Investigating the Impress of the Active Tectonics and the Rate of Fractures in Ilam Formation, Fars Area, SW Iran

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Abstract

The evolution of the Active Tectonics of the Ilam Formation (Santonin) form potential reservoir rocks at oilfields and structures in costal fars. Core and cuttings samples and wire-line logs from wells in the East Gardan field were used to investigate microfacies types and porosity evolution. Facies modelling was applied to predict the relationship between facies distribution and reservoir characteristics to construct a predictive geologic model which will assist future exploration in East Gardan field. Microfacies analysis and electofacies identification and correlations indicate that the limestones of the Ilam Formation were deposited in a ramp setting. The ramp developed over the distal margin of the Santonin proforeland basin, adjacent to the evolved forebulge. Inner ramp facies are characterized by carbonate bank bioclastic packstones. Middle ramp facies dominate the Ilam Formation and consist of bioturbated, massive, dolomitic and bioclastic limestones. Biclasts include benthic and planktonic foraminifera. Intense less common Palaeophycus bioturbation has enhanced the porosity of this facies. Outer ramp deposits consist of alternating mid-ramp bioturbated bioclastic massive limestones and argillaceous and marly limestones. Bioclastic packstones and intensively bioturbated bioclastic limestones of the mid-outer ramp are the primary source of fabric-selective porosity which is greatly enhanced by diagenetic overprints.

Keywords
Zagros, Iran, Ilam Formation, Field, Carbonate Reservoir

1. Introduction

The associated foreland basin represents one of the oldest and richest hydrocarbon provinces known [1]. The

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fold-and-thrust belt formed as a result of Neogene convergence and suturing between the Arabian Plate and the Iranian block [2]. The Zagros Main Thrust and accompanying ophiolites form the northern margin of the belt and separate it from the Central Iran block. The deformation front of the Iranian part of the belt has an irregular geometry in map view, and is characterized by two major bulges, referred to as the Coastal Fars and Fars salient, separated by the Izeh Embayment (Figure 1). The Fars area has a long history of hydrocarbon exploration and production but relatively few wells drilled here have been successful. Both high quality source rocks and regional seals are present and carbonates in the Santonian Ilam Formation form a major reservoir unit although permeability varies significantly due to variations in depositional facies and diagenesis.

Figure 1. Location map of the Fars region with the main structural features and subdivisions of the Zagros fold-and-thrust belt.

1.1. Location

The numerous studies of the Zagros fold-and-thrust belt which have been made, relatively little has been published concerning the link between structural evolution and foreland basin development. Some authors [3] have suggested that basement faults had a significant effect on the geometry of the Zagros deformation front and the evolving foreland basin. Thickness and facies variations, as well as local and regional unconformities, have been related to the reactivation of basement faults or the migration of the foreland basin between Late Cretaceous ophiolite obduction and late Miocene collision [2] [4]. The major regional angular unconformity between the Aghajari Formation has previously been considered to mark the climax of the orogeny in the late Pliocene [5]. More recently, the beginning of Zagros deformation has been dated at different times before the late Pliocene [6] [7] based on various types of geological evidence and methodologies. As a result of its complex stratigraphy and the wide variations in sediment facies and thicknesses, the Fars area is an ideal location in which to study foreland basin development. This paper presents the results of a regional-scale study of basin evolution in the Fars salient (Figure 2), based on recent fieldwork, together with unpublished logged surface sections of the Late Cretaceous and the early Miocene. The objective was to investigate the effects of the Zagros orogeny and of basement fault activity on basin evolution in Fars.

1.2. Geology Setting

The separation of Arabia from Africa and its convergence with Eurasia was the last in a series of separation-
collision events which gave rise to the Alpine-Himalayan orogenic system [8]. The Zagros fold-and-thrust belt, part of this system, is bounded to the NW by the East Anatolian left-lateral strike-slip fault and to the SE by the Oman line [9] [10] summarized the evolution of the Zagros orogeny in terms of three sequential phases: 1. Subduction of Neo-Tethyan oceanic crust beneath the Iranian lithospheric block during the Early to Late Cretaceous; 2. Emplacement (obduction) of ophiolite sheets derived from the Neo-Tethyan ocean floor over the Arabian continental margin in the Late Cretaceous (Turonian to Campanian) [2] suggested that the beginning of compressional deformation in the Zagros occurred during this time period, during the final closure of Neo-Tethys with the suturing of Arabia with Central Iran. 3. Collision of Afro-Arabian continental lithosphere with the Iranian plates during Late Cretaceous and later times. The growth of anticlines in the Holocene [11], together with recent seismicity, indicate that deformation in the fold-and-thrust belt is continuing, particularly at deep crustal levels [7]. Regional north-south convergence is taking place at rates which have been estimated at between 25 - 30 mm per year [12] and 20 - 25 mm per year. The rate of convergence varies in different parts of the Zagros belt [13] and the convergence rate is less in Fars than in Fars to the east, based on an Arabia-Iran pole of rotation [14].

