IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)\
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)

*IBGM (**2025**, Vol 21; Issue 1)* *365-397*

BIOSTRATIGRAPHY OF THE SOUTH CASPIAN BASIN: INSIGHTS FROM OFFSHORE AND ONSHORE WELLS AND OUTCROPS IN TURKMENISTAN AND IRAN

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Type of the Paper (Article)
Received: 02/ 08/ 2024
Accepted: 17/ 03/ 2025
Available online: 27/ 06/ 2025

Abstract

A biostratigraphic comparison was conducted between the offshore and onshore regions of the Gorgan-Dag-Ekerem uplift zone in Turkmenistan and offshore Iran, utilizing published data from the Gorgan Plain in northern Iran. The study focuses on the Pliocene Red-bed, Akchagylian, and Quaternary deposits in the South Caspian Basin. Pliocene deposits hold significant economic and scientific interest due to their commercial reservoir potential beneath thick Quaternary formations. The practical study of Quaternary sediments is crucial for selecting suitable engineering and construction sites for offshore platform installation and identifying safe locations for exploratory wells. Industrial hydrocarbons have also been extracted from the Quaternary deposits (Apsheron stage) in Turkmenistan.

A total of 533 core and drill-cutting samples were analyzed from shallow and deep exploration wells across three onshore and seven offshore structures in Turkmenistan and Iran. This included 161 samples from shallow offshore wells, 209 from deep offshore wells, and 163 from onshore near-coastal structures. Abundant ostracod assemblages were identified, enabling detailed biostratigraphic characterization of the Pliocene Red-bed strata, Akchagylian deposits, and Quaternary formations.

Pliocene deposits exhibited relatively low microfaunal diversity. The Quaternary deposits displayed a rich assemblage of predominantly brackish ostracods, along with euryhaline and freshwater species.

Keywords: South Caspian Basin; sedimentology; lithology; biostratigraphy; Pliocene/ Quaternary deposits; Tectonostratigraphy.

ISSN 1811-4539, EISSN 3005-3714
https://doi.org/10.59150/ibgm2101a20
IBGM: http://ibgm-iq.org/
Academic Scientific Journals: www.iasj.net

1. Geological Setting

The Western Turkmen Depression of the South Caspian Basin (SCB) is located southwest of Turkmenistan and occupies the eastern part of the extensive South Caspian subsidence region (Torres, 2007). To the north, it is bordered by the Bolshoi Balkhan and Kuba-Dag mountains, to the east by the western trough of the Kopetdag mountain system; in the south, it runs along the state border with Iran, while to the west, the Western Turkmen Depression opens into the Caspian Sea. The following tectonic elements within the Western Turkmen Basin are distinguished: the Gogran Dag-Ekerem uplift zone, the Kelkor Depression, and the Kyzyl Kum Depression.

The Gogran Dag-Ekerem uplift zone is located along the boundary fault between the South Caspian and Amu Darya microplates. This zone is 30 – 60 Km wide and extends for 180 Km in length. Individual folds in the zone, oriented north-south, reach lengths of up to 45 Km and widths of 10 – 15 Km, with vertical uplift amplitudes ranging from 100 to 400 meters (Ashirmamedov et al., 1976; Markova, 1962; Torres, 2007).

The Kyzyl Kum Depression is a local depression between the two uplift zones. Here, the thickness of Pliocene-Quaternary deposits reaches approximately 6,000 – 7,000 meters.

The Turkmen Step (or Turkmen Monocline) is located in the waters of the Caspian Sea. In this part of the Western Turkmen Basin, large anticlines cover areas of up to 1,500 square kilometers, although their vertical uplift amplitudes are limited to 200 – 250 meters. The permeable thickness of Middle Pliocene-Quaternary deposits exceeds 5,500 meters.

In the southern part of the Western Turkmen lowland, near the Keimir-Chikshilyar area, several mud volcanic mounds stand out. Western Turkmenistan constitutes a significant part of the South Caspian oil and gas-bearing basin, where numerous oil and gas fields, as well as prospective structures, have been discovered since the last century.

The Gogran Dag-Ekerem uplift zone forms the eastern edge of the Western Turkmen region, stretching for 250 Km from north to south and 50 – 80 Km from west (Caspian coast) to east. The main uplifts, including Gogran Dag, Kamyshlydzha, Ekerem, Keimir, Chikshilyar, and others, are located in the western part of the zone, forming a significant trough about 200 Km long and 10 – 15 Km wide near the coastal area (Ali-Zadeh et al., 1985).

Western Turkmenistan forms a significant part of the South Caspian oil and gas basin, where numerous oil and gas fields and perspective structures have been discovered from the last century to the present day. The Gogran Dag-Ekerem uplift zone constitutes the eastern margin of the West Turkmen region, extending over 250 Km from north to south and 50 – 80 Km from the west (Caspian coastline) to the east. The major uplifts, including Gogran Dag, Kamyshldza, Ekerem, Keymir, Chekishler, etc., are situated in the western part of the zone, forming a significant swell approximately 200 Km long and 10 – 15 Km wide, near the coastal area (Figure 1).

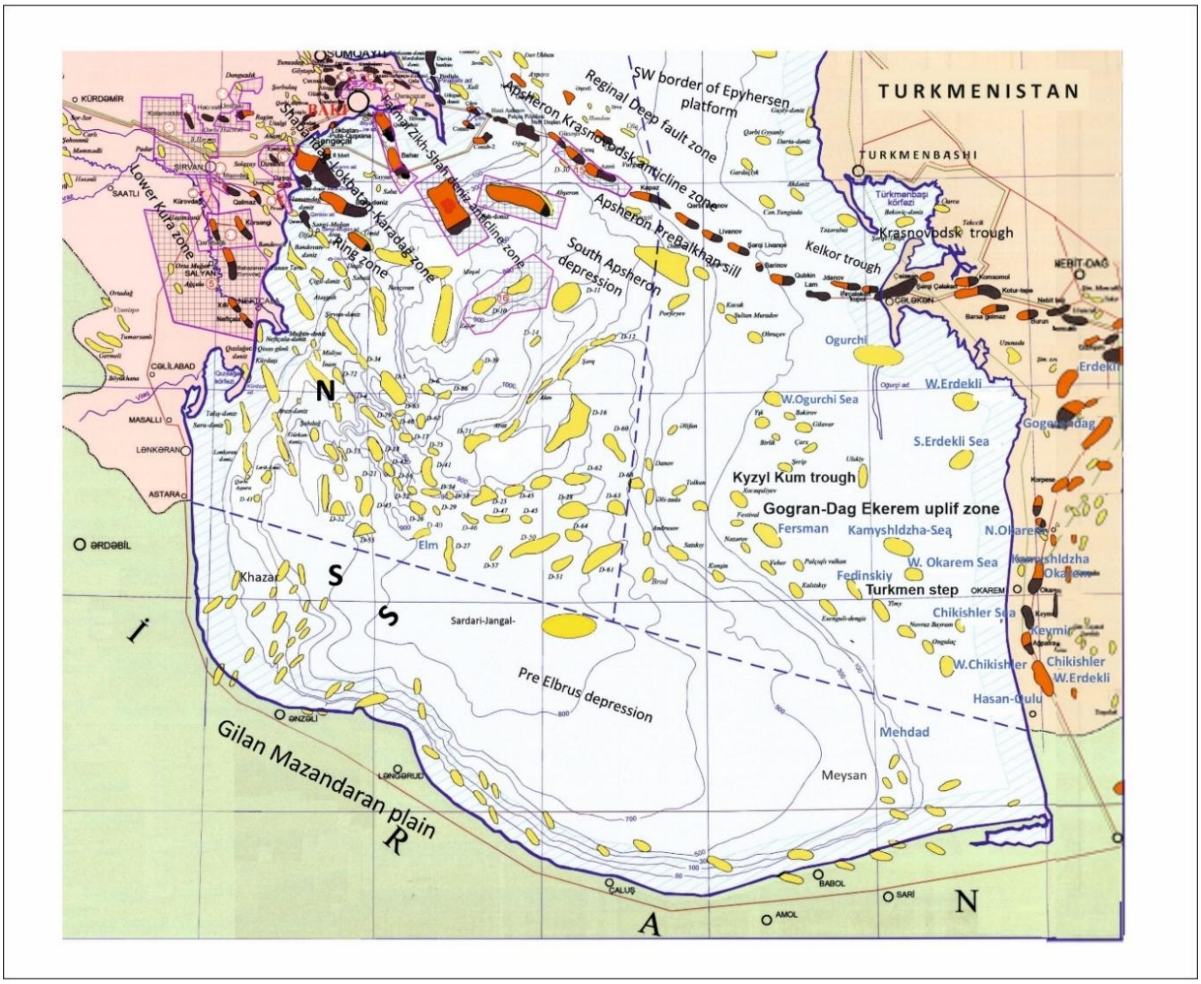

Figure 1. South Caspian Basin. Blue-marked structures under study.

The sedimentary cover within Western Turkmenistan comprises Mesozoic and Cenozoic rocks. Notably, fields are predominantly situated in the Gogran Dag-Ekerem Zone, including fields like Kamishldzha and Keimir onshore (Ali-Zadeh et al., 1985). The sedimentary succession of the SCB is characterized by two mega-sequences: the pre-molasse Mesozoic-Early Pliocene and the molasse Middle Pliocene-Quaternary (Melikhov et al., 2021). Petroleum reserves discovered thus far have primarily been found in the Middle Pliocene and younger sections, with older strata rarely penetrated by drilling. Prospective reservoir sandstones and carbonates have been identified in the Mesozoic (Jurassic and Cretaceous), Paleogene, and Miocene but have not yielded commercial quantities of oil or gas (Wood Mackenzie, 2007). The Paleogene harbors promising source rock horizons, particularly in the Maikop mudstones, though these have seldom been reached by oil field drilling. The highly prospective Pliocene section in SCB is stratified into Early (Pontian), Middle (Red-bed strata), Late (Akchagylian), and Quaternary (Apsheronian) stages (Figure 2).

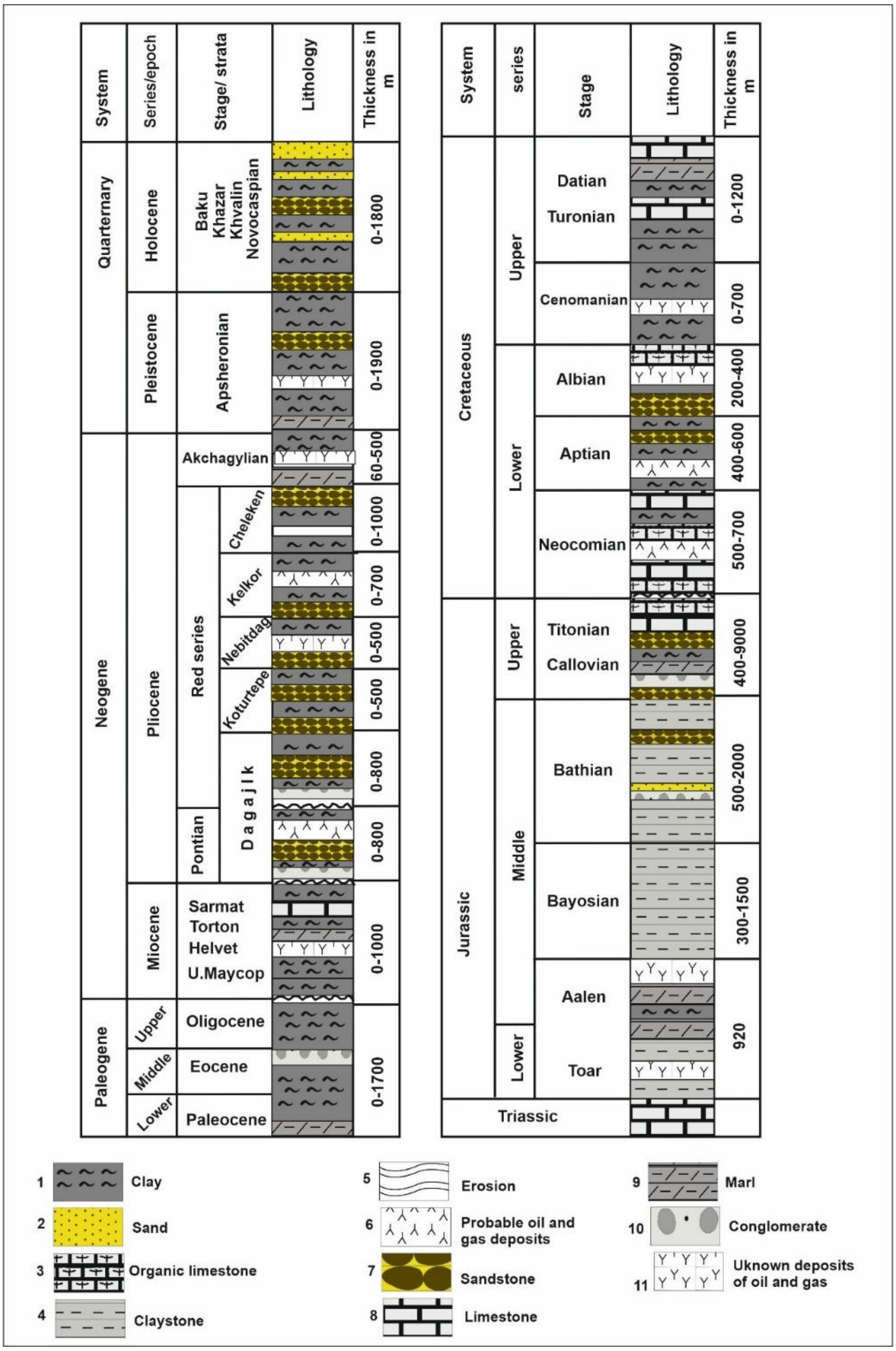

Figure 2. Litho-Stratigraphic column of South Caspian Basin.

