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Paleogeography and regional interpretation of facies in Tirgan Formation, west of Kopet-Dagh sedimentary basin, northeast of Iran

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ABSTRACT

In order to study the lithostratigraphy, biostratigraphy, microfacies, depositional setting and also to reconstruct the paleo-environmental conditions of the Tirgan Formation, three outcrop sections were selected in the western part of the Kopet-Daghh sedimentary basin. These sections locate at the Estarkhi village (30 km East of Shirvan city), the Jozak (40 km West of Bojnourd city) and the Zaw Mountain (45 km far from the Kalaleh city). Geographical coordinates of these outcrop sections are: 57º, 51ˋ, 31ˋˋ longitude and 37º, 11ˋ, 29’’ latitude in Estrakhi section, 56º, 42ˋ, 25ˋˋ longitude and 37º, 24ˋ, 55.8ˋˋ latitude in Jozak section, and finally, 55º, 45ˋ, 10.6ˋˋ longitude and 37º, 31ˋ, 20ˋˋ latitude in Zaw section. The Tirgan Formation has a thickness of 129 m in Estarkhi, 362 m in Jozak and 639 m in Zaw section, in which measured and samples to be used in this study. A total number of 62, 102 and 226 rock samples was taken respectively from the Estarkhi, Jozak and Zaw sections, and used for the microscopic studies. Therefore, a total number of 700 thin-sections were prepared from the rock samples and studied under the microscope. In Estarkhi section, the Shurijeh Formation is overlain conformably by the Tirgan Formation. Moreover, the upper contact of the Tirgan Formation with the upper rock unit, the Sarcheshmeh Formation, is continues and conformable. In this outcrop section, the Tirgan Formation begins with siliciclastic deposits with intercalations of marls, representing a gradational passage from the continental Shurijeh Formation to the marine deposits of the Tirgan Formation. The Jozak section represents a conformable and continues contact between the Tirgan Formation with the underlying Shurijeh Formation, but, its upper contact with the overlying Abderaz Formation is cut by a fault. In Zaw section, the lower contact of the Tirgan Formation with the Zard Formation is continues and conformable, but, its upper contact with the younger deposits is covered and unclear. Based on the distribution of facies belts, three paleogeographical maps were prepared for the study area. They are: Hauterivian?-lower Barremian, lower Barremian-upper Barremian and upper Barremian-lower Aptian. Analysis of these maps shows that during the Hauterivian?-lower Barremian, in the far eastern part of the study are (e.g. Estarkhi section), the Tirgan Formation includes in siliciclastic deposits with some marine marls, in that the detrital sediments was carried to the foreland basin as a result of erosion of high structures. In the same time, the western parts of the study area was covered by deposits belonging to a tidal-flat depositional setting, representing a deepening trend from the East towards the West of the area. During the Barremian (lower Barremian-upper Barremian), a major deepening trend has occurred for the both vertical and horizontal extend regionally in the study area. Therefore, the Estarkhi area was covered by tidal-flat deposits, and in the same time, the deepening trend was continued towards the west, led to the deposition of shoal and open marine facies in the Jozak and Zaw area. Finally, in the upper Barremian-lower Aptian, a stable condition was govern for the entire area, led to the deposition of orbitolina bearing limestones totally in the study area. Vertical distribution of facies belts shows that the eastern part of the study area (e.g. Estarkhi section), represents a major deepening upward trend during the upper Barremian-lower Aptian, which is comparable with general and global transgressive trends for the Barremian-Aptian interval. But, in the western part (e.g. Jozak and Zaw areas), the bathymetry was often stable, and somehow, shows a shallowing trend, that probably belongs to the role of basement faults and local tectonic activities, creating various accommodation space on the shallow platform setting in this part of the Kopet-Daghh Basin.

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1. Introduction

One of the largest Cretaceous advances in Iran took place during the Barremian and Aptian stages. From the Barmen to the Aptian, vast seas gradually began to advance over the Late Jurassic continental lands, and as a result, the outcropped areas gradually sank under the Cretaceous Progressive Sea. At this time, the vast and shallow sea covered all of Iran, resulting in uniform orbitolite-bearing limestones. In this paper, the long-standing geographical situation of the study area and the regional expansion of facies during the Hauterivian, Barremian and Aptian stages are investigated along with paleogeographic maps of the area.

