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Regional Factors Controlling the Type of Pliocene Deposits in the Southeastern Caspian Basin, NE Iran: Implication for Tectono-stratigraphic Analysis

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Abstract

Providing information about the role of the major elements controlling the type of Pliocene deposits in the southeastern part of the Caspian Basin by assessing regional and global parameters is very important to demonstrate the relationship between the tectono-sedimentary evolution and facies distribution of the area, and thereby discover the fields with the best stratigraphic and structural traps potential. Also, there is an indispensable query: which factors had controlled the the Type of Pliocene Deposits in the Southeastern Caspian Basin, NE Iran? In the present research, the Cheleken and Akchagyl formations with the Pliocene age, as the most potent constituents of reservoir intervals in the Caspian Basin, were investigated by considering facies types and the factors that controlled their variations. This research was done based on field observations, microscopy studies, and 2D seismic interpretations. Interpretation of facies and correlation along three surface stratigraphic sections and eleven exploration wells clearly justify the role of tectono-sedimentary agents controlling the distribution of the Pliocene formations in the Gorgan and Gonbad plains. Furthermore, the thickness of the Cheleken Formation increases towards the South Caspian Basin (SCB), and lithologically, it is mainly composed of conglomerates and gravely sandstones at the marginal parts grading into the silty claystone to marl facies towards the SCB. In addition, deposition of the Cheleken was accompanied by sea-level falling, and rapid subsidence resulted from the uplift and subsequent erosion of the Alborz and Kopet Dagh mountains. In contrast, the Akchagyl Formation represents a relatively uniform thickness, and lithologically, it is consists of high-energy carbonate facies in the northeastern Gonbad-e Kavous area changing into the claystone and siltstone facies towards eastern parts of the South Caspian Basin. Ultimately, according to this study, it is found out that Akchagyl Formation records a major regional transgression and reconnection of the study area to the global oceans, which was confirmed by the presence of marine biota and flat geometry pattern of the sedimentary basin.

Key words: Facies, Pliocene Deposits, Southeastern Caspian Basin, NE Iran

INTRODUCTION

The Pliocene Cheleken and Akchagyl formations are the main reservoir units in adjacent countries of the Caspian Basin (including Azerbaijan, Russia, Turkmenistan, and Iran), which have been deposited in a non-marine lacustrine system with the thickness of approximately 5–7 km in deep parts of the basin [1,2]. In the South Caspian Basin, the Lower-Middle Pliocene deposits contain thick intervals of yellow and brown colored claystones, marls, siltstones, limy sandstones, and yellowish-brown to red-colored conglomerates with limy pebbles, which are attributed to the continental setting. These types of sediments including some freshwater fossils such as ostracods, are transported into the basin through erosion of the Miocene and Cretaceous successions [3,4]. The most thickness of the Cheleken Formation in Turkmenistan reaches approximately 4,000 m.

The Akchagyl Formation, at its type section in Turkmenistan, contains marls, claystones, and gray to white- colored sandstones as well as some fossil species of ostracods, gastropods, and bivalves, which disconformably overlies the Cheleken Formation and covered by the Quaternary deposits [5].

In recent decades, the Caspian Basin, in the Iranian sector, has been considered as one of the areas with suitable hydrocarbon potential, and some exploratory researches have been carried out. In spite of the remarkable role of the Caspian reservoir elements (i.e., Cheleken, Akchagyl,

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and Apsheron) in Iran, there is not enough information on their sedimentological properties, depositional environment, diagenesis and reservoir potential, distribution and spatial expansion, and sequence stratigraphy, particularly in the southeastern Caspian Basin. Because of the existence of vegetation cover in the study region, the Paleogene-Neogene deposits have non-uniform distribution and crop out only in some limited regions, in which the deposits have been measured and sampled. Furthermore, core sampling through the Cenozoic successions of the Caspian Basin is associated with some problems due to the loose nature of deposits. Thus, there are a few data on the drilled wells over the area. Since the age and depth of the Pliocene deposits in the southern Caspian Basin are unknown, and due to lack of direct access to them, facies, and tectono-stratigraphic analysis of the surrounding outcrops is necessary to determine the evolutionary parameters governing the basin.