The Productive/Red-bed strata generally correspond to the local Kimmerian-Balakhanian stage of the Eastern Paratethyan stratigraphy (Jones & Simmons, 1997). However, its exact correlation with the global stratigraphic framework remains uncertain due to conflicting paleomagnetic and biostratigraphic data (as discussed in Popov et al., 2006). The limited biostratigraphic information makes age dating within the Productive Series challenging, and therefore, its stratigraphy is typically divided based on lithostratigraphic criteria.

The Red-bed strata (analogue of Productive strata on the Azerbaijan side of SCB) formation, tentatively dated to the Pliocene, is a clay-sand formation with a highly complex structure and a debated origin (possibly deltaic?). It has been significantly reworked by mud volcanism. The red streak on the mountain slope consists of ferruginous-carbonate deposits from an extinct hot spring in a region of mud volcanism. The Red-bed strata contain numerous clay diapirs and are characterized by abnormally high reservoir pressures. Oil extraction from this formation has been ongoing for over 100 years (and artisanal production for several centuries), but the few outcrops of this formation on the surface remain almost unstudied (Figure 3).

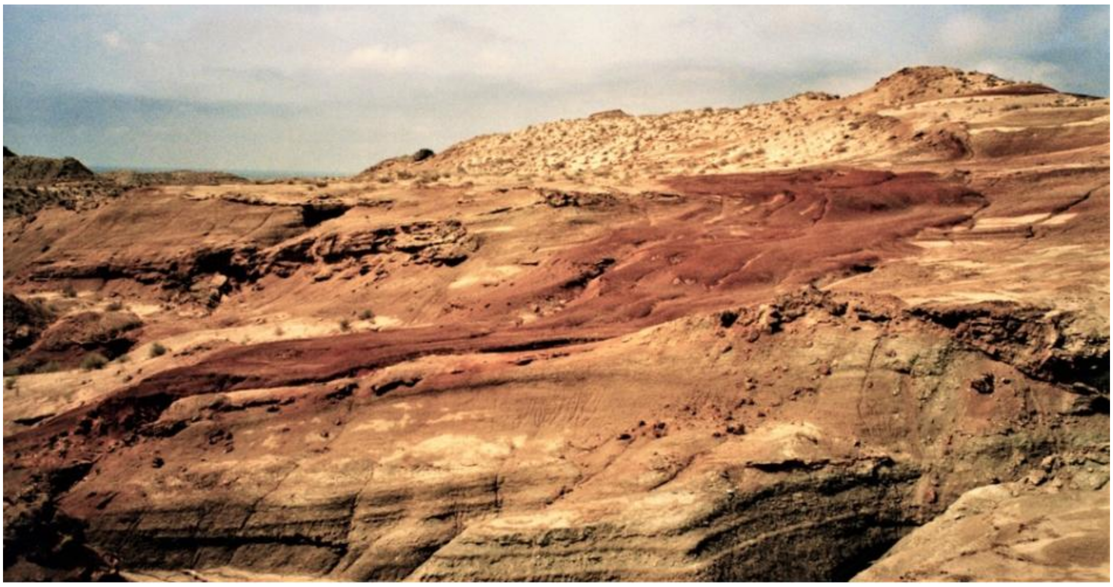

Figure 3. Caspian Red-bed strata. Cheleken Peninsula, Turkmenistan. Photo taken from Public Domain Dedication (after Egorov, 1997).

On the eastern edge of the South Caucasus, Red-bed strata deposits are considered to be the same age as Productive strata (Figure 4). These deposits have been extensively drilled in numerous offshore uplifts across Turkmenistan. In the western part of the near-Turkmen region, the Red-bed strata consist of alternating sands and shales. However, the lower section shows a notable increase in clay content, accompanied by a reddish tint in the rocks. This coloration results from material transported from the eroded Red-bed formations located east of the SCB. The Red-bed strata exhibit a distinct cyclical pattern, with rhythmic alternations of sands, sandstones, and clays. Unlike the Productive strata, the clay content in the Red-bed section increases progressively from the top to the bottom. In the coastal zone, the Red-bed strata are divided into three distinct layers: the upper layer is predominantly composed of clays, the middle layer contains both clays and sands, and the lower layer is primarily sandy (Glumov, et al., 2004).

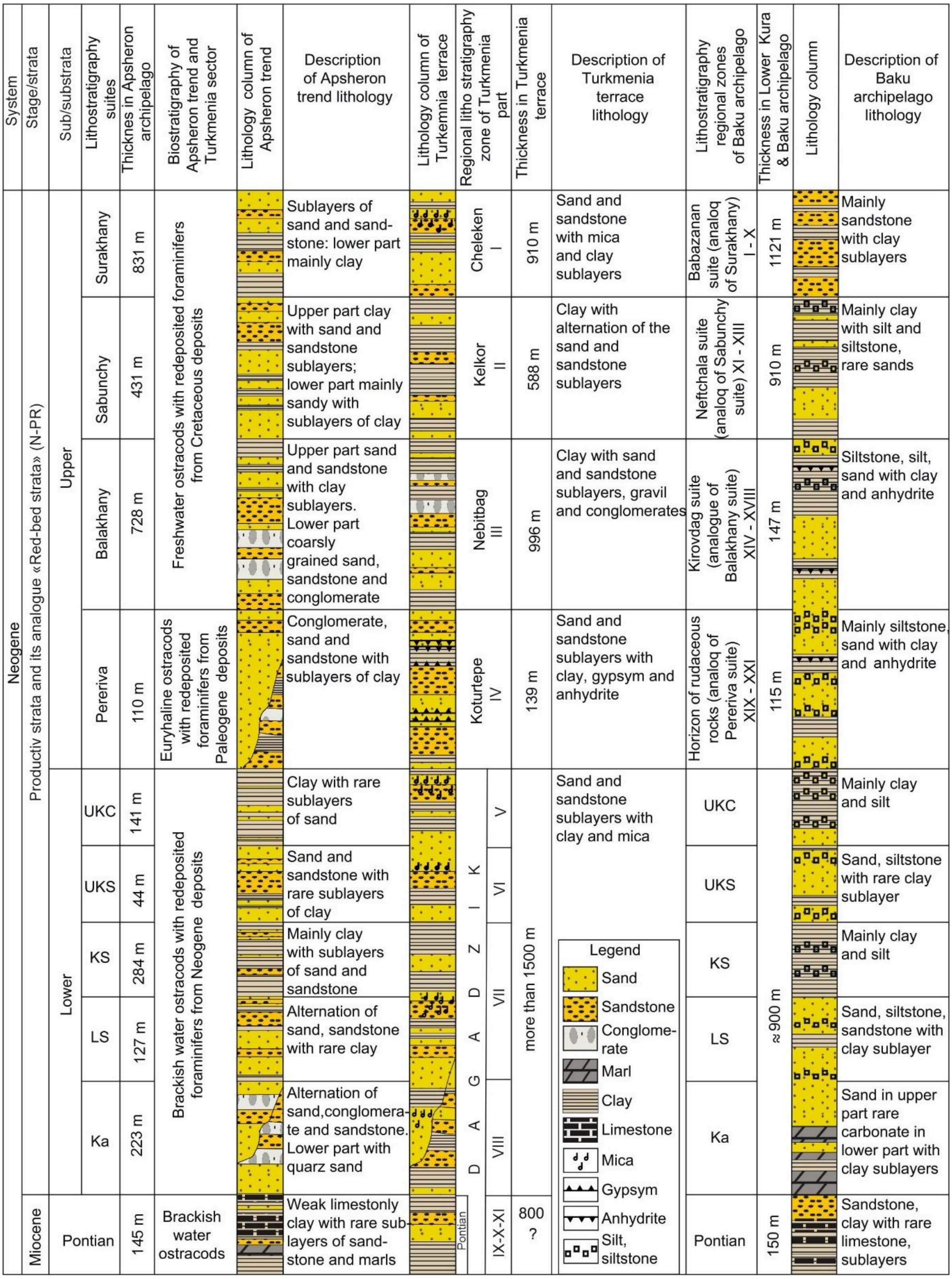

Figure 4. South Caspian basin. Correlation of regional lithostratigraphy.

The thickness of individual stages and the Pliocene varies significantly depending on the position within the paleo-delta system, with a maximum total thickness of nearly 6,000 meters

(Torres, 2007). Additional source rocks may be present in the mudstones, although these are generally found to be organically lean (Ali-Zadeh et al., 1985).

Meridional brachyanticlines, linear folds, insignificant faulting, and the absence of outcrops characterize this zone. The Mesozoic eastward's relatively smooth step-like rise corresponds to the Pliocene folds. The West Turkmen terrace on the offshore side of the Gogran Dag-Ekerem uplift zone encompasses a major deeply submerged block covering approximately 5,000 square kilometers of the South Caspian shelf. A well drilled in its central part (Fersman structure) encountered the Lower Red-bed formation at 6,000 m depth. The Lower Red-bed Formation, which is regionally oil-gas bearing in the inner marginal zone, occurs at depths of 5,500 – 6,500 m and deeper in the central part of the Turkmen Step. Individual wells drilled in the offshore West Turkmen terrace exhibit similarly favorable lithology in the Pliocene (sandy-silt and clayey beds; Ali-Zadeh et al., 1985).

The neighboring Chekishler-Gryazevulkanicheskaya (Mud Volcano) uplift zone, which encompasses over 20 discovered structures, bounds the West Turkmen Terrace to the south and extends northwestward, exhibiting a more complex geological structure. The confinement of the zone to the basement uplift, coupled with intense mud volcano activity and dislocated Pliocene folds, renders it analogous to the Pribalkhan-Apsheron uplift zone and suggests a high potential for oil and gas (Ashirmamedov et al., 1976).

By integrating published outcrop data from various sites in the neighboring Gorgan Plain zone (Iran), we aimed to compare regional biostratigraphic data. The Gorgan Plain is located in the northern part of Iran, southeast of the Caspian Sea between longitudes 53º00´to 56º00´ East and latitude 36º45´ to 38º00´ North. It comprises Jurassic to Quaternary sediments. The Gorgan zone lies almost entirely in Turkmenistan, with a small part in Iran. It is a lowland area surrounded by the Caspian Sea from the west, the northernmost flanks of the Alborz Range from the south and southeast, the Kopeh Dagh fold-and-thrust belt from the east, and the West Turkmenistan Basin from the north. To the east, the Gorgan Plain fades out into the anticlines and synclines of the Kopeh Dagh Cenozoic formations have been investigated at several localities by Taadi & Mohajer Soltani (2019) (Figure 5).

2. Geotectonic Overview

In terms of tectonic setting, the SCB is situated within a back-arc setting and constitutes an active component of the broader Arabia-Eurasia collision zone (Allen et al., 2004; Allen, Ghassemi, et al., 2003; Allen, Vincent et al., 2003; Brunet et al., 2003). The tectonic interaction among the Eurasian and Iranian Plates and the South Caspian microplate indicates that West Turkmenistan lies along two tectonic plate boundaries. During the Sinemurian, a rifting phase occurred in the southern margin of the collision zone concurrently with the opening of the Great Caucasus Thoroughfare. This opening manifested as a back-arc extension of a notably long basin, as evidenced by the presence of significant Middle Jurassic volcanism extending from the Pondites to the Alborz (Berberian, 1983; Allen et al., 2003a; Allen, Vincent, et al., 2003b).

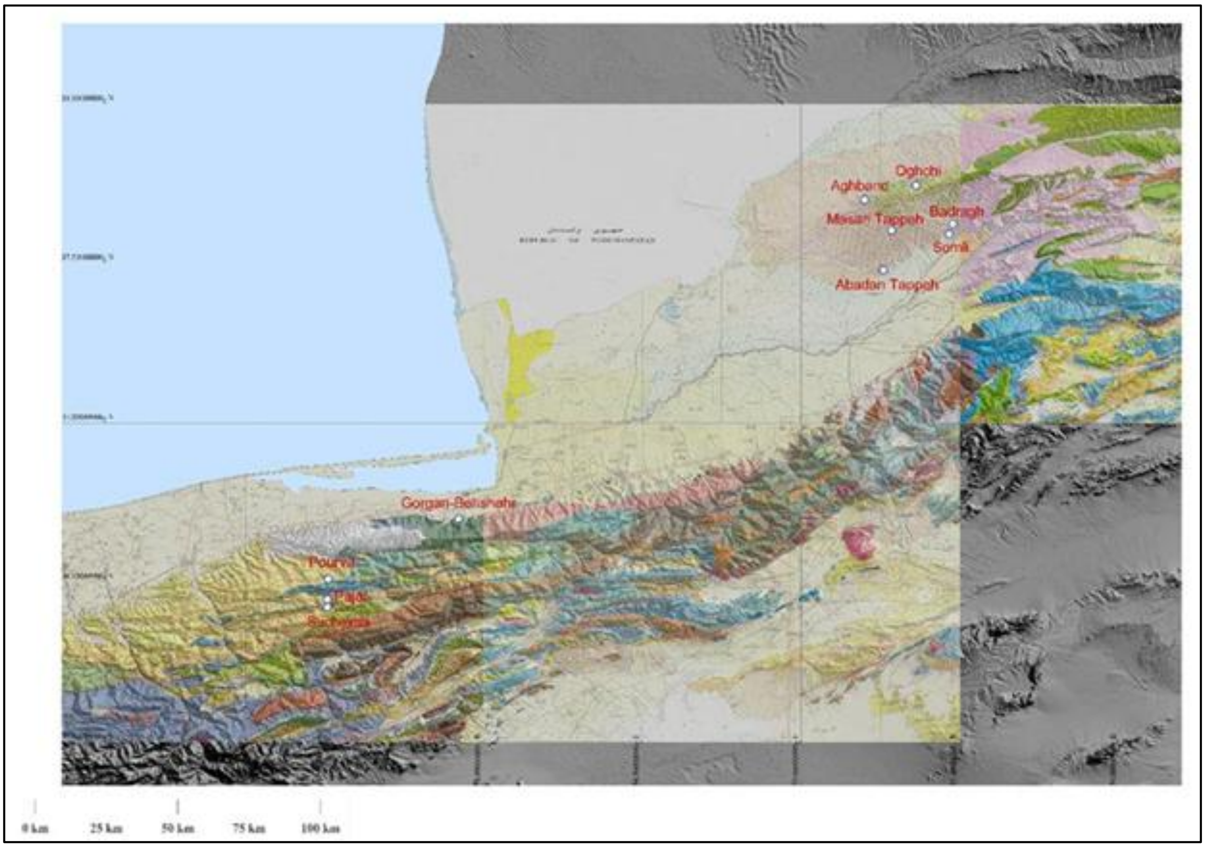

Figure 5. The Gorgan Plain. Gorgan Plain boundary and outcrop's location on the geological map (After Taadi & Mohajer Soltani, 2019).