2. Material and Methods

2.1. Geographical location and Material & Methods of achieving the studied section

In this study, Tirgan Formation was collected and sampled in three stratigraphic sections as follows. Estarkhi section according to the geographical coordinates mentioned in Table 1 is located 180 kilometers west of Mashhad and 30 kilometers south of Shirvan (Estarkhi village). The thickness of Tirgan Formation in this section is 129 meters and the studied formation is sloping and continuous above the Shurijeh Formation and is located below Sarcheshmeh Formation.

Jozak section: It is located 40 km west of Bojnourd city according to the geographical coordinates mentioned in table 1. The thickness of Tirgan Formation in the mentioned section is 362 meters and the studied formation is located steadily and continuously on Shurijeh Formation and as a sharp and fault below Abderaz Formation. According to the geographical coordinates mentioned in the table below, Zaw section mountain is located in Zaw village and near Gorganrood which is from Pishkamar section and at a distance of 45 km from Kalaleh city. The thickness of Tirgan Formation in this section is 639 meters. It should be noted that the upper contact surface of the study formation is covered and the lower contact surface with Shurijeh Formation is sloping and continuous (Figure 1).

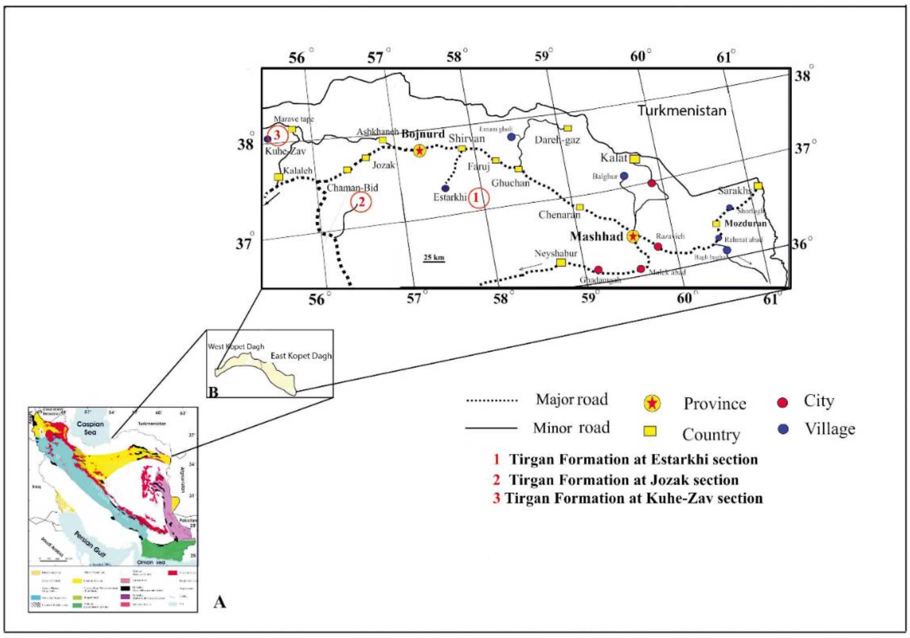

Fig. 1. Geographical location and access to the studied section

Table 1. Geographical latitude of Tirgan Formation in the studied sections, west of Kopet-Daghh basin

Studied sections	Geographical coordinates	
	Eastern longitude	Northern latitude
Estarkhi	57° 51' 31"	37° 11' 29"
Jozak	56° 42' 25"	37° 24' 55.8"
Zaw	55° 45' 10.6"	37° 31' 20"

3. Results and discussion

3.1. Paleogeography and regional tectonics of sedimentary basins in Iran and the world

Late Cimmerian tectonic movements in Iran probably coincided with the separation of continents of India, Australia, and the Antarctic from the Gondwana supercontinent. This phase in our country is characterized by drought and compaction movements (Barbarian and King, 1980). At this time, the expansion of Tethys Ocean has ended and drift has occurred along its entire length (Figure 1-6). After Late Cimmerian orogenic movements in the Upper Jurassic, marine facies have expanded a lot and sedimentary basins have been subsiding (Darvishzadeh, 2001). During this time, many modern structures in Iran, including Cretaceous ridges, have been developing (Darvishzadeh, 2001; Barbarian and King, 1981). Tectonic movements (Late Cimmerian orogeny) between the Jurassic and Cretaceous in most parts of Iran have caused a sedimentation vacuum or rubble sediments. During the Cretaceous period, Iran was slightly above the equator, so that the 20 degree north orbit passed through central Iran. Early in this period, the Iranian subcontinent was located in the form of a long strip between the great Caucasus synod and the ocean of Neo-Tethys in the south, into which branches of Neo-Tethys entered, which were probably in a rift shape.

