Stratigraphic evidence for development of Aptian intrashelf basin in the Zagros area, eastern Fars Province, SW Iran

Neda KHOSHFAM1, Hossain RAHIMPOUR-BONAB2,*, Davoud JAHANI3, Davoud MORSALNEZHAD4
1Department of Geology, Science and Research Branch, Islamic Azad University, Tehran, Iran
2School of Geology, Faculty of Science, University of Tehran, Tehran, Iran
3Department of Geology, North Tehran Branch, Islamic Azad University, Tehran, Iran
4National Iranian Oil Company, Exploration Directorate, Tehran, Iran

* Correspondence: hrahimpor@gmail.com

Abstract: The Lower Cretaceous of the Arabian Platform is renowned for the development of intrashelf basins. The study area is located in eastern Fars Province on the northeast Arabian plate and has experienced this environmental condition. The present study investigated two surface sections (Genau and Anguru) of the Dariyan Formation and compared the results with three neighboring wells in eastern Fars (eastern Zagros Fold Belt) in southern Iran to determine the development of rudist-bearing carbonates and intrashelf basin sediments. The Dariyan Formation was deposited in the Aptian as shallow-to-deep water carbonate facies. Lagoon, rudist banks/barriers, and open marine/basinal facies and six microfacies types have been distinguished. In the Genau section, the upper formation contains shallow rudistid limestone separated from the orbitolinid limestone of the lower formation by a deep pelagic unit. The pelagic sets disappear toward the Anguru section, but the rudistid unit remains. Abrupt changes were observed from shallow rudist facies to deep planktonic foraminifer facies. Comparison of the surface and subsurface sections (wells) suggests an intrashelf carbonate depositional model for the Dariyan Formation in the eastern Fars area. The term "Genau intrashelf" is proposed for this intrashelf basin surrounded by a shallow ramp. This intrashelf appears to be a northern subbasin of the Bab basin of the southern Persian Gulf. Extension of the Genau intrashelf subbasin and development of rudists around the margins of this intrashelf can be defined by tracing changes in the lateral facies of the Dariyan Formation.

Key words: Dariyan Formation, Cretaceous, Aptian, Arabian plate, intrashelf basin, rudist

1. Introduction
In the geological record of the Arabian Platform and Zagros fold-thrust belt, the Cretaceous successions constitute thick sedimentary packages that host numerous economically important hydrocarbon reserves (Setudehnia, 1978; Alsharhan and Nairn, 1993; Hollis, 2011). These thick successions contain a considerable portion of global hydrocarbon reserves (Scott et al., 1993) and most of the oil reserves in the Middle East. The Cretaceous is important to Iranian and global geologic history (Sharland et al., 2001). This time interval has been the subject of several studies in southwestern Iran and Iraq. It is divided into three parts (Lower: Neocomian-Aptian, Middle: Albian-Turonian, Upper: Coniacian-Maastrichtian) and marine sediment predominates (Setudehnia, 1978). The present study focused on the Aptian period, which features the deposits known as the Dariyan Formation in the northern Persian Gulf and the Shu’aiba Formation to the south and the Hawar member in the Oman and UAE. The Lower Cretaceous of the Arabian Platform is renowned for the development of intrashelf basins. In the Aptian-Early Albian period, a sudden change from shallow ramps to intrashelf basins has been recorded along transects in the exposures of the Zagros Mountains (Vincent et al., 2010). The study area in eastern Fars Province is located on the northeast Arabian plate and features this environmental condition (Figure 1). The creation of Aptian intrashelf basins in the Fars area appears to be the result of Kazerun fault activity. It has also been suggested that, in the eastern sectors farther from this fault, infra-Cambrian salt (Hormoz salt) movement generated intrashelf basins (Sharland et al., 2001; Van Buchem et al., 2010b).
In the Aptian, coral was replaced by rudists along the margins of the intrashelf basins (Scott, 1988; Ross and Skelton, 1993; Gili et al., 1995b). No competitive replacement and no extensive reef buildup can be observed. This replacement in the Cretaceous was the result of global environmental change and was not connected to the formation of the rudists (Gili et al., 1995a). Rudist limestones are common in the Tethyan Cretaceous successions that contain significant hydrocarbon reserves in the Middle East, the Gulf of Mexico, and, to a lesser extent, the Mediterranean Sea (Coogan, 1977; Alsharhan and Nairn, 1993; Ross and Skelton, 1993; Dravis, 1996; Skelton and Gili, 2011). During the Barremian to Maastrichtian, rudist bivalves developed extensively on the tropical-subtropical carbonate factories of the Neo-Tethys realm (Sanders, 1998; Steuber and Löser, 2000; Scott, 2007). They formed reef-like communities on the interior and margin of the platforms. The distribution of their buildup was structurally controlled by paleotopographic highs (Jordan et al., 1985; Dravis, 1996). Because they contain high-quality reservoirs, the Aptian rudist barriers in the Persian Gulf and neighboring areas have been frequently studied (Masse and Philip, 1981; Frost et al., 1983; Scott, 1990; Marzouk and El-Sattar, 1995). The uppermost Dariyan Formation in the Fars area is composed of shallow orbitolinid facies, but rudist-bearing facies have been reported in a few sections in the eastern part. The objectives of the present study deal with the description and interpretation of microfacies in order to document and delineate the existence of an intrashelf basin surrounded by shallow carbonate platforms. The study outlines the extension of the Aptian intrashelf subbasin in eastern Fars and determines the development and distribution of rudist facies based on changes in the lateral facies in the Dariyan Formation.

