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Original Research

The impact of the Hendijan fault on formations located at the border of the Aghajari and Pazanan oil fields (paleo-highland setting, Eastern Tethys)

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Abstract

In this study, the Gurpi Formation was studied in one of the wells of the Aghajari oil field. The thickness of the Gurpi Formation in this well is 130 meters, and 65 thin sections of its drilling cores were examined. The main lithology of this formation in the aforementioned well includes argillaceous limestone, marly limestone, shale, and marl. In this research, thirty-three species belonging to thirteen genera of foraminifera and four biozones were identified. To determine the boundaries of biozones, classification was performed by studying thin sections, in which the criteria of first appearance and last occurrence of indicator species were used. The designated biozones are: *Dicarinella asymetrica* Zone, *Globotruncanita elevata* Zone, *Radotruncana calcarata* Zone, *Gansserina gansseri* Zone. In this study, the *Contusotruncana plummerae* Zone is absent and can therefore only be explained by a sedimentary hiatus or faulting. Based on the identified biozones, the age of the Gurpi Formation in the studied well is suggested to be from the Late Santonian to Middle Maastrichtian. The Gurpi Formation is covered in its upper part by shales of the Pabdeh Formation. In the lower part of this formation, the Sarvak Formation is located, and the Ilam Formation is absent. By determining the status of the lower part of the Gurpi Formation using biostratigraphic data, we were able to justify the absence of the Ilam Formation based on the activity of the Hendijan Fault. Therefore, in paleo-highland setting, such as the boundary of the Aghajari and Pazanan oil fields, the decrease and increase in sediment thickness on both sides of the fault can have a significant impact on the distribution of different rocks, especially source and reservoir rocks.

Keywords: Biostratigraphy; Foraminifera; Fault; Paleo-highland setting; Tethys

1. Introduction

The Zagros Mountains and its foreland both belong to the northeastern part of the African-Arabian plate. The closure of the Neo-Tethys Ocean, which occurred as a result of the convergence between the African-Arabian and Central Iranian plates during the Cenozoic Era, led to the formation of this belt. The Zagros Fold Belt, located in the middle part of the Alpine-Himalayan belt, is one of the most active tectonic regions where numerous folds and faults are observed. Changes caused by folding and faults exist both in the basement and in the sedimentary crust (Hatzfeld et al., 2010; Vergés et al., 2024; Ait Haddou et al., 2025). The existence of thrust, transverse faults in this basin is part of important discussions in structural geology. In this regard, Khoshmagham et al. (2025) studied the geological characteristics of the Zagros Basin and how to determine the mechanical properties of the rock. Also, Ghalandari et al. in 2023 pointed out the effect of basement faults on the type of folding and investigated its effect.

On the other hand, from a sedimentary perspective, the deposits of the Gurpi Formation are considered one of the important Cretaceous litho-stratigraphic units due to their extension throughout the Zagros and Neo-Tethys sedimentary basins, such as parts of southwestern Iran and equivalent formations in the western neighboring countries, their richness in biological content (e.g. planktonic foraminifera, calcareous nannofossils), the presence of the Cretaceous/Tertiary (K/T) boundary, their potential source rock, and also as the cap rock of the Bangestan Group (Ghasemi-Nejad et al., 2006; Hadavi and Senemari, 2010; Ezampanah et al., 2022). This formation, which is the cap rock of the Sarvak-Ilam oil reservoirs, is of particular importance in petroleum studies (Motiei, 1995). The type section of this formation is located in Tang- e Pabdeh, north of Lali oil field, northeast of Masjed Soleyman, and its thickness is 320 meters (m), which includes argillaceous limestone and gray shale in the Zagros Basin (Aghanabati, 2006). Its base age varies from Fars to Khuzestan and Lorestan, from Santonian to Campanian, and its upper age ranges from Maastrichtian to Paleocene (Alavi, 2004). A stratigraphic and paleontological study of the formations of the Fars, Khuzestan, and Lorestan regions was conducted by Wynd (1965), and three biozones were introduced for the Ilam and Gurpi formations. Meantime, the lithostratigraphy and biostratigraphy of the Gurpi Formation in the Lorestan region and the Dezful Embayment and Abadan plain were studied by Taheri (1998), and the age of this formation was determined to be from Campanian to Late Maastrichtian in the Dezful Embayment. Also, Kameli-Azan (2004), introduced 6 biozones in the study of the Gurpi Formation in the type section and determined its age from the Early Campanian to the Late Maastrichtian. Zarei (2005) determined the age of the Gurpi Formation in the type section to be Late Campanian based on foraminifera and dinocysts. Hemmati-Nasab (2007) introduced eleven biozones in a study of the biostratigraphy and sequence stratigraphy of the Gurpi Formation in the Kavar section in the south of Kabirkuh and attributed its age to the Upper Campanian to Selandian. Mahdavian Rad (2009), in his biostratigraphic and lithostratigraphic studies of the 341-meter-thick Gurpi Formation in the Kamestan anticline (northwest of Izeh) determined its age based on planktonic foraminifera from the Campanian to the Danian. Tavallaeian Talabadi (2011) introduced eleven bio-zones in his biostratigraphic study of the Gurpi Formation in the Siah Kuh section (southwestern Ilam) and determined the age of this formation from the early Campanian to the early Paleocene. Rahimi et al. (2015), introduced 8 biozones based on the biostratigraphy of the Gurpi Formation in the Kuh-e Sefid section in eastern Ramhormoz, indicating a late Santonian-late Maastrichtian age for this formation. In Iraqi Kurdistan, studies were also conducted by Ghafor et al. (2012) on the limestones of the region, which led to the determination of the age of the sediments equivalent to the Gurpi Formation. In addition to the aforementioned studies, research based on calcareous nannofossils was conducted for the Gurpi Formation, which determined whether the Cretaceous-Paleogene boundary is continuous or discontinuous (Hadavi et al., 2007). Edalatimanesh et al. (2015) also studied the source rocks of the Pazanan and Aghajari fields based on geochemical and petrophysical data. Alipoor et al. (2019) also analyzed the structural anticlines of Pazanan and Aghajari. Their studies showed that in the Pazanan field, the Sarvak, Ilam, Gurpi, and Pabdeh formations are regularly superimposed on each other, and there is no discontinuity between Gurpi and Sarvak formations. However, no study has been presented so far on the sedimentation controlled by the Hendijan fault at the boundary of the Aghajari-Pazanan fields, and therefore, the present study attempts to take a broader look at the sedimentation aspects of the formations present in the fault zones of this region. The aim of this study is to investigate the Gurpi Formation in one of the wells of the Aghajari oil field, focusing on the function of the Hendijan fault and its consequences on the distribution of planktonic foraminifera and the development of the formations in comparison with the formations of the Pazanan oil field. In this study, the explicit hypotheses are: (1) the activity of the Hendijan fault is the reason for the absence of the Ilam Formation in the region; (2) There are differences in the sediments on both sides of the fault; (3) Modification of biostratigraphic correspondence to standard Tethys zones.