The Zagros fold-and-thrust belt can be divided into a number of zones which differ according to their structural style and sedimentary history [2]. In Fars, the belt is bounded in the NE by the Main Zagros Reverse Fault and Main Recent Fault (Figure 1). The Main Zagros Reverse Fault is thought to mark the suture zone between Arabia and Eurasia [8] and has been outlined by earthquake focal mechanism solutions [15]. This fault marks the southern boundary of the Sanandaj-Sirjan metamorphic belt. However, some authors [16] [17] have included the metamorphic rocks located to the NE of the Main Reverse Fault within the Zagros fold belt. The Main Recent Fault, a relatively recent, right-lateral fault, which is currently seismically active along a few segments [18], follows the trace of the Main Zagros Reverse Fault out of Turkey to approximately lat.32oS, the northern limit of Fars. To the SW, the High Zagros Zone (Figure 1) contains highly imbricated slices of sedimentary cover rocks.
and fragments of Cretaceous ophiolites [18]. This zone is up to 80 km wide and forms the topographically highest part of the Zagros [19]; it contains the oldest exposed rocks and is limited to the SW by segments of the High Zagros Fault. To the SE of the High Zagros zone is the Simply Folded Zone which includes the study area for this paper, and which is bounded to the SW by the Mountain Front [20] or the Mountain Front Fault [18] (Figure 1). The Zagros belt can also be divided by a series of transverse lineaments. The Bala Rud Fault (or line) separates eastern Fars from the Izeh Embayment [4]. To the west, Fars is bounded by the Khaneqin fault which separates it from the Kirkuk Embayment (Figure 1).

1.3. Zagros Foreland Basin

Some 7 to 12 km of sediments were deposited in an epicontinental synorogenic foreland basin which developed in front of the evolving Zagros orogeny [10]. The sedimentary cover rests on Proterozoic metamorphic rocks of the pan-African basement, considered to be the NE continuation of the Arabian Shield which is exposed in the SW of the Arabian Plate. The only exposed basement rocks within the Zagros fold-and-thrust belt are blocks of metamorphic material brought to the surface in salt diapirs [5], but these are not present in Fars. North-south faults have controlled the facies and thickness of Phanerozoic sedimentary rocks, at least from the middle Cretaceous [20]. A thickness and facies pattern parallel to the developing Zagros (NW-SE trending orogeny) was gradually superimposed on the pre-existing north-south trending subsidence pattern after the Late Cretaceous. Authors have proposed that there are no major angular unconformities within the sedimentary column in the Zagros between the Lower Cambrian and the Pliocene. However, recent studies [4] have documented the occurrence of unconformities which are interpreted to reflect tectonic activity. Thickness variations of Miocene sediments across the Zagros belt are related to patterns of synorogenic sedimentation [4].

1.4. Sedimentary Characteristics

There are significant differences in sedimentary thickness and facies between Fars and the Izeh Embayment. For example, The Dalan Formation (limestones) and Dashtak Formation (anhydrites) in the Izeh Embayment pass into the Adaiyah Formation (evaporites), Mus Formation (carbonates), Alan Formation (evaporites), Sargelu Formation (shale and marls), Najmeh Formation (carbonates) and Gotnia Formation (evaporites) in Fars. Similarly, Cretaceous sedimentary rocks of the Lower Khami Group, including the Fahlian, Gadvan and Darian Formations which mostly consists of neritic carbonates, pass into pelagic facies of the Garau Formation. Thickness and facies changes within the Santonian I lam Formation have been documented in subsurface data and in the field. The Sarvak Formation, a Paleocene-Eocene limestone in the Izeh Embayment, passes into the Amiran Formation (marls, shales and sandstones), the Talehzang Formation (carbonates), the Kashkan Formation (conglomerate and sandstone) and the Shahbazan Formation (dolomite). A generalized lithologic and stratigraphic column for the study area, based on data from a variety of sources, is shown in (Figure 3). Data sources include the surface section in the NE of the study area for the Lower Palaeozoic; the Homawells for the Permian to Jurassic; (See Figure 2 for the location of the structures) for the Cretaceous; and a number of measured stratigraphic surface sections for the Upper Cretaceous to lower Miocene interval. These observations indicate significant thickness variations for most of these formations in the study area. However, average thicknesses for each formation are given in the chart of Figure 3.