Based on the basin subduction rate (Berberian, 1983), the initial indications of oceanic crust formation become apparent in the Middle (Callovian)-Late Jurassic. However, due to insufficient information in the central part of the SCB, there exist various interpretations regarding the age of basin initiation (Brunet et al., 2003). It is hypothesized that sedimentation commenced during the Callovian–Late Jurassic period, with the total thickness of Mesozoic sediments estimated to be no more than 5 km. Nevertheless, the predominant sedimentary infill of the SCB consists of Oligocene and younger deposits (Allen et al., 2002; Vincent et al., 2005).

The thickest sedimentary series is represented by the Pliocene–Quaternary period, with over 10 km of sediments deposited within a relatively brief interval (5,5 Myr) (M. B. Allen et al., 2002). During the Miocene epoch, two principal events coincided: the active closure of the Great Caucasus led to the separation of the Eastern Black Sea and the SCB, and the underthrusting of the SCB towards its northern margin. The final phase of basin evolution occurred during the Pliocene-Quaternary period, characterized by an unusually rapid subsidence rate, coinciding with the uplift of the Great Caucasus, Alborz, and Kopet Dagh mountains (Allen et al., 2003; Vincent et al., 2003; Brunet et al., 2003; Vincent et al., 2005). These surrounding mountain ranges (Great Caucasus, Alborz, and Kopet Dagh) effectively isolate the SCB and contribute a significant volume of sediment to the basin through three main drainage systems: the Paleo Volga from the North, the Paleo Kura from the West, and the Paleo-Amudarya from the East.

Additionally, medium-sized rivers originating from the Iranian side, such as Sefidrud and Atrak, also supply delta materials to the southern Caspian region.

In the Gograndag-Okarem region, folding is observed up to the Akchagilian and is overlain by undeformed Quaternary sediments. This relationship suggests that the Himalayan orogeny concluded in the late Pliocene Figure 6. Based on seismic data and analyzed borehole lithology, the depositional environment of the Upper Red-bed Formation is interpreted as a fluvial-dominated, low-energy deltaic system that prograded southwest and west across a broad, low-relief coastal plain under arid to semi-arid conditions. This seismic geometry is interpreted as evidence of the cessation of major thrusting activity in the Late Pliocene within the Kopet Dagh thrust belt, associated with the final closure between the Indian and Eurasian continents.

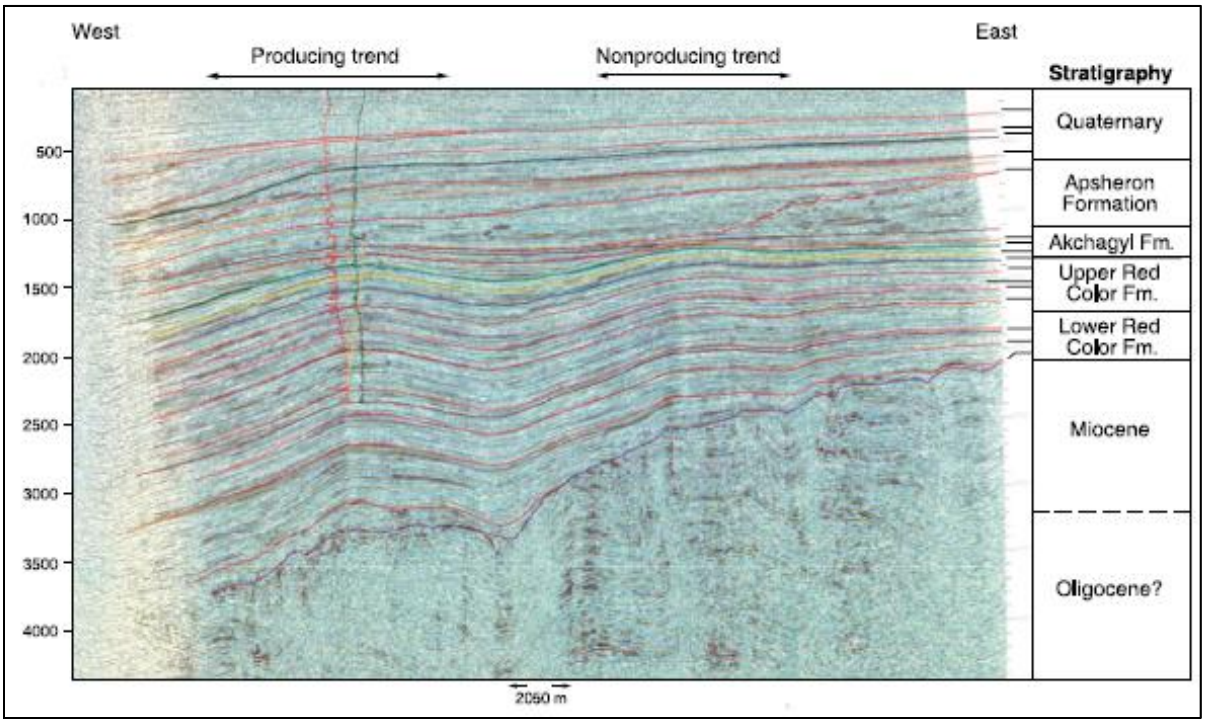

Figure 6. An east-west dip seismic line displaying stratigraphic nomenclature and third-order sequences within the Pliocene, Pleistocene, and Quaternary intervals. The line also highlights producing and nonproducing fold trends (After Torres, 2007).

3. Aim and Purpose of the Research

Our investigation aims to assess the micropaleontological content and biostratigraphy of onshore coastal and offshore wells within the SCB, encompassing regions of Turkmenistan and Iran. Specifically, we compare the studied sections with published data from onshore Iranian outcrops in the Gorgan Plain, summarize the paleontological content, and evaluate the consistency of the regional biostratigraphy. Given the limited availability of core and cutting samples and the absence of foraminifera, our paleontological analysis focuses on ostracods. Lithological and biostratigraphic surveys were conducted to determine formation tops in the studied sections. Ostracods have proven particularly valuable for biostratigraphy in neritic marine sediments where planktonic microfossils are scarce.

4. Materials and Methods

Tables 1, 2, and 3 list the studied wells in the Gogran Dag-Ekerem regions (both onshore and offshore), including the Ekerem wells in the Kysyl Kum Trough and the Mehdad well offshore in the Iranian Gorgan Plain. The tables detail the age, depth intervals, and thickness of the geological deposits in these wells.

For detailed biostratigraphic analysis, we investigated 533 core and drill cutting samples from shallow and deep exploration wells across three onshore and seven offshore structures (Tables 1, 2, and 3). The breakdown of the total quantity of core and cutting materials studied is as follows: 161 samples from shallow-drilled engineering offshore wells, 209 samples from deep-drilling exploration offshore wells, and 163 samples from onshore near-coastal structures. Unfortunately, the coordinates of Elm, Fedinskiy, and West Chikishlyar structures were not available, but their schematic location is shown in Figure 1 and Table 3.

The core and drill-cutting materials were washed and dried many years ago and have been kept in a private collection for almost 40 years without being published. Due to constraints such as limited access to electron microscopy for SEM photos and taxonomic reviews of Ostracods during years spent in oil and gas Exploration and Development, opportunities for further analysis were restricted. However, efforts were made to periodically update paleontology and stratigraphy investigations in the SCB. When possible, SEM photos of Ostracoda and Foraminifera from the previously washed and dried collection of samples were organized at various institutions, including the Geology Institute of Azerbaijan National Academy of Sciences, as well as universities in Germany, such as Jena and Frankfurt am Main.

5. Biostratigraphy Analysis

Biostratigraphic studies conducted in the last century were based mainly on onshore sections and outcrops on individual islands. A total of 9 wells from 5 onshore structures and 43 wells from 12 offshore structures in the Gogran Dag-Ekrem uplift zone were studied. In total, 112 species of Ostracode were identified in the core materials from the Quaternary and Pliocene deposits of the Gogran Dag-Ekerem uplift zone structures that we studied. 48 taxa of ostracods were found in the red-bedded strata, and 70 taxa were found in Akchagyl. These figures are significantly lower than the previous studies by (Agalarova et al., 1961) and (Mandelshtam et al., 1962).

Table 1. Gogran Dag-Ekerem uplift zone's list of analyzed core and drill cutting samples from onshore wells.

Well Name	X UTM39N WGS84	Y UTM39N WGS84	Stratigraphy	Top Depth Meter	Bottom Depth Meter	Thickness	core and cutting intervals	total core and cutting samples
Erdekli 02	781362.25	4320348.655	Pleistocene + Holocene	0	1151	1151	500-510 1000-1005 -	15
			Apsheron Formation	1151	2124	973	1151-1161 1700-1710 2000-2010 2119=2124	
			Akchagyl Formation	2124	2517	393	2124-2129 2510-2517	
			Upper Red Bed Formation	2517	3684	1167	2517-2522 3000-3005 3679-3084	
			Lower Red Formation	4750	4787	37	4750-4755 4760-4765 4780-4787	
Erdekli 03	782114.893	4325848.772	Pleistocene + Holocene	0	1246	1246	50-55 140-145 190-195 500-510 705-710 1100-1110 1240-1246	21
			Apsheron Formation	1246	2181	935	1246-1251 1500-1510 2100-2010 2176-2081	
			Akchagyl Formation	2181	2612	431	2181-2186 2200-2210 2400-2410 2607-2612	
			Upper Red Bed Formation	2612	3680	1068	2612-2017 2700-2710 3200-3210 3670-3680	
			Lower Red Formation	4600	4616	16	4600-4610 4610-4616	
Erdekli 13	777325.149	4315196.935	Pleistocene + Holocene	0	1243	1243	50-55 105-110 500-510 1000-1010 1200-1210 1238-1243	24
			Apsheron Formation	1243	1968	725	1243-1248 1300-1310 1910-1920 1960-1968	
			Akchagyl Formation	1968	2460	492	1968-1978 2205-2210 2450-2460	
			Upper Red Bed Formation	2460	2972	512	2460-2470 2550-2560 2740-2745 2967-2972	
			Lower Red Formation	2980	4200	1220	2980-2985 3100-3105 3500-3510 3800-3810 3900-3905 4100-4105 4195-4200	
Erdekli 19	787983.076	4325126.915	Pleistocene + Holocene	0	1020	1020	500-510 900-905 1010-1020	19
			Apsheron Formation	1020	2238	1218	1020-1025 1500-1510 1800-1810 2230-2238	
			Akchagyl Formation	2238	2688	450	2238-2248 2500-2510 2680-2688	
			Upper Red Bed Formation	2688	4851	2163	2688-2698 2900-2910 3500-3505 3900-3910 4200-4210 4700-4710 4849-4851	
			Lower Red Formation	4851	5000	149	4851-4856 4990-5000	
Ekerem 49	771812.134	4225740.021	Pleistocene + Holocene	0	1200	1200	1000-1010 1190-1200	14
			Apsheron Formation	1200	1600	400	1200-1210 1590-1600	
			Akchagyl Formation	1600	1980	380	1600-1610 1800-1810 1970-1980	
			Upper Red Bed Formation	1980	2800	820	1980-1990 2500-2510 2790-2800	
			Lower Red Formation	3000	4500	1500	3000-3010 3500-3510 4000-4010 4490-4500	
Ekerem 55	772760.739	4224351.941	Pleistocene + Holocene	0	1226	1226	1200-1210 1220-1226	15
			Apsheron Formation	1226	1610	384	1226-1236 1500-1510 1600-1610	
			Akchagyl Formation	1610	1829	219	1610-1620 1700-1710 1820-1829	
			Upper Red Bed Formation	2100	3500	1400	2100-2110 2210-2220 2800-2810 3490-3500	
			Lower Red Formation	3500	4300	800	3500-3510 3800-3810 4290-4300	
Kamishlidzha 28	768933.69	4256510.259	Pleistocene + Holocene	0	321	321	255-260 316-321	16
			Apsheron Formation	321	837	516	321-326 555-565 700-710 827-837	
			Akchagyl Formation	837	1031	194	837-847 1021-1031	
			Upper Red Bed Formation	1031	2805	1774	1031-1040 1500-1510 2600-2610 2800-2805	
			Lower Red Formation	2805	4330	1525	2805-2015 3600-3610 4090-4100 4320-4330	
Chikishlyar 1			Upper Red Bed Formation	1700	3250	1550	1700-1705 1900-1905 3200-3205 3245-3250	15
			Akchagyl Formation	1200	1700	500	1200-1210 1500-1555 1690-1700	
			Apsheron Formation	600	1200	600	600-605 700-710 900-910 1100-1110 1190-1200	
			Pleistocene + Holocene	0	600	600	100-110 300-310 590-600	
Chikishlyar 2			Upper Red Bed Formation	1792	3339	1547	1792-1797 1850-1855 2000-2010 2500-2510 2800-2810 3000-3010 3290-3300 3329-3339	24
			Akchagyl Formation	1537	1792	255	1537-1542 1600-1610 1685-1695 1700-1710 1782-1792	
			Apsheron Formation	792	1537	745	792-797 1000-1010 1055-1065 1300-1310 1527-1537	
			Pleistocene + Holocene	0	792	792	40-50 60-70 150-160 550-560 700-710 782-792	
								163

Table 2. Gogran Dag-Ekerem uplift zone's list of analyzed core and drill cutting samples from offshore wells.