1.1. Geographical location of Aghajari oil field

The Aghajari oil field is located 90 km southeast of Ahvaz and about 5 km northeast of the city of Omidieh. Its geographical location is 49°49′41″ E longitude and 30°41′41″ N latitude. Geologically, this oil field is located in the Dezful Embayment on the border between North Dezful and South Dezful. Compared to its neighboring oil field, this oil field is limited by the Karanj oil field to the north, the Ramshir oil field to the south, the Pazanan oil field to the southeast, and the Marun oil field to the west. The studied well is located southwest of the Aghajari oil field (Figs. 1, 2, 3). In all areas of the Zagros, the basement and sedimentary crust have undergone changes in thickness due to tectonic activities (folding and fault activity), and since these areas were either on land (paleo-highland setting) or underwater, this has had a direct impact on the presence or absence of some formations or even changes in their thickness and age. The Hendijan Fault (HF) is one of the important lineaments that shows the subduction-abductions structure of the Arabian Plate. This structure extends northward through the Zagros Mountains (Fig. 3a). The map of underground contours (UGC) is shown in Figure 3b. This fault passes through the area between the northwest of the Pazanan anticline and the southeast of the Aghajari anticline. The aforementioned fault is a vertical basement fault that has affected all of the Asmari formations and those before it (Fig. 4).

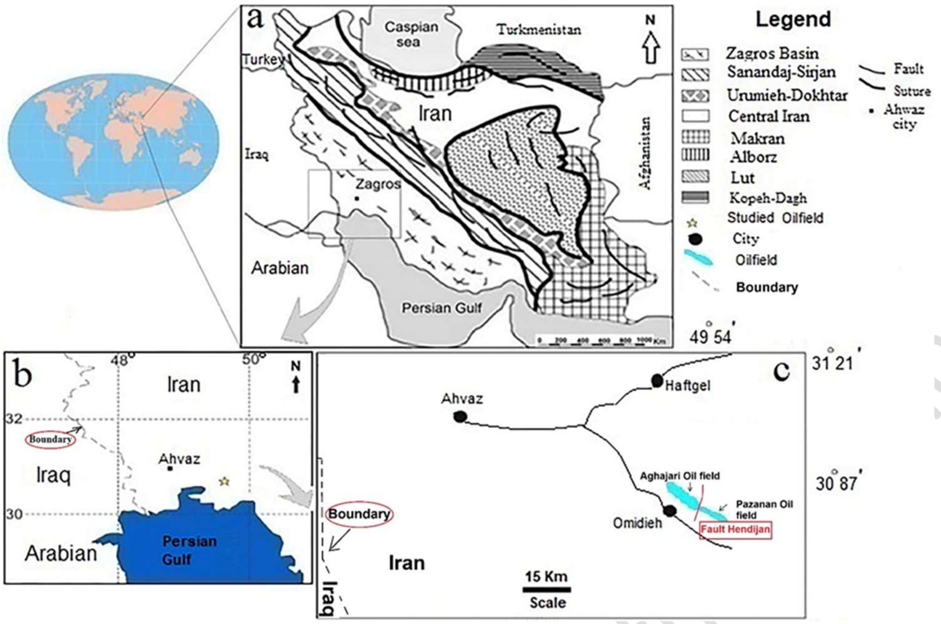

Figure 1. a) Geographical location of the Zagros Basin, b) Aghajari oil field (star-shaped), c) and access ways to the studied oil field in southwestern Iran.

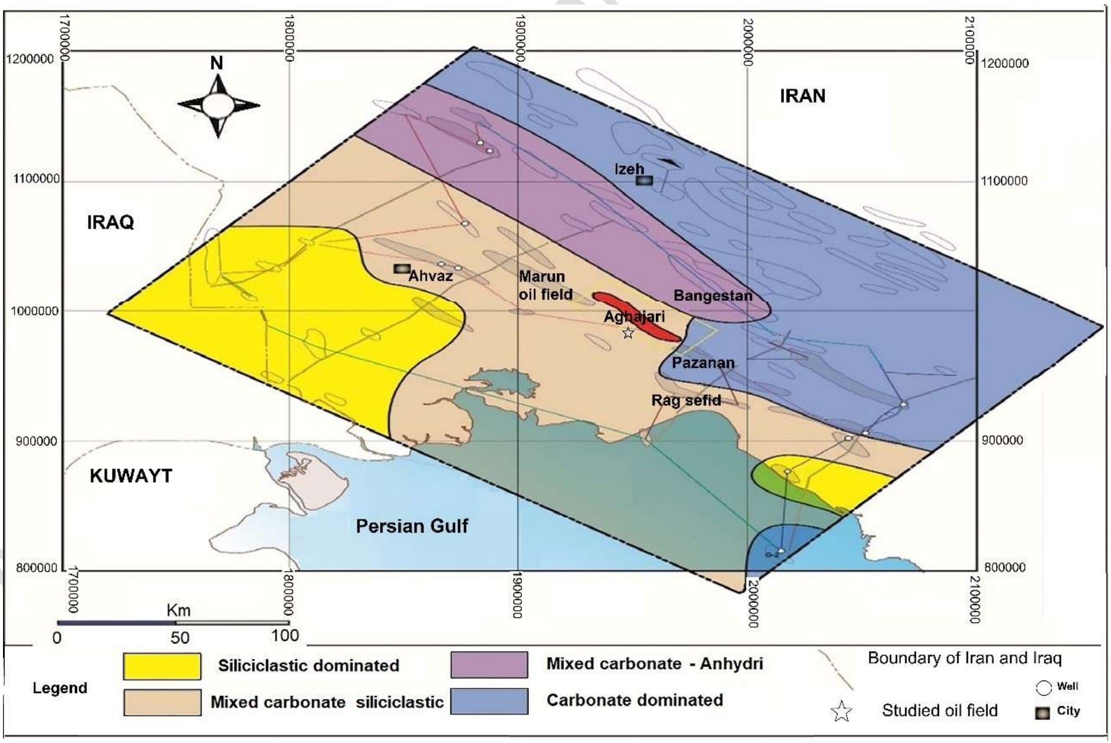

Figure 2. Location of the Aghajari oil field in the Dezful embayment based on the spread of sedimentary systems (van Buchem et al., 2010).