1.5. Foreland Basin History

In order to investigate the evolution of the Zagros foreland basin in the study area between the mid-Cretaceous and the onset of Zagros folding, a number of isopach maps for time intervals between the Santonian and Miocene were prepared. These maps were constructed using re-evaluated logged sections originally prepared by, (Figure 1) together with available well data.

2. Materials and Methods

For the preparation of the isopach maps, the thickness of sedimentary rocks for each time interval was obtained from surface sections and well data. These values were then adjusted for the exact location of the data sources (surface section or well), and were contoured using minimum curvature equations. Santonian sediments were studied in order to investigate the influence of pre-existing basement lineaments
and Zagros folding (Santonian) on the evolution of the basin. The Santonian Ilam Formation is an important carbonate reservoir unit in Fars. Field observations show that the formation is composed of both neritic and pelagic...
facies in different parts of the study area. In the eastern part of the Homa anticline (Figure 2), the formation is dominated by pelagic facies (upper Santonian and Turonian) which overlie neritic facies (Santonian) (Figure 4). The pelagic facies locally follow the approximately north-south trend of the Gardan lineament, within which the axis of the Gardan anticline demonstrates marked sinuosity (Figure 2). Bedding within the Ilam Formation indicates a clinoform geometry in the Homa anticline (Figure 5). The presence of pelagic facies in the westernmost part of the Homa anticline and the presence of clinoform stratal patterns in carbonate intervals towards the WNW confirms the palaeo slope of the Ilam Basin from ESE to WNW in this part of the region (Figure 5). The isopach map for the Santonian (Figure 6) indicates thickness variations along roughly north-south (or NE-SW) trending anomalies. One of the north-south trending anomalies appears to be aligned with the Gardan lineament. This anomaly coincides with the eastern part of the Homa anticline, where pelagic facies in the Ilam Formation rest on neritic deposits. The thickness of Santonian sediments decreases towards the western and eastern margins of the trend (Figure 6). The Campanian-Maastrichtian isopach map (Figure 7) demonstrates thickness variations along a NW-SE trending anomaly parallel to the general trend of the Zagros fold-and-thrust belt. North-south trending anomalies (i.e., those at high angle to the Zagros belt, are absent from this isopach map. The heavy dashed line parallel to the Zagros trend is the best-fit line through the foreland basin depocentres. The Palaeocene-Eocene isopach map is based on measured stratigraphic surface sections and well data. A number of NW-SE trending anomalies are apparent on the map. As with Figure 7, the heavy dashed line is the best-fit line through the foreland basin depocentres. Note that this line of this map is displaced SWwards compared to the Campanian-Maastrichtian isopach map (Figure 7), demonstrating SWwards migration of the foreland basin depocentre. Further SWwards migration of the depocentre is indicated on the isopach map, relative to the Albian isopach map. The map also shows a NW-SE trending isopach anomaly in the northern part of the study area, and a roughly north-south trending anomaly, aligned with the Gardan lineament, in the southern part. This change in trend is supported by field observations. In the north of the Gardan lineament, there is some evidence for the

Figure 4. Field photographs from the eastern part of the Homa anticline (see Figure 2 for location). The photos show pelagic facies of the Santonian Ilam Formation overlying neritic facies.
Figure 5. Field photographs from the core of the Homa anticline (see Figure 2 for location). The photographs show the clinoform stratal pattern within the Asmari and Jahrom Formations indicating deepening of depositional conditions towards the NW along the Gardan lineament.

