The Challenge of Interpreting 3-D Seismic in Shaybah Field, Saudi Arabia

Mohammed N. Alfaraj, Edgardo L. Nebrija and Michael D. Ferguson
Saudi Aramco

ABSTRACT

The giant Shaybah field, situated in the northeastern Rub’ Al-Khali Desert in Saudi Arabia, was discovered in 1968. 2-D seismic and well control were used at the time to delineate the field. A 3-D seismic program was launched in 1993 to develop a detailed geological picture of the field. Over 120 million seismic traces, covering an area of about 1,100 square kilometers, were acquired in flat sabkhas and high sand dunes. The dunes, exceeding 200 meters in height in places, posed a severe statics correction problem. Up to 200 milliseconds of time correction was sometimes applied to the seismic traces in order to compensate for sand-related statics. Also, as verified by vertical seismic profiles, the reservoir level was severely obscured by strong multiples.

In addition to complex topography and multiples, the 3-D structural seismic interpretation had to overcome two further problems. First, the lithology of the gas-capped Shu’aiba reservoir consists predominantly of carbonates which are sealed by a denser, compacted shale. The decrease in density and increase in velocity, at the top of the Shu’aiba reservoir, result in a weak reflection. Second, the top of the Shu’aiba reservoir undulates as a result of rudist build-ups and therefore is not conformable with its base. For these reasons, the top of the Shu’aiba reservoir cannot be mapped as a “phantom” of the much better reflection from the base of the reservoir.

To resolve the uncertainties described above, borehole seismic measurements (specifically offset and zero-offset vertical seismic profiles in vertical wells) were incorporated. These additional measurements provided the required calibration of the seismic, and hence the validation of the structural interpretation. These borehole surveys continue to serve as a reference for on-going efforts to further improve the data quality using more advanced processing techniques.

INTRODUCTION

The Shaybah field was discovered in the Rub’ Al-Khali Desert of Saudi Arabia in 1968 (Figure 1). Shortly after the discovery, the field was delineated using a sparse 2-D seismic grid and widely-spaced well control over an area of approximately 800 square kilometers (sq km). In 1993, several years prior to the planned development of the Shaybah field, a comprehensive 3-D seismic program was launched. The objective of this seismic survey was to develop a preliminary model of the Shu’aiba reservoir which could be used in locating production wells.

Before this objective could be achieved, however, several major problems and constraints had to be accounted for; namely:

(1) acquisition over a very rough sand-dune terrain caused large and complex datum statics which required calibration and removal;
(2) the acoustic properties of the top of the Shu’aiba reservoir precluded a good reflection;
(3) within the Shu’aiba reservoir itself, the stratigraphy varies laterally from undulating rudist build-ups to layered slope facies, and together with erosion at its top, the reservoir top could not be “phantomed” from its better-imaged base; and
(4) strong multiples caused by the dense, high-velocity layers in the shallower section interfered with key reflections at the reservoir level.
These observations are contrary to what has been reported for the Shu’aiba seismic reflection in nearby countries such as Oman (Yibal field), Qatar (Idd El Shargi field), and Abu Dhabi (Jarn Yaphour field). Seismic reflection at the Shu’aiba reservoir in some of these fields is of sufficient quality that even water encroachment along faults can be imaged (Husseini and Chimblo, 1995). Unlike those fields, the density in the Shu’aiba Formation at Shaybah usually decreases, relative to the sealing shale, which gives rise to a weak reflection. The decrease in density is due to the high porosity of the Shu’aiba rocks, irrespective of fluid content.

This paper initially describes the general geology of the Shaybah field and the terrain and conditions under which the 3-D data were acquired. This is followed by a brief review of the processing sequence and the problems mentioned earlier that hampered the interpretation. The final discussion covers the vertical-seismic-profiling (VSP) program that alleviated some of these difficulties. We explain how this VSP program impacted the drilling plan, and emphasize its use as an important reference in ongoing efforts to further improve the data quality using advanced processing techniques.

RESERVOIR GEOLOGY OF THE SHU’AIBA

The reservoir in Shaybah field (Figure 2) lies within the Lower Cretaceous Shu’aiba Formation (Aptian). Within the Rub’ Al-Khali basin, the Shu’aiba Formation reaches its maximum thickness in the North Kidan and Shaybah areas (Soliman and Al Shamlan, 1982). In Shaybah field, the Shu’aiba Formation consists of a shoaling-upward carbonate sequence with a thickness of 300 to 400 feet (ft).