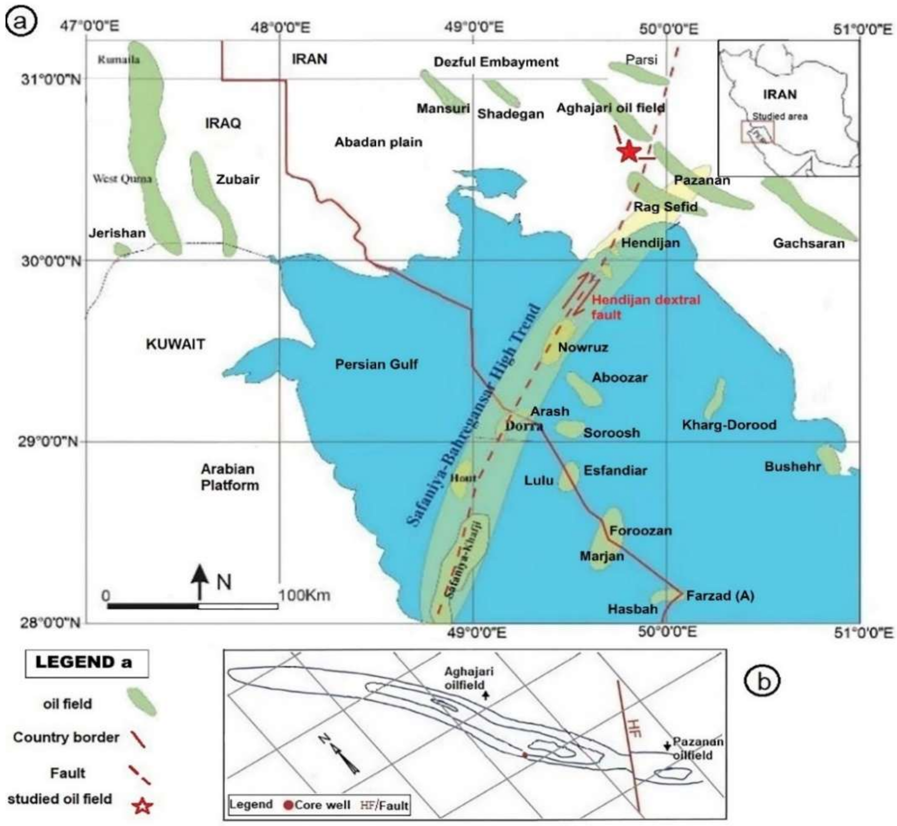

Figure 3. a) Trend of the Hendijan fault (NS trending fault), which passes between the Aghajari and Pazanan oil fields, the star in the figure above indicates the Aghajari oil field and adjacent fields (adapted from Mansouri Siahgoli et al., 2025), b) Map of the underground contour lines (UGC) in the Aghajari oil field and the location of the studied well (adapted from Fathi Isvand et al., 2023 with minor modifications), HF (Hendijan Fault); Pay attention to the Pazanan oil field.

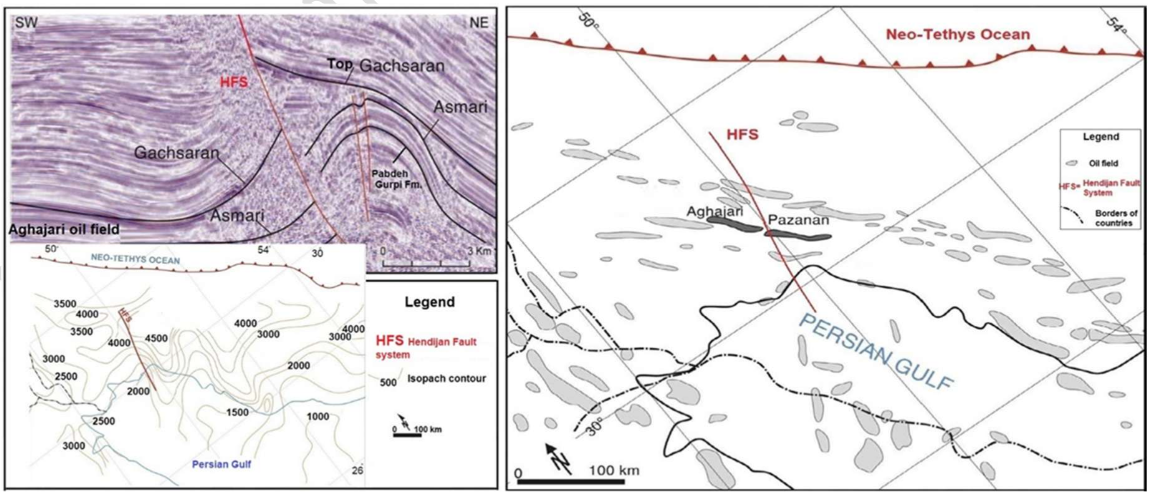

Figure 4. Location of the Hendijan fault, fault section and isopach map.