Despite some geological studies [6,7,8], there is no particular research on sedimentological properties and depositional conditions of the Pliocene formations in the study area. Therefore, the present study has investigated lateral facies changes and depositional setting of the Pliocene rock units. This research aims to provide information about the role of the major elements controlling the type of Pliocene deposits in the Southeastern part of the Caspian Basin with considering regional and global parameters to demonstrate the relationship between the tectono-sedimentary evolution and facies distribution of the area. The results of this research can provide useful information on the discovery of the fields with the best stratigraphic and structural traps potential [3]. Surface and subsurface sections investigated in this research are located in Golestan Province, around 100 km northeast of the Gonbad-e-Kavous area (Figure 1). According to the Iranian structural division map, the study area is a part of the Caspian Basin and western block of the Kopet Dagh [9,10].

Regional Tectonic Context

The present structural setting of the Caspian Basin is formed due to two major compressional stages and the last stage closure of the Neo-Tethys Basin in relation to the Arabian-Eurasian convergent movements from the Oligocene to present [13,14]. The first stage is related to early Arabian compression (Oligocene−Miocene), and the latter phase in the last Arabian compression occurred during Pliocene-Quaternary. The first Arabian compressional stage mainly formed folds of NW-SE trending and reverse faults along with northward thrusting of Alborz mountains and subduction of the South Caspian Basin [13,15,16,17].

According to many researchers [14,15,18,19,20], a back-arc extension and stretch movements within Caucasus Trough led to the formation of the primary South Caspian Basin from the Callovian stage (Middle Jurassic) to the Eocene, as seen in Figure 2. It seems that the South Caspian Basin (SCB) oceanic crust subducted below the Alborz and Great Caucasus orogens toward southeast-northwest as a result of the oblique-slip detachment into strike-slip and reverse faults [4].