2. Materials and methods
The Dariyan Formation was studied in detail by using samples from the Anguru and Genau surface sections in eastern Fars in the Zagros Fold Belt (Bandar Abbas
Province; Figures 1 and 2). These outcrops were compared with three neighboring wells to define the characteristics of the regional deposits of this unit. The thickness of the Dariyan Formation is about 56 m in the Anguru and 60.5 m in the Genau section. Detailed petrographic studies were carried out on more than 150 thin sections using the Dunham textural classification (Dunham, 1962; Embry and Klovan, 1971). The types of facies and the depositional setting were interpreted on the basis of the matrix and grain content, compositional and textural fabric, fossil content, energy index, and other sedimentary data. The depositional environment was interpreted by using standard models (Wilson, 1975; Tucker and Wright, 1990; Wright and Burchette, 1996; Flügel, 2010). The neighboring wells selected for comparison were the Dasht-e Kunar, Finu, and Sarkhun; they were compared to determine changes in the Dariyan facies in the study area using gamma ray (GR) logs and recognized biozones (Wynd, 1965). A north-south transect (AA': Dasht-e Kunar, Finu, and Sarkhun wells and Genau section) and an east-west transect (BB': Anguru, Genau sections and Sarkhun well) were selected for comparison and to trace facies changes. Changes in the Dariyan facies and the sedimentary environment during the Aptian were then reconstructed in eastern Fars.

3. Geological setting
During the Cretaceous, the Arabian plate moved toward tropical and subtropical latitudes (Murris, 1980; Beydoun, 1991; Beydoun et al., 1992; Sharland et al., 2001; Alavi, 2004, 2007; Heydari, 2008). The basin configuration was radically changed by local salt diapirs and movement of the basement blocks, which triggered sporadic regional uplift and intrashelf basin formation (Sepehr and Cosgrove, 2005; Casini et al., 2011; Hollis, 2011; Van Buchem et al., 2011; Mehrabi and Rahimpour-Bonab, 2014). The study area is situated on the northeastern portion of this moving plate. It is located in the Zagros mountain chain in southern Iran, which is the result of complex geodynamic evolution of the northern margin of the Arabian plate (Stampflil and Borel, 2002). During the Mesozoic, a carbonate platform was established in the southeastern Zagros that is known as the Fars platform. Two main features of this platform are uplift and salt diapir activity (Setudehnia, 1978); together,