Figure 2) Schematic paleogeographic and regional tectonic map of Gondwana and Eurasia and the formation of intercontinental oceans (Adapted from Kendall et al., 2010).

During the Neocumin, the sea had a general decline and large areas of Iran were out of water and continental conditions prevailed in them, so that Cretaceous orbitolite-bearing limestones were left on various Mesozoic and sometimes Paleozoic formations. This issue is attributed to the Late Cimmerian orogenic movements in the late Jurassic (Darvishzadeh, 2001; Barbarian and King, 1981). The period of calm continued along the northeastern coast of Iran until the end of the Jurassic, but gradually a vast sea began to advance over the Late Jurassic continents from Barmen to the Aptin, and as a result the outlying areas were gradually submerged by the Cretaceous. The water is sinking. This advance, which is perhaps one of the largest Cretaceous advances in Iran, took place during the Barremian and Aptian riots. At this time, the vast and shallow sea covered all of Iran, resulting in uniform orbitolite-bearing limestones. In parts of the Kopet-Dagh basin (such as the Binalood area), due to folding and fragmentation and the presence of Cretaceous faults, there is only a small outcrop of orbitoline limestones with a conglomerate and sandstone unit on the remains. PaleotiTethys and Philit are located in Mashhad (Darvishzadeh, 2001). The presence of detrital sediments in the Kopet-Dagh basin can be thought to be the result of erosion of heights and the transport of large amounts of detrital sediments to the Forland basin, which have been deposited as red sandstone layers (Alavi, 1991).

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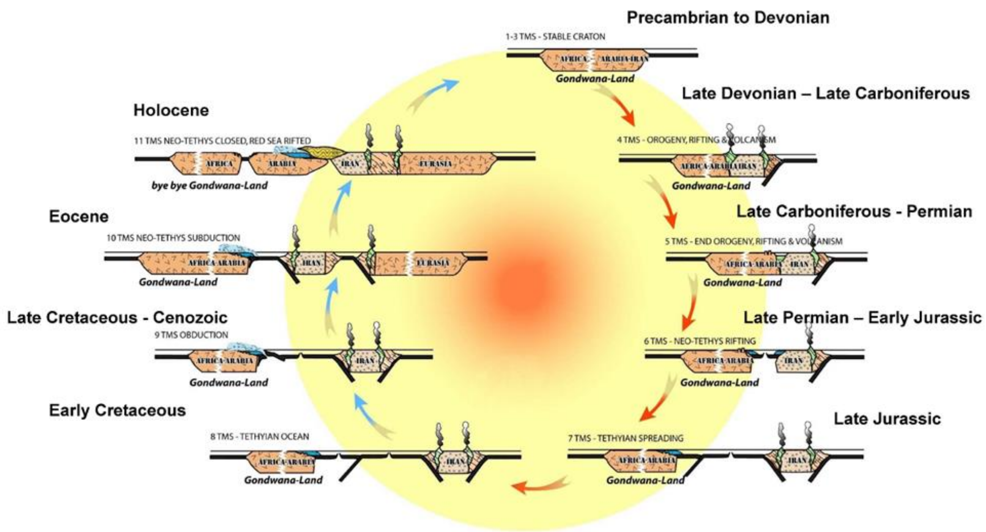