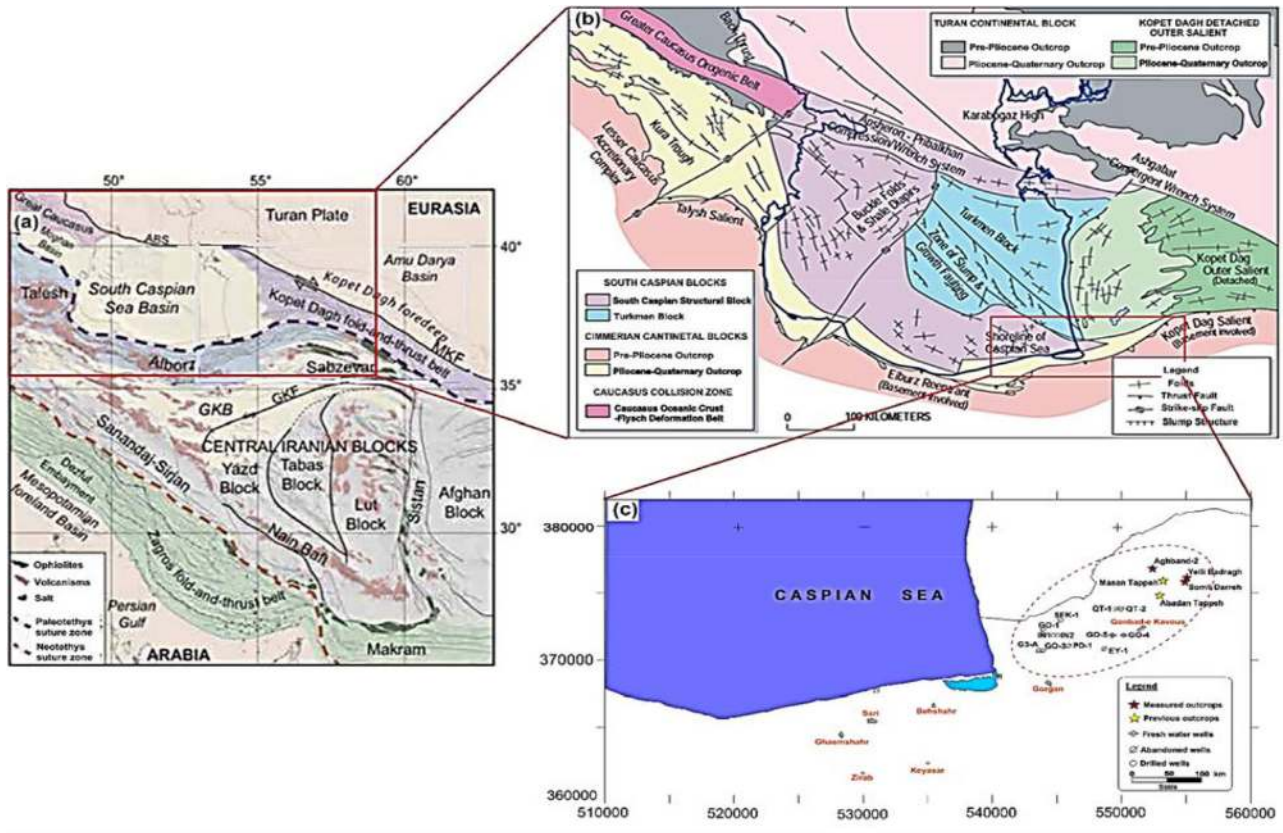

Fig 1: (a) Map of the different zones and main structural divisions of Iran [11], (b) Major structural blocks in the South Caspian Basin [12], location of the study area outlined in a red rectangle. (c) The outcrops are shown in a red dashed curve along with the subsurface sections in northeastern Iran.

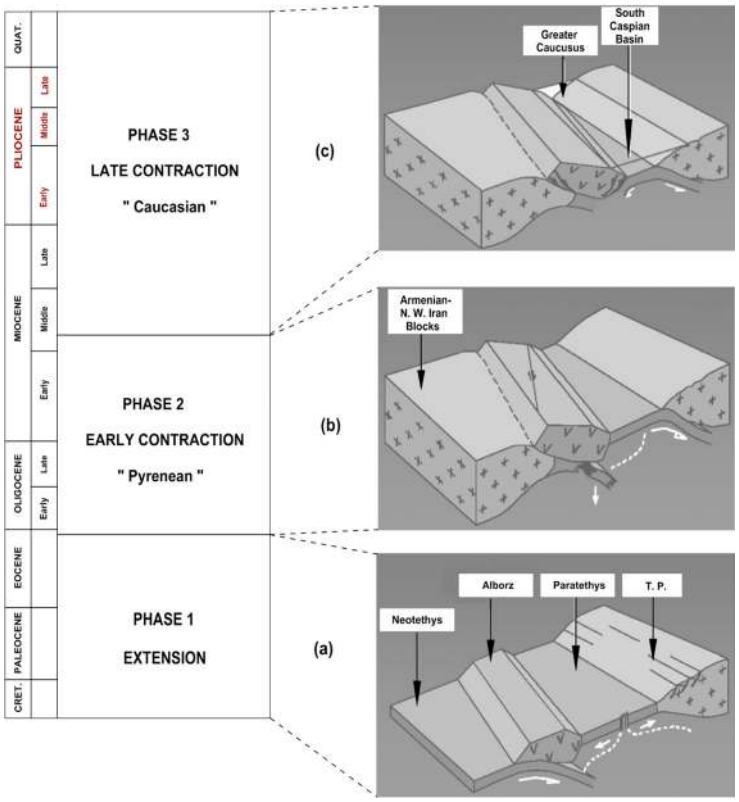

Fig 2: Three major stages of the Caspian Basin formation and evolution (modified from [23]); (a) Late Cretaceous−Late Eocene: Extension of Caspian (back-arc) Basin; (b) Early Oligocene−Middle Miocene: Initial contraction of the oceanic lithosphere, and (c) Middle Miocene−Quaternary: Late contraction of the oceanic lithosphere resulted in the formation of greater Caucasus (NW of the SCB) and Kopet Dagh, NE Iran.

Based on conducted studies by Brunet et al. [14], the final evolution of the Caspian Basin is associated with several major orogenic belts, including the Eastern Caucasus, Talesh, Alborz, and Kopet Dagh (Figure 1b). The major uplift stage in the Kopet Dagh and Alborz orogens was occurred due to the Late Eocene/ Early Oligocene transpressional stages simultaneously with the rapid subsidence phase of the South Caspian Basin [14,21]. The structural deformations and tectonic activities in the Late Miocene have led to the Caspian Basin isolation from the global ocean [11]. These changes have been assigned to the crust shortening that occurred as a result of the collision between Eurasia and Arabian plates [1,13,18,22].

