Sequence stratigraphy of Oxfordian and Kimmeridgian shelf carbonate reservoirs, offshore Abu Dhabi

Ahmed S. Al-Suwaidi, Abu Dhabi Marine Operating Company, and Sabah K. Aziz, Abu Dhabi National Oil Company

ABSTRACT

Carbonate reservoirs on the eastern flank of the Oxfordian-Kimmeridgian intrashelf basin in offshore Abu Dhabi had received little attention until commercial oil accumulations in structural traps were discovered in the late 1980s and early 1990s. In order to clarify the geometric and chronostratigraphic relationships of the Oxfordian-Kimmeridgian reservoirs, a multidisciplinary study (seismic, lithobiofacies, geochemistry, strontium isotope dating, and well-log data) was used to develop a sequence stratigraphic model.

After deposition of the Callovian upper Araej Formation, a differentiated carbonate platform was established in the early Oxfordian in offshore and western onshore Abu Dhabi. Tectonic subsidence coupled with sea-level fluctuations controlled the geometry, deposition, and distribution of the lithofacies. These ranged from organic-rich, limy mudstones in the basinal area, to porous and permeable bioclastic packstones, grainstones, and dolomites in shallow waters on the eastern flank of the intrashelf basin. The upper Kimmeridgian Arab-D Member of the Arab Formation overlies the basinal deposits.

Three third-order Depositional Sequences were identified in the offshore area. They are named according to their contained Maximum Flooding Surface; a fourth sequence is an intermediate unnamed Depositional Wedge. Depositional Sequence Jurassic 50 is of Oxfordian age and was deposited during transgressive and highstand periods. The lower Kimmeridgian Depositional Sequence Jurassic 60 is a well-defined lowstand system tract overlain by short-lived transgressive and highstand system tracts. Overlying Depositional Sequence Jurassic 60 is the Depositional Wedge. Finally, Depositional Sequence Jurassic 70 consists of transgressive and highstand system tracts developed on an undifferentiated platform that had localized depressions in the west. The best reservoir developments are in highstand bioclastic packstones and grainstones below the type-1 sequence boundaries that cap Depositional Sequences Jurassic 50 and Jurassic 60. The reservoir units have porosities greater than 20 percent and permeabilities of more than 1,000 milliDarcies. The basinal facies of Depositional Sequence Jurassic 50 have the best source-rock potential in the intrashelf basin.

INTRODUCTION

During the Late Jurassic, the wide, 2,000-km-long Arabian Platform contained several intrashelf basins (Murris, 1980; Ayers et al., 1982; Beydoun, 1988). The Abu Dhabi intrashelf basin covered the offshore and western onshore areas of present-day Abu Dhabi in the United Arab Emirates (Figure 1). Until recently, it was generally accepted that only organic-rich mudstones were deposited in the Abu Dhabi basin and no attention had been paid to its eastern margin. However, in the late 1980s and early 1990s, the Abu Dhabi National Oil Company discovered several oil accumulations in carbonate reservoirs along the eastern margin of the Abu Dhabi intrashelf basin, both offshore and onshore (discovery wells G, H, and I of Figure 2).

De Matos and Hulstrand (1995) studied the Upper Jurassic rocks of Abu Dhabi and demonstrated for the first time the importance of adopting a sequence stratigraphic approach in order to understand the relationship of the carbonates in the shallow-shelf areas and the intrashelf basin.

This paper provides details of the Upper Jurassic Oxfordian to Kimmeridgian sequences and depositional environments in offshore Abu Dhabi by utilizing regional seismic lines, cores, strontium
isotope dates, and electric logs from more than 50 wells (Figure 2). The study was not intended to provide a new lithostratigraphic scheme for companies to use, but rather to illustrate the application of sequence stratigraphic techniques as tools for exploration and development purposes. Additional data, including high-resolution seismic and the collection of closely spaced samples for dating by chemostratigraphy, will be needed in order to provide more details of the three dimensional geometry and the distribution of significant reservoir intervals and, ultimately, to discover additional structural and stratigraphic traps.

Figure 1: Location map of the Lurestan-Abu Dhabi intrashelf basins, and environments of deposition during the Oxfordian and Kimmeridgian (after Murris, 1980; Meyer and Price, 1993; and McGuire et al., 1993).