name of structure	Stratigraphy	Top Depth Meter	Bottom Depth Meter	Thickness	core and cutting intervals					total core and cutting samples
Fersman Bank 1	Upper Red Bed Series	2900	5480	2580	2890-2900	2988-2993	5050-5055	5262-5266	5470-5480	15
	Akchagyl Formation	2700	2900	200	2695-2700	2890-2900				
	Apsheron Formation	1550	2700	1150	1545-1550	1924-1929	2020-2025			
	Pleistocene + Holocene	0	1550	1550	245-253	275-281	379-385	560-568	610-617	
Fersman Bank 2	Upper Red Bed Series	2900	6000	3100	5145-5150 2900-2910 3621-3626 4230-4235	5150-5155 3300-3305 3760-3765 4312-4317	5440-5445 3420-3425 3876-3881 4696-4701	5725-5730 3550-3555 4093-4098		28
	Akchagyl Formation	2700	2900	200	2701-2710	2797-2802	2890-2900			
	Apsheron Formation	1550	2700	1150	1611-1616	1820-1825	2160-2165	2350-2355	2680-2685	
	Pleistocene + Holocene	0	1550	1550	100-110	250-255	500-510	1390-1395	1500-1505	
island Ogurchinskaya 2	Lower Red Formation	4459	5834	1375	4459-4464	5500-5510	5829-5834			20
	Upper Red Bed Series	3300	4459	1159	3290-3300	3500-3510	4450-4459			
	Akchagyl Formation	2647	3300	653	2643-2647	2690-2700	3290-3300			
	Apsheron Formation	1835	2647	812	1835-1845	1850-1860	2400-2410	2630-2640	2642-2647	
	Pleistocene + Holocene	0	1835	1835	90-95 900-910	180-190 1700-1710	500-510 1830-1835			
island Ogurchinskaya 3	Upper Red Bed Formation	3231	3669	438	3231-3241	3300-3310	3590-3600	3650-3660		19
	Akchagyl Formation	2500	3231	731	2500-2510	2500-2510	3200-3210	2900-2910	2926-2931	
	Apsheron Formation	1541	2500	959	1541-1546	1700-1710	2400-2410	2490-2500		
	Pleistocene + Holocene	0	1541	1541	50-60 1200-1210	110-120 1536-1541	500-510	810-820		
island Ogurchinskaya 1	Upper Red Bed Formation	2811	3509	698	2811-2821	2850-2855	2970-2975	3500-3509		17
	Akchagyl Formation	2228	2811	583	2228-2238	2500-2510	2806-2811			
	Apsheron Formation	1230	2228	998	1230-1235	1270-1275	2000-2010	2190-2200	2223-2228	
	Pleistocene + Holocene	0	1230	1230	250-255	455-465	890-900	1200-1210	1220-1230	
West Erdekli 1	Lower Red Formation	4600	5705	1105	4600-4610	4800-4810	5000-5010	5600-5610	5700-5705	29
	Upper Red Bed Formation	2600	4600	2000	2600-2605	2800-2810	3200-3210	4500-4510	4590-4600	
	Akchagyl Formation	1900	2600	700	1900-1905	2005-2010	2500-2510	2590-2600		
	Apsheron Formation	1300	1900	600	1300-1310	1500-1510	1600-1605	1800-1810	1890-1900	
	Pleistocene + Holocene	0	1300	1300	20-30 500-510	50-55 700-710	70-80 900-905	100-110 1100-1110	350-355 1290-1300	
West Erdekli 2	Lower Red Formation	4640	5758	1118	4640-4650 5700-5705	4890-4900 5750-5758	5200-5210	5500-5510		30
	Upper Red Bed Formation	2600	4640	2040	2600-2605 4100-4110	2800-2810 4500-4555	3200-3210 4630-4640	3800-3810		
	Akchagyl Formation	2100	2600	500	2100-2110	2300-2310	2500-2510	2590-2600		
	Apsheron Formation	1500	2100	600	1500-1505	1570-1580	2000-2010	2090-2100		
	Pleistocene + Holocene	0	1500	1500	20-30 800-805	50-60 1100-1110	100-110 1400-1405	300-310 1495-1500	500-505	
West Erdekli 3	Lower Red Formation	4200	5626	1426	4200-4205 5200-5205	4300-4305 5500-5505	4500-4510 5621-5626	4800-4810		31
	Upper Red Bed Formation	2200	4200	2000	2200-2210 3700-3710	2250-2260 3900-3910	2700-2710 4100-4110	3300-3310 4190-4200		
	Akchagyl Formation	1700	2200	500	1700-1705	1900-1910	2100-2110	2190-2200		
	Apsheron Formation	1300	1700	400	1300-1310	1400-1410	1500-1510	1605-1615	1690-1700	
	Pleistocene + Holocene	0	1300	1300	100-110 900-910	150-160 1100-1110	255-265 1290-1300	555-565		
Mehdad	Late Cretaceous	5385	5767	382	5385-5391	5470-5476	5500-5507	5703-5710		20
	Red Bed Formation	2550	5385	2835	3020-3026 4293-4299	3530-3535 5090-5100	3995-4000	4001-4008	4011-4014	
	Akchagyl Formation	2320	2550	230	2325-2335	2545-2550	drill cutting			
	Apsheron Formation	715	2320	1605	1515-1523	1525-1533	1890-1898	2200-2205		
	Pleistocene + Holocene	0	715	715	0-10	250-255	700-715	drillcutting		

Table 3. Gogran Dag-Ekerem uplift zone's list of analyzed core and drill cutting samples from offshore shallow drilled wells.

Well Name	**Stratigraphy**	**Top Depth Meter**	**Bottom Depth Meter**	**core intervals**					**total core samples**
Fersman- 679	Pleistocene + Holocene	0	115	0-5 45-55	5-10 65-75	10-15 75-85	15-25 85-95	35-45 105-115	10
Fersman-688	Pleistocene + Holocene	0	110	0-5 100-110	40-50	70-80	80-90	90-100	6
Ferman-689	Pleistocene + Holocene	0	90	0-5 80-90	5-10	10-20	40-50	50-70	6
Fersman-680	Pleistocene + Holocene	0	80	0-5 40-50	5-10 50-60	10-20 60-70	20-30 70-80	30-40	9
Fersman-681	Pleistocene + Holocene	0	95	0-5 35-45	5-15 45-55	15-25 65-75	25-35 75-85	85-95	9
Elm-805	Pleistocene + Holocene	0	90	30-40 90-100	40-50	60-70	70-80	80-90	6
Elm-806	Pleistocene	15	50	15-30	30-40	40-50			3
Elm-807	Pleistocene (freshwater layer)	10	80	10-20	50-60	70-80			3
Elm-702	Pleistocene+Holocene	0	120	0-2 20-22 90-100	2-5 22-25 100-110	5-7 25-30 110-120	7-10 48-50	10-12 70-80	13
Elm-706	Pleistocene + Holocene	0	120	0-5 80-90	15-25 90-100	25-35 110-115	60-70 115-130	70-80	13
Elm- 675	Pleistocene + Holocene	0	120	0-10	20-30	60-70	110-120		4
Elm- 761	Pleistocene + Holocene	0	110	0-10	20-30	50-60	70-80	100-110	5
Elm-832	Pleistocene + Holocene	0	100	20-30	50-60	90-100			3
Elm -831	Pleistocene (freshwater layer)	15	55	15-25	25-35	45-55			3
Elm-704	Pleistocene + Holocene	0	100	0-15 55-70	15-25 70-80	25-35 80-90	35-45 90-100	45-55	9
Elm-705	Pleistocene + Holocene	0	100	0-5 50-65	5-15 65-80	15-30 80-90	30-40 90-100	40-50	9
Elm-703	Pleistocene + Holocene	0	110	0-5 50-60	5-15 60-70	25-35 70-85	35-40 85-95	40-50 95-110	10
Elm-709	Pleistocene + Holocene	0	120	0-10 50-60	10-20 60-70	20-30 70-80	30-40 80-90	40-50 90-100	10
Elm-822	Pleistocene (freshwater layer)	25	65	25-35	35-45	45-55	55-65		3
Elm-823	Pleistocene (freshwater layer)	30	70	30-40	50-60	60-70			3
Fedinskiy-690	Pleistocene + Holocene	0	125	0-10 70-80	10-20 90-100	20-30 100-110	30-40 120-125	50-60	9
Fedinskiy-683	Pleistocene + Holocene	0	110	0-5 30-40 90-100	5-10 50-60 100-110	10-20 60-70	20-25 70-80	25-35 80-90	12
Fedinskiy-684	Pleistocene + Holocene	0	100	0-5 40-50 90-100	5-10 50-60	10-20 60-70	20-30 70-80	30-40 80-90	11
Fedinskiy-694	Pleistocene + Holocene	0	115	0-5 45-55 105-115	5-10 65-75	20-30 75-85	30-40 85-95	40-45 95-105	10
Fedinskiy-692	Pleistocene + Holocene	0	125	0-5 40-50 95-105	5-10 50-60 205-115	10-20 60-70 115-125	20-30 75-85	30-40 85-95	13
Fedinskiy-701	Pleistocene + Holocene	0	115	25-35 85-95	45-55 95-105	55-65 105-115	65-75	75-85	8
Fedinskiy-691	Pleistocene + Holocene	0	115	0-5 40-50 90-100	5-10 50-60 100-110	10-20 60-70 110-120	20-30 70-80	30-40 80-90	13
Fedinskiy-697	Pleistocene + Holocene	0	130	0-5 40-50	5-10 50-70	10-20 70-80	20-30 80-90	30-40 120-130	10
West Chikishlyarskaya-732	Pleistocene + Holocene	0	95	0-5 45-55	5-15 55-65	15-25 65-75	25-35 75-85	35-45 85-95	10
West Chikishlyarskaya-686	Pleistocene + Holocene	0	115	0-5 35-45 85-95	5-10 45-55 95-105	10-15 55-65 105-115	15-20 65-75	25-35 75-85	13
West Chikishlyarskaya-655	Pleistocene + Holocene	0	115	0-5 35-45 85-95	5-10 45-55	10-15 55-65	15-25 65-75	25-35 75-85	11
West Chikishlyarskaya-700	Pleistocene + Holocene	0	115	0-5 35-45 85-95	5-10 45-55 95-105	10-15 55-65 105-115	15-25 65-75	25-35 75-85	13
West Chikishlyarskaya-655	Pleistocene + Holocene	0	95	0-5 35-45 85-95	5-10 45-55	10-15 55-65	15-25 65-75	25-35 75-85	11
West Chikishlyarskaya-737	Pleistocene + Holocene	0	80	0-10 60-70	20-30 70-80	30-40	40-50	50-60	7
4 structures	34 wells							samples	161

From a historical point of view, the Gorgan Dag-Ekerem uplift zone, encompassing both onshore and offshore areas, remains relatively understudied from a biostratigraphic perspective, despite significant geological-geophysical research and drilling activities identifying numerous promising structures for oil and gas exploration. Notable contributions to the biostratigraphy of the Turkmenistan region, both onshore and offshore, have been made by researchers, such as Mandelshtam et al. (1962) and Stepanaitys (1959).

5.1 Pontian deposits

Deep exploratory wells reaching about 2000 m depth in Keymir and near Ekerem, have not yet penetrated the bottom of the Pontian deposit. (Markova L.P., 1962). According to literature sources, a few wells drilled in Boyadag, Kumdag, and Nebitdag have encountered Pontian deposits characterized by a specific ostracod fauna. These Pontian deposits typically consist of thinly bedded silts with a notable mica content and a clayey conglomerate containing dark grey, bluish, and grey-green clays interspersed with large rounded clayey pebbles. Within the middle part of the Pontian deposits, dark grey clays with occasional thin layers of oolitic limestone, strongly cemented with pyrite veins, are encountered. In the lower section of the Pontian sequence, greenish-grey and light-brown marls predominate, displaying indistinct bedding characteristics alongside interlayers of grey fine-grained sand. In these marls, a typical Pontian fauna was discovered, featuring the following ostracod assemblage: *Pontoniella acuminate* (Zal), *Caspiocypris sp*., *Xestoleberis lutrae* Schneider, *Loxoconcha djafarovi* Schneider, *Cytherura pyrama Schneider*, *Amnicythere malva* (Liv), *A. saljanica* (Liv), *A. picturata* (Liv), *Loxoconcha petasa* Liv., *Cyprideis torosa* (Jones).

In the southern region of the western Turkmen lowland, Pontian deposits have yet to be identified. However, there are indications from Agalarova (1956) suggesting the presence of Pontian ostracods in samples obtained from mud volcanoes in the Chekishlyar field, located near the Gogran Dag-Ekerem uplift zone. The composition of ostracods found in the Pontian sediments of the Gogran Dag- Ekerem uplift zone indicates that the waters in this area, as well as the entire Pontian lake-sea, likely had low salinity. This low salinity environment favored the development of genera from brackish-water genera such as *Leptocythere*, *Amnicythere*, *Euxinocythere*, *Loxoconcha*, and others. Additionally, the presence of species like *Loxocorniculina djafarovi*, found in Pontian deposits, suggests a potential short-term connection between the Caspian and Black Seas during the Pontian period. This connection is further supported by the widespread distribution of these species in both the South Caspian Basin and the Pontian deposits of the Crimean-Caucasian region.

None of the studied wells within the Gogran Dag-Ekerem uplift zone, whether in the onshore coastal or offshore areas, have uncovered Pontian deposits. Literature sources indicate that the transition from Pontian deposition to the Red-colored group of formations in neighboring regions, such as the Azerbaijan sector of the SCB and southwestern Turkmenistan, is well-documented by changes in microfauna, particularly ostracods. The microfauna of the Pontian stage near the boundary with the Early Pliocene Red-bed Formation shows a significant reduction, with only a few ostracod genera such as *Leptocythera, Loxoconcha, Cyprideis*, and *Cytherissa* persisting into the Red-bed formations. Consequently, the Lower Red-bed Formation is characterized by a mixed microfauna complex comprising Cretaceous, Paleogene, and Miocene reworked foraminifera along with the aforementioned ostracod fauna (Markova, 1962; Javadova, 2024). The distribution patterns of microfauna, coupled with logging data, have facilitated the establishment of the upper boundary of the Pontian Stage. (Ashirmamedov et al., 1976) observed that paleontological analyses of core material across southwestern Turkmenistan indicate a non-uniform distribution of Pontian Formations within its boundaries.