Stratigraphy

Over the Lower−Middle Pliocene, a rapid and prominent subsidence occurred in the southern Caspian Basin, which was accompanied by the uplift in Greater Caucasus, Kopet Dagh, and Alborz orogens. The uplift and subsequently severe erosion of the mountains resulted in the production of a huge volume of deposits [14,24]. These sediments transported into the southern part of the Caspian Basin, causing the development of a high-quality petroleum system during the unusual subsidence stage [14].

During the Late Pliocene, the "Akchagyl transgression" again developed a short-time marine condition [12,25]. Following this marine transgression, the previous compressional stage of the Arabia–Eurasia movement caused to establish a deep lacustrine condition [15].

The Pliocene deposits in the northern regions of Iran include the two major Cheleken and Akchagyl stratigraphic units, as seen in Figure 3. The first contains reddish brown coarse to fine-grained continental facies with Early-Middle Pliocene in age; the latter comprises white-colored limestones, mudstones, and intercalations of sandy facies with the Late Pliocene in age. The boundary between the Cheleken and Akchagyl is often related to unconformity so that the Cheleken Formation of the Lower-Middle Pliocene has not been formed in the northeastern parts (towards outcrop locations in NE Iran) (Figure 3). In these regions, the Upper Pliocene formations immediately covered the Cretaceous-Pliocene unconformity. The maximum thickness of the Akchagyl Formation in outcrops was determined in the Abadan Tappeh (NE Golestan Province) by 20 m [6]. In the drilled wells of Golestan Province, the formation has a different thickness from 100 to 200 m [26]. The existence of foraminifera (such as *Globigerinoides fistulosus, Pullenia praecursor*), and *Cardium dombra* suggest the Late Neogene age for the Akchagyl in Gonbad-e Kavous area [8,26]. According to the presence of fossil components such as Ostracoda (*Leptocythere*) and gastropods (*Potamia caspius*), the Piacenzian-Gelasian age was determined in the subsurface sections of Golestan-Mazandaran Provinces, too [8,26]. The Akchagyl Formation, in Azerbaijan, consists of gray-colored mudstones, some intervals of siltstone, limestone with calcarenite intercalations, crystalline limestones, and minor volcanic ashes. Based on radiometry dating on some volcanic rocks, the age of the Akchagyl unit is approximately 3.4 to 6 Ma [7].

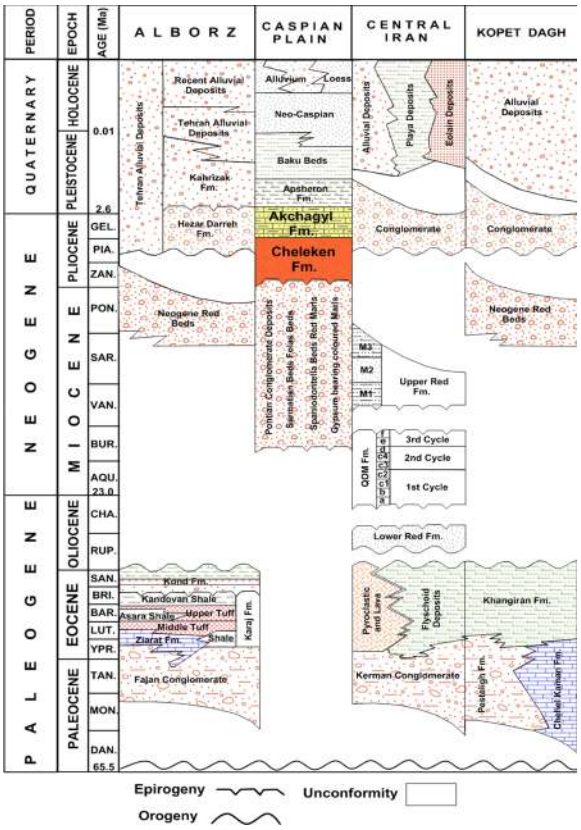

Fig 3: Lithostratigraphic chart representing the Cenozoic formations in the north and central parts of Iran (modified from [10]).