The crest of this anticlinal structure is rimmed by a band of rudist build-ups grading laterally basinward to barrier then to shelf-slope facies. Behind the rudist barrier is a shallow lagoonal facies. Porosity varies within a narrow range in the reservoir, but permeability, which is known to be facies-dependent, varies both vertically and horizontally.
The seal is a shaley unit, interchangeably referred to as Khafji or Nahr Umr Shale. It is a member of the Wasia Formation (Albian) which is a thick marine shale sequence. Its contact with the Shu’aiba reservoir is an undulating unconformity, making it difficult to visualize isopach trends within the reservoir. The base of the reservoir is the Lower Cretaceous (Barremian) Biyadh Formation.

The Shaybah field has a large gas cap that provides the primary drive mechanism for the reservoir. Current development is aimed at the narrow oil window around the structure so as to avoid water coning and gas cusping.

**DATA ACQUISITION AND PROCESSING**

The terrain blanketing this field consists of flat sabkhas and mountainous sand dunes. As shown in Figure 3, the height of the dunes reaches, and sometimes exceeds, 200 meters (m) relative to the flat sabkhas whose elevations are about 80 m above sea-level. During acquisition, the summer temperature reached nearly 55°C (130°F). As a result of operating in such a rugged environment, the acquisition of the 3-D seismic data, which was carried out simultaneously by two seismic crews, lasted one full year.

Due to the rough terrain, particularly the steep, unstable sand dune slip-faces, use of vibrators was considered unsafe. Therefore, the 3-D seismic survey was acquired using dynamite as the seismic

---

**Figure 2: Lithostratigraphic column at Shaybah field.**

---

| PERIOD / AGE | LITHOLOGY |
|--------------|-----------|
| **LATE** (Senonian) | **MAASTRICHTIAN** |
| 65 | Aruma Formation |
| 71 | Mahruf |
| 83 | Rumaila |
| 86 | Ahmadi |
| 89 | Wara |
| 93.5 | Mauddud |
| 99 | Safaniya |
| **MIDDLE** | **TURONIAN** |
| 112 | Wasia Formation |
| 121 | Khafji/Nahr Umr Shale |
| 127 | Shu’aiba |
| 132 | Biyadh |
| 136.5 | Buwaib |
| 144 | Yamama |
| **EARLY** | **ALBIAN** |
| 83 | Wasia Group |
| **NEOCOMIAN** | **APTIAN** |
| 127 | Thamama Group |
| 144 | Sulaib |

---

The seal is a shaley unit, interchangeably referred to as Khafji or Nahr Umr Shale. It is a member of the Wasia Formation (Albian) which is a thick marine shale sequence. Its contact with the Shu’aiba reservoir is an undulating unconformity, making it difficult to visualize isopach trends within the reservoir. The base of the reservoir is the Lower Cretaceous (Barremian) Biyadh Formation.

The Shaybah field has a large gas cap that provides the primary drive mechanism for the reservoir. Current development is aimed at the narrow oil window around the structure so as to avoid water coning and gas cusping.

**DATA ACQUISITION AND PROCESSING**

The terrain blanketing this field consists of flat sabkhas and mountainous sand dunes. As shown in Figure 3, the height of the dunes reaches, and sometimes exceeds, 200 meters (m) relative to the flat sabkhas whose elevations are about 80 m above sea-level. During acquisition, the summer temperature reached nearly 55°C (130°F). As a result of operating in such a rugged environment, the acquisition of the 3-D seismic data, which was carried out simultaneously by two seismic crews, lasted one full year.

Due to the rough terrain, particularly the steep, unstable sand dune slip-faces, use of vibrators was considered unsafe. Therefore, the 3-D seismic survey was acquired using dynamite as the seismic
Figure 3: Sand dunes surrounding a flat sabkha in Shaybah field (top). A close-up of the high sand dunes (bottom).
source. Over 120 million seismic traces, covering an area of about 1,100 sq km, were recorded with over 100,000 shot points.

The receiver geometry consisted of 12 lines per swath, with line spacing of 200 m and a group interval for each receiver line of 50 m. The source line spacing and group interval were also 200 m and 50 m, respectively. The maximum source-receiver offset was 2,400 m, and the nominal fold obtained from a 25 by 25 m processing bin was 72. Processing of the data, which started shortly after the commencement of the acquisition program, was carried out in-house by Saudi Aramco and lasted about 18 months.