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The Aptian-Albian period is a vital period in the geological history of Neo-Tethys basin. Subduction zones near Gondwana may have formed at the same time (Grover, 1991). The construction of this integrated subduction zone in the Neo-Tethys Basin increased the velocity of tectonic plates around the world and led to the rise of seawater on a global scale. The advance of Aptian was not continuous everywhere and in some places it was continued by a regression and the advance of water was repeated again in Albian (in Iran, for example, Alborz and Talesh Mountains, and Afghanistan can also be exemplified) (Grover, 1991). The large advance of Aptian, along with the temporal and spatial increase in sediment production, contributed to the spread of extensive carbonate-rich facies on carbonate platforms and ridges at this time (Pederson and Clavert, 1990). Grover (1991) examined the paleogeographic evolution of Tethys Basin in the Aptin-Albian period based on global factors such as extensive advances, and examined the Aptian-Albian facies on both the northern and southern margins of the Neo-Tethys and mapped Tectonic and paleogeographic features of this basin during this period. According to him, the reconstruction of the Aptian-Albian sedimentation in the Tethys Basin first of all requires the exact age of the sedimentary deposits, but such accurate stratigraphy is not available everywhere in the Tethys belt. As we move east from the well-studied Alps and the Mediterranean, the data on the Aptian-Albian sediments are scattered progressively, and no accurate data are available. In addition, in many places the sediments are either metamorphosed or not preserved due to subsequent erosion. During the Aptian-Albian, shelf conditions prevailed over large areas of the northern margin of Neo-Tethys, in the Alpine and Mediterranean regions, orbitolinated marls and orgonine limestones together with glauconite sandstones, conglomerates, and detrital granular sediments. They were deposited in many areas, such as the Abaru, the holotik, the Moesic, and the pontic shelves (Grover, 1991). It seems that in Iran, orbitolinated limestones have overcome the detrital sediments (Davoodzadeh and Schmidt, 1984). In Kopet-Dagh Basin, Lower Aptian orbital limestones (Tirgan Formation) are covered by middle-upper Aptian ammonite shales and marls with deep shelf environment (Davoodzadeh and Schmidt, 1985) which clearly shows that the shelves have started to deepen after the lower Aptian. Shelf sediments continue from Iran to Afghanistan with similar facies.

3.3. Paleogeography and evolutionary stages of Zagros and Kopet-Dagh sedimentary basins
Evolutionary stages of Zagros basin

In short, the land of Iran, which is located in the west of the main thrust fault of Zagros and northeast of the Arabian plate, is called the Zagros zone (Figure 3), which is bounded on the east by Minab fault, but in the west its characteristics in Arabic countries is also found, especially in Iraq, Kuwait, Oman, the UAE and Saudi Arabia, and on the southern shores of the Persian Gulf. The Zagros Basin consists of three separate units, which are: the Khuzestan Plain, the folded or external Zagros, and High Zagros or driven or inland Zagros. The initial stage of evolution of this basin includes the platform stage which lasted from Infra Cambrian to Middle Triassic and during which sediments similar to Central Iran and Alborz were left. Infra-Cambrian saline sediments in the east and south of Zagros are similar to sediments deposited in eastern Saudi Arabia. During this time, parts of the water were out. Because Silurian to Permian sediments have not been found in some places, even in oil drilling. In the early Permian Zagros, it was covered by continental evaporitic sediments, which were later replaced by shallow sea limestone sediments with shale and Kolabi facies up to the Middle Triassic. The second stage of evolution of this basin began in the late Triassic and continued until the Miocene. At this time, the Zagros Basin was separated from other parts of Iran and became a submerged basin that was constantly "subsiding" in which Mesozoic to Neogene sediments with a thickness of more than 10,000 meters have accumulated on top of each other. Basically, carbonate and in that marl, sandstone and shale are more or less seen. The presence of evaporitic sediments and some short-term stratigraphic absence is a sign of vertical movements (drought) in this sedimentary basin. That being said, all of these sediments are co-located on the Paleozoic sediments, and only during the last alpine (Mio-Pliocene) phase orogeny did they fold out of the water and into a lake environment, a river emerged in which evaporative sediments emerged. Due to the erosion of the adjacent heights, it was deposited in a steep state (Bakhtiari Conglomerate). No activity of magmaTethysm and metamorphism is observed during the alpine phase in this basin. The post-orogenic phase in the Zagros Basin coincided with the deposition of the Bakhtiari Conglomerate during the Mio-Pliocene, and the Zagros Basin, in other words, the entire Iranian plateau, passed the Pasadenian orogenic phase, and thus the Bakhtiari conglomerate and its equivalent, Hezar Darreh in South Alborz was wrinkled. It seems that with the emergence of Zagros-Oman mountain range in the late Cretaceous, the Zagros region folded and part of the Saudi platform became a marginal pit that evolved into an evaporative groove during the Miocene. The folded strip of the Zagros gradually leads to a northeastern area in the northeast, resulting in a highly fragmented and faulted zone that forms a narrow, narrow strip (10-70 km) between the Sanandaj-Sirjan and The Zagros is folded and because it includes the highest mountains of the Zagros, it is called the High Zagros. Therefore, due to severe crushing and drift, it is also called the crushed zone, the crushed zone, and the thrust zone.