Figure 2 (below): Study area showing location of wells and seismic lines used in the interpretation. The offshore Abu Dhabi area is located in the eastern part of the Abu Dhabi intrashelf basin. The center of the basin is in the western part of the study area and has its axis running in a NNW-direction straddling well-A and well-J.
GEOLOGICAL SETTING AND PREVIOUS WORK

The Callovian upper Araej and upper Fadhili formations were deposited on a relatively shallow-water, stable platform that covered a vast area of present-day eastern Saudi Arabia and the southern part of the Arabian Gulf. Subsidence coupled with marine transgressions is believed to have caused the development of a differentiated platform in the early Oxfordian. As a result, three major intrashelf basins were established along the northeastern margin of the Arabian Platform from Lurestan in the north to Abu Dhabi in the south (Murris, 1980; Ayers et al., 1982; Alsharhan and Kendall, 1986; Azer, 1989; McGuire et al., 1993; Meyer and Price, 1993; de Matos and Hulstrand, 1995; and Al-Husseini, 1997) (Figure 1). These intrashelf basins were generally relatively shallow. Organic-rich carbonates were deposited within the basins under euxinic conditions, and shallow-water grainstones, coral/stromatoporoid patch reefs, and oolites formed along the margins.

The offshore Abu Dhabi area is located in the eastern part of the Abu Dhabi intrashelf basin. The center of the basin is in the western part of the study area and has its axis running in a NNW-direction straddling wells A and J (Figure 2). The origin of the Abu Dhabi intrashelf basin is not yet fully understood, but it appears to have been formed by subsidence coupled with a eustatic rise in sea level during the early Late Jurassic.

The Upper Jurassic succession of Abu Dhabi has been traditionally correlated with the succession identified by Powers (1968) for Saudi Arabia, and by Sugden and Standring (1972) for Qatar (Figure 3). In offshore Abu Dhabi, the interval between the top of the Araej Formation and the base of the Arab-D reservoir (Oxfordian to middle Kimmeridgian) is correlated with the Diyab Formation of Qatar. Azer (1989) subdivided the Diyab on the basis of the gamma-ray log response into upper, middle, and lower Diyab. The lower and middle Diyab are replaced in the east by a shallow-water carbonate facies called the Delta Member. An angular unconformity separates this member from the overlying upper Diyab.

De Matos and Hulstrand (1995) also studied the Oxfordian and Kimmeridgian sequences of the onshore and offshore areas. They recognized two main depositional sequences corresponding to the Tuwaiq Mountain Limestone and the Hanifa Formation. A post-Hanifa ramp-margin wedge was identified as occurring above the Hanifa Formation and as being equivalent to the middle Diyab of Azer (1989) and to the lower part of the Jubaila Formation in Saudi Arabia (Figure 3). De Matos and Hulstrand (1995)

| Period | Series | Stages | Saudi Arabia | Qatar | United Arab Emirates | Interior Oman |
|--------|--------|--------|--------------|-------|-----------------------|---------------|
| Jurassic | Upper | Hith | Manifa reservoir | Hith | Hith | Hith | Jubaila |
| | | Arab | Arab-A reservoir | Qatar | Arab | Qatar | Hanifa |
| | | | Arab-B reservoir | Fahahil | | | |
| | | | Arab-C reservoir | | | | |
| | | Jubaila | Jubaila | | | | post-Hanifa wedge |
| | | Hanifa | Hanifa reservoir | | | | Hanifa |
| | | Jubaila | Lower Hanifa | | | | Hanifa |
| | | | Hadriya reservoir | | | | Hanifa |
| | | | Lower Hadriya | | | | Hanifa |
| | | Oxfordian | Tuwaiq Mountain Limestone | | | | Tuwaiq Mountain Limestone |
| | | | Aradja | | | | |
| | | | Tuwaiq Mountain Limestone | | | | |
| | | | Hadda | | | | |
| | | | Taken | | | | |
| | | | Hith | | | | |
| | | | Nefud | | | | |
| | | | Wahbah | | | | |

Figure 3: Regional Upper Jurassic correlation, southern Arabian Gulf.
recognized sequence boundaries at the tops of the Tuwaiq Mountain Limestone and the Hanifa Formation. Most recently, Sharland et al. (2001) published the first chronostratigraphic interpretation of the rock units of the Arabian Plate using Genetic Stratigraphic Sequences and Maximum Flooding Surfaces to describe and correlate the sedimentary architecture.

**PREVIOUS SEQUENCE STRATIGRAPHIC FRAMEWORK**

The Upper Jurassic succession in offshore Abu Dhabi has considerable lateral and vertical lithofacies variations from west to east. Apart from the work of de Matos and Hulstrand (1995), none of the regional consultancy studies conducted for the Abu Dhabi National Oil Company and the operating companies provided a reliable chronostratigraphic framework for the Oxfordian and Kimmeridgian sequences that could be used for exploration purposes. This was mainly due to poor biostratigraphic resolution in the Upper Jurassic, the long ranges of identified benthic foraminifera, widely spaced wells, and the generally poor seismic resolution below the Lower Cretaceous. Moreover, the seismically surveyed areas were generally small and did not extend across the entire platform.