5.2 Red-bed deposits

Onshore sections often reveal Red-bed Formations with significant erosion at the top of Cretaceous, Paleogene, and Miocene rocks. (Markova, 1962) notes that near the southern part of the West Turkmen lowland, particularly in the Keimir-Chikishlyar region, the stripped thickness of the Red-bed strata exceeds 1900 m in the Ekerem field. (Markova, 1962) elucidates that conglomerates constitute the basal portion of the Lower Red-bed Formation.

The Early Pliocene Red Formation is recognized as the principal oil-bearing formation both onshore and offshore Turkmenistan (Figures 7 and 8). It was originally thought to belong to Miocene deposits. However, for over fifty years, its exact stratigraphic position remained uncertain due to limited exposure and the absence of its lower boundary. The Red-bed strata have since been encountered in numerous boreholes across the western Turkmen depression, including the Gogran Dag-Ekerem uplift zone, where it lies beneath a thick layer of Late Pliocene and Quaternary sediments.

Exploratory wells studied in the onshore coastal region of the Gogran Dag-Ekerem uplift zone have revealed the Lower Red-bed Formation with thicknesses ranging from 16 meters (Erdekli well-3) to 1545 meters (Kamishlidzha well-28). The Upper Red-bed Formation has thickness variations from 512 meters (Erdekli well-13) to 2163 meters (Erdekli well-19).

In the offshore areas of the Gogran Dag-Ekerem uplift zone, the Middle Pliocene Red strata are encountered at depths of 1000 – 1200 meters. It then sharply descends to depths of 3000 – 4000 meters within the Turkmen structural terrace offshore, and further plunges to depths exceeding 6000 meters in the deep-water basin of the South Caspian (Aliev, 1988).

In studied offshore wells within the Turkmenistan sector of the SCB, the thickness of the Lower Red-bed Formation ranges from 430 meters (Fersman well-1) to 1426 meters (West Erdekli well-3). Similarly, the thickness of the Upper Red-bed Formation varies between 698 meters (Island Ogurchinskaya well-1) and 2250 meters (Fersman well-2).

According to Javadova (2019) and Javadova (2024), the Pliocene ostracods found in the offshore part of the SCB consist of 48 species of *Podocopida*. These ostracods are endemic to the Productive and Red strata and have been identified in sections of these deposits by various paleontologists in previous studies. Some Pontian ostracods persisted into the Early Pliocene basin (Table 4).

The microfossils recovered from these deposits are notably scarce and lack clay in areas where sand dominates. This suggests a reducing environment at the bottom of the basin, a conclusion supported by the low abundance of benthic microfossils. However, the coarse sediment does not provide evidence of a reducing environment. The sandy sediments are primarily associated with the Pereriva (sometimes named Fasila or Break suite) suite (analogous to the Koturtepe suite in Turkmenistan) of the Middle Productive series, which is characterized by a predominance of sand lithology. The fauna found in these sediments is adapted to turbulent waters, indicating that it can withstand the mechanical effects of waves. However, the fauna has not evolved significantly due to the considerable deficiency of salt in the water.

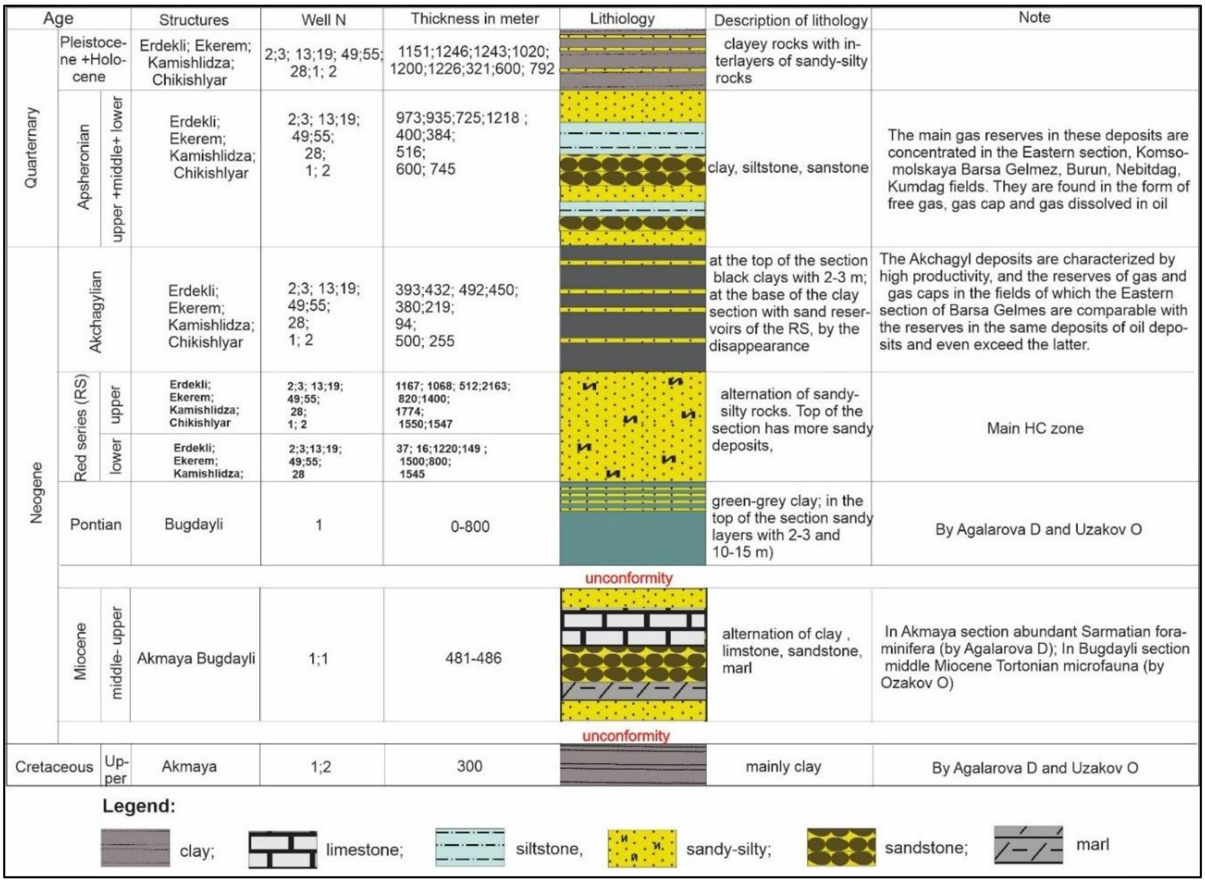

Figure 7. Generalized stratigraphy of Onshore Gogran Dag-Ekerem uplift zone.

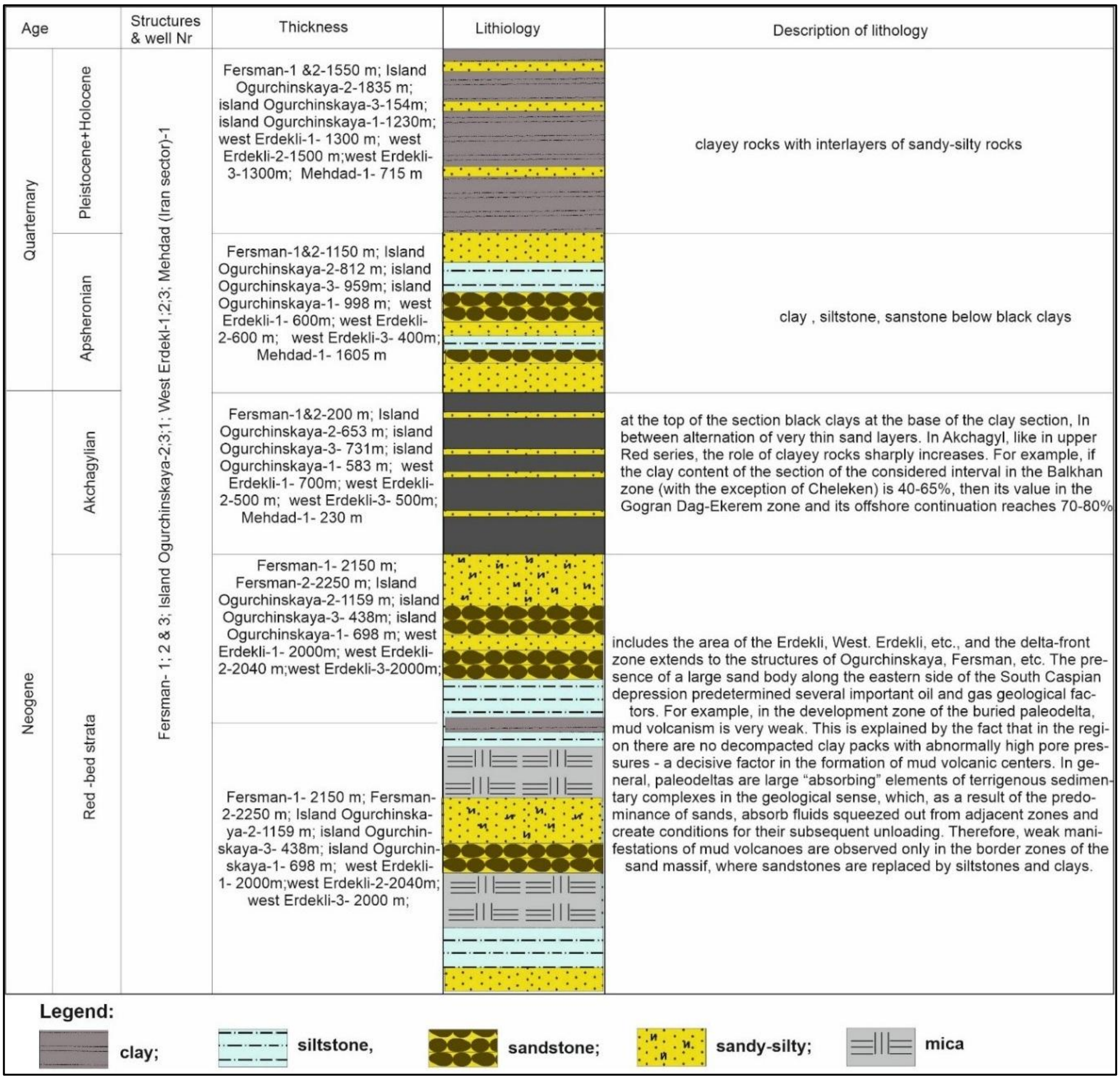

Figure 8. Generalized stratigraphy of Offshore Gogran Dag-Ekerem uplift zone.

Table 4. Generalized Ostracoda and Foraminifera assemblages of Pliocene and Quaternary deposits of Gogran Dag Ekerem uplift zone. Legend for a number of Ostracod species: green-abundant; orange-medium; yellow-rare.

Name of ostracoda	Pliocene				Quaternary				
	Pontian stage (based on Azerbaijan sector of SCB)	Productive and "Red" series		Akchagilian Stage	Eopleisocene	Early Pleistocene	Middle Pleistocene	Late Pleistocene	Holocene
		Lower	Upper		Apsheronian	Bakunian	Khanzarian	Khvalinian	Novo-Caspian
Bacuniella dorsoarcuata (Zalany, 1929)	yellow			yellow		green	yellow	yellow	yellow
Caspiocypris candida (Livental,1929)	yellow		yellow	orange					
C.rotulata (Livental, 1940)				orange	orange				
C. lyrata Livental in. litt in (Agalarova et al., 1961)					orange				
C. filona Suzin, 1956					green				
Camptocypria acronazuta (Livental,1929)	orange		orange	orange					
C. balcanica (Zalany, 1963)			yellow	yellow					
C.gracilis (Livental,1938)			orange	orange					
C. liventalina (Evlachova, 1949)						orange			
Pontoniella loczyi (Zalany,1929)	green	yellow							
P.accuminata (Zalany,1929)	orange	yellow							
Ilyocypris bradyi (Sars,1928)			orange	orange	green	green			
I.gibba (Ramdohr,1808)			orange	orange	green				
I. sp			yellow						
Condona convexa Livental,1929			orange	green					
C.sp	yellow	yellow		yellow					
C. sulakensis Mandelstam, sp nov				orange	yellow				
C. cavis Mandelstam, 1962				yellow	orange				
C.abichi Livental,1929			yellow	green					
C.contorta Suzin, 1956				yellow					
C. kurendagensis Rosyjeva, *1954*				yellow					
C. decorusa Rosyjeva sp nov				yellow					
C.neglecta Sars,1887			orange	green		yellow	yellow		
C. rostrata Brady et Norman, 1880							yellow		
C.elongata (Schweyer,1949)			orange	green		orange	orange		
Candoniella albicans (Bradyi, 1924),						yellow	orange		
C.subelipsoida (Scharapova in.litt.,1961)						yellow	orange		
Cypridopsis vidua (Müller,1776)			yellow						
Cypridopsis sp.			yellow						
Cyprinotus sp				yellow	yellow	yellow			
Zonocypris membranae (Livental,1956)			yellow	orange		yellow			
Paracyprideis naphtatscholana (Livental,1929)	orange	yellow	orange	orange	orange	orange	orange	orange	green
Eucypris sp			yellow		yellow				
Cytherissa bogatschovi (Livental,1929)			yellow	yellow					yellow
A. caspia (Livental, 1938)									green
A. pediformis (Schornikov, 1966) Tarasov, 1996					yellow	green	orange	orange	orange