Materials And Methods

In the current study, three surface stratigraphic sections of Pliocene formations were measured through field observations in the northeast of Gonbad-e-Kavous, NE Iran. A total of 149 samples were collected, and thin sections were prepared for facies and depositional interpretations. A 2D seismic section was interpreted to clarify changes in the thickness of the studied formations. The results of these studies, along with the available sedimentological data from other studied outcrops and wells, were used for correlation and reconstruction of isopach and isolith maps. The integration of the results allowed us to determine the factors controlling the facies changes and depositional setting of the Pliocene strata in the study area.

Results And Discussion

Surface sections in this research are the thickest Pliocene outcrops, which have been measured in the southeastern part of the Caspian Sea. Three main outcrops (Aghband, Somli Darreh, and Yelli Badragh) were selected to achieve the sedimentological characteristics given in this study. The Akchagyl Formation ovelies the Cretaceous deposits, and overlain by the Apsheron successions in the northeastern parts of Iran. The thickness varies from 30 m (in Somli Darreh section) to 62 m (in Yelli badragh section), which covered the Cretaceous rocks [27]. Based on field studies and petrographic analyses of microscopic thin sections from the surface sections, five siliciclastic and carbonate facies including conglomerate, microbial laminate, bioclastic sandy packstone, peloid-ooid grainstone, and silty bioclastic wacke to mudstone, which have been deposited in five facies associations including alluvial fan, mud-flat, foreshore, shoreface, and offshore [27]. The presence of low-angle (2 to 3 degrees) cross-beds and high-energy peloid-ooid grainstones [28] indicates that the Akchagyl Foramtion was deposited in a shallow (wave-dominated) lacustrine environment [27]. Lithologically, well logs represent that siliciclastic deposits of the Lower to Middle Pliocene (Cheleken Formation) include conglomerates, sandstones, and silty mudstones, as seen in Figure 4. These types of sediments are attributed to a fluvio-deltaic to a lacustrine system [25,29]. In the studied wells, the Cheleken overlies disconfromably the Cretaceous strata (i.e., Aitamir Formation), and its thickness ranges between 100 and 900 m. On the other hand, the thickness of the Upper Pliocene Akchagyl in wells ranges from 80 to 110 m, with some minor discrepancies in lithological properties. Stratigraphic correlation in the studied area (both outcrops and wells) (Figure 4) represents minor variation in the thickness of the Akchagyl Formation.

According to Brunet et al. [14], an abnormally rapid subsidence occurred in the South Caspian Basin (SCB). It was coincident with the uplift of the Kopet Dagh, Alborz, and Great Caucasus orogens and their subsequent erosion during the Pliocene-Quaternary. Furthermore, a major regression phase, along with salinity reduction, was occurred in the Caspian Basin during the Early Pliocene [29,30]. This situation, along with compressional phases, may justify the rapid subsidence throughout the basin [14]. Furthermore, intense erosion of the Great Caucasus, Kopet Dagh, and Alborz mountains surrounding the basin resulted in a large input of sediments, especially during the deposition of the Cheleken Formation.