![Figure 2. The location map of the two sampled sections (1, 2), three comparable neighboring wells (3, 4, 5), and the two transects in the east of Fars (Bandar-e-Abbas hinterland).](image-url)
these have caused local and regional shallowing and deepening of the platform and several episodes of sea-level fluctuation. In Fars Province in the Zagros area, the Lower Cretaceous is composed of the Fahliyan, Gadvan, and Dariyan formations. The Dariyan Formation is composed of the upper and lower Dariyan carbonate units, which are separated by a shale unit in Fars and eastern Khuzestan. These carbonates become black shale and radiolarite limestone toward the Lorestan (Setudehnia, 1978). The Dariyan, formed during the Aptian, is a member of the Khami group and has previously been called Orbitolina limestone or Albian-Aptian limestone, or included as Khami limestone (Kent et al. 1951). The term “Dariyan Formation” was selected for this rock unit by James and Wynd (1965) after its measurement on Gadvan Mountain north of the village of Dariyan (northeast of Shiraz). The Dariyan Formation is equivalent to the Shu’aiba Formation of Saudi Arabia, Oman, the UAE, Kuwait, and Iraq (James and Wynd, 1965; Van Buchem et al., 2010a). The porous Shu’aiba Formation is a major reservoir in Oman (Droste, 2010) and the Arabian Peninsula (Hughes, 1997). Subsurface data obtained from core samples have allowed extensive study of the Shu’aiba Formation in the southern parts of the Persian Gulf (Frost et al., 1983; Alsharhan and Nairn, 1986, 1988, 1990, 1993; Alsharhan, 1989; Hamdan and Alsharhan, 1991; Azer and Toland, 1993; Banner and Simmons, 1994).

4. Stratigraphy
The carbonates of the Dariyan Formation and shales of the Kazhdumi Formation were deposited on the northeastern portion of the Arabian plate during the Aptian-Albian (Ziegler, 2001). The Dariyan Formation is the youngest member of the Khami group and features distinct unconformity at the top (Kheradpir, 1975; Setudehnia, 1978). It gradually (conformably) overlies the Gadvan Formation and (unconformably) underlies the marl and thin-bedded limestone of the Kazhdumi Formation in the Fars area (Figure 3). These beds are sandy, glauconitic, and slightly weathered. In the interior Fars region, the latter disconformity disappears and the top of the unit becomes younger. This unconformity separates the Aptian units (e.g., the Shu’aiba and its equivalent Dariyan Formation) from the Albian (e.g., the Nahr Umr and Kazhdumi Formations). This disconformity shows an important hiatus and nonsedimentation in the Aptian-Albian boundary with a 40-m fall in water depth (Ziegler, 2001; Pierson et al., 2010; Raven et al., 2010). The late Aptian unconformity caused erosion (Droste, 2010) and local karstification (Van Buchem et al., 2002; Al-Ghamdi, 2006; Yose et al., 2010) in some parts of the Arabian plate. The Early-Late Aptian age is suggested for this unconformity (Van Buchem et al., 2002).

In the Genau section, the first unit of the Dariyan Formation is composed of about 43 m of thick, layered, light-brown orbitolinid limestone. There are layers stained by Fe between the lower and middle units. The middle unit is 15 m of thinly layered, gray shaly limestone and the ends are 2.5 m of massive rudistid limestone. About 1 m of Fe-stained, red, sandy limestone is related to the unconformity just above the rudistid zone. In the Anguru section, the sedimentary alternations of the Dariyan Formation differ from the Genau section. It begins with about 20 m of thin-to-thick layered, light-brown orbitolinid limestone. The shaly middle portion disappears into this section and continues with 30 m of massive rudistid limestone that ends in 6-m-thick layered orbitolinid limestone. The sandy and weathered layers of the unconformity can also be seen at the top of the formation in the Anguru section.

Figure 3. The schematic stratigraphic column of the Zagros basin and the Dariyan Formation, figure after James and Wynd (1965).
In the Early and Late Aptian, different types of rudist developed in the carbonate ramps (Masse et al., 1998; Skelton and Gili, 2011). Recumbent rudists (especially caprinids) appeared in the Early Aptian in the Shu‘aiba Formation and grew and colonized in the steep margins bordering the open ocean (Ross and Skelton, 1993; Masse et al., 1998; Al-Ghamdi, 2006). Radiolitidae dominated in the upper Aptian successions (Masse et al., 2002). In the Anguru and Genau sections, *Mesorbitolina* (from the *parva-texana* group) and *Eoradiolites* appear at top of the Dariyan Formation and support the Late Aptian for this part of the Formation (Figures 4a and 4b). The presence of *Palorbitolina lenticularis* at the base of the formation confirms the Early Aptian age for the lower Dariyan (Figure 4c). In some parts of the Fars area (e.g., Genau section), a shaly carbonate unit separates the lower and upper parts of the Dariyan Formation and is known as the middle Dariyan.