existence of a palaeohigh during deposition of the Santonian Ilam Formation carbonates. Thus Figure 8(a) shows an area close to the eastern plunge of the Saiwah anticline (location in Figure 2). The photo shows the progradation of Ilam Formation carbonates towards the deeper parts of the Ilam basin from west to east. Also, on the northern flank of the Saiwah anticline (Figure 8(b), location in Figure 2), reefal packages within the Ilam carbonates pass into thinner beds to the east, towards the deeper part of the Ilam basin. The western margin of the Gardan lineament at the northern limb of the Genu anticline, NW of Ilam City, is shown in Figure 8(c) (location on Figure 2). At this location, the progradational stratal pattern indicates deepening of the Ilam basin towards the west. Finally, a Bouguer anomaly map of the study area with a low-pass filter [21] (Figure 9) shows thickening of the sedimentary package from SW to NE, at high angle to the Zagros belt.
3. Results and Discussion

In Fars, both reactivation of basement faults and/or Zagros deformation controlled the evolution of the foreland basin between the Late Cretaceous. Below, we discuss the isopach maps compiled in order to study the effect of these two elements on foreland basin evolution.

3.1. The Effect of North-South Trending Basement Structure on Basin Characteristics

Previous studies have drawn attention to the presence of north-south trending strike-slip faults in the basement of the Iranian Zagros [22] [23]. The effects of some of the north-south structural trends in the basement can be recognized on Landsat images, for example from the sinuosity of the fold axes [24]. Thus, the sinuosity of the Gardan anticline in the southern part of the study area is attributed to offset on a basement lineament which can tentatively be followed into the northern flank of the Homa anticline, SE of Ilam City (Figure 10). As mentioned above this trend, which may be a reactivated north-south basement fault, is referred to here as the Gardan lineament. Phases of basement activity during the evolution of the Zagros basin have affected facies and thickness. Both thickness changes in the Santonian isopach (Figure 6), and the change from neritic facies in the Santonian Ilam Formation to mostly pelagic facies elsewhere in the southern part of the study area, take place along the roughly north-south Gardan lineament (Figure 2). This suggests that this lineament or palaeohigh was active during deposition of Santonian Ilam Formation. After the mid-Cretaceous tectonic phase (post-Santonian), a series of highs aligned in general north-south, parallel to the Arabian trend, originated in the Izeh embayment area. Documented the existence of several palaeohighs during deposition of Cretaceous Bangestan Group sediments along pre-existing basement lineaments in the Izeh Embayment. Other authors emphasized that transverse
strike-slip basement faults in the Zagros (i.e. Arabian trend faults) have controlled the facies and thickness of sediments deposited since at least the middle Cretaceous. The Kazerun and Hendijan-Bahregansar faults (Figure 1) correspond to a series of roughly north-south striking linear uplifts along pre-existing basement trends. Proposed that these trends were reactivated in response to ophiolite obduction in the Late Cretaceous, and may have influenced sedimentation. Based on seismic data and field observations at Izeh and in the Izeh Embayment documented thickness and facies variations in Albian-Santonian strata along the Hendijan-Bahregansar fault. It is suggested here that the Gardan lineament represents a roughly north-south striking, linear uplift along a pre-existing Arabian basement lineament which was reactivated in the Late Cretaceous (activation before the late Cretaceous is unknown), in response to the onset of the Zagros orogeny and ophiolite obduction. The effects of activity on the Gardan lineament on the evolution of the foreland basin appear to decrease both with time (as indicated by isopach maps: Figure 7) and in a northwards direction. This demonstrates that, from the Late Cretaceous to the present day, Zagros deformation has been the most important factor controlling the evolution of the foreland basin. However, the influence of the Gardan lineament on sedimentation during the Oligocene-lower Miocene (including the Ilam Formation) can also be detected. As mentioned above, thickness variations and stratal patterns (Figures 8(a)-(c)) indicate that the basin deepened both east- and westwards away from the Gardan lineament. Thus, the lineament appears to have controlled sedimentation in Santonian time especially in the southern part of the study area. However, its impact at this time apparently decreases northwards, unless its effects are obscured by the superimposed Zagros trend.