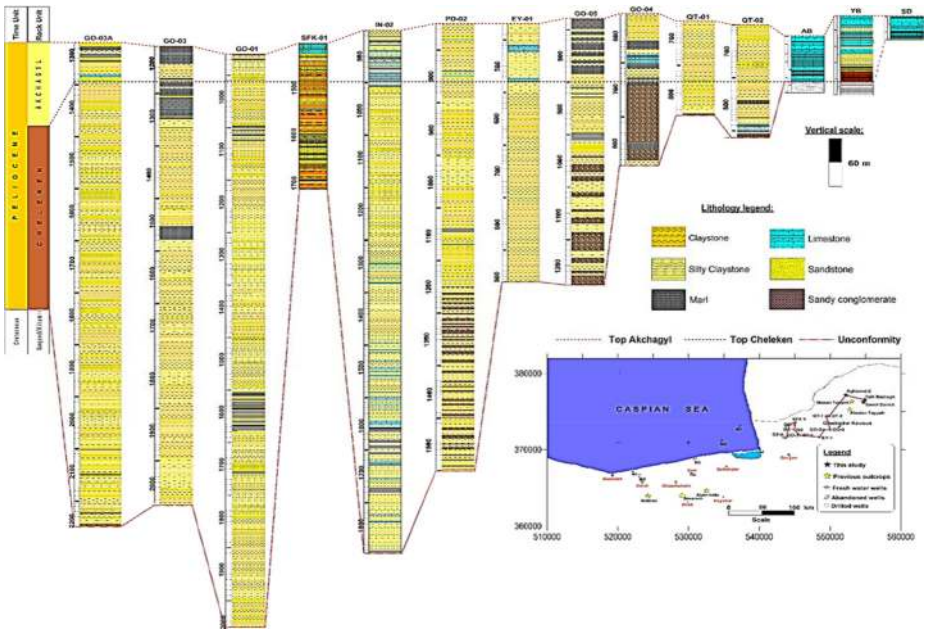

Fig 4: A NE-SW cross-section throughout the study area indicating changes in thickness and lateral facies of the Pliocene deposits.

A 2-D seismic section (Figure 5) in the Gorgan-Gonbad areas shows a sector crossing the well locations and western part of the surveyed outcrops. The red curve shows the angular unconformity (the Cretaceous-Pliocene boundary), the light green-colored horizon corresponds to the near top Mid-Pliocene, and the yellow dashed line corresponds to the Upper Pliocene, as obsedrved in Figure 5. The seismic line represents the progradational pattern of the Lower to Middle Pliocene deposits on the Cretaceous-Paleogene unconformity covered by the flat geometry of the Akchagyl Formation. Furthermore, the different thickness of the Cheleken Formation could be observed in this seismic section so that the thickness increases from the NE/E towards the S/SW part of the studied area. In contrast, the Akchagyl stratigraphic unit represents a constant thickness throughout the area. The significant thickness of the Cheleken deposits over the study area could be indicative of a remarkable subsidence rate and tectonically active condition in the basin during Early to Middle Pliocene. On the other hand, the uniform variations in the Akchagyl strata (the interval between light green-yellow horizons) indicate deposition in a generally established tectonic setting with the flat sedimentary substrate by the Late Pliocene, as seen in Figure 5