Wynd (1965) carried out a detailed biostratigraphic study and suggested three biozones (#16, #17, and #18) for the Dariyan Formation in the Zagros basin. The equivalents of these biozones were also determined for the Shu‘aiba Formation (Hughes, 2000). These equivalent Dariyan and Shu‘aiba units can be divided into three stacked units on the basis of their distinct micro- and macrobiofacies. Biozone 16 has been identified in the Dariyan Formation in most of the Fars area. The main fossil contents are *Orbitolina, Choffatella decipiens, Hensonella cylindrical,* and *Lithocodium aggregatum.* The age of this biozone is indicated by the genus of the Orbitolinidea. In this study, it is the Early Aptian, based on the presence of *Palorbitolina.*

Wynd (1965) identified biozone 17 as the interval with abundant *Globigerina* and *Hedbergella* accompanied by Radiolaria and sponge spicules located on biozone 16. This biozone is not indicative of a distinct age. For example, Afghah and Shaabanpour-Haghighi (2014) suggested the Late Aptian age based on planktonic fauna in northern

---

**Figure 4.** a) *Eoradiolites* from upper Dariyan Formation indicating Late Aptian age for this unit (Anguru section); b) *Mesorbitolina* with rudists accompaniment, indicating Late Aptian age for the uppermost of the Dariyan Formation (Anguru section, Sample number 2568); c) *Palorbitolina lenticularis* from lower Dariyan Formation, with Early Aptian age (Anguru section, Sample number 2544).
5. Analysis of facies

In the Anguru and Genau outcrops, the Dariyan Formation is composed of lagoon, rudist banks/barriers and open marine/basinal facies groups and six microfacies types. Some of these facies only occur in one section, but others exist in both sections. In eastern Fars Province, this formation contains shallow-to-deep water carbonates composed of skeletal and nonskeletal grains. The sediment types are described below, arranged from lagoon to basinal facies.

5.1. Mudstone to wackestone (F1: lagoon)

This facies includes shallow carbonate mudstones that are mainly brown to black in color. It contains shallow ramp skeletal grains, including small benthonic foraminifers (textularids, miliolids, and trocholinids), algae (Hensonella dinarica), bivalves (rudist and pelecypod), large foraminifers (Orbitolina), and gastropods. Nonskeletal grains are not present in this facies. The inner platform and uppermost photic zone can be envisaged from the presence of miliolids, Hensonella dinarica algae, and encrusting Lithocodium aggregates (Burchette and Wright, 1992; Ghabeshiavi et al., 2010). The low biodiversity, rare rudist fragments, and dominance of shallow-environment fauna point to a semirestricted lagoon. This facies occurs in the lower part of the Dariyan Formation in the Genau section and the upper and lower parts of the Anguru section (Figure 5a).

5.2. Bioclast peloid packstone (F2: lagoon/back-rudistid barriers)

This facies shows few matrix and skeletal grains (up to 50%) and peloids (the only nonskeletal grains; Figures 5b and 5c), demonstrating a high-energy setting in back-barrier lagoon. The presence of shallow skeletal grains of textularids, miliolids, Orbitolina, small benthonic foraminifera, rudist fragments with micritic coats, rounded and sorted peloids (fecal pellets), and angular peloids (micritic bioclasts) suggests the interior areas of a shallow inner platform. The conical shape of the orbitolinids specifies the photic zone and a shallow water environment. Al-Ghamdi (2006) identified similar facies from the Shu’aiba Formation that belong to a shallow lagoon (inner platform) environment. This facies is present in the lower Dariyan Formation (Genau section) and the upper Dariyan Formation (Anguru section).