During the processing phase, special algorithms had to be included in the processing sequence in order to enhance data quality. For example, the high sand dunes caused static time shifts as great as 200 milliseconds (msec). Refinement of these statics using the reflection mode was hampered by the large velocity contrast between the dry sand dune (having approximately the velocity of sound in air or nearly 2,000 ft/sec) and the fast sabkha evaporites (approximately 20,000 ft/sec). Therefore, a customized refraction-based algorithm that compensates for such sand-related remanent statics was employed.

To assist the interpreters in better understanding the nature of the data, several differently composed and processed 3-D seismic volumes were prepared. Examples of such volumes were: limited-offset stacks (stacks generated from near-, middle-, and far-offset traces), conventional stacks with and without dip move-out (DMO) correction, and a post-stack migrated volume (one-pass 3-D migration of the DMO-corrected stack).

Prior to the development of the field, and stemming from the analyses of synthetic seismograms, the seismic data was believed to be heavily contaminated with strong multiples, particularly in the vicinity of the Shu’aiba reservoir. This hypothesis was substantiated based on results from VSP data acquired shortly after the drilling program began. In fact, one reason for generating limited-offset stacks, as mentioned above, was to have a better understanding of multiple interference. The far-offset stack, for example, would most likely be indicative of genuine events rather than multiples (assuming a reasonable velocity differential between the two, which was not necessarily true in the Shaybah 3-D data).

Removing multiples in the initial processing of the data was emphasized by using conventional algorithms (for example, inside muting and gapped deconvolution). These, however, were ineffective in attenuating all multiples, especially the shallow ones (Shu’aiba level) with time moveouts similar to those of primaries. The multiple-ridden data was of sufficient quality to map most horizons; however it was decided to attack them further with advanced processes after understanding them better from the VSP data.

Candidate multiple-removal schemes included inverse velocity stacking using parabolic transform (Hampson, 1986), and macromodel-based multiple prediction and subtraction. Only after adequate removal of the remaining interfering multiples and surface-related effects can stratigraphic interpretation of the data (from the results of seismic inversion, for example) be attempted.

The main multiples confirmed by the VSP data consist of bounces between the Aruma and surface. The multiples under the sabkhas are usually more pronounced than those under the sand dunes, because the reflection coefficient for the evaporite-air interface exceeds that for the evaporite-sand one. Strong Aruma-generated inter-bed multiples have also been observed in the seismic.

**LITHOLOGY AND THE SEISMIC REFLECTIVITY**

From wireline logs, the shaley sealing layer within the Wasia Formation has been shown to have a relatively higher density than that of the underlying Shu’aiba reservoir. This phenomenon is observed in most drilled wells irrespective of fluid content, and it is attributed to the higher porosity of the Shu’aiba Formation relative to the shale above it. Furthermore, the sonic velocity in the Shu’aiba is
only slightly higher than that seen in the overlying shaley unit. Figure 4 shows typical sonic and density logs recorded in one of the vertical wells in the field, along with the calculated acoustic impedance and a corresponding synthetic seismic trace. It is evident that the density decreases just above the reservoir, whereas the velocity slightly increases.

Unfortunately, this density/velocity combination results in a weak seismic reflection from the top of the reservoir. In fact, the top was always a difficult seismic pick even in areas where multiple interference was insignificant. The reflection coefficient at the base of the reservoir, however, is significantly higher than that at the top, and therefore its reflections are easily traceable. Consequently, the base was used as a guide in estimating the depth of the otherwise blurred reservoir top. Figures 5 and 6 show examples of lines extracted from the 3-D seismic cube; the base of the reservoir is readily identifiable whereas seismic imaging of the interpreted top is poor.
Figure 5: Portion of a sub-line extracted from the 3-D seismic cube showing the relatively easy pick of Biyadh and the poorly-defined Shu’aiba due to a combination of weak reflectivity and multiple interference.

Figure 6: Portion of a sub-line extracted from the 3-D seismic cube showing continuous Biyadh pick and poorly-defined Shu’aiba.
In addition, strongly obscuring multiples (Figures 5 and 6) further hamper the identification of the seismic pick from the top of the reservoir. Therefore, the need for borehole seismic measurements was considered crucial in order to calibrate the seismic and to confirm the validity of the seismic picks and the interpretation.