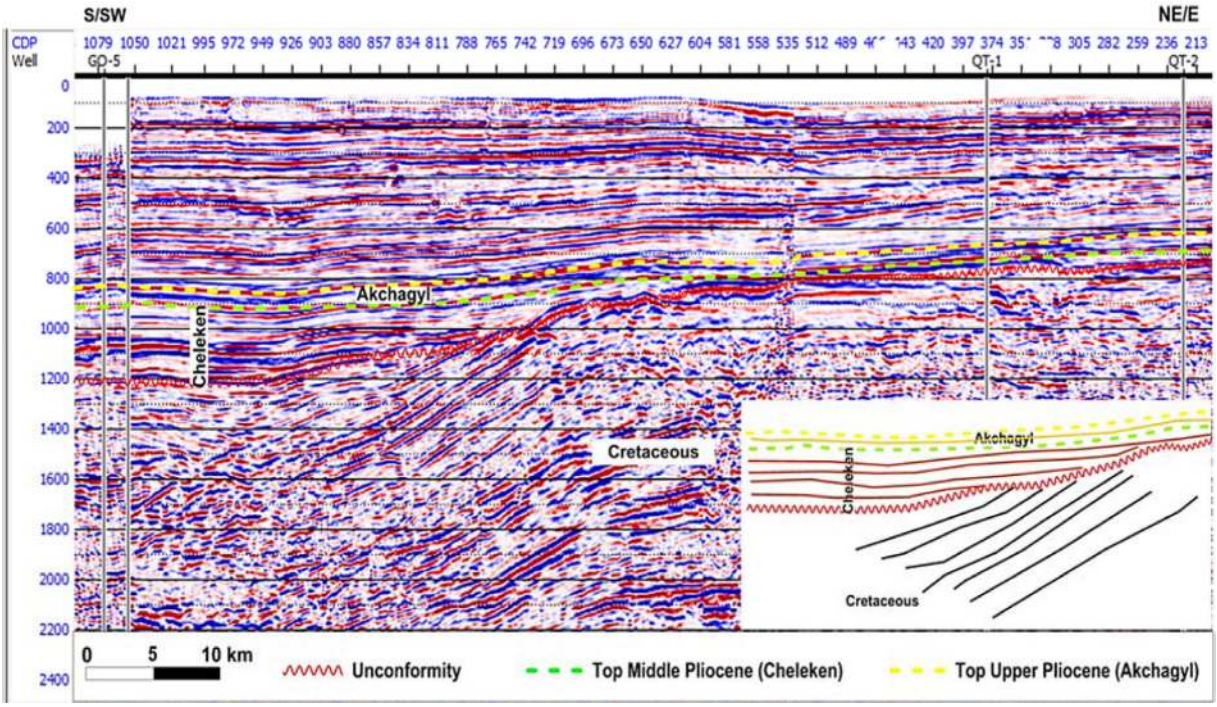

Fig 5: 2D interpreted the seismic section from the Gorgan-Gonbad plain (location in Figures 1 and 4), representing a dramatic subsidence rate towards the southeastern part of the South Caspian Sea.

Para-Tethys Basin has been begun to close in the Late Eocene. At the same time, two marine basins (i.e., Mediterranean Sea and Eurasian depositional basin) developed in the western part of Para-Tethys, resulting in the formation of a hydrocarbon province [31,32].

The present morphology of the Mediterranean Basin was developed in the Zanclean stage as a result of a transgressive phase of the Atlantic Ocean. The Eastern parts of Para-Tethys, including the Caspian Basin, have flooded again via the Aegean and Dardanelles passages at the maximum transgression phase of the Middle Pliocene [31]. Therefore, by developing marine transgression occurrence and reconnection of the SCB to the free waters during Late Neogene (2.6 Ma), the Cheleken (Productive Series) is overlain by the Akchagyl Formation. The evidence obtained from seismic and variations in thickness and lithological characteristics demonstrated that subsidence rate and sea-level fluctuations in the basin are considered as the most effective mechanisms responsible for its geometry and evolution. These documents are following the Late Neogene uplifting stages caused by the nowadays evolution and structural status of the various sub-basins in the Para-Tethys, including the Mediterranean, Romanian, Dacian, and Pontic-Caspian [17,33]. In the South Caspian Basin, it appears that a huge amount of sedimentary infills were accumulated during the Oligocene to Late Neogene, in which the accumulation results from the syn-compressional stages of the Alpine movements [11].

Based on numerous available data (this study and the previous research) on the thickness and lithology of the outcrops and wells, isopach/isolith maps of the Pliocene Formations were constructed, as seen in Figure 6. As shown in Figure 6a, the thickness of the Cheleken Formation decreases from the western part towards the east and the north towards the southern part of the study area. In most parts of the northeastern of the Gonbad-e Kavous, there is no outcrop from the Cheleken Formation. Lithologically, the Cheleken unit is mainly composed of conglomerates and gravely sandstones (at the marginal part of the basin), which grades into the silty claystone to marl facies (towards the well locations and the SCB), as observed in Figure 6a.

Numerous studies indicated that during the deposition of the Cheleken Formation, the tectonic phases were dormant and did not have any effects on the sedimentation of this area [34], and these variations in thickness and facies related to the different rates of basin subsidence presumably. Therefore, in this area, the following results could be achieved: (1) the Cheleken Formation was deposited in depression places, (2) depositional basin was separated from the open waters, and thereby (3) the base level of the basin was influenced by local factors (i.e. local subsidence and clastic sediment supply) rather than sea-level fluctuations. Furthermore, (4) it could be concluded that an increase in the rate of uplifting and intense erosion of the surrounding mountains, mainly Kopet Dagh and Alborz led to produce the significant infilling sediments and further subsidence in the basin.

Unlike the Cheleken, the Akchagyl stratigraphic unit represents a relatively uniform thickness in the studied area. In terms of lithology, this unit consists of shoreface limestones in the northwest of Kopet Dagh, and it changes into the clayey and silty facies towards the SCB, as seen in Figure 6b. Moreover, the Upper Pliocene transgression, at the end of the Gelasian stage, indicates the establishment of a carbonate platform on the margins of the southeastern Caspian Basin. In addition, these conditions correspond to the sea level falling (700-800 m) in the Zanclean (Kimmerian) stage (Figure 6c) and sea level rising (+150 m) of the Akchagylian transgression event in the Caspian Basin (Figure 6c) [33].