Continuation of Table 4

Name of ostracoda	**Pliocene**				**Quarternary**				
	Pontian stage (based on Azerbaijan sector of SCB)	**Productive and "Red" series**		**Akchagilian Stage**	**Eopleisocene**	**Early Pleistocene**	**Middle Pleistocene**	**Late Pleistocene**	**Holocene**
		Lower	**Upper**		**Apsheronian**	**Bakunian**	**Khanzarian**	**Khvalinian**	**Novo-Caspian**
A.cymbula (Livental,1929)									
A. striatocostata (Schweyer, 1949)									
A. maltiosa (Scheider in litt in Mandelshtam M.I. et al., 1962)									
A. modesta (Schneider in litt, in Mandelshtam M.I. et al., 1962),									
A. notabilis (Schneider in litt, in Mandelstam et al., 1962)									
A. tinulla (Stepanaitys, 1962)									
A. unicornis (Schweyer, 1949)									
A. lunata (Stepanaitys, 1958)									
A. medicata (Stepanaitys, 1962)									
A. hildae (Stepanaitys, 1959)									
A. uschkoi (Schneider in litt, Mandelshtam M.I. et al., 1962)									
A. praeclara (Stepanaitys, 1962)									
A. periculosa (Stepanaitys, 1958)									
A. stepanaitysae (Schneider in litt in Mandelshtam M.I. et al., 1962)									
A. rezupina (Stepanaitys, 1962)									
A. pravoslavlevi (Schweyer, 1940)									
A. quadrituberculata (Livental, 1929)									
A. accreta (Stepanaitys, 1962)									
A. flexiuosa (Stepanaitys, 1962)									
A. volgenesis (Negadaev, 1957)									
A. camelii (Livental,1949)									
A.verricosa (Suzin,1956)									
A.rosalinae (Schneider,1940)									
A.picturata (Livental,1929)									
A. arevina (Livental, 1940),									
*A. andrusssovi (*Livental, 1929),									
A. olivina (Livental,1938)									
A. bicornis (Livental,1938)									
*A.cellula (*Livental,1929)									
A. pirsagatica (Livental in Agalarova et.al., 1940)									
A. malva (Livental, 1929)									
A.saljanica (Livental, 1926)									
A. ofortha (Livental, 1929)									
A. litica Livental, 1929									
A.palimpsesta (Livental,1940)									
A.multituberculata (Livental,1929)									
A. bendovanica (Livental in Agalarova et al.,1940)									
A.propinqua (Livental,1929)									
A. martha Livental, 1929									
A. quinquetuberculata (Schweyer, 1949)									
A. apsheronica Suzin, 1956									
Leptocythere rostrata (Evlachova,1940)									
L. spectabilis Markova, 1957									
L. nostrata Livental, 1929									
L. pontica (Suzin,1961)									

Continuation of Table 4

Name of ostracoda	**Pliocene**				**Quaternary**				
	Pontian stage (based on Azerbaijan sector of SCB)	**Productive and "Red" series**		**Akchagilian Stage**	**Eopleisocene**	**Early Pleistocene**	**Middle Pleistocene**	**Late Pleistocene**	**Holocene**
		Lower	**Upper**		**Apsheronian**	**Bakunian**	**Khanzarian**	**Khvalinian**	**Novo-Caspian**
E. (M) bosqueti (Livental, 1929)									
E. (M) praebosqueti (Suzin, 1929)									
E. virgata (Schneider, 1962)									
Cyprideis torosa (Jones,1850)									
C.pontica Kristic, 1968									
C. punctulata var pliocenica (Brady)									
Rozyjeva var. nov									
Tyrrhenocythere pontica (Livental,1961)									
T. amnicola donetziensis (Dubowsky,1926)									
T. azerbaidjanica Livental, 1940									
Loxoconcha laevatula (Livental,1949)									
L. liventalini Scheidaeva, 1958									
L. unodensa Mandelstam, 1962									
L. lepida Stepanaitys, 1962.									
L.pontica (Agalarova et al., 1961)									
L.gibboides (Livental, 1929)									
L. endocarpa Scharapova, 1949,									
L. bairdyi Müller, 1850									
L.sp									
Loxoconissa petasus (Livental,1929)									
L. eichwaldi (Livental,1929)									
Loxocorniculina djafarovi (Schneider in Suzin, 1956)									
L. ralicryi (Lübimova in.litt in Agalarova et al., 1961).									
Scaloconcha edita (Schneider sp nov in Mandelstam et al, 1962)									
Xestoleberis lutrae Schneider,1939									
X. manticae Stepanaitys, 1962									
X. chanakovi Livental,(Agalarova et al., 1961)									
Cypris subglobosa Sowerby, 1840									
Heterocypris sp									
Limnocythere sp									
L. luculenta Livental, 1929									
Darwinula stevensoni (Brady & Robertson, 1870)									

Salinity plays a crucial role in determining the distribution of ostracods, as highlighted by (Horne & Boomer, 2000). The concentration and variability of salt in water are important factors affecting ostracod habitats (Frenzel & Boomer, 2005). Salt is essential for the formation of thick-walled shells in ostracods. Only euryhaline ostracods capable of tolerating such conditions can thrive in environments with continuous detrital inflow and increased freshwater input. During the Early Pliocene in the South Caspian Basin, the environment was characterized by high-energy conditions. The primary difference between the Productive Series and the Iranian continental series lies in the depositional environment, as the Productive sediments appear to have been deposited in freshwater to oligohaline lakes (Yasini, 1986). Sedimentary deposits from the Productive and Red-bed formations typically contain only adult and larger juvenile ostracods. Some Pontian ostracods adapted to brackish water conditions, such as *Amnicythere multituberculata, Euxionocythere (Maeotocythere) bacuana, Tyrrhenocythere amnicola donetziensis, Paracyprideis naphtatscholana*, and *Camptocypria acronasuta*, exhibit strong euryhaline characteristics (Javadova, 2019b). Some stenohaline ostracods, such as *Cyprides torosa*, *Amincythere olivina*, and *A. cellula*, as well as foraminifera like *Ammonia beccarii* and *Elphidium macellum*, were gradually replaced by euryhaline species, such as *Cyprideis torosa*, which were capable of tolerating significant drops in salinity. Researchers suggest that the salinity of the Early Pliocene basin decreased from around 12 – 13‰ to 8‰ by the end of the Early Pliocene (Babazadeh, 2011).

The scarcity of molluscs and the rare occurrence of ostracods in the sediments of the Red-bed formations suggest unfavorable environmental conditions. The basin's geographic setting, surrounded by young mountainous ranges, led to a small, enclosed sea that was primarily fed by systemic rivers and temporary streams. In this environment, the Red-bed formations were deposited in the SCB, which likely had lower salinity than the Pontic Basin. As a result, most of the Pontic fauna would have struggled to survive, unable to adapt to the lower salinity levels. These geological features likely hindered the development of organic life. Moreover, the basin received significant amounts of eroded material from Cretaceous and Paleogene deposits (Agalarova et al., 1961).

The presence of ostracods in sediments, particularly in clays and bedrock, suggests specific depositional environments within the SCB. Ostracods with smaller and more stable shells are typically preserved in clays, while larger particles and species with larger shells may be found in coastal areas or carried to more distant parts by water currents. The occurrence of brackish-water ostracods like *Caspiocypris, Leptocythere, Amnicythere*, and *Loxoconcha*, which are typically associated with higher salinity conditions, indicates that the basin had undergone desalination by the end of the studied period. The appearance of freshwater ostracods such as *Cypris, Eucypris*, *Ilycypris*, *Limnocythere*, and *Darwinula* in the upper Red-bed Formation further supports the hypothesis of desalination. This suggests that the salinity levels in the basin decreased, allowing for the colonization of freshwater ostracods in previously brackish or saline waters.

The variability in the genera and species of ostracods indicates that the paleoenvironment of the SCB was dynamic, with fluctuations in depths, temperatures, and salinity levels over time. The life and distribution of microorganisms, including ostracods, were closely tied to these changing environmental conditions. Overall, the composition of ostracod assemblages in the SCB reflects the complex interplay between environmental factors and biological responses, providing valuable insights into the paleoenvironmental history of the region. The high abundance of ostracods in brackish water environments, often forming nearly or completely monospecific associations, is a characteristic feature of these ecosystems. It is common for fewer than 10 ostracod species to be present in a single sample, indicating a relatively low diversity within these environments (Horne & Boomer, 2000). Typically, fewer than 10 ostracod species are present in a single sample, indicating relatively low diversity in these environments (Horne &

Boomer, 2000). We adhere to this opinion since in many cases in the samples we studied the number of ostracods in Pliocene deposits and in some cases, Quaternary deposits are not very abundant.

In the Iranian onshore and offshore areas, the Cheleken deposit serves as an analogue to the Red-bed deposit. Information regarding the Cheleken deposits in the southwestern coastal areas of the Caspian Sea and the northern foothills of the Alborz Mountains is limited. The Iranian offshore Mehdad 1 well provide limited information on the ostracods of the Cheleken deposits. These deposits generally consist of alternating layers of clay, greyish-brown sandstone (poor in fossils), and arenaceous marls, unconformably overlying the Cretaceous deposits (Figure 9).

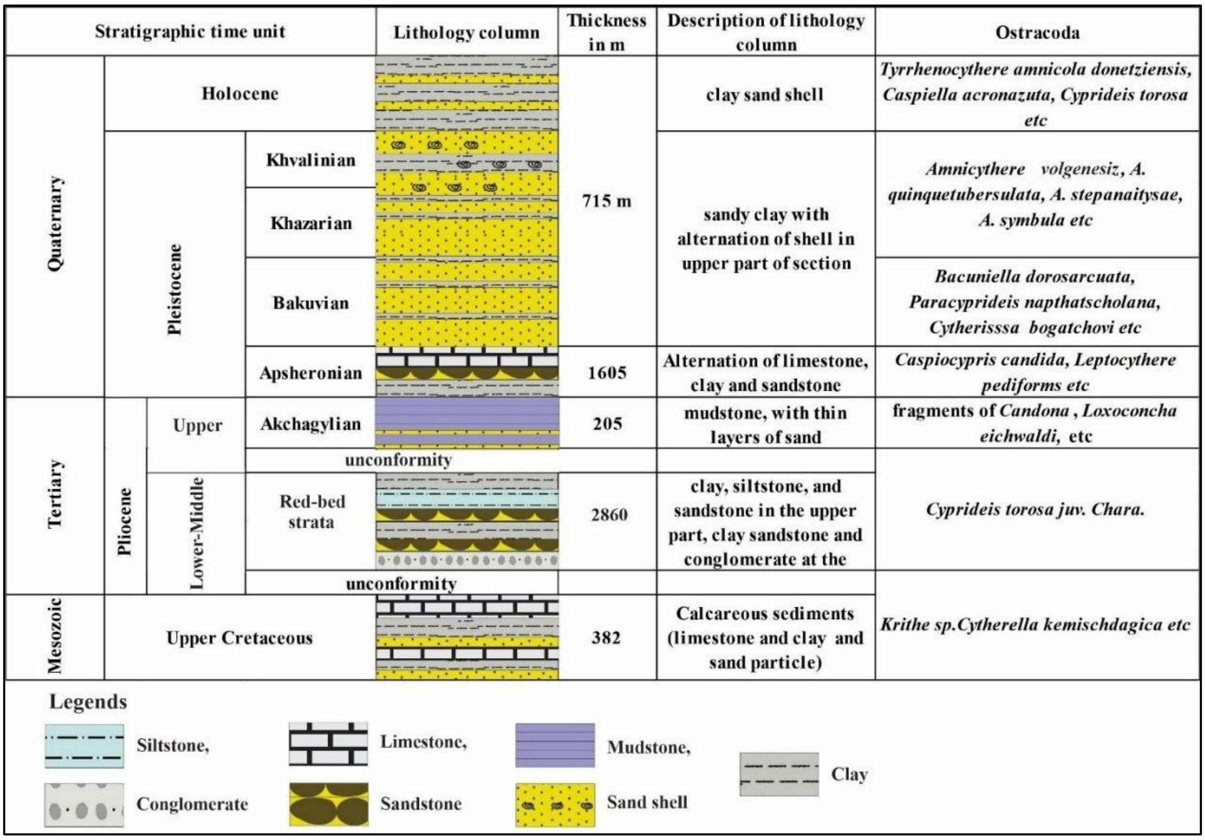

Figure 9. Iranian shelf zone of SCB. Drilled sequences of Mehdad well-1.

In the Mehtad Structure, the scarcity of microfauna made it impossible to distinguish the Red-bed strata into upper and lower layers. The total thickness of the entire Red-bed strata in Mehtad was measured at 2,835 meters. The identified ostracod content mainly consists of freshwater species such as *Candona*, *Caspiocypris*, and *Ilyocypris*, along with some brackish taxa like *Paracyprideis naphtascholana*, among others Table 5.

According to (Taadi & Mohajer Soltani, 2019), ostracods from the Cheleken deposit outcrops in the Gorgan Plain are mostly freshwater species, with fewer euryhaline ostracods. This indicates a continental paleoenvironment during this period.

Table 5: Distribution of ostracods from the offshore deep drilled Mehdad structure well-1 (Iranian shelf zone of SCB). Legend for the number of Ostracod species: green-abundant; orange-medium; yellow-rare.