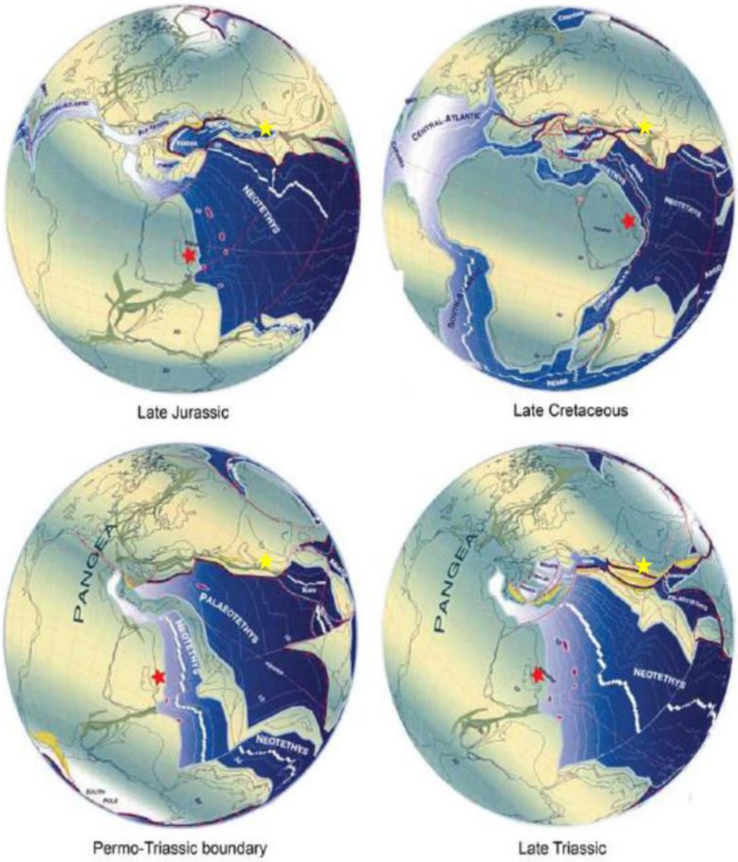

Fig. 3. Paleogeographic map and tectonic evolution of the Tethys Ocean, Neo-Tethys and the Caucasus Sea from the Permian to Late Cretaceous (adapted from Stampfli and Borel, 2002 and taken from Hosseini, 2014). The location of Zagros (red star) and Kopet-Dagh (yellow star) basins is shown.

3.4. Evolutionary stages of Kopeh Hot basin

As shown in global paleogeographic maps, the Kopet-Dagh basin is located on the southern edge of the Eurasian supercontinent, and its evolution is related to the formation and separation of important supercontinents and oceans in the Tethys area (Figures 3 and 4). Kopet-Dagh zone is located in the form of a long strip in the north of Khorasan and its northern part in Turkmenistan. Therefore, the border region of northeastern Iran with Turkmenistan is considered. The southern boundary of Kopet-Dagh is limited to Binalood and its northern boundary is Turan Plateau. From the evolutionary point of view and the formation process, this zone becomes a separate sedimentary basin after the former Cimmerian orogeny, that is, In it, from the Jurassic-Miocene, thick sediments have accumulated without significant stratigraphy but with diverse facies. These sediments consist mainly of shale, limestone, marl, sandstone, and sometimes conglomerates and evaporitic rocks, which are eventually covered by dry red layers similar to the upper red formations of the Lower Oligocene or possibly Miocene age. The sum of these series is unconformably below the Pliocene conglomerate. Following the rock of this basin, four main faults have been identified that were active at least before the Jurassic. These faults later shifted from normal to inverted faults during subsequent compressive movements. Dag Kopeh faults coincide with the old continental margin of South Turan platform in the Paleozoic and part of the Triassic. In Aq Darband area, beneath the Mesozoic sedimentary rocks of this sedimentary basin, older rocks belonging to the Devonian to Triassic S can be seen. It is because the Jurassic and Cretaceous sediments of Kopet-Dagh reach 6000 meters, which is more than Zagros sediments at this time.