2. Materials and methods

The Gurpi Formation sediments in one of the wells of Aghajari oil field with a thickness of 130 m were biostratigraphy studied. In this study, 65 thin sections of the core of this formation were prepared at intervals of about 2 m and then studied using a transmitted optical microscope (Plane Polarized Light/PPL) under 20× to 40× magnification equipped with a camera. These hard samples were cut in a directionally manner to obtain suitable thin sections. The study of oriented samples revealed the nature of microfossils embedded in the sediments. Finally, all samples were stored in the National Iranian Oil Company's Exploration Management Complex. Identification and naming of genera and species based on the classification and naming of some sources such as: James and Wynd (1965), Postuma (1971), Robaszynski et al. (1984), Caron (1985), Bolli et al. (1985), Loeblich and Tappan (1988), Nederbragt (1991), Berggren and Norris (1997), Olsson et al. (1999), Premoli Silva and Verga (2004), Coccioni and Premoli Silva (2015), and pforams@mikrotax database. To determine biozones, the first apparent datum (FAD) and last apparent datum (LAD) criteria were used for classification. In general, foraminifera are relatively abundant and the specimens are largely complete and detailed, but the number of species obtained from different layers varied. In this study, the research process is in the form of the following flow chart (Fig. 5):

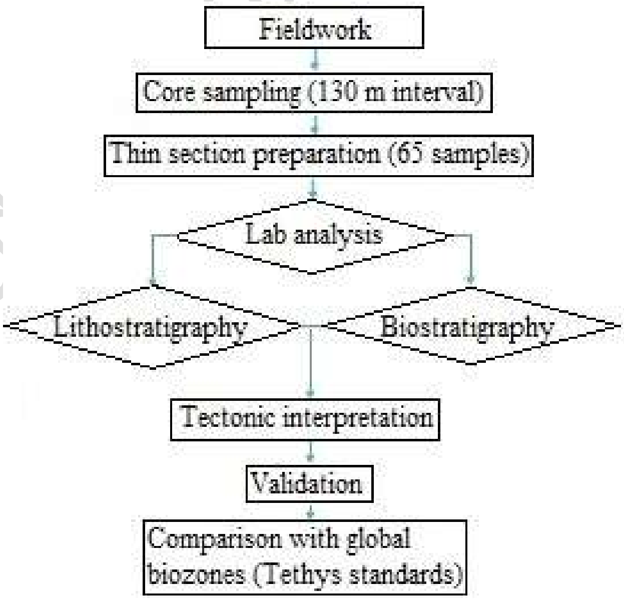

Figure 5. Flowchart in this study. Fieldwork; Lab analysis; Tectonic interpretation; Comparison with global biozones.

3. Results and discussion

3.1. Lithostratigraphy

The Gurpi Formation in this well is generally composed of shale, argillaceous limestone with interlayers of marl and shale. In addition to the 130-m-thick Gurpi Formation, samples were also taken from the upper sediments of the Sarvak Formation (limestone sediments at the bottom of the well) and the lower sediments of the Pabdeh Formation (shale sediments at the top of the well). The Sarvak Formation in this study is discontinuously located below the Gurpi Formation (Fig. 6).

Such discontinuity has been reported in some studied sections in the Zagros, such as southwest of Borujen (Senemari and Foroughi, 2019). In the upper part, the argillaceous limestone deposits of the Gurpi Formation gradually reach the shale deposits of the Pabdeh Formation.

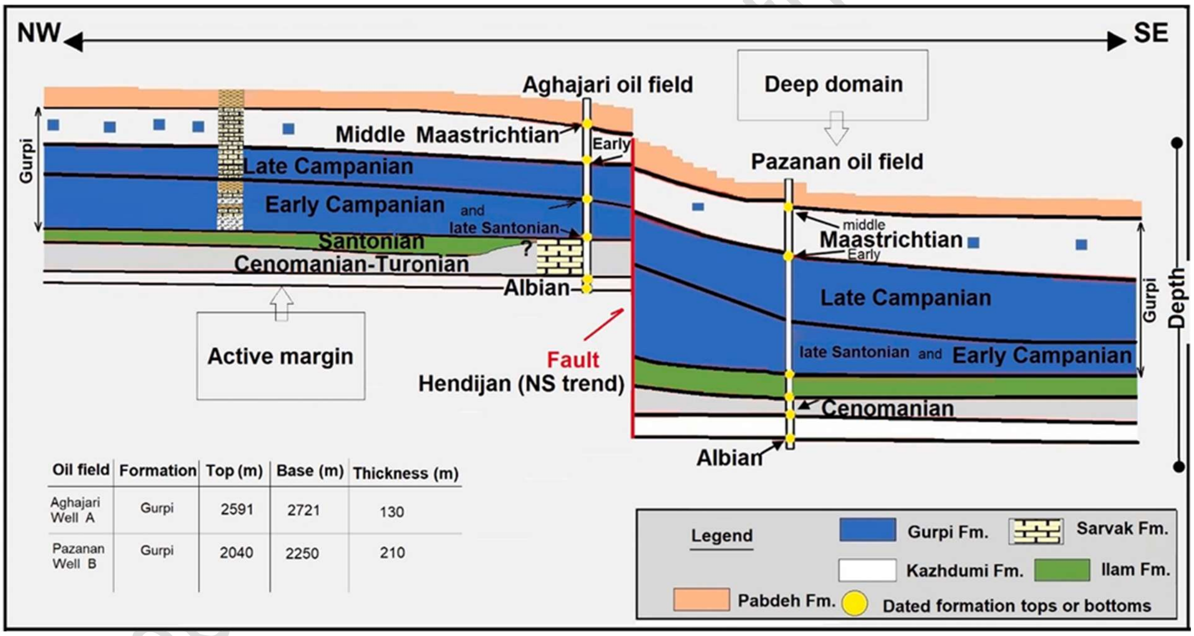

Figure 6. Schematic comparison of sediments from two wells in the Aghajari and Pazanan oil fields in contact with the fault. Note the deposition of formations resulting from the action of the Hendijan fault. The thickness of the sediments is hypothetical.

3.2. Biostratigraphy

The Gurpi Formation has been identified in this well at a depth range of 2591–2721 m and a thickness of 130 m (Fig. 7). Based on its planktonic foraminifera, four biozones have been identified:

3.2.1. *Dicarinella asymetrica* Zone

The first biozone was identified in the depth range of 2698.5 –2721 m and with a thickness of 22.5 m and is located at the base of the Gurpi Formation. The identified microfossils are as follows (Figs. 8, 9):

Globotruncana lapparenti, Globotruncana bulloides, Globotruncana arca, Dicarinella concavata, Dicarinella asymetrica, Marginotruncana schneegansi, Laeviella bollii, Globigerinelloides prairiehillensis, Planoheterohelix globulosa, Gavelinella pertusa, Lenticulina sp.