In Al-Suwaidi and Aziz (1998), we correlated detailed logs from about 50 wells that penetrated Jurassic strata, with core data, regional seismic interpretations, and strontium isotope dating. As a result, four third-order depositional sequences, probably controlled by local and regional subsidence coupled with eustatic changes (see Imbrie, 1985; Vail et al., 1991), were identified in offshore Abu Dhabi between the top of the upper Araej and the base of the Arab-D reservoir (Figure 4). Each sequence consisted of numerous fourth-order cycles that were more easily correlated beyond the margins and toward the basin. The third-order sequences were labeled Sequence I to Sequence IV from the base up.

In the east, the tops of Sequences I and II showed evidence of paleoexposure that resulted from sea level falling beyond the shelf break. De Matos and Hulstrand (1995) identified similar surfaces in wells in the southeastern onshore area. The contacts between Sequence I and the underlying upper Araej and between Sequence IV and the overlying Arab-D reservoir appeared to be conformable with no indications of erosion.

A wide spectrum of lithofacies associations was deposited across the platform in offshore Abu Dhabi. For example, in Sequence I of Al-Suwaidi and Aziz (1998), the lithofacies within individual parasequence cycles change laterally down systems tract from shallow-water bioclastic, peloidal packstone and grainstone facies with local stromatoporoid/coral debris and oolites in the east, to mud-prone fine-grained, thinly bedded and organic-rich peloidal limestone in the west. The best reservoir characteristics are found in the grainstone facies in association with the shallowing-upward cycles of the identified parasequences that were deposited during the highstand periods. They generally occur at the tops of the cycles and below the overlying transgressive section and sequence boundaries. Two distinctive intervals at the tops of Sequences I and II have the highest porosity-permeability values in the succession. This was the result of dissolution of the limestone and the consequent drastic improvement of the connectivity of the porosity system. Correlation between wells in the eastern part of the area indicated that these high porosity and permeability intervals could extend over a large distance along the basin margin.

Based on the available biostratigraphic and strontium isotope dating, an Oxfordian age was assigned to Sequence I, whereas Sequences II, III, and IV were given an early to late Kimmeridgian age (Figure 5). The exact position of the boundary between the lower and upper Kimmeridgian sequences could not be determined.

**SEQUENCE STRATIGRAPHIC MODEL**

In order to keep readers up to date, we propose a relationship between depositional sequences in the sense of Vail et al. (1991) and the genetic stratigraphic sequences of Galloway (1989). Figure 6 is a comparison of the sequence stratigraphic schemes of Vail and Galloway. The 'Exxon' model of Vail et al. uses unconformities and their correlative conformities to define the lower and upper boundaries of ‘Depositional Sequences’, whereas the Galloway model delineates ‘Genetic Stratigraphic Sequences’ by means of Maximum Flooding Surfaces (MFS).
Figure 4: Regional sequence stratigraphic correlation of the Oxfordian and Kimmeridgian of offshore Abu Dhabi (see Figure 2 for location). Sequences I, II, and IV are third-order sequences between the top of the upper Araej and the base of the Arab-D reservoir; each consists of numerous fourth-order cycles. Sequence III is a sedimentary wedge between Sequences II and IV in wells A to G. In the east, the tops of Sequences I and II show evidence of paleoexposure. The contacts between Sequence I and the underlying upper Araej, and between Sequence IV and the overlying Arab-D reservoir, appear to be conformable with no evidence of erosion. From Al-Suwaidi and Aziz (1998) with Depositional Sequences (see below) added for convenience.
In our scheme, a Depositional Sequence contains the relevant MFS from Sharland et al. (2001) and is named accordingly; for example, Depositional Sequence Jurassic 50 (abbreviated to DS J50) contains the J50 MFS. Our Sequences I, II, and IV (Al-Suwaidi and Aziz, 1998) have been renamed as third-order Depositional Sequences. Hence, Sequence I becomes DS J50; Sequence II is renamed DS J60; and Sequence IV is DS J70. Sequence III is a special case. Based on public-domain data, Sharland et al. (2001) were unable to confidently identify and widely correlate an MFS within the sedimentary wedge making up Sequence III. As a result, it was felt inappropriate at this stage to name an intermediate Depositional Sequence between DS J60 and DS J70. Instead, the descriptive term ‘Depositional Wedge’ will be used for Sequence III. Consequently, the Depositional Wedge is not designated as a third-order depositional sequence in the new sequence stratigraphic model. Figure 7 is a generalized depositional model for offshore Abu Dhabi, and Figure 8 shows the thickness variations in the Oxfordian and Kimmeridgian depositional sequences.