Although the seismic horizon associated with the base of the reservoir was prominent, its use in identifying the top (by flattening and phantom picking on seismic, for example) was limited. This was primarily due to the variable and unpredictable thickness of the reservoir. Two geologic factors, the depositional setting (undulating rudist build-ups) of the carbonate reservoir and the nature of the reservoir top as an unconformity, give rise to this variation in thickness across the reservoir.

NON-CONFORMABLE TOP AND BASE SHU’AIBA

Unlike the top of the reservoir, the base displayed density/velocity trends that reinforce one another resulting in a relatively high reflection coefficient (Figure 4). This, in turn, produced a seismic horizon for the base that was usually prominent and readily traceable on the 3-D seismic data (Figures 5 and 6). However, picking the base did not always help in distinguishing the weak top (through phantom picking, for example). The difficulty in identifying the weak top, even after having picked the base, is attributed mainly to the fact that carbonate mounds (rudist build-ups) naturally dominated that surface. Consequently, this resulted in two interfaces (undulating top and well-behaved base) that do not track one another (i.e., structurally non-conformable).

In addition to the undulation caused by the carbonate build-ups, the top of the reservoir is also interpreted as an unconformity that is associated with non-deposition and possibly erosion. It follows that a surface of this nature would most likely not parallel any deeper geologic boundaries, including its base. Fischer et al. (1996) also characterized the top of the Shu’aiba as structurally irregular in the United Arab Emirates further south in the Arabian Gulf region.

VERTICAL SEISMIC PROFILING

With all the issues mentioned above, it became imperative that an independent source of data be incorporated in order to minimize the degree of uncertainty in interpreting the seismic data and, ultimately, to impact the drilling program in an optimal way. As a result, a VSP program to cover the majority of planned vertical wells was adopted, including both zero and non-zero offset profiles. The design of this VSP program included optimization of acquisition parameters by forward elastic VSP modeling of the geology of the field. The actual VSP results had considerable impact on the interpretation of the 3-D seismic data.

Use of synthetic seismograms alone to identify seismic horizons and multiples on surface-seismic data is not necessarily reliable. For this reason VSP seismograms, when available, are usually used to calibrate log-based synthetic seismograms. Stated differently, the ultimate seismogram an interpreter ought to use is the one constructed from VSP data. There are quite a few reasons why a synthetic seismogram would not yield a true representation of the earth; for example:

1. Sonic and density logs are usually blocked (averaged over some intervals) by the interpreter before being used to generate the synthetic seismogram. This could result in a misrepresentation of the reflectivity series.

2. The alteration in log measurements due to drilling and invasion is usually not compensated for.

3. Effects of washouts may not be properly removed.

4. An oversimplified wavelet is usually assumed.

5. Synthetic seismograms require a model of the wave propagation process in the sub-surface, which is often crudely approximated as the convolution of a simple wavelet with the earth reflectivity obtained from blocked logs.

216
Figure 7: Zero-offset VSP modeling honoring the geology of Shaybah field. The first arrivals are muted out from the time-corrected record (left). Both the base and top (Shu’aiba and Biyadh) are clearly imaged. The polarity here is opposite to that in 3-D surface seismic. (Note that accurate time corrections were applied only down to the area of interest, resulting in poor alignment of events deeper than Biyadh).
(6) The sonic and density logs in the shallow portion of a borehole are generally not acquired.

(7) Synthetic seismograms typically do not account for the effects of anisotropy.

(8) Log measurements are taken at frequencies much higher (a few orders of magnitude) than surface seismic, and hence a discrepancy exists between the two due to dispersion. Drift correction of sonic logs, if velocity surveys (check shots) are available, can nevertheless alleviate the discrepancy.

(9) Synthetic seismograms are one-dimensional, and cannot account for 2-D and 3-D wave propagation.

Seismograms constructed from VSP surveys are free from most, if not all, of the above shortcomings associated with log-based seismograms. As Balch and Lee (1984) indicated: “VSPs involve real measurements of real seismic phenomena in the real earth, using real seismic sources. It is therefore not surprising that they often yield a better match with surface data.”