This biozone corresponds to zone 32 classified by Wynd (1965). Its age has been suggested to be Late Santonian. In the Bandar Abbas (Ezampanah et al., 2022) and also in the Shahneshin section in Fars province, the age of the base of the Gurpi Formation has been reported to be Coniacian.

3.2.2. *Globotruncanita elevata* Zone

The stratigraphic distribution of this zone is from 2646–2698.5 m deep and occupies 52.5 m of the Gurpi Formation. Its lower boundary corresponds to the last occurrence of the species *Dicarinella asymetrica* and its upper boundary corresponds to the last occurrence of *Globotruncanita elevata* or the first occurrence of *Contusotruncana plummerae*. The following microfossils were identified in this zone (Figs. 8, 9):

Globotruncanita stuartiformis, Globotruncana linneiana, Globotruncana lapparenti, Globotruncana bulloides, Globotruncana arca, Globotruncana hilli, Contusotruncana fornicata, Rugoglobigerina rugosa, Heterohelix globulosa, Heterohelix striata, Heterohelix carinata, Globigerinelloides prairiehillensis, Laeviella bollii, Calcisphaerula innominata, Globotruncanita elevata, Gavelinella pertusa, Gavelinella sp., *Lenticulina* sp.

In this foraminiferal biozone, crustaceans, larger benthic imperforate foraminifera, ostracods, and fragments of echinoids are observed. This biozone is compatible with Wynd (1965) zone 33 (*Globotruncana elevata elevata* Zone) and the *Globotruncanita elevata* partial range zone of Coccioni and Premoli Silva (2015). Its age is suggested to be early Campanian.

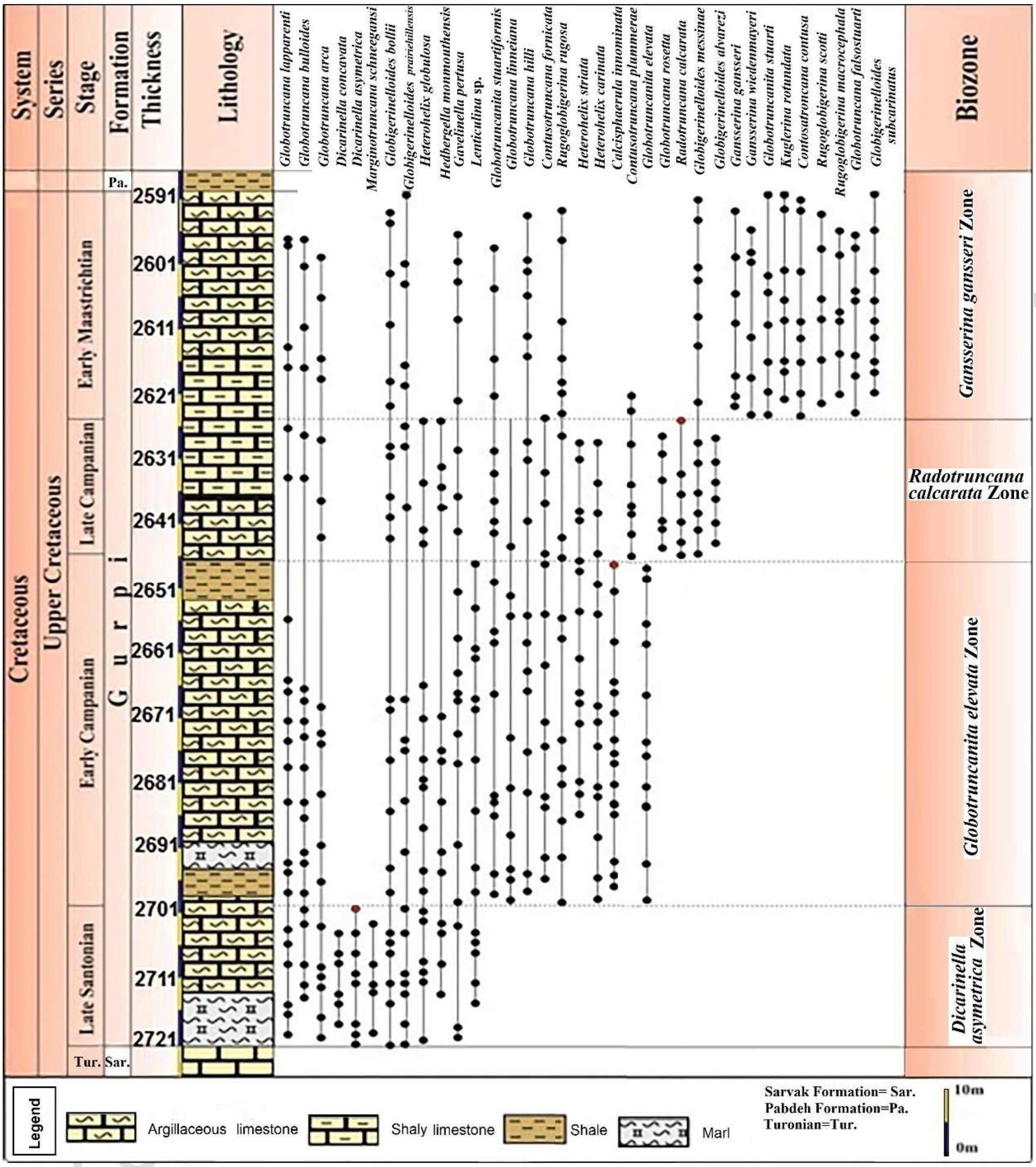

Figure 7. The lithostratigraphic column of the studied well; The expansion of biozones and the distribution of planktonic foraminifera in this well.

3.2.3. *Radotruncana calcarata* Zone

Another bio-zone, identified between 2625–2646 m deep, occupies 21 m of the Gurpi Formation. Its lower boundary corresponds to the extinction of *Globotruncanita elevata* and its upper boundary corresponds to the extinction of *Radotruncana calcarata*. The following microfossils were identified in this zone (Figs. 8, 9):

Globotruncanita stuartiformis, Globotruncana linneiana, Globotruncana lapparenti, Radotruncana calcarata, Globotruncana bulloides, Globotruncana arca, Globotruncana hilli, Globotruncana rosetta, Contusotruncana fornicata, Contusotruncana plummerae, Rugoglobigerina rugosa, Heterohelix globulosa, Heterohelix striata, Heterohelix carinata, Planohedbergella messinae, Globigerinelloides alvarezi, Globigerinelloides prairiehillensis, Laeviella bollii, Gavelinella pertusa. The age of this biozone was determined based on the identified fossil assemblage, Late Campanian.

