-W to N-S offshore in the eastern Kura basin. These folds are generally of low seismicity in regions, most likely because they are separated by thick mud sequences from their underlying basement. In summary, it seems clear that the South Caspian basin has a westward component of motion relative to both Eurasia and Iran, and that this enhances the underthrusting in the Talysh. The likelihood is that the basin moves SSW in relation to Iran at y10-15 mm yrx1 and NW in relation to Eurasia at 8-10 mm yrx1.

It should be noted that the formation of hot spots, which are the cause of this deep water area of the Caspian Sea focal parameters of earthquakes with ML $\geq$ 4 is associated with this fault line. The few sporadic strong earthquakes are associated with this fault line. All of these points can guide that this area requires new serious researches.

Conclusion

1. Within the Caspian megatrough are four major structural and tectonic units: North, Central, South Caspian basin and the last separating from each other and directed in the south-east of Absheron-Balkhan threshold.

2. One of the Middle Caspian's main tectonic units is Agrakhan Krasnovodsk, which limits the pleated Alps system with the Skiph-Turan epihersin platform.

3. Information obtained in the identification of anomalous geophysical fields in gravimetric and magnetometric field transformations shows that there are deep defects in the direction of Makhachkala, Krasnovodsk.

4. Formation of the hotbeds of tension, which are the cause of this water area of the Caspian deep focus earthquakes with ML $\geq$ 4 parameters associated with this fault line.

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Xülasə

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Cənubi Xəzər və Abşeron-Balxanyanı kəndarında güclü zəlzələlərin səbəbi və geotektonik identifikasiyası

Araşdırmalar göstərmişdir ki, gərginlik nöqtələrinin formalaşması zəlzələlərin əsas səbəblərindən biridir. Abşeron-Balaxanı kəndarı və ya antiklinal strukturu şərq sahillərində qitəni Qubadağ-Biqbalxan meqaantiklinorisi ilə birləşdirən ara quruluşdur və qərb barajının şimal sərhədləri Əsas Qafqaz və Siyəzənin cənub-şərq istiqaməti ilə kəskin bir açı və morfogenetik cəhətdən əlaqələndirilir. Seysmiklik baxımından, Səngəçal Okurca güclu zəlzələlərin sərhədi sayılır.

Açar sözlər: Cənubi Xəzər hövzəsi, meqahövzə, zəlzələlər, çöküntülər, Abşeron-Balaxanı kəndarı.

Резюме

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Причины сильных землетрясений в Южно-Каспийском бассейне и Абшерон-Балханской антиклинальной зоне и их геотектоническая идентификация

Исследования показали, что формирование очагов напряженности является причиной землетрясений. Абшерон-Балханский порог или антиклинальная структура является промежуточной структурой, которая связывает континент с мегантиклинорием Губадаг-Бигбалхан на восточном побережье, а северная граница западного порога расположена под острым углом и морфогенетически связана с юго-восточной протяженностью Главного Кавказа и Сиязани. С точки зрения сейсмичности, порогом границы сильных землетрясений является Сенгечал Окурджа.

Ключевые слова: Южно-Каспийский бассейн, мегавпадина, землетрясения, отложения, Абшерон-Балханский порог.