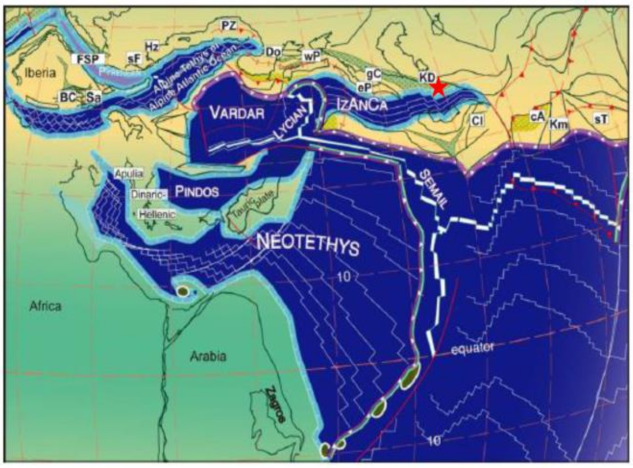

Fig. 4. Paleogeographic map of Tethys Basin at the time of Aptian (adapted from Stampfli and Borel, 2004 and taken from Taherpour et al., 2012) showing the location of Kopet-Dagh Basin (Red Star). Abbreviations are: BC: Betic Cordilera, cA: Central Afghanistan, CI: Central Iran, eP: Pontides, Do: Dobrogea, FSP: French-Spanish Pyrenees, gC: Great Caucasus, KD: Kopet-Daghh, Km: Karakoram terrane, pB: Pre-Balkan, Sa: Sardinia, sF: southern France, sT: south Tibet, wP: western Pontides, IzAnCa: Izmir-Ankara-Casoian Ocean.

The main feature of this zone is the lack of magmatic activity during the emergence and persistence of this sedimentary basin. However, a Quaternary basaltic eruption has also been reported on the southern boundary of Kope Dagh, which is thought to be related to the Late Pliocene fold and has given gentle folds to Kope Dagh sediments. It should be noted that in Kopet-Dagh basin, such as Zagros basin, no significant orogenic movements have occurred after the Lias period, and only the effects of brief drought movements are observed in some cases. As there were no folds during the Paleocene, but this area temporarily "rose" above the water level and then began to subside from the Eocene-Oligocene, due to changes in the layers' thickness during the Mesozoic and Tertiary, it was concluded that the depression axis has gradually deviated towards the anterior parts of Turan Plateau. The general trend of this zone is the same trend of Eshqabad fault. Kashafrood depression has been formed with the same trend.

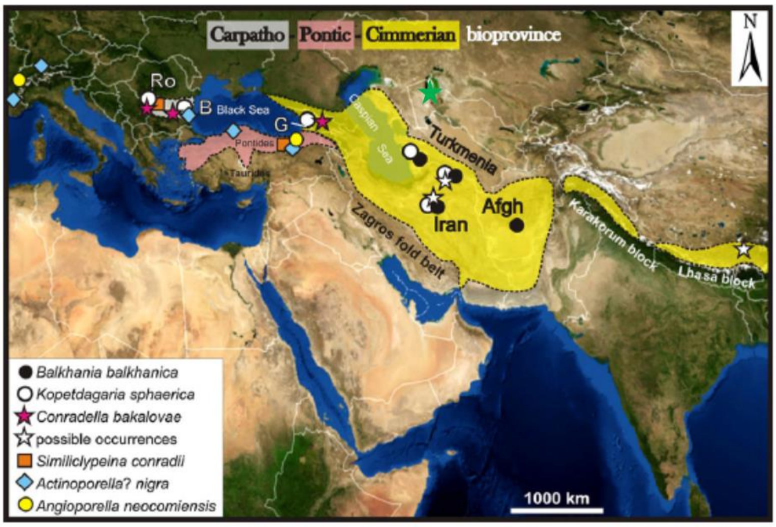

Fig. 5. Map of geographical distribution of index taxa of benthic foraminifera and calcareous algaeae in Kopet-Dagh, Central Iran, Afghanistan, Turkmenistan, Turkey, Romania and Black Sea regions (taken from Taherpour et al., 2012). The location of indicator forms such as *Balkhania balkhanica* and *Kopetdagaria sphaerica*, which are reported from the sections studied in this study, is also shown (green star).

Apart from general geological studies and studies in this basin, paleontological studies and the trend of fossil fauna development in this basin and its comparison with adjacent areas have contributed significantly to the paleogeographic analysis of this basin. As the presence of special taxa of Benthic foraminiferal fossils and calcareous algaeae that are found in abundance in Tirgan Formation, in other areas such as Central Iran, Turkmenistan and Afghanistan, Romania, the Black Sea basin is also widespread. Therefore, by creating a region that is based on the presence of special taxa of benthic foraminifera and calcareous algaeae, the ancient geographical relationship of this part of the Iranian plateau with other sedimentary basins of Turan, Balkans and North Tethys has been drawn (Figure 5).