3.2.4. *Gansserina gansseri* Zone

The last biozone was identified in the depth range of 2591 to 2625 m, occupying 34 m of the top of the Gurpi Formation. The following microfossils were identified in this biozone (Figs. 8, 9):

Gansserina gansseri, Gansserina wiedenmayeri, Globotruncanita stuarti, Muricohedbergella monmouthensis, Globotruncanita stuartiformis, Kuglerina rotundata, Contusotruncana fornicata, Contosatroncana contusa, Contusotruncana plummerae, Rugoglobigerina scotti, Rugoglobigerina macrocephala, Rugoglobigerina rugosa, Globotruncana falsostuarti, Heterohelix sp., *Globigerinelloides* sp., *Globotruncana* sp., *Globotruncana lapparenti, Globotruncana bulloides, Globotruncana arca, Globotruncana hilli, Globigerinelloides subcarinatus, Planohedbergella messinae, Globigerinelloides prairiehillensis, Laeviella bollii, Gavellinel lapertusa*.

This biozone corresponds to Wynd (1965) zone 39 (*Globotruncanita stuarti- Pseudotextularia varians* assemblage zone) and the *Gansserina gansseri* Interval Zone and *Contusotruncana contusa* Interval Zone of the Coccioni and Premoli Silva (2015) zoning. It is noteworthy that, according to Chauris (1998), the extinction of inoceramid shells (inoceramid extinction event/IEE) occurred in this zone. The age of this zone is suggested to be from the Late Campanian to the middle Maastrichtian.

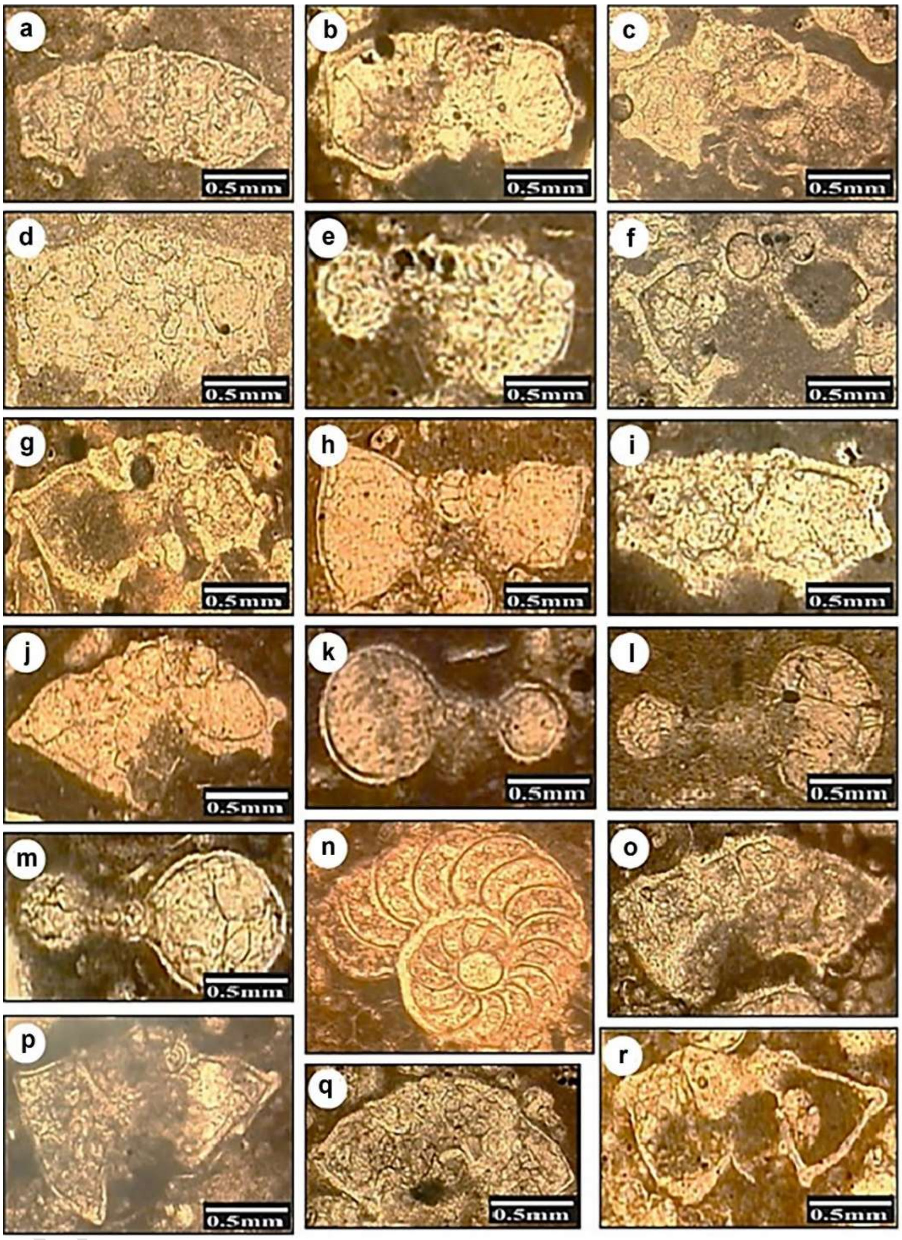

Figure 8. a. *Globotruncana lapparenti* (Brotzen, 1936, emended, Pessagno, 1967) (sample No. 15), b. *Globotruncana bulloides* (Vogler, 1941) (sample No. 5), c. *Globotruncana* cf. *bulloides* (Vogler, 1941) (sample No. 42), d. *Globotruncana linneiana* (d'Orbigny, 1839) (sample No. 32), e. *Globotruncana hilli* (Pessagno, 1967) (sample No. 7), f. *Globotruncana rosetta* (Carsey, 1926) (sample No. 21), g. *Globotruncana falsostuarti* (Sigal, 1952) (sample No. 10), h. *Dicarinella asymetrica* (Sigal, 1952) (sample No. 57), i. *Globotruncana* cf. *lapparenti* (Brotzen, 1936, emended, Pessagno, 1967) (sample No. 6), j. *Marginotruncana schneegansi* (Sigal, 1952) (sample No. 55), k, l. *Planohedbergella prairiehillensis* (Huber and Leckie, 2011) and *Globigerinelloides prairiehillensis* (Pessagno, 1967) (sample No. 7, 10), m. *Planohedbergella prairiehillensis* (Huber and Leckie, 2011) (sample No. 10), n. *Gavelinella pertusa* (Marsson, 1878) (sample No. 25), o. *Globotruncanita stuartiformis* (Dalbiez, 1955) (sample No. 22), p. *Globotruncanita elevata* (Brotzen, 1934) (sample No. 40), q. *Globotruncana esnehensis* (Nakkady, 1950) (sample No. 2), r. *Globotruncanita* cf. *insignis* (Gandolfi, 1955) (sample No. 17).