The main objectives of the VSP program here were to identify the top of the reservoir on the 3-D seismic cube, and to identify, and hence avoid the erroneous picking of multiples. A secondary objective was to confirm the presence (or absence) of faults seen on surface seismic. The former was achieved through zero-offset VSP, and the latter through offset VSP. The parameters, in particular the source distance (offset) from the borehole in the case of offset VSP acquisition, were selected based on results from forward elastic VSP modeling. Various source offsets were modeled for optimal imaging of geology at a depth of about 5,000 ft.

Figure 7 shows a modeled zero-offset VSP seismogram synthesized from the known geology in this field. Both the pre-stack, time-corrected (flattened) record and the corresponding corridor stack are shown after filtering out the downgoing wavefield. In this figure, both the top and the base of the reservoir were clearly imaged by the VSP. This encouraged the launching of a comprehensive VSP program in this field. As for offset-VSP forward modeling, Figures 8a, b and c show imaged VSP data with offsets of 2,000, 3,000 and 4,000 ft, respectively. Of all the offsets modeled (only three are shown here), an offset distance of 3,000 ft was deemed optimal (Figure 8b) and was later applied in the field.

Intuitively, the larger the offset, the wider the imaged area. But, at farther offsets converted waves start overwhelming the primary compressional P-wave reflections, and the frequency bandwidth deteriorates because of the longer travel path. The upper limit (in this case 3,000 ft) was determined by assessing results from the different offsets that were modeled. For example, a quick visual inspection of Figure 8c (offset = 4,000 ft) reveals strong mode-converted (P-SV) waves interfering with the primary upgoing waves precisely in the zone of interest. The mode-converted waves, in this example, originate at a reflector whose depth is about 4,000 ft, as illustrated in Figure 8c. Of course there were also converted waves with offsets of 2,000 and 3,000 ft (Figures 8a and 8b); however their effects were not as severe as those from offsets of 4,000 ft or larger.

At a vertical delineation well (Shaybah-A) on the west flank of the Shaybah field, one zero-offset and two offset VSPs were acquired. Figure 9 shows the comparison between the synthetic seismogram derived from sonic and density logs, and the VSP corridor stack obtained from the zero-offset VSP. There is clearly a good match between the two because the synthetic seismogram was, in this case, calibrated using the VSP data. In the VSP-synthetic calibration process, up to 10 msec of drift-time correction was necessary at the reservoir zone in order to make the synthetic better match the VSP. More importantly, the Shu’aiba top is now correctly identified on the VSP and can readily be used as a reference in the 3-D seismic interpretation.

However, there are discernible differences in the amplitudes of various reflectors between the synthetic and the VSP corridor stack, though both were similarly gained. This can be expected for various reasons as previously explained. Nevertheless, the relative amplitudes among the various reflectors in either the synthetic or the VSP trace are generally similar. Hence, it is evident in Figure 9 that the reflection from the top of the Shu’aiba reservoir is indeed much weaker than that from its base.
Figure 8: Offset VSP modeling of the geology of Shaybah field. The polarity here is opposite to that in 3-D surface seismic. (a) The small source offset distance of 2,000 ft here generated weak converted waves causing only minor interference over the reservoir zone. The noisy signals seen at shallow depths result from elastic modeling that accounts for the entire wavefield (converted waves, multiples, direct arrival, near-source effect, etc.). The record is not time-corrected, and the direct arrivals are muted-out. (b) Offset VSP with the source offset distance of 3,000 ft. Here, the generated converted waves are barely affecting the reservoir zone but are of increasing strength over the deeper zones. (c) Offset VSP with source offset distance of 4,000 ft. The generated converted waves here are significantly affecting the reservoir and deeper zones.
Figure 9: Comparison between synthetic and VSP seismograms at a well in Shaybah field. About 10 msec of drift-time correction were applied to the synthetic at the reservoir zone. Also, note the weak reflection at the top of the Shu’aiba relative to the top of the Biyadh.