Figure 5: Chronostratigraphic correlation and strontium isotope age determinations of the Oxfordian and Kimmeridgian sequences in offshore Abu Dhabi (see Figure 2 for location). From Al-Suwaidi and Aziz (1998) with Depositional Sequences (e.g. DS J50) added.

Figure 6: Comparison of the sequence stratigraphic schemes of Vail and Galloway. ‘Depositional Sequences’ (DS) are bounded by unconformities and their correlative conformities; ‘Genetic Stratigraphic Sequences’ (GSS) are bounded by Maximum Flooding Surfaces (MFS). HST = Highstand Systems Tract; MRS = Maximum Regression Surface; TST = Transgressive Systems Tract. Modified from Figure 2.11, p. 41, Sharland et al. (2001).
Depositional Sequence Jurassic 50—DS J50

Depositional Sequence Jurassic 50 (DS J50) corresponds to Sequence I of Al-Suwaidi and Aziz (1998) and contains MFS J50 of Sharland et al. (2001). It also corresponds to all of Sequence I of de Matos and Hulstrand (1995) as well as the lower part of their overlying Sequence II. The overall stratal geometry and parasequence-stacking pattern identified this sequence. DS J50 is defined as being bounded at its base by the apparent correlative conformity at the top of the upper Araej ‘marker’, and at its top by the first occurrence of anhydrite from the overlying early lowstand system tract of DS J60 (wells-A, B, and C, Figure 4). In the east, the top of the sequence is taken to be the upper limit of a thick shoaling-upward cycle, the rocks of which show significant dissolution and minor dolomitization. The boundary between DS J50 and DS J60 is a type-1 sequence boundary and overlies the Hadriyah reservoir (de Matos and Hulstrand, 1995).

Figure 7: Generalized depositional models, offshore Abu Dhabi. Type-1 sequence boundaries occur at the tops of Depositional Sequence Jurassic 50 (DS J50) and DS J60. (a) DS J50 bounded below by the upper Araej and above by anhydrite of DS J60. On the shallow shelf were deposited thick limey mudstones and wackestones grading up into bioclastic packstones and grainstones; in deeper waters are thin condensed, organic-rich, peloidal wackestone and limey mudstone. (b) DS J60 and the Depositional Wedge: deposition of DS J60 began with a basin-restricted lowstand wedge of interbedded anhydrite and lime mudstone whose deposition was ended by a rise in sea level. In the shelf area, oolitic, bioclastic grainstone was deposited, whereas packstone and wackestone with bioclasts formed in deeper water. A fall in sea level ended DS J60 and caused deposition of a thick lowstand wedge of lime mudstone and wackestone; a highstand shelf-margin wedge (SMW) formed during a later rise in sea level; together they constitute the Depositional Wedge. A transgressive systems tract could not be positively defined due to lack of physical expression of a maximum flooding surface. LST = lowstand systems tract.
The deposition of DS J50 began after a major transgression had flooded the entire platform. The flooding was followed by rapid sedimentation during the highstand period in the shallow shelf area in the east, whereas a much slower rate of sedimentation prevailed in the deeper water of the western offshore area. The overall geometry of each parasequence is thus that of initial aggradation followed by rapid clinoform progradation (Figure 4). In the shallow shelf area, the major components of the facies in each parasequence are fine-grained limey mudstones and wackestones in the lower toeset part, grading up into predominantly peloidal, bioclastic packstones, and grainstones with minor oolites. A variable degree of dolomitization of the original facies has taken place, particularly in the extreme eastern offshore region and in offshore Dubai (not examined in this study). In deeper water to the west, and in parts of the central area, the sequence is composed of thinly laminated basinal facies of organic-rich, fine-grained peloidal wackestone and limey mudstone.

A shelf margin is inferred to have existed between well-F and well-G in the eastern area. This margin was delineated by detailed well-log correlations, by the onlapping limit of the overlying lowstand system tract of Sequence II, and by the far-westward progradation of the shallow-water facies of the youngest parasequence (Figures 4 and 7). The total thickness of DS J50 ranged from less than 100 ft in the intrashelf basin in the condensed western offshore area, to more than 600 ft in the shallow shelf area in the east (Figure 8a). The depth of water in the deeper parts of the basin could therefore have been at least 500 ft.

Strontium isotope dating in well-J of DS J50 (Figure 5) indicated an age of 154.9 Ma. As Harland et al. (1990) calibrated the Oxfordian/Kimmeridgian boundary at 154.7 Ma, and Gradstein and Ogg (1996) at 154.1 ± 3.3 Ma, DS J50 is considered Oxfordian in age. Sharland et al. (Figure 4.42, 2001) assigned a middle Oxfordian age to MFS J50 and dated it at 156 Ma based on the time scale of Gradstein and Ogg (1996).