Figure 9. a. *Rugoglobigerina rugosa* (Plummer, 1927) (sample No. 5), b. *Rugoglobigerina scotti* (Bronnimann, 1952) (sample No. 19), c. *Rugoglobigerina macrocephala* (Brönnimann, 1952) (sample No. 7), d. *Muricohedbergella monmouthensis* (Olsson, 1960) (sample No. 18), e. *Ventilabrella* sp., (sample No. 45), f. *Planoheterohelix striata* (sample No. 24), g. *Heterohelix carinata* (Cushman, 1938) (sample No. 22), h. *Heterohelix globulosa* (Ehrenberg, 1840) (sample No. 27), i. *Calcisphaerula innominata* (Bonet, 1956) (sample No. 30), j. *Gansserina gansseri* (Bolli,1951) (sample No. 7), k. *Globotruncanita angulata* (Tilev, 1951) (sample No. 2), l. *Kuglerina rotundata* (Bronnimann, 1952) (sample No. 17), m. *Contusotruncana contusa* (Cushman, 1926) (sample No. 5), n. *Contusotruncana fornicata* (Plummer, 1931) (sample No. 31), o. *Contusotruncana plummerae* (Gandolfi, 1955) (sample No. 19).

3.3. Tectonic interpretation

In tectonic settings, fault structures often control the sedimentation process (Vergés et al., 2002). This causes a difference in the thickness of the sediments on both walls during the time of fault activity. Therefore, by studying the formations on both sides of the fault, it is possible to understand the extent of the fault's function and its displacement. The thinning of Cretaceous deposits also corresponds to fault activity and uplift of the Hendijan-Izeh paleo-highland setting during the Cretaceous. The Hendijan Fault had high tectonic activity during the Late Cretaceous, which led to a reduction in sediments thickness or the lack of sedimentation of formations such as Ilam and Gurpi in some parts of this region (Fig. 10). In this regard, paleo-highland setting are areas that were at a higher elevation than their surrounding areas during the activity of the Hendijan fault (Fig. 11). These areas were formed due to the reactivation of basement faults (such as the Nowruz-Hendijan-Izeh faults/NHI) and during the collision of the Arabian and Central Iranian plates. Therefore, on the sides of faults, the lack of formation, reduction, and increase in sediment thickness have an important impact on the spread and distribution of various rocks, such as the creation of folds and reservoir rocks (Fig. 6). This situation is also observed in the Fars region of the Zagros Basin. Of course, the aforementioned area is affected by left-lateral strike-slip faults in the basement, such as the Nezamabad, Razak, and Hendurabi faults, so that the activity of these faults has affected the folding system of the region (Ghalandari et al., 2023). On the other hand, the difference in age of the same formations in a region, which is based on the determination of biozones, can be due to lateral changes in facies as a result of the behavior and activity of the region's faults. Such as the Coniacian age in the Bandar Abbas region compared to the Late Santonian age at the base of the Gurpi Formation in this study.

Therefore, as mentioned above, the Ilam Formation is not present in this well in the Aghajari oil field, and the lower boundary of this formation with the Sarvak Formation was determined based on the presence of the Turonian species *Montcharmontia apenninica* and *Mangashtia viennoti*. Finally, based on the identified biozones, the age of the base of the Gurpi Formation in the studied well was determined to be Late Santonian. It seems that the creation of continental conditions due to fault activity in the southeast of the Aghajari oil field caused the Ilam Formation not to be deposited and then the marine sediments of the Gurpi Formation were deposited on the Sarvak Formation with discontinuity in the late Santonian. In fact, the Late Turonian to middle Santonian sediments have been removed in this oil field, and this plays a role in the placement of the reservoir rock (Sarvak Formation) and the cap rock (Gurpi Formation) in this field. In addition, the decrease in the thickness of the Aghajari oil field sediments from the Cretaceous to the Paleogene can also be related to the uplift of the Hendijan heights (paleo-highland setting). This is while, based on biostratigraphic data received from one of the wells of the Pazanan oil field near the Hendijan fault, the Ilam Formation exists in the lower part of the Gurpi Formation. The research also compares the study area well with other regions, including Tethys (Fig. 12). Figure 12 shows that the boundaries of biozones have changed significantly compared to the global standard biozones.

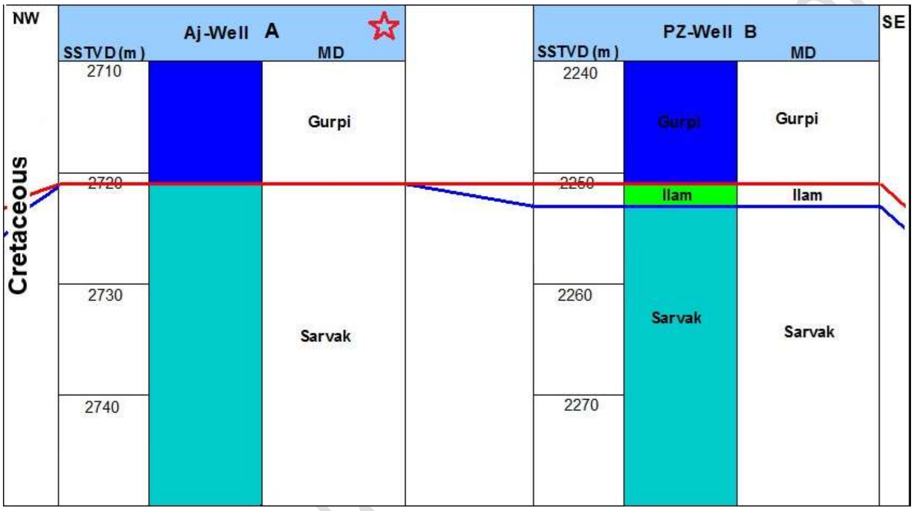

Figure 10. Correspondence between two wells located in the Aghajari and Pazanan oil fields. Note the absence of the Ilam Formation in the Aghajari oil field.