Figure 10 shows the tie between the VSP stack with the seismic data through a dip line passing through the Shaybah-A well. This verifies the validity of the seismic pick and interpretation at the reference Biyadh horizon. Although the top of the reservoir can be identified from the VSP stack, it was not correctly picked on the 3-D seismic prior to the VSP. This is due to the presence of several strong multiples in the seismic which are clearly absent from the VSP data. Without VSP control for confirmation, many of these multiples, having approximately the same gentle dips as the primaries, may easily be mistaken for the latter.
One of the offset VSPs was acquired at Shaybah-A. A seismic line passing through this well was extracted from the 3-D volume and is shown in Figure 11a. The offset VSP was acquired to investigate subtle lineaments in the structure observed from first-derivative (dip) maps of the time structure. The processed VSP result is shown in Figure 11b as a cutout insert within the seismic section of Figure 11a. Aside from the character change observed within the reservoir in Figure 11b, the VSP data does not support the presence of significant, i.e., seismically-imaged, faults along the VSP section. However, image-log data in the vertical well Shaybah-A indicated a small cemented fault plane trending roughly east-west, perpendicular to the VSP section. The magnitude of the throw of this fault was initially assessed to be a few feet, which is way below the resolution of conventional seismic, but could possibly be detected by dip maps generated from 3-D seismic. Additionally, after integrating all available information, the fault is believed to be strike-slip with a very minor vertical throw.

Figure 10: Tie between 3-D seismic and VSP acquired at Shaybah-A well. Top Shu’aiba was confidently identified on 3-D seismic after VSP results were incorporated. Note the strong multiples encasing top Shu’aiba.
Figure 11a: Seismic line, extracted from the 3-D volume, along the acquisition path of an offset VSP aimed at imaging a possible fault seen as lineaments on a Biyadh dip map. The suspected fault is to the right of well Shaybah-A.

Figure 11b: Offset VSP section superimposed on surface seismic of Figure 11a. No major-throw faults are detected at the Biyadh level by VSP. As supported by image-log data, this anomalous zone was later characterized as possibly having a strike-slip fault whose minor vertical throw is below the resolution of conventional seismic, but its trend could possibly be picked by dip maps generated from 3-D seismic.
VSP-GUIDED 3-D SEISMIC INTERPRETATION AND DRILLING

The successful identification of multiples on 3-D seismic, after incorporating zero-offset VSPs, led to a new approach in dealing with those multiples, i.e. smart picking of multiples. This is simply a mapping of those identified multiples throughout the seismic volume, as one would typically do when tracing a genuine seismic horizon. Having mapped the multiples, the interpreters would simply avoid picking them by mistake as primaries. In some instances, the interpreters would even make logical inferences about their effects on, for example, obscured primaries. This methodology has proven to be a very powerful interpretation tool, especially in areas with no well control.

For example, Figure 12 shows a dip section on the east flank of the structure where the yellow event has been confirmed by surrounding VSPs as a definite multiple and mapped areally. In this section, by knowing the yellow event to be a multiple, the ramp structure was mapped as shown by the red event. A vertical well, Shaybah-B, was subsequently drilled on this section and the VSP acquired at this well confirmed the yellow event to be indeed a multiple.

More importantly, the zero-offset VSPs played an invaluable role in the design of horizontal wells. Due to the rugged topography of the Rub' Al-Khali Desert, operations and facilities in Shaybah area have to be sited on the flat sabkhas. The development scheme adopted was, therefore, to drill a vertical delineation well at selected sabkhas in order to calibrate the top of the reservoir and determine the facies distribution in this local area. After analysis of all the data collected at this vertical well, horizontal wells with surface locations within the sabkha are then planned to drain the reservoir beneath the sabkha and its surroundings (Figure 13).

Figure 12: VSP-confirmed multiple, identified in yellow, was mapped areally so as to avoid confusing it with genuine primary, shown in red. A vertical well, Shaybah-B, was subsequently drilled and confirmed this interpretation.
The VSP data provided critical local velocity control for time-to-depth conversion of the 3-D seismic data, validation of the interpretation of the reference Biyadh horizon, identification of the top reservoir, and assessment of interfering multiples. In essence, the vertical well drilled at each sabkha and its associated VSP data together comprise a “pilot well” for 4 or more horizontal wells that are drilled from that sabkha. Due to the gentle structure, the relatively thick target window, and the general absence of small-throw subseismic faults, a single pilot well per sabkha has yielded acceptably accurate depth prognoses for the horizontal wells drilled to date.