5.3. Bindstone (F3: lagoon/back-rudistid barriers)

In this facies, sticky algae surround organisms such as worm tubes, rudists, gastropods, and pelecypods (Figure 5d). Abundant encrusting algae formed irregular lamination that surround the other skeletal grains. This facies is only seen in the Anguru section and resembles the standard facies introduced by Wilson (1975; SMF7), Flügel (2004; RMF3), and Al-Ghamdi (2006; Lithocodium wackestone/bindstone). It is evident that this facies formed in a lagoon environment just behind the rudist banks (Hughes, 2000). This could also have formed in a photic zone above a storm wave base in a moderate to relatively-deep open marine environment (Al-Ghamdi, 2006).

5.4. Bioclastic rudist wackestone (F4: rudist banks/barriers)

Rudist wackestone of about 2.5–30 m in thickness was observed in the upper Dariyan Formation. The skeletal packstone to wackestone matrix occurs between the rudist debris and lime matrix that usually partially fills intraskeletal voids. Calcite-rich rudists dominated the Late Aptian (Skelton and Gili, 2011); therefore, these rudists have preserved the texture of their outer shell layers because of their low-Mg calcite mineralogy (Figure 5e). Many types of biota, including rudists, corals, foraminiferal-algal communities, and nonskeletal grains (especially peloids), participated in rudistid sets (Gili et al., 1995a). In this facies, skeletal grains such as gastropods and pelecypods (including large rudist shells and ostracods) are present in a micritic matrix. Rudist shells are usually whole shells, but are sometimes broken. Very large rudist shells that have broken from the effect of storms on the ramps and smaller whole shells are usually present in this facies. The existence of many whole rudist shells suggests that this facies was deposited near their original habitat. The absence of benthonic lagoon foraminifera such as textularids and miliolids, the diversity of shallow marine fauna, and the presence of large rudist shells indicate the higher energy sector of the carbonate factory. This facies shows the highest energy level in the studied sections. It formed sporadic rudist shoals and banks on the outer end of the inner platform and at midplatform. Hughes (2000) thought that the basinal shoals and internal paleoshelf margins hosted rudist banks. The rudist barriers are mainly composed of different sizes of rudist shells with micrite in their pores and tunnels. In the upper Dariyan, the rudist facies appears as cliff-builder limestone in the
Figure 5. a) F1 Facies with Hensonella (H), algae, and miliolids (M) in a wackestone texture; b and c) F2 facies with conical orbitolinids, bivalves, and small benthonic foraminifera associated with abundant peloid grains in a packstone texture in the Genau section, Sample number 4251 (b) and Anguru section, Sample number 2572 (c); d) bindstone facies, only occurring in the Anguru section (Sample number 2558); e) bioclast rudist wackestone, Eoradiolite (R) with preserved texture of the outer shell layer (Genau section, Sample number 4264); f) F5 facies, bioclast mudstone (Anguru section, Sample number 2546); g) F5 facies, bioclast wackestone (Anguru section, Sample number 2547), belonging to deeper parts of the platform with small, thin septum gastropods (G), calcisphere (C), and other fossil fragments in a brown to black matrix; h) F6 facies, planktonic foraminifera with calcisphere in a wackestone texture (Genau section, Sample number 4262), Fe stain, brown to dark brown matrix (Fe).
outcrops and is comparable to the bioclast floatstone/rudstone facies introduced by Maurer et al. (2006) in Abu Dhabi.

5.5. Bioclast mudstone to wackestone (F5: open marine)
This mud-supported facies is brown, gray, and black in color. The grain content is low and includes flattened Orbitolina, gastropods (small with thin septa on the deeper parts of the platforms), ostracods, echinoderms, and rudist fragments. There is a lack of restricted marine fauna such as miliolids and textularids (Figures 5f and 5g). Rudist fragments are generally transported from a shallow platform to deeper areas. This facies only occurs in the Anguru section (lower portion of Dariyan Formation) and is similar to the standard microfacies introduced by Al-Ghamdi (2006; RMF1, 3), Wilson (1975; SMF8), and Al-Alm and Wilson (1975; SMF3). This is probably the deepest facies in the Dariyan Formation and it was deposited in the Aptian intrashelf basin in eastern Fars.