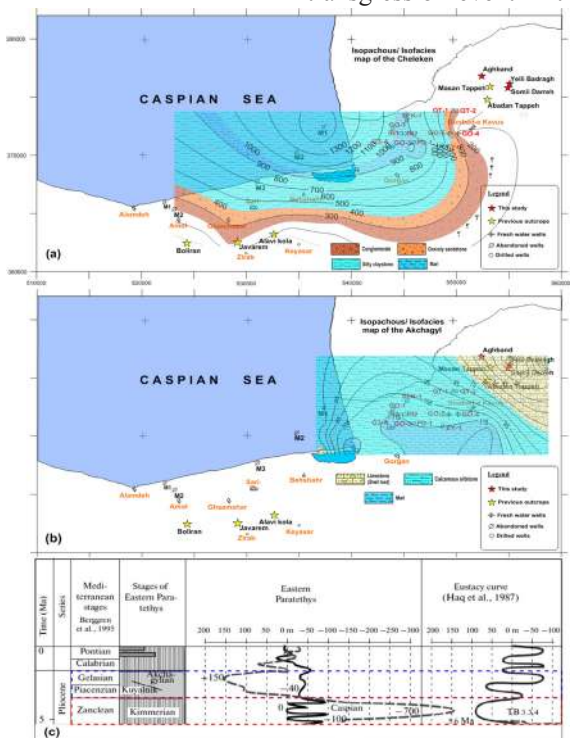

Fig 6: (a and b) Isopach/ Isofacies map of the Cheleken and Akchagyl Formations, (c) Main sea-level fluctuations of the Mediterranean [35] and Eastern Para-Tethys [30] compared with the eustacy curve [36] during the Early (Zanclean stage, red dashed rectangle) to Late (Piacenzian- Gelasian stages, blue dashed rectangle) Pliocene. The curve of sea-level fluctuations in the Caspian Basin is shown with a dashed curve.

A prominent regional transgression was recorded during the formation of the Akchagyl succession, when the Caspian Basin reconnected to the free waters [25]. This episode was also confirmed by the presence of some marine fauna like *Globigerinoides fistulosus, Ammonia becccarii, Pullenia praecursor*, and *Cardium dombra* beside some nanoplanktons including *Discoaster brouweri* and *Discoaster pentaradiatus* within the Akchagyl deposits in the studied sections [27]. The hemi-marine Akchagilian fossils of the Caspian Basin possibly had a Mediterranean origin. In this regard, marine fauna such as bivalves, ostracods, foraminifera, polyhaline nannoplanktons investigated in Azerbaijan suggest probable route from eastern part of the Mediterranean to eastern part of the Transcaucasia (South Caspian Basin). However, the corridor of the upper Euphrates Valley was also proposed by some researchers [32,35,37].

Conclusions

By making a comparison between the Cheleken and Akchagyl formations in northeastern Iran, it is concluded that the thickness of the Cheleken decreases from the eastern part of the Southern Caspian Basin (SCB) towards the northeastern part of Gonbad-e-Kavous plain in Golestan Province. This formation has not been deposited as a result of regression governed over the Early to Middle Pliocene time. Therefore, the Akchagyl stratigraphic unit disconformably overlies the Cretaceous. This condition was attributed to the different rates of subsidence and sea-level changes during the Pliocene time interval. During the Early to Middle Pliocene, the variations in thickness and lithology of the Cheleken Formation were predominantly controlled by subsidence rate, which was accompanied by orogeny and following erosion of the Kopet Dagh and Alborz mountains, and consequently, a significant input of sediments into the basin. Therefore, these huge amounts of sediments have caused more subsidence towards the SCB. Unlike the Cheleken Formation, the Akchagyl Formation represents a relatively uniform thickness through the Southeastern Caspian Basin. This stratigraphic unit, in the northeast of the Gonbad-e-Kavous area, mainly contains highly energy carbonate facies belonging to the costal margin. In addition, this formation is graded into the siltstone and shale facies, towards the western parts of the basin (the SCB). This lateral facies change was known in relation to the sea-level rising (i.e. the Akchagyl transgression episode). Finally, these conditions indicate the tectonic stability of the basin, and marine transgression and regression (or rising and falling sea level) have controlled the facies distribution of the Akchagyl Formation by the end of Pliocene (i.e. Gelasian Stage).

Nomenclatures

SCB: South Caspian Basin

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