A comparison between DS J50 of this study and that interpreted by de Matos and Hulstrand (1995) shows a good similarity in terms of the overall geometry. However, the major part of the lowstand

![Figure 8: Thickness variations in the Oxfordian and Kimmeridgian depositional sequences.](https://pubs.geoscienceworld.org/geoarabia/article-pdf/7/1/31/5440543/alsuwaid.pdf)
wedge of the overlying Sequence II of de Matos and Hulstrand (1995) is interpreted here as belonging to DS J50. In addition, the boundary between DS J50 and DS J60 is a type-1 sequence boundary, and not a type-2 as proposed by de Matos and Hulstrand but without supporting evidence.

Depositional Sequence Jurassic 60—DS J60

Depositional Sequence Jurassic 60 (DS J60) corresponds to Sequence II of Al-Suwaidi and Aziz (1998) and contains MFS J60 of Sharland et al. (2001). It also corresponds to the upper part of Sequence II of de Matos and Hulstrand (1995). DS J60 is bounded above and below by type-1 sequence boundaries. The upper sequence boundary overlies the Hanifa reservoir (de Matos and Hulstrand, 1995).

DS J50 sedimentation ended with a fall in sea level. The deposition of DS J60 commenced with a basin-restricted lowstand wedge composed of interbedded anhydrite and limey mudstone. Three distinctive anhydrite beds are recognized within the wedge in the center of the basin (Figure 7) and they are interpreted as onlapping the underlying DS J50 toward the east. The deposition of the anhydrite probably took place under arid climatic conditions in which evaporation increased to cause salinity stratification and the precipitation of anhydrite (de Matos and Hulstrand, 1995). No sedimentation is believed to have taken place on the shallow shelf in the east during this time. Deposition of the anhydrite was ended by a rise in sea level, and sedimentation resumed across the entire region. A distinctive package deposited during the highstand dominated the upper part of DS J60. In the shelf area, shallow-water conditions prevailed and the deposition of oolitic, peloidal, bioclastic grainstone with minor corals and stromatoporoids took place (Figure 7). In contrast, in the deeper water in the west and in the central offshore areas, thinly laminated, peloidal packstone and wackestone with bioclasts, including echinoids, ostracods, and sponge spicules, were deposited.

The interpretation of a type-1 sequence boundary at the top of DS J60 is based mainly on the sharp contact between the grainstone facies of DS J60 and the dolomitic and anhydritic section of the overlying DS J70 in the shelfal area in well-H. In addition, the extremely high permeability in the upper part of DS J60 was probably caused through dissolution by fresh water. Further support was obtained from a regional seismic line (Figure 9) aligned northeast oblique to the depositional strike in the vicinity of wells F and H. The seismic interpretation shows the onlap of the Depositional Wedge onto DS J60. The thickness of DS J60 varies from about 200 ft in the northwest to less than 75 ft in both the southwest and the eastern offshore areas (Figure 8b).

Strontium isotope dating of DS J60 in well-K indicated an age of 153.8 Ma. As Harland et al. (1990) calibrated the Oxfordian/Kimmeridgian boundary at 154.7 Ma, and Gradstein and Ogg (1996) at 154.1 ± 3.3 Ma, DS J60 is considered to be of Kimmeridgian age. Sharland et al. (Figure 4.42, 2001) interpreted MFS J60 in the upper Hanifa (in the sense of de Matos and Hulstrand, 1995) organic-rich carbonate mudstone and dated it as early Kimmeridgian at 154 Ma based on the time scale of Gradstein and Ogg (1996).

Depositional Wedge

A thick wedge of sediments overlies Depositional Sequence Jurassic 60 (DS J60). As explained on p. 36 in the introduction to the Sequence Stratigraphic Model, an MFS could not be reliably identified and correlated within the package of sediment lying between DS J60 and DS J70. In the present scheme, the wedge of sediment is referred to as the Depositional Wedge and corresponds to Sequence III of Al-Suwaidi and Aziz (1998) and the lower part of the post-Hanifa wedge of de Matos and Hulstrand (1995). Alternatively, this wedge of sediments could be a longer-lived transgressive system tract leading to the J70 MFS.

A fall in sea level ended DS J60 and created conditions suitable for the formation of the thick lowstand wedge of mainly limey mudstone and wackestone with minor bioclasts. The water depth was probably deeper, relatively, than during the lowstand period of the underlying DS J60 and no anhydrite was deposited. Detailed correlation showed that the lowstand wedge is composed of several fourth-order cycles that indicated pseudo-extension toward the east and a gradual rise in sea level after the initial sea-level fall.
A rise in sea level after the formation of the lowstand wedge led to the deposition of a uniformly thick sedimentary package of mainly clean peloidal wackestone and limey mudstone. It may represent a shelf-margin wedge that was deposited during a highstand. A transgressive system tract could not be positively defined due to the lack of a physical expression of a maximum flooding surface.