5.6. Bioclast planktonic foraminifer wackestone (F6: deep basinal/intrashelf facies)
This facies includes basinal fauna such as pelagic mud with a wackestone texture, planktonic foraminifers, calcispheres, and radiolarians in some horizons. It is ferruginous and shows traces of organic matter in some horizons (Figure 5h). The facies occurs only in the middle Dariyan Formation in the Genau section, where it appears as about 15 m of dark gray argillaceous lime. It is comparable to the standard microfacies introduced by Wilson (1975; SMF3). The presence of planktonic foraminifers and ammonites in the

6. Distribution of facies
The changes in the fossil content of the Dariyan Formation help distinguish three distinct biozones (#16, #17, and #18) introduced by Wynd (1965). The Dariyan Formation is divided into two parts in the Anguru section and three parts in the Genau section (Figures 6, 7a, and 7b). In the Anguru section, the lower Dariyan Formation is composed of mudstone and wackestone alternations (F5 facies). The presence of Orbitolina indicates the early Aptian age for this unit and is equal to biozone 16. The upper region continues this facies pattern with shallow mudstone and wackestone (F1 and F2). The upper part is mainly composed of bioclast rudist wackestone (F4) and bindstone (F3). The presence of late Aptian rudists (Eoradiolites) shows that this unit is time-equivalent to biozone 18.

In the Genau section, the lower Dariyan is composed of alternations of shallow bioclast mudstone to wackestone (F5) and bioclast packstone (F2). This unit is similar to the lower Dariyan Formation in the Anguru section. The boundary between the middle and lower parts shows a shallowing cycle distinguished by a red oxidized layer (Figure 7c). The middle Dariyan Formation is composed of pelagic foraminifer wackestone facies (F6), which equals to biozone 17. Aldabal and Alsharhan (1989) introduced a similar facies set in the open-marine environment of the intrashelf basins in the UAE, Qatar, and Oman. They reported planktonic foraminifers and ammonites in the

---

**Figure 6.** Generalized facies column of the Dariyan Formation in the Anguru (a) and Genau (b) sections; c) facies distribution and changes of the Dariyan Formation in the studied area (no scale).
The boundary between middle and lower Dariyan Formation in the Genau section; b) whole facing of the Dariyan Formation in the Anguru section; c) the boundary between middle part of the Dariyan Formation (pelagic mudstone) and the lower part of the Dariyan Formation in the Genau section; d) close facing of the whole *Eoradiolites* shells of the upper part of the Dariyan Formation in the Anguru section; e) the upper weathered and oxidized boundary between the Dariyan Formation (the upper part of the Dariyan Formation) and the Kazhdumi Formation in the Genau section.

Figure 7. a) Whole facing of the Dariyan Formation in the Genau section; b) whole facing of the Dariyan Formation in the Anguru section; c) the boundary between middle part of the Dariyan Formation (pelagic mudstone) and the lower part of the Dariyan Formation in the Genau section; d) close facing of the whole *Eoradiolites* shells of the upper part of the Dariyan Formation in the Anguru section; e) the upper weathered and oxidized boundary between the Dariyan Formation (the upper part of the Dariyan Formation) and the Kazhdumi Formation in the Genau section.
deeper parts. As in the Anguru section, the upper Dariyan Formation is composed of rudist facies (bioclast rudist wackestone; F$_4$; time-equivalent to biozone 18; Figure 7d). This limy cliff-building interval overlies the shaly and muddy successions in the middle Dariyan. The boundary between the Dariyan and Kazhdumi formations shows shallowing and subaerial exposure distinguished by a 1-m red oxidized layer (Figure 7e). Frequency analysis of the facies belts of the two sections indicates that the restricted lagoon facies were dominant (Figure 8). A semirestricted lagoon appears to have been created behind the low-lying rudist barriers.

Diagenetic processes have affected the Dariyan Formation in the study area. The presence of micritic bioclasts and micrite-coated grains show the effect of micritization, which is a feature of lagoon environments. This occurred in the F$_1$, F$_2$, and F$_3$ facies and confirms the shallow, stagnant, and restricted lagoon environment for these facies. The main diagenetic alterations were limited dissolution, dolomitization as euhedral crystals, microfractures, and the lack of major karstification. Most of these diagenetic imprints belong to a burial diagenetic regime rather than a meteoric setting.