The present study also shows that important and significant taxa such as *Balkhania balkhanica*, *Kopetdagaria sphaerica* are widely distributed in Barman-Aptian period of Tirgan Formation in the studied sections (Astrakhi, Jozak and Zaw) and the long-term geographical continuity of this section proves the connection of the ancient geography of this part of Kopet-Dagh basin with other adjacent areas in the southern part of Eurasian subcontinent.

3.5. Paleographic geographical maps and regional interpretation of facies in the study area

The distribution of facies in Tirgan Formation and studied sections are briefly as follows:

1. Detrital facies of continental origin including quartz-arnite, sub-arcose and sub-litarnite which are deposited in coastal and deltaic parts,
2. Dolestone and Madstone Facies that lack fossil elements or Grainstone facies with good sorting and high destructive that indicate the presence of tidal zones
3. Facies containing pellets, ostracods, green algae and myeloid algaeae, gastropods and orbitolins with high amounts of limestone, which indicates the deposition of this facies in a lagoon and low energy environment
4. Intraclasty and Ooids Grainstone facies and that confirms sedimentation in an energetic belt and barrier environment for the facies
5. A range of skeletal fragments including orbitolins, brachiopods, echinoderms, and bivalves and bryozoans are more sensitive to salinity and their ideal habitat is the open sea. Due to the expansion of these facies, paleontographic maps in Hauterivian-Barremian, Lower Barremian - Upper and Upper Barremian – Lower Aptian time periods are drawn and evaluated based on the distribution of dominant facies for the above time periods.

3.6. Hauterivian- lower Barremian's ancient geographical map

In the easternmost part of the study area (layered section), Tirgan Formation has spread with destructive and detrital facies and between limestone and marl layers, which probably includes the geological age of Lower Hervin - Lower Barremian. Debris in Kopet-Dagh basin can be thought to be the result of erosion of heights and the transport of large amounts of detrital sediments to Forland basin, which are deposited as red sandstone layers and attributed to Late Cimmerian tectonic movements, which are characterized by drought and compaction movements.

As shown in the paleogeographic map prepared for this period in the study area, simultaneously with the deposition of destructive facies in the eastern part of the area, the western parts of the sedimentary basin are covered by deeper facies deposited in the tidal zones. And indicates the deepening of the basin from east to west (Figure 6).

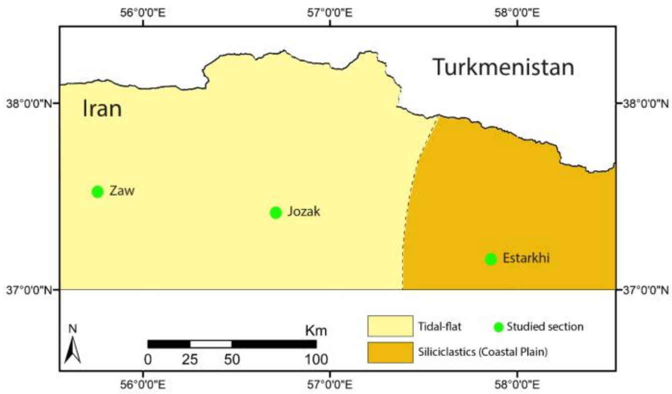

Fig. 6. Regional map of ancient facies and geography in Upper Hauterivian - Lower Barremian perod in the study area

3.7. Lower – upprt Barremian geographical map

According to the Paleogeographic map prepared for this period, the Barremian Sea has a general and significant progress in the study area and all of them show significant deepening in horizontal and vertical scale (Figure 7). Therefore, the sturgeon area is covered by tidal sediments and at the same time, the deepening to the west of the basin continues and the Jozak and Zaw areas are covered by sediments of the dam and open sea areas, respectively. Therefore, in addition to the presence of Barremian Sea, the deepening of the basin from the east (despite the tidal facies) to the west of the basin (with the deposition of sediments and the open sea) is well visible (Figure 7).