A porous and permeable interval about 50 ft thick occurs in the upper part of the wedge in well-G. The interval is composed of alternating peloidal, oolitic grainstone, dolomite, and dolomitized limestone. It may either represent the eastern limit of the shelf-margin wedge or it could be part of DS J60 as in wells H and I (Figures 4 and 7). The interval is thin and beyond the resolution of conventional seismic. Both interpretations are considered valid at this stage. The total thickness of the Depositional Wedge ranges from 400 ft in western offshore to zero in the eastern offshore (Figure 8c).

The Depositional Wedge has not been dated by the strontium isotope method. Based on its stratigraphic position between the Kimmeridgian DS J60 and late Kimmeridgian DS J70, the Depositional Wedge is interpreted as being of middle Kimmeridgian age.

**Depositional Sequence Jurassic 70—DS J70**

Depositional Sequence Jurassic J70 (DS J70) consists of several fourth-order cycles. No erosional or exposure surfaces were observed between DS J70 and the conformable overlying Arab-D reservoir. DS J70 corresponds to Sequence IV of Al-Suwaidi and Aziz (1998) and contains MFS J70 of Sharland et al. (2001). It also corresponds to the upper Diyab interval of de Matos and Hulstrand (1995).

This sequence is characterized by a generally high gamma-ray response over the study area, except in the east where a low gamma-ray interval was observed. DS J70 was deposited following a major rise
in sea level that flooded the entire platform after the deposition of the underlying Depositional Wedge. The fourth-order cycles can be correlated throughout the offshore region. In the western part of the area, bioclastic wackestones and limey mudstones were probably deposited in an open-marine shelf below wave base. Eastward, shallower carbonate facies consisting of peloidal and bioclastic packstone and grainstone indicate shoal environments. In places, this shallow-water facies continues into the overlying upper Kimmeridgian Arab-D reservoir. Dolomite and dolomitized limestone are common particularly in the extreme eastern area. No erosional or exposure surfaces were interpreted between DS J70 and the Arab-D reservoir. The thickness of DS J70 ranges from more than 550 ft in the west to less than 300 ft in the east (Figure 8d).

Strontium isotope dating in the lower part of DS J70 in well-F (Figure 5) indicated an age of 153.1 Ma. This age corresponds to the Kimmeridgian according to both Harland et al. (1990) and Gradstein and Ogg (1996). Sharland et al. (Figure 4.42, 2001) interpreted MFS J70 in the upper Jubaila/Diyab Formation and dated it as late Kimmeridgian at 152.25 Ma, based on the time scale of Gradstein and Ogg (1996).

HYDROCARBON SYSTEM

The Oxfordian to late Kimmeridgian succession in offshore Abu Dhabi contains all the required elements necessary to establish a complete hydrocarbon system. The Oxfordian DS J50 deposited in an intrashelf depression in the western offshore area contains the best organic-rich carbonate source rock, as determined by the geochemical investigations of core and cutting samples. The Total Organic Carbon (TOC) content of DS J50 is about 5 percent (Figure 10), whereas DS J60, the Depositional Wedge, and DS J70 contain less than 2 percent TOC. The Oxfordian in northern Saudi Arabia has also been identified as a major source rock (Ayers et al., 1982). Depositional Sequence J50 in the intrashelf basin is composed of condensed dark-gray, thinly laminated carbonates alternating with light-colored, laminae containing less organic material.

![Figure 10: Log characteristics and Total Organic Carbon content of the Oxfordian and Kimmeridgian of western offshore Abu Dhabi. DS J50 contains organic-rich carbonate rocks (about 5% TOC), whereas the TOC content of DS J60, the Depositional Wedge, and DS J70 is less than 2 percent. Modified from Al-Suwaidi and Aziz (1998).](http://pubs.geoscienceworld.org/geoarabia/article-pdf/7/1/31/5440543/alsuwaid.pdf)
Along the eastern flank of the intrashelf basin in the eastern offshore area, shallow-water carbonates deposited during the highstand periods predominate in DS J50 and DS J60. Carbonate reservoirs with excellent properties are found in the upper parts of the individual shallowing-upward cycles and below the main sequence boundaries (Figure 11). The reservoir characteristics have been drastically improved by dissolution, particularly in the grainstone facies where core permeability is greater than 1,000 mD. Oil, gas, and condensates have been confirmed in reservoirs of DS J50 and DS J60 along the eastern flank of the Abu Dhabi intrashelf basin in both offshore and onshore areas (discovery wells G, H, and I of Figure 2). There are encouraging indications that additional oil and gas accumulations could be found in the future. Revisiting the wells that penetrate the shelf facies of the Oxfordian and Kimmeridgian succession in the eastern region might prove rewarding.