Paleontological logs produced by the National Iranian Oil Company (NIOC) indicate that these biozones (biozones 16, 17, and 18) can be tracked along the AA’ and BB’ transects (Figures 9 and 10). The lower Dariyan Formation is orbitolinid (biozone 16), which continues as a thin tongue of basinal facies (biozone 17) in the Sarkhun well. The rudistid zone (biozone ~18) occurs in the uppermost Dariyan Formation in this well. In the Finu well (Figures 9 and 10), this formation begins in the orbitolinid zone (biozone 16) and suddenly changes to a planktonic zone (biozone 17). The upper unit terminates in a conical Orbitolina biozone (biozone 18). Towards the Dasht-e Kunar well (Figures 9 and 10), biozone 16 expands and is completely composed of an orbitolinid zone (biozone 16).

7. Discussion
Paleogeographical studies of the Cretaceous carbonate ramps by Murris (1980) and Koop and Stoneley (1982) proposed a ramp-type depositional regime associated with shelf carbonates that was established and gradually surrounded most parts of the Middle East in response to the eustatic rise in sea level. In the study area, limited expansion of high-energy facies, the absence of real reefs and turbidity facies, and widespread mud-supported facies with semirestricted fauna indicate the presence of stagnant lagoons behind reef-like rudist accumulates. The salt diapirs are more and better developed within the eastern Fars area than the western parts. The movement of these diapirs might be a reason for sudden breakage on the Aptian ramp and the development of locally deep intrashelf subbasins (Sharland et al., 2001; Van Buchem et al., 2010b). These basins are called salt diapir platforms by Bosence (2005) and are described as bathymetric highs and salt dome islands by Purser (1973). Considering the abrupt changes in facies from shallow rudist to deep planktonic foraminifera, an intrashelf basin model can be suggested for the Dariyan Formation in eastern Fars (Figure 11). The term “Genau intrashelf” is proposed for the deep Aptian basin located in the Genau and Finu sections. James and Wynd (1965) suggested that formation of an intrashelf basin led to deposition of deep facies within the middle Dariyan platform. Although the upper Dariyan shelf edge is composed of rudist facies, pelagic mudstone and wackestone were deposited in the Genau intrashelf basin. The pelagic facies set located in the middle of the Dariyan Formation is known as the Kazhdumi tongue in the Zagros area. It is equivalent to the shaly Bab member in the southern Persian Gulf. Masse et al. (1998) identified similar environmental changes in the Shu’aiba Formation in Oman.
Figure 9. Exhibition of the AA’ transect, including Genau section plus Sarkhun, Finu, and Dasht-e Kunar wells.

Figure 10. Exhibition of the BB’ transect, including Anguru and Genau sections along with the Sarkhun well.
The eastern and western boundaries of the Genau intrashelf were determined in the Genau section. The northern boundary continues beyond the Finu well. Unpublished NIOC data from the Gahkum structure (Figure 12) show better development of the pelagic intrashelf facies in the northwestern parts. This information suggests the southward extension of the pelagic facies in the Gavarzin well (Figure 12). As in eastern Fars, the creation of an intrashelf has been reported from the Bab basin to the southern Persian Gulf. This latter basin was surrounded by a shallow ramp that likely contained narrow channels (Murris, 1980; Fischer et al., 1995; Grabowski and Norton, 1995; Hooper et al., 1995). The limited communication of the Aptian intrashelf basins with the adjacent Neo-Tethys Ocean established suitable conditions for organic-rich sediment deposition (Van Buchem et al., 2010a). Part of this basinal organic-rich facies is Aptian in age, but it extends well into the Albian (Vincent et al., 2010). The Bab member within the Shu’aiiba Formation (southern Persian Gulf) and the Kazhdumi tongue in the Dariyan Formation (northern Persian Gulf) both contain these organic-rich facies in the Aptian. Bordenave and Burwood (1995) first described these source rocks and their description was improved by detailed geochemical and stratigraphic studies by Vincent et al. (2010).
Many records exist of rudist facies on the Tethyan ramp throughout the Aptian, but these were primarily established in the Early Aptian (Roberts et al., 1980; Masse and Chartrousse, 1997), the Late-Early Aptian (Al-Ghamdi et al., 2010; Maurer et al., 2010; Van Buchem et al., 2010a; Vincent et al., 2010) and the Late Aptian (Iba and Sano, 2007; Takashima et al., 2007). In the present study, the presence of *Eoradiolites* supports rudist occurrence in the Late Aptian in the upper Dariyan Formation. The rudist facies of this unit are wackestone in texture and were deposited in the margins of the Genau intrashelf basin. The interior platform indicates that the shallower facies are typified by micritic skeletal grains such as miliolids and textularids.