Age	Cretaceous					Pliocene Red series							Pl. Akchagyl		Apsheronian				Pleistocene+ Holocene		
thickness, m	382					2835							230		1605				715		
top, m	5385					2550							2320		715				0		
bottom, m	5767					5385							2550		2320				715		
	sampling interval																				
ostracods	5703-5710	5500-5507	5470-5476	5385-5391	Unconformity	5090-5100	4293-4299	4011-4014	4001-4008	3995-4000	3530-3535	3020-3026	2545-2550	2325-2335	2200-2205	1890-1898	1525-1533	1515-1523	700-715	250-255	0-10
Krithe sp.	yellow			yellow																	
Cythereis sp		yellow																			
Cytherella sp		yellow		yellow																	
Cytherella kemischdagica	yellow	yellow		yellow																	
Candona chelekenica												yellow									
Candoniella suzini													yellow								
Candoniella albicans														yellow		yellow	yellow		yellow		
Candoniella subelipsoida													yellow		yellow					yellow	
Cyprinotus salininus												yellow			yellow						
Camptocypria acronazuta						yellow			yellow		yellow				green	yellow			green	green	green
Ilycypris bradyi							yellow		yellow												
Ilycypris gibba												yellow		yellow							
Candona sp														yellow			yellow				
Caspiolla liventalini														yellow	yellow		yellow				
Fragment of freshwater ostracods						yellow						yellow						yellow			
Ostracoda sp;								yellow				yellow					yellow				
Chara							yellow	yellow								yellow		yellow			
Paracyprideis naphtatscholana															yellow	yellow	green	green	green	green	green
Cytherissa bogatschovi															yellow						
Bacuniella dorsoarcuata																			orange	orange	orange
Caspiocypris candida															orange	orange					
Caspiocypris filona																orange	orange	orange			
Cypridopsis vidua																	yellow		yellow		
Amnicythere multituberculata										yellow				yellow				yellow		green	yellow
Amnicythere propinqua																	yellow	yellow			
Amnicythere martha																yellow				yellow	
Amnicythere quinquetuberculata															yellow				yellow	yellow	yellow
Euxionocythere (Maeotocythere) bacuana																				yellow	yellow
Cyprideis torosa					yellow							yellow		yellow		green				yellow	green
Tyrrhenocythere amnicola donetziensis																	yellow			yellow	green
Loxoconcha endocarpa														yellow	yellow			yellow	yellow	yellow	yellow
Loxoconcha bairdyi																		yellow	yellow	yellow	yellow

5.3. Akchagyl deposits

The fresh-water, shallow Red-bed basin was replaced by the relatively deep and brackish Akchagylian Sea. The Late Pliocene Akchagyl Formation in SCB is characterized by sedimentary sequences primarily comprising foliated marls, calcareous greenish-grey clays, and occasional interlayers of siltstones and sandstones. These deposits reach a maximum thickness of 500 meters in the onshore Chikishlyar area, as evidenced by well N1. In the offshore Gorgan Dag-Ekarem zone, Akchagyl deposits attain a maximum thickness of 700 meters, observed in well N1 drilled in West Erdekli. The Akchagyl stage is distinguishable from underlying deposits such as the Miocene, Paleogene, and Cretaceous, found in areas such as the south of the Western Turkmen lowland or neighboring regions, by changes in faunal ecological composition and log diagram information. New forms, such as the numerous representatives of the genera *Ammicythere* and *Candona*, appeared alongside species that had migrated from the Pontian and the Productive Series basin.

Determining the upper boundary of the Akchagyl stage presents challenges. While the totality of lithological and faunal data suggests gradual shallowing and desalination of the basin towards the end of the Akchagyl century and the onset of the Apsheron stage, no drastic changes in physical, chemical, and geographical conditions occurred at the Akchagyl-Apsheron boundary. Consequently, establishing an exact boundary between these stages is challenging across all sectors of the SCB. Notably, black clays occurring at the base of the Akchagyl in oil fields aid lithological differentiation from the lower Apsheron. The final emergence of Akchagyl ostracods occurred at the boundary with the Apsheronian period when the entire ostracod complex was fully formed.

In the study conducted in the Gorgan Plain, by Taadi & Mohajer Soltani (2019) Cenozoic deposits from seven surface sections were analyzed from the perspective of ostracods. The attempt to date these deposits using ostracods was generally successful. According to data (Taadi & Mohajer Soltani, 2019) from outcrops on the Gorgan Plain, the youngest deposit is Akchagylian. Ostracodes from the Akchagylian deposits, are identical to the Akchagylian ostracods of the SCB and well-correlated. Analysis of outcrops from the Gorgan Plain indicates that during the Early Akchagyl period, desalinated conditions prevailed, allowing only the most euryhaline forms of ostracods to adapt. These forms, however, exhibited significant stress.

It is worth noting that the quantity of ostracods found in the outcrops of the Gorgan Plain is significantly lower than what has been observed in the wells of both the onshore and offshore regions of Turkmenistan.

5.4. Apsheron deposits

(Mandelshtam et al., 1962) noted that the change in the ostracod fauna at the boundary between the Akchagyl and Apsheron periods occurred gradually. This gradual transition was confirmed in the well sections we studied. Ostracods present in the Quaternary” 's lower Apsheron deposits closely resemble those of the Akchagyl, requiring persistent and long-term investigations by numerous geologists and paleontologists to identify emerging signs of a new Apsheron basin. The ostracod fauna is rich in both the upper Akchagyl and lower Apsheron, sharing many common features as several genera from the lower Apsheron originated from the Akchagyl. The Quaternary's Apsheron deposits are characterized by grey and light grey marls, calcareous clays, siltstones, sands, and sandstones with occasional interlayers of clayey limestones. Notably, the maximum thickness of Apsheronian deposits, reaching 1150 meters, was observed in the Fersman structure (wells 1 and 2).

In the Iranian offshore Mehdad structure, Apsheronian deposits exhibited the greatest thickness, measuring up to 1605 meters (Figure 9). The ostracod assemblages obtained from both onshore and offshore sections of the Gorgan Dag-Ekerem zone structures allow for the classification of this interval as Apsheronian deposits. Most of these ostracod species closely resemble those found in the Apsheron deposits of Azerbaijan and the Iranian sectors of the SCB, with minor variations attributable to local conditions (Table 5).

5.5. Pleistocene + Holocene deposits

Regarding the Pleistocene + Holocene deposits in the Gorgan Dag-Ekerem zone, the onshore Ekerem area (well N3) exhibits a thickness of 1246 meters, whereas the offshore Ogurchinskaya island (well N2) reaches a thickness of up to 1835 meters. A summary of ostracod and foraminifera assemblages from Pliocene and Quaternary deposits in the Gogran Dag-Ekerem uplift zone is provided in Table 4. In these sediments, isolated ostracodes from genera such as *Leptocythere, Amnicythere, Loxoconcha, Camptocypria*, and other poorly preserved specimens were identified. Quaternary sediments in the offshore areas of the Gogran Dag-Ekrem uplift zone are extremely rich in ostracods. The Mehdad structure, drilled in the Iranian sector of the Caspian Sea, also shows a high abundance of Quaternary ostracods. However, in the onshore sections we studied in Turkmenistan, Quaternary ostracods were found in significantly lower quantities compared to the offshore areas. In addition to ostracods, we often encountered embryonic shells of pelecypods and gastropods, and less commonly, fish otoliths and plant remains (Figures 10, 11 and 12).

6. Discussion

The complete lack of macrofaunal remains, along with the rarity of stressed ostracods and foraminifers, represents one of the greatest mysteries of the Productive Series. The reasons behind such a significant extinction event at the Pontian-Pliocene boundary remain unclear. Consequently, the biostratigraphy and biostratigraphic correlation of the Red-bed sediments has long been ambiguous due to the absence of key organic groups essential for stratigraphic analysis. To date, the classification of these sediments has relied on their lithofacial characteristics as an accepted approach. All ostracoda forms exhibit increasing stress characteristics as they progress upward in the Productive Series section, eventually disappearing gradually from the faunal associations.

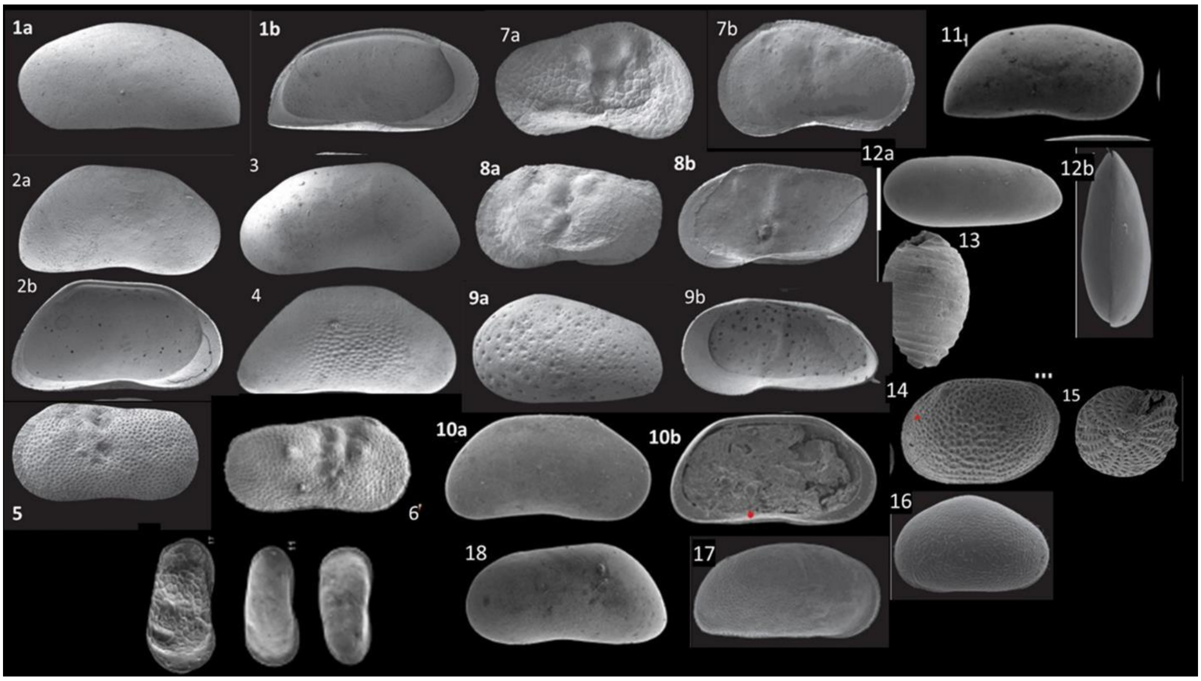

Figure 10. Selected species of Ostracods from the Turkmenian onshore near coastal and offshore wells. **1a)** *Camtocypris acronazuta*, exterior of RV; **1b)** interior of LV; **2a)** *Caspiocypris candida*, exterior of LV, **2b)** interior of LV; **3)** *Candona combibo*, exterior of LV; **4)** *Caspiolla grasilis*, exterior of LV; **5)** *Ilycypris bradyi*, exterior of LV; **6)** *Ilycypris gibba*, exterior of RV; **7a)** *Limnocythere alveolata*, exterior of LV; **7b)** interior of RV; **8a)** *Limnocythere luculenta*, exterior of LV; **8b)** interior of RV; **9a)** *Eucythere naphtatscholana*, exterior of LV; **9b**) interior of RV; **10a)** *Caspiocypris candida*, exterior of RV; **10b)** interior of LV; **11)** *Camptocypria punctulate*, external of RV; **12)** *Darwinula stevensoni*, external of RV; **13)** *Chara* (plany remains); **14)** *Loxoconcha eichwaldi*, external of LV; **15**) Foraminifera: *Elphidium crispum*, side view; **16)** *Cypridopsis vidua*, external of LV; **17)** *Cyprideis torosa*, external of RV; **18)** *Candona neglecta*, external of LV; **19a)** *Amnicythere symbula*, external of LV; **19b)** external of RV; **20)** *Amnicythere multituberculata*, external of RV.

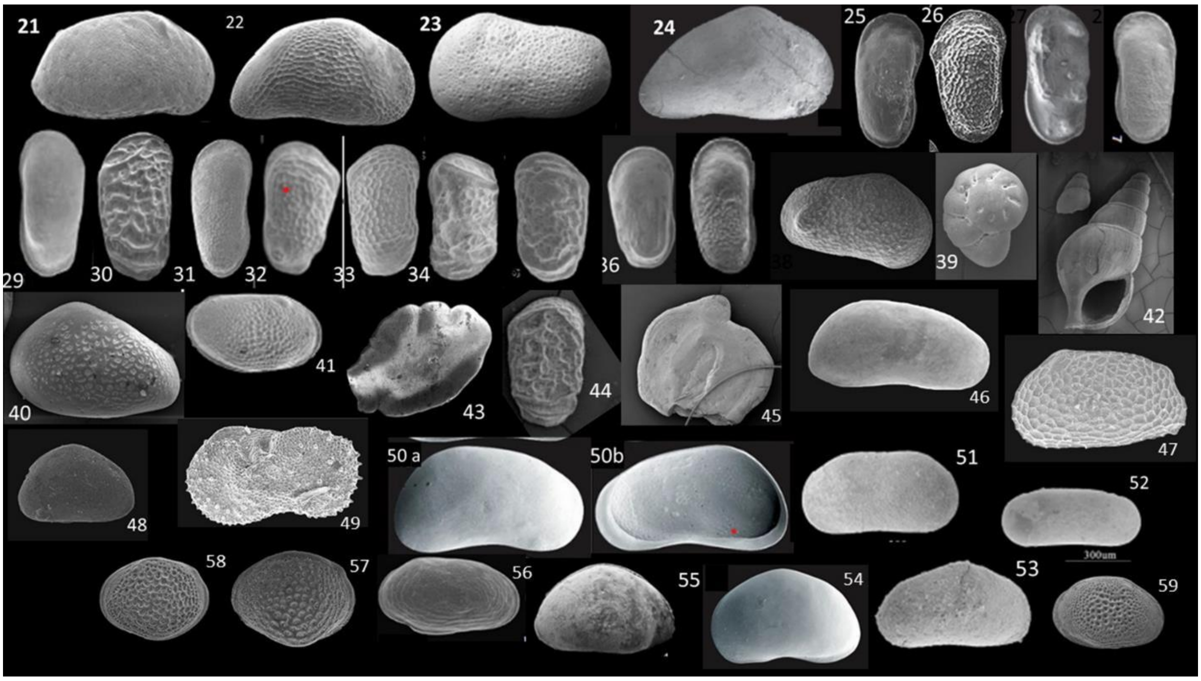

Figure 11. 21) *Tyrrhenocythere amnicola donetziensis*, external of RV; **22)** *Bacuniella dorsoarcuata*, external of RV; **23)** *Cytherissa bogatschovi*, external of RV; **24)** *Eucypris sp*, external of RV; **25)** *Amnicythere palimpsesta*, external of RV; **26)** *Amnicythere arevina*, external of RV; **27)** *Amnicythere quinqubertuberculata*, external of LV; **28)** *Amnicythere pediformis*, external of LV; **29)** *Amnicythere cymbula*, external of LV; **30)** *Amnicythere bosqueti*, external of RV; **31)** *Amnicythere stepanaitysae*, external of RV; **32)** *Amnicythere volgenesis*, external of LV; **33)** *Amnicythere martha*, external of RV; **34)** *Euxinocythere bacuana*, external of RV; **35)** *Euxinocythere virgata*, external of RV; **36)** *Amnicythere hildae*, external of LV.