**CONCLUSIONS**

The study of the Oxfordian to late Kimmeridgian succession in offshore Abu Dhabi reveals the presence of three third-order depositional sequences, a depositional wedge, and many fourth-order cycles. These sequences were formed in depositional environments that ranged from intrashelf basins and deeper-shelf marine in western offshore area, to shallow-water shelves in the eastern offshore area.

Two type-1 sequence boundaries have been interpreted as occurring at the top of Depositional Sequences J50 and DS J60 in the eastern offshore area. DS J50 is dated as Oxfordian, and DS J60, the Depositional Wedge, and DS J70 are early to late Kimmeridgian.

![Figure 11: Log characteristics and core analysis of porous DS J60 of eastern offshore Abu Dhabi. Carbonate reservoirs with excellent properties are present in the upper part of the individual shallowing-upward cycles and below the main sequence boundaries. The reservoir characteristics had been drastically improved by dissolution to give core permeabilities of greater than 1,000 mD. Modified from Al-Suwaidi and Aziz (1998).](http://pubs.geoscienceworld.org/geoarabia/article-pdf/7/1/31/5440543/alsuwaid.pdf)
Excellent source-rocks are present in the basinal facies of the Oxfordian DS J50 in the western offshore area, whereas DS J60, the Depositional Wedge, and DS J70 have only marginal source-rock potential. The best reservoir developments are in the grainstone facies of DS J50 and DS J60 in the eastern offshore area. Future exploration activities should be concentrated on the eastern flank of the intrashelf basin where favorable conditions occur for hydrocarbon generation, migration, and entrapment.

ACKNOWLEDGMENTS

The authors thank the management of the Abu Dhabi National Oil Company for permission to publish this paper. We also thank the Geology Department and core store staff of the Abu Dhabi Marine Operating Company and the Upper Zakum Development Company for providing assistance and access to core material. We thank the anonymous reviewers for their constructive comments, and Peter Sharland and GeoArabia editors David Grainger and Moujahed Al-Husseini for helpful suggestions on the sequence stratigraphic correlation. The design and drafting of the final graphics was by Gulf PetroLink.

REFERENCES

Al-Husseini, M.I. 1997. Jurassic sequence stratigraphy of the western and southern Arabian Gulf. GeoArabia, v. 2, no. 4, p. 361–382.
Alsharhan, A.S. and C.G.St.C. Kendall 1986. Precambrian to Jurassic rocks of the Arabian Gulf and adjacent areas: their facies, depositional setting, and hydrocarbon habitat. American Association of Petroleum Geologists Bulletin, v. 70, p. 977–1002.
Al-Suwaidi, A.S. and S.K. Aziz 1998. Regional basin modelling: an approach to understand shelfal carbonate reservoirs of the Oxfordian and Kimmeridgian in offshore Abu Dhabi. Society of Petroleum Engineers, SPE Paper 49471, p. 148–158.
Ayres, M.G., M. Bilal, R.W. Jones, L.W. Slentz, M. Tartir and A.O. Wilson 1982. Hydrocarbon habitat in main producing areas, Saudi Arabia. American Association of Petroleum Geologists Bulletin, v. 66, p. 1–9.
Azer, S.R. 1989. Preliminary investigation into possible stratigraphic traps, offshore Abu Dhabi. Society of Petroleum Engineers, SPE Paper 17999, p. 739–753.
Baydoun, Z.R. 1988. The Middle East: Regional Geology and Petroleum Resources. Scientific Press Ltd., UK, 292 p.
Cantrell, D.L., P.K. Swart, R.C. Handford, C.G. St.C. Kendall and H. Westphal 2001. Geology and production significance of dolomite, Arab-D reservoir, Ghawar field, Saudi Arabia. GeoArabia, v. 6, no. 1, p. 45–60.
de Matos, J.E., and R.F. Hulstrand 1995. Regional characteristics and depositional sequences of the Oxfordian and Kimmeridgian, Abu Dhabi. In, M.I. Al-Husseini (Ed.), Middle East Petroleum Geosciences, GEO’94. Gulf PetroLink, Bahrain, v. 1, p. 346–356.
Droste, H.H.J. 1990. Depositional cycles and source rock development in an epeiric intra-platform basin: the Hanifa Formation of the Arabian Peninsula. Sedimentary Geology, v. 69, p. 281–296.
Galloway, W.E. 1989. Genetic stratigraphic sequences in basin analysis; I: architecture and genesis of flooding surface bounded depositional units. American Association of Petroleum Geologists Bulletin, v. 73, p. 125–142.
Gradstein, F.M. and J. Ogg 1996. A Phanerozoic Time Scale. Episodes, v. 19, p. 3–5.
Harland, W.B., R.L. Armstrong, A.V. Cox, L.E. Craig, A.G. Smith and D.G. Smith 1990. A Geologic Time Scale 1989. Cambridge University Press, 263 p.
Hassan, T.M. and S. Azer 1985. The occurrence and origin of oil in offshore Abu Dhabi, UAE. Society of Petroleum Engineers, SPE Paper 13696, p. 143–155.
Hughes Clarke, M.W. 1988. Stratigraphy and rock unit nomenclature in the oil-producing area of interior Oman. Journal of Petroleum Geology, v. 11, p. 5–60.
Imbrie, J. 1985. A theoretical framework for the Pleistocene ice ages. Journal of the Geological Society, London, v. 142, p. 417–432.
Kompanik, G., R.J. Heil, Z.A. Al-Shammari and M.J. Al-Shammery 1993. Geologic modelling for reservoir simulation: Hanifa reservoir, Berri field, Saudi Arabia. Society of Petroleum Engineers, SPE Paper 25580, p. 517–532.
Al-Suwaidi and Aziz