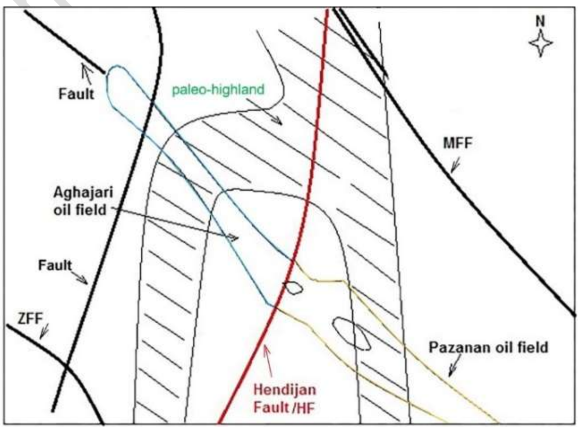

Figure 11. Faults and paleo-highland setting (hatched) in the Zagros and the location of the Aghajari and Pazanan oil fields in southwestern Iran (Eastern Tethys) (Hendijan Fault: HF, Mountain Front Fault: MFF, Zagros Foredeep Fault: ZFF). This map is schematic and not to exact scale.

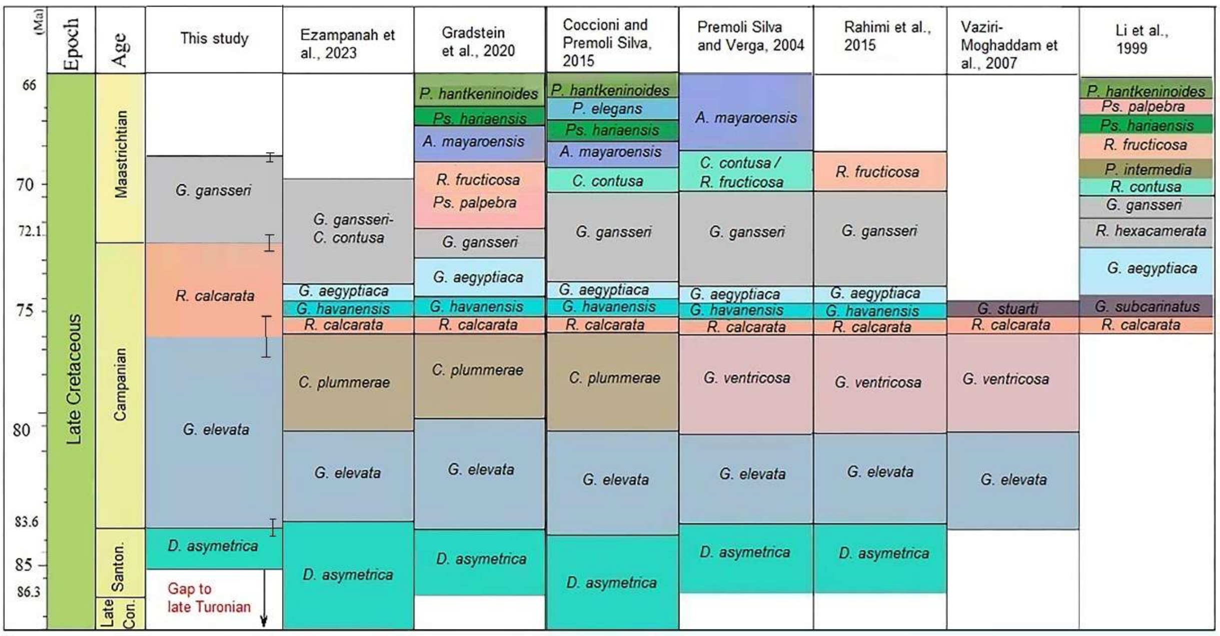

Figure 12. Comparison of the biozones introduced in the studied well in the Aghajari oil field with other areas of the Zagros Basin and the standard zoning of the Tethys Ocean. Pay attention to error bars or confidence intervals to show the variability of the data.

4. Conclusion

In this study, thirty-three species belonging to thirteen genera of planktonic foraminifera were identified in the studied well in the Aghajari oil field. Foraminifera were relatively abundant and largely complete in detail. In biostratigraphic studies, four biozones were introduced, based on the first and last occurrence of indicator species. These biozones are compatible with those presented by Wynd (1965), Coccioni and Premoli Silva (2015). Based on the introduced biozones, the age of the Gurpi Formation in this well was determined to be from the late Santonian to the middle Maastrichtian. The biozones introduced in this study are as follows: *Dicarinella asymetrica* Zone, *Globotruncanita elevata* Zone, *Radotruncana calcarata* Zone, *Gansserina gansseri* Zone. In this study, the *Contusotruncana plummerae* Zone is absent and therefore can only be explained by a sedimentary hiatus or faulting. Of course, insufficient sampling density could also be responsible for this situation. Also, according to this study, in the lower part of the Gurpi Formation, instead of the Ilam Formation, the Sarvak Formation is located, which indicates a disconformity and probably indicates the creation of continental conditions (paleo-highland setting) due to the activity of the Hendijan fault. While in the Pazanan oil field, there is a continuity between the Ilam and Gurpi formations. It should be noted that, based on the data received, the thickness of the sediments in the Aghajari oil field is less than that of the Pazanan field. The decrease in the thickness of the Aghajari oil field sediments from the Cretaceous to the Paleogene could be related to the uplift of the Hendijan fault. In fact, Late Turonian to Middle Santonian sediments have been removed in this oil field, and this plays a role in the placement of reservoir rock (Sarvak Formation) and cap rock (Gurpi Formation) in this field. The upper part of the Gurpi Formation in both the Pazanan and Aghajari wells is covered by shales of the Pabdeh Formation. Of course, investigating the role of fault activity definitely requires further investigation, and definitive conclusions cannot be reached solely based on litho-biostratigraphic studies.

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