Late Aptian paleogeographic maps emphasize the presence of Late Aptian rudists (e.g., *Eoradiolites* and *Praeoradiolites*) on the northern margins of the Tethys in a tropical climate (Dercourt et al., 1993; Hooper et al., 1995; Hughes, 1997; Masse and Gallo Maresca, 1997). Skelton and Gili (1991) categorized the rudist shells as paleoecological morphotypes (recumbents, elevators, and clingers). In Southwest Asia, elevators (*Eoradiolites*) are reported in Pakistan (Douvillé, 1926), Afghanistan (Montenat et al., 1982), and India (Mathur and Vogel, 1988). In southwestern Iran, elevators are documented in the uppermost Dariyan Formation and are better developed in southeastern Fars. Two main locations have been distinguished for the distribution of rudist facies in eastern Fars. Two main locations have been distinguished for the distribution of rudist facies in eastern Fars (Figure 12). The Sarkhun well is at the far eastern limit of a rudist facies extension. Unpublished NIOC data suggest that the west-northwest limit of the rudist facies distribution continues farther than the Anguru structure; it has been reported in the Khamir, Shu (west), and Baz (northwest) structures (Figure 12). Northward of the study area, these facies disappear; southward they show better development. Comparison of GR logs of the

![Figure 12. The probable borders of the Genau intrashelf basin (blue line) and limits of the rudist development in the studied area (green line).](image-url)
surface sections and wells shows that the rudist facies have similar peaks. The GR generally decreases in these facies and shows similar peaks for the Anguru section and Sarkhun well (Figure 13).

8. Conclusions
The present study demonstrates that the Dariyan Formation in eastern Fars Province in the Zagros Fold Belt contains shallow-to-deep water carbonate facies in the Genau and Anguru outcrops. By considering carbonate facies succession, this unit can be divided into three parts in the Genau and two parts in the Anguru. The upper parts of both sections are mainly composed of rudist facies. The stratigraphic boundary between the uppermost part of the Dariyan Formation and the overlying Kazhdumi Formation shows a shallowing cycle and subaerial exposure distinguished by red oxidized layers. The middle Dariyan Formation is composed of pelagic foraminifer wackestone facies. The boundary between the middle and lower parts shows shallowing distinguished by red oxidized layers. The lower Dariyan is composed of alternations of shallow bioclast mudstone to wackestone and bioclast packstone. A comparison of existing facies with the deeper section adjacent to the Anguru (Genau) suggests that the

Figure 13. The similar gamma ray peaks in the rudistid zone of the Dariyan Formation (the Anguru section and Sarkhun well).
depositional environment of the Dariyan Formation was the Genau intrashelf. Analysis of facies frequency shows an abundance of restricted lagoonal facies in both sections, likely from the presence of low-lying barriers (rudist banks) on the margins of this intrashelf basin. The boundaries of the Genau intrashelf are located east and west of the Genau section. Its northern limit continues toward the north beyond the Finu well. There is evidence southward of pelagic facies development. Comparison of the sections and three adjacent wells (AA’ and BB’ transects) shows that the Genau intrashelf basin is bounded by the Genau section and the Finu well. It is surrounded by a shallow platform located in the Anguru section, the Sarkhun well section and the Finu well. It is surrounded by a shallow platform located in the Anguru section, the Sarkhun well section and the Finu well.

Acknowledgments

We would like to thank Islamic Azad University, Science and Research Branch, for providing the facilities for this research, and Exploration Management of the National Iranian Oil Company for their support and data preparation. We are thankful to Jean-Pierre Masse (Aix-Marseille University) for advice and identification of orbitolinid foraminifera and rudists given in this study.

References


Al-Ghamdi NM (2006). Facies, sequence framework, and evolution of rudist buildups, Shu’aiba Formation, Saudi Arabia. MSc, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA.


161