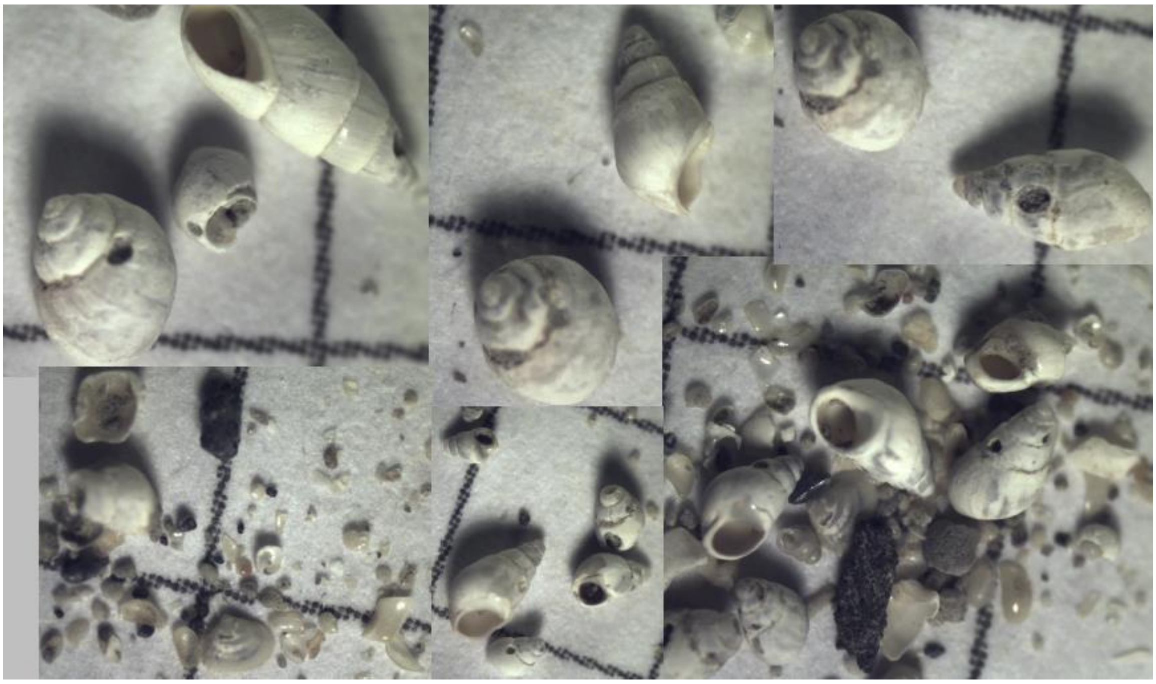

Figure 12. Embrional pelecypoda and gastropoda.

The discovery of a rich Pliocene-Quaternary ostracod fauna in both onshore and offshore environments within the Gogran-Dag-Ekrem uplift zone has significantly altered our understanding of the nature and composition of these faunas. This new evidence suggests considerable changes when compared with data from the Gorgan Plain outcrops (Taadi & Mohajer Soltani, 2019). The examination of offshore ostracod compositions shows that most ostracods changed, resulting in the formation of "Pontic type" ostracods (*Bacuniella dosrsoarcuata, Cytherissa naphtatscholana, C. bogatschovi, Caspiocypris filona, Loxoconcha djafarovi, Amnicythere subcaspia, Leptocythere lata, Euxionocythere praebacuana, E. bosqueti, Amnicythere multituberculata, A. quinquetuberculata, A. palimpsesta, A. subcaspia).*

Conversely, another group of ostracods, which exhibited minimal systematic changes, led to the development of characteristic Akchagyl and Quaternary ostracods, preserving features of their ancestral species (*Xestoleberis lutrae, Loxoconcha eichwaldi, l. bairyi, Leptocythere stabilis, L. salute, L.suzini, Amnicythere symbula, A. striatocostata, Cythereis grasilis, Cyprideis torosa,Tyrhenocythere azerbaijanica).*

Study of borehole data from onshore and offshore areas of the South Caspian indicate that Akchagyl deposits in several regions overlie older strata than the Red-bed deposits, separated by an angular unconformity (Ali-zadeh, 1967; Javadova, 2022). Consequently, in Western Turkmenistan, brackish waters flowing from the Aral-Karakum relic, which carried transformed Miocene fauna, did not mix with the freshwater of the Red-bed basin. Instead, these waters flooded the flat and foothill regions of the Gogran-Dag-Ekrem zone. According to (Ali-zadeh, 1967), who studied macrofauna, the relict forms—being somewhat stenohaline—

could not penetrate deeply into the slightly saline basin. Instead, they were preserved within depression corridors, serving as pathways for the Aral-Karakum relict basin waters to flow into the Caspian Sea.

The unconformable occurrence of Akchagyl deposits on older strata was also observed in outcrops of the Gorgan Plain, particularly in Abadan-Tappeh, Yella Badrakh, and Okhchi. Similar conclusions can be drawn regarding the ostracod fauna. Many brackish-water ostracods formed in relatively small bodies of water and then spread over large areas by connecting previously isolated bodies of water. According to (Zhizhchenko, 1964), the Pontic fauna should be considered colonial. The Akchagyl fauna can also be considered colonial, having formed in the small Turkmen basin and subsequently spreading throughout the relatively vast Akchagyl basin, which was previously an almost fresh reservoir during the period of the Red-bed strata. Consequently, it is not surprising that the following freshwater ostracods are found in the Akchagyl sediments in the outcrops of the Gorgan Plain on the Iranian side of the SCB: *Cyprideis littoralis*, *Cyprideis cf. punctillata*, *Cyprideis sp.*, *Loxoconcha levatulata*, *Loxoconcha sp.*, and *Candona sp.*, are associated with *Ammonia becarrii*, gastropods, and bivalves (Figures 13 and 14).

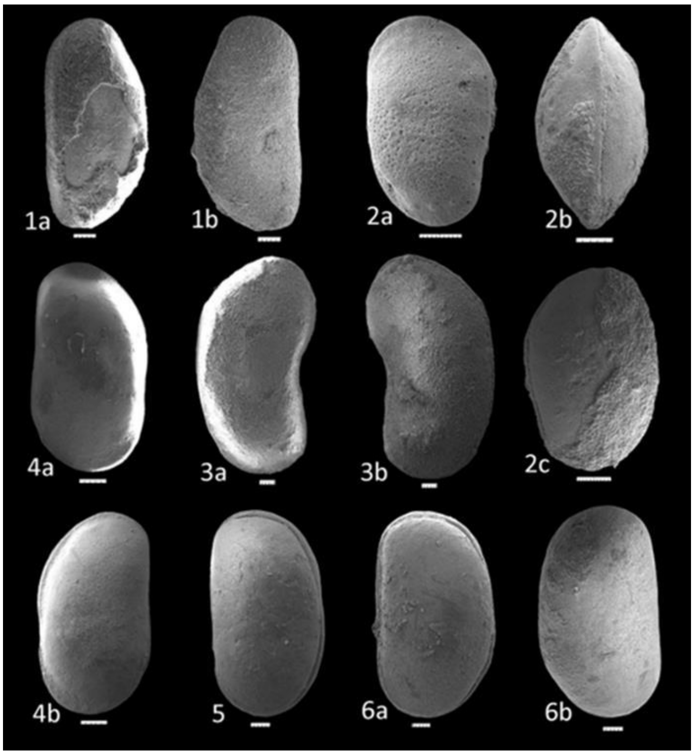

Figure 13. SEM photos of selected Ostracoda species from the Yelli-Badragh Section of Gorgan Plain, onshore Iran *(after Taadi et al, 2019).* **1a – c:** *Loxoconcha levatula* (a & c: R.V, b: Dorsal view), **2a – c:** *Cyprideis torosa* (a: L.V, b: Dorsal view, c: R.V); **3a** and **b:** *Loxoconcha petasa* (a: R.V, b: interior of R.V); **4a** and **b:** *Cyprideis torosa* (a: interior of L.V, b: L.V); **5:** *Loxoconcha petasa* (a: L.V, b: Dorsal view, c: R.V); **6a** and **b:** *Cyprideis torosa* (a: L.V, b: R.V).

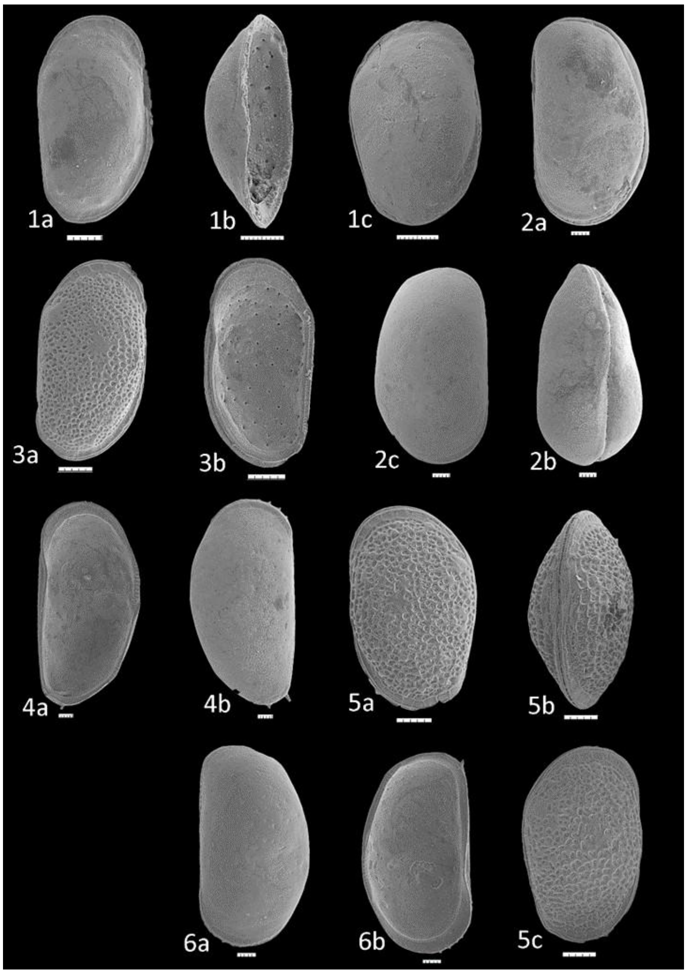

Figure 14. SEM photos of selected Ostracoda species from the Somli Darreh Gorgan Plain, onshore Iran *(after* Taati & Mohajer Soltani, 2019*).* **1a** and **b:** *Candona* sp. (a: L.V, b: R.V); **2a – c:** *Loxoconcha* sp. (a: L.V b: dorsal view, c: R.V); **3a** and **b:** *Candona neglecta* (a: L.V, b: R.V); **4a** and **b:** *Loxoconcha levatulata* (a: L.V, b: R.V); **5:** *Cyprideis torosa* (L.V) and **6a** and **b:** *Cyprideis torosa* (a: L.V, b: R.V).

7. Conclusions

This research analyzed offshore cores that were previously inaccessible due to constraints in offshore geological data. With approval from the State Oil Company of Azerbaijan, extensive micropaleontological data from offshore and coastal boreholes have been published for the first time. Earlier biostratigraphic studies mainly focused on onshore sections and outcrops from individual islands, making the materials used in this study exceptionally valuable.

The study of the ostracod fauna in the Gogran Dag Ekrem Uplift and the Iranian sector of the South Caspian Sea underscores the significant biostratigraphic role of these organisms. For the first time, both offshore and coastal borehole sections have been examined for their faunal composition, highlighting the biostratigraphic importance of ostracods in these regions. A comparative analysis of the offshore and coastal onshore sections of Turkmenistan and Iran reveals regional consistency in the biostratigraphic characteristics of the Red-bed/Cheleken and Akchagyl formations.

Our findings confirm a gradual transition in the ostracod fauna between the Akchagyl and Apsheronian stages. The Pontus and Akchagyl faunas can be considered colonial, with the Akchagyl fauna originating in the small Turkmen basin and later expanding to the wider Akchagyl basin. During the deposition of the Red-bed strata, this basin was nearly freshwater, explaining the presence of specific freshwater ostracods in the Akchagyl sediments.

The Quaternary offshore sediments in the Gogran Dag Ekrem Uplift and Mehdad structures exhibit an exceptional diversity of ostracod fauna, while onshore coastal sections in Turkmenistan show a significantly lower density of Quaternary ostracods. Additionally, the presence of embryonic shells of pelecypods, gastropods, fish otophytes, and plant remains further enriches the diversity of the fauna.

Overall, comparative studies across different regions reinforce the consistent biostratigraphic significance of ostracods, emphasizing their essential role in reconstructing regional geological histories and interpreting sedimentary environments.

During the Pliocene, the Iranian shelf and coastal zone, including the Gorgan Plain area, featured continental and lake-like sediments containing freshwater euryhaline ostracods. In contrast, the onshore and offshore regions of Turkmenistan were characterized by marine sediments with brackish-water ostracods.

Acknowledgments

I gratefully acknowledge Farid Taadi from the Caspian Oil Company of Iran for his invaluable support throughout this study. His assistance was instrumental in facilitating access to data and resources on the outcrop data of Coastal Iran, which was necessary for the completion of this study.

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