3.2. The Influence of the Zagros Orogeny on Foreland Basin Evolution

Foreland basins are generally accepted to express downward flexure of the lithosphere in front of a tectonic load
Figure 8. (a) Field photo on the southern limb of the Saiwah anticline, near the eastern side of the Gardan lineament (location in Figure 2). Photo shows SEward progradation of Santonian Ilam Formation carbonates over Coniacian pelagic marls of the Kazhdomi Formation. (b) Field photo on the northern limb of the Saiwah anticline near the eastern margin of the Gardan lineament (location in Figure 2). Photo shows west-to-east thinning of a carbonate reefal package within the Ilam Formation. (c) Field photo on the northern limb of the Homa anticline, to the west of the Gardan lineament (location in Figure 2). Photo shows east-to-west clinoform pattern of carbonate intervals in the Ilam Formation.
imposed by the advancing thrust sheets [25] [26]. In the Zagros area, evolution of the foreland basin was accelerated by Late Cretaceous ophiolite obduction in the Izeh Zone. A Bouguer anomaly map of Fars (Figure 9) [21] shows that the thickness of the sedimentary cover increases perpendicular to the generally NW-SE Zagros trend from the Mountain Front Fault towards the High Zagros Fault, i.e. from SW to NE. This is a common feature of many foreland basins. Thickness variations in the Zagros fold-and-thrust belt during specific time intervals (Campanian-Maastrichtian, Paleocene-Eocene and Oligocene-early Miocene) indicate that the advancing orogenic wedge resulted in downward flexure of successively more external portions of the foreland, and caused the fore-bulge and the depocentre to migrate to more external parts of the foreland. Therefore, locations which were originally far from the advancing orogenic load may have been uplifted before subsiding as a result of the approach of the orogenic wedge. One piece of evidence which is consistent with foreland basin migration in the study area is the presence of a relatively low-angle unconformity between the Kazhdomi and Ilam Formations, some 45 km SE of Ilam City (Figure 10). This is similar to the unconformity reported by [4] some 40 km north of Izeh, which was interpreted to indicate uplift of the Kazhdomi Formation, and its exposure to surface erosion, before deposition of the Ilam limestone. Successive isopach maps show (Figure 7).

SW ward migration of the foreland basin depocentre between the Campanian and the early Miocene. In order to trace the effects of the Zagros orogeny on basin evolution, a graph of geological time versus depocentre location was prepared (Figure 11) (the best-fit line through the depocentres is marked as a dashed line on the isopach maps). Using the Campanian-Maastrichtian isopach map as a reference. The orthogonal distance between successive best-fit lines was considered to indicate the amount of depocentre migration towards the SW from the end-Maastrichtian to the end-early Miocene. The graph shows that about 40 km of SWward depocentre migration took place at a rate of about 1 km/Ma between 66 Ma and 34 Ma (Albian-Santonian). From 34 to 16 Ma (Maastrichtian), the depocentre migrated some 26 km to the SW at a faster rate of 1.45 km/Ma. Thus there was an increase in the rate of the depocentre migration towards the SW in the Santonian-Campanian compared to the Maastrichtian. The reasons for this change in the rate of depocenter migration remain speculative and are not discussed here.

Figure 9. Bouguer anomaly map of the study area with a 20 km low pass filter. The map shows NW-SE thickening of the sedimentary cover in the Fars foreland basin, at high angle to the general Zagros trend.
3.3. Relative Active Tectonics of the Zagros Orogenic Belt

The study area is situated in Zagros fold and thrust belt [27]-[34] (Figure 1). From tectonics view, it contains orogenic belt of Arabian plate [35]-[37]. Based on previous work on the salt and mud diapirism [38]-[49] and neotectonic regime in Iran [50]-[55], Zagros is the most active zone [56]-[78]. Then, Alborz [79]-[120] and Central Iran [121]-[138] have been situated in the next orders. Therefore, active tectonics have got an important rule on the rate of fractures on Ilam Formation in the study area.

4. Conclusion

The analysis of the basin depocentre between Late Cretaceous obduction and the Santonian indicates progressive SWward migration of the depocentre at different rates during the Zagros orogeny, and documents the evolution of a typical foreland basin in the Fars area. During deposition of the Santonian Ilam and Ilam Formations
in southern Fars, the architecture of the foreland basin was influenced by the deep-seated, approximately north-south trending Gardan lineament. During the Santonian to Campanian time interval, this lineament was reactivated to form a palaeohigh in the southern part of the study area. This palaeohigh caused facies and thickness changes in the Ilam Formations. Facies changes in the Ilam Formation may explain the observed variations in reservoir quality in the Fars region.

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References


East of Varamin to the East of Semnan.

in the Chalus Drainage Basin in the Alborz, Iran.


Karbasi and Khaftar Anticlines, Interior Fars, Iran.


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