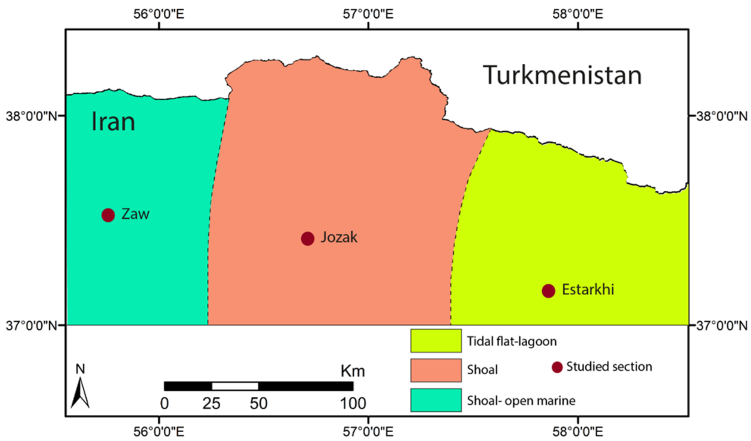

Fig. 7. Regional map of ancient facies and geography during the Lower-Upper Barmen in the study area

3.8. Old Barremian geography map of Upper-Lower Aptian

According to the regional facies map and ancient geography prepared for the study area during this period, at this time, it was almost "calm" in the prevailing area, and as a result, the wide and shallow sea covered all the study areas. As a result, orbitolite-bearing limestones are formed relatively uniformly in the area (Figure 6-7). The vertical distribution of the facies indicates that the easternmost part of the study area (such as the lanceolate section) shows significant deepening over time, comparable to general advances in Barremian-Aptian period. But the western parts of the basin (such as the Jozek and Zaw sections) show almost "uniform" and sometimes even "shallow" depth conditions, which are probably due to the local tectonic effect and the function of the bedrock faults. In particular, it has created a temporal and spatial expansion in the production of sediments on the carbonate platform in this part of Kopet-Dagh basin.

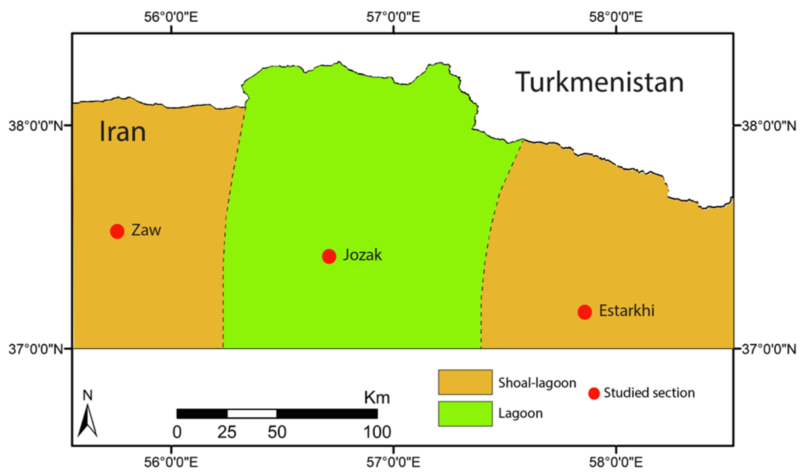

Fig. 8. Regional map of ancient facies and geography in Upper Barremian-Lower Aptian period in the study area

4. Conclusion

Due to the spread of facies in the study area, the ancient geographical map was drawn and evaluated and analyzed in the time periods of Hauterivian -Barremian, Lower-Upper Barremian and Upper Barremian-Lower Aptian. During the Hauterivian -Barremian period, in the easternmost part of the study area (lanceolate section), the Tirgan Formation has spread with destructive and detrital facies between limestone and marl layers as a result of erosion of heights and carrying large amounts of Detrital sediments whih are formed in the Forland Basin. Simultaneously with the deposition of destructive facies in the east, the western parts of the sedimentary basin are covered by deeper facies deposited in the tidal zones, indicating the deepening of the basin from east to west of the basin. During the lower-upper Barremian period, significant deepening in horizontal and vertical scales occurred in the whole study area. Therefore, the sturgeon area is covered by tidal sediments and at the same time, the deepening to the west of the basin continues and the Jozak and Zaw areas are covered by sediments of the dam and open sea areas, respectively. In the Upper Barps-Lower Aptian, the period was almost "calm" in the prevailing area, and as a result, a wide and shallow sea covered all the study areas, resulting in a relatively uniform orbitolite-bearing limestone in the area. The vertical distribution of the facies indicates that the easternmost part of the study area (such as the lanceolate section) shows significant deepening over time, comparable to general advances in the Barremian-Aptian period. But the western parts of the basin (such as the Jozak and Zaw sections) show almost "uniform" and sometimes even "shallow" depth conditions, which are probably due to the local tectonic effect and the function of the bedrock faults. In particular, it has created a temporal and spatial expansion in the production of sediments on the carbonate platform in this part of the Kopet-Dagh basin.

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