McGuire, M.D., R.P. Koepnick, J.R. Markello, M.L. Stockton, L.E. Waite, G.S. Kompanik, M.J. Al-Shammary and M.O. Al-Amoudi 1993. Importance of sequence stratigraphic concepts in development of reservoir architecture in Upper Jurassic grainstones, Hadriya and Hanifa reservoirs, Saudi Arabia. Society of Petroleum Engineers, SPE Paper 25578, p. 489–499.
Meyer, F.O. and R.C. Price 1993. A new Arab-D depositional model, Ghawar field, Saudi Arabia. Society of Petroleum Engineers, SPE Paper 25576, p. 465–474.
Mitchum, R.M. Jr., P.R. Vail, and S. Thompson III 1977. Seismic stratigraphy and global changes of sea level, Part 2: the depositional sequence as a basic unit for stratigraphic analysis. In, C.E. Payton (Ed.), Seismic Stratigraphy: Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists Memoir 26, p. 53–62.
Murris, R.J. 1980. The Middle East: stratigraphic evolution and oil habitat. American Association of Petroleum Geologists Bulletin, v. 64, p. 597–618.
Powers, R.W. 1968. Arabie Seoudite. Lexique Stratigraphique Internationale, III, 10b, Centre National de Recherche Scientifique, 177 p.
Sharland, P.R., R. Archer, D.M. Casey, R.B. Davies, S.H. Hall, A.P. Heward, A.D. Horbury and M.D. Simmons 2001. Arabian Plate Sequence Stratigraphy. GeoArabia Special Publication 2. Gulf PetroLink, Bahrain, 371 p.
Sugden, W. and J.J. Standring 1975. Qatar Peninsula. Lexique Stratigraphique Internationale, III, 10b3, Centre National de la Recherche Scientifique, 120 p.
Vail, P.R., F. Audemard, S.A. Bowman, P.N. Eisner and C. Perez-Cruz 1991. The stratigraphic signature of tectonics, eustasy and sedimentology—an overview. In, G. Einselel et al. (Eds.), Cycles and Events in Stratigraphy. Part II: larger cycles and sequences. Springer-Verlag, Berlin, p. 617–659.

ABOUT THE AUTHORS

Ahmed S. Al-Suwaidi is Assistant General Manager, Development for the Abu Dhabi Marine Operating Company (ADMA-OPCO). He received a BSc in Geology from the University of South Carolina in 1985. After graduation, he joined ADMA-OPCO and worked in the Geology Department as a Wellsite and Reservoir Geologist until 1996 when he joined the Exploration Division of the Abu Dhabi National Oil Company. In 2001, he moved to his present position with ADMA-OPCO. Ahmed is Chairman of the Emirates Society of Geoscience (ESG), and a member of AAPG, and SPE.

Corresponding author. E-mail:asalsuwaidi@adma.co.ae

Sabah K. Aziz is a Senior Production Geologist with the Abu Dhabi National Oil Company (ADNOC). He has a BSc in Geology from Baghdad University. He worked as a Wellsite Geologist and Reservoir Geologist for the Abu Dhabi Company for Onshore operation for nine years before joining ADNOC. He moved to his present position in the Offshore Division in 1998. Sabah has interests in the application of sequence stratigraphy to exploration, and in reservoir modeling. He is a member of the Emirates Society of Geoscience (ESG) and of SPE.

E-mail: skarim@adnoc.com

Manuscript Received January 1999
Revised August 28, 2001
Accepted September 25, 2001