CONCLUSIONS

Interpretation of the 3-D seismic data over Shaybah field includes an understanding of the effects of the complex and rugged topography on the data, awareness of the lack of a mappable reflector at the top of the Shu’aiba reservoir, and of the obstruction of the remaining trackable reflectors by strong surface multiples. To mitigate many of the uncertainties introduced by the nature of the 3-D data in this field, borehole seismic measurements, particularly VSP surveys, have provided the critical calibration of the seismic and the validation of the structural interpretation. Furthermore, these surveys are serving as a vital reference in on-going efforts to further improve the data quality using more advanced processing techniques with focus on multiples suppression.
It is truly a challenge to try to seismically map the blind top of a reservoir that is distorted by noise. But, by carefully following its base, by correctly identifying the significant multiple noise trains obstructing the view, by developing a reasonable depositional model of the reservoir, and by properly integrating all available data, it has been possible to plan and implement a horizontal well development drilling program with acceptable accuracy. This is precisely the approach followed in this early development phase of Shaybah field.

ACKNOWLEDGMENTS

The authors would like to thank Saudi Aramco and the Ministry of Petroleum and Mineral Resources, Saudi Arabia, for permission to publish this work. In particular, we thank Mahmoud Abdul-Baqi for his encouragement to write and publish this paper. Thanks are also due to Moujahed Al-Husseini for his interest in this work. We thank John Empoliti and Gurhan Aktas for reviewing an earlier draft of this paper, Ahmed Al-Mousa for producing some of the figures, and Peter Green for useful discussion on the processing of the Shaybah 3-D seismic data. We thank the Cartography Division of the Exploration Organization, Saudi Aramco, and Gulf PetroLink for editing and finalizing our graphics. We also thank the anonymous reviewers for their critiques.

REFERENCES

Balch, A.H. and M.W. Lee 1984. Vertical Seismic Profiling, Technique, Applications and Case Histories. International Human Resources Development Corporation, Boston, p. 57.

Fischer, K.C., U. Moller and R. Marschall 1996. Advanced Seismic Data Interpretation for Carbonate Targets Based on Optimized Processing Techniques. GeoArabia, v. 1, no. 2, p. 285-296.

Hampson, D. 1986. Inverse Velocity Stacking for Multiple Elimination. Journal of Canadian Society of Exploration Geophysicists, v. 22, no. 1, p. 44-55.

Husseini, M. and R. Chimblo 1995. 3-D Seismology in the Arabian Gulf Region. In M.I. Al-Husseini (Ed.), Middle East Petroleum Geosciences, GEO’94. Gulf PetroLink, v. 1, p. 95-97.

Soliman F.A. and A. Al Shamlan 1982. Review on the Geology of the Cretaceous Sediments of the Rub’ al-Khali, Saudi Arabia. Cretaceous Research, p. 187-194.

ABOUT THE AUTHORS

Mohammed N. Alfaraj received a BSc degree in Electrical Engineering from the University of Wisconsin-Milwaukee in 1983, and MSc and PhD degrees in Geophysics from the Colorado School of Mines in 1987 and 1993, respectively. Since 1984, Mohammed has been with Saudi Aramco, Saudi Arabia. His interests include seismic data processing, vertical seismic profiling, reservoir characterization, and working in multi-disciplinary teams. Currently, Mohammed is in charge of all 2-D seismic processing in Saudi Aramco, and is the President of the Dhahran Geoscience Society. He is a member of the SEG and EAGE.
Edgardo L. Nebrija received a PhD in Geophysics from the University of Wisconsin at Madison. From 1979 to 1992, he worked for Shell Offshore, Inc. in New Orleans, Louisiana, in various capacities as Marine Seismic Party Chief and Explorationist and Exploitation Geophysicist. Since 1992, Edgardo has been a staff member of the Northern Area Reservoir Geology Division of Saudi Aramco and since 1996 has been responsible for the seismic interpretation of the Shaybah 3-D seismic data in support of development drilling and reservoir characterization of the Shu’aila reservoir. He has also worked in the Marjan field offshore in the Arabian Gulf. Edgardo is a member of the SEG, DGS and EAGE.

Michael D. Ferguson was awarded an Amoco Foundation Honors Scholarship in Geophysics at the University of South Florida and received his BA in Geology with a minor in Physics and Mathematics in 1977. From 1977 to 1981 he worked as a Geophysical Engineer with Geophysical Services International in Saudi Arabia. In 1981, Michael joined Aramco Overseas Company as an Exploration Geophysicist based in Croydon, UK. Since 1982 he has been with Saudi Aramco as an Exploration Geophysicist involved with the interpretation of several 3-D seismic projects. In 1993, Michael was responsible in overseeing the processing and seismic interpretation of the Shaybah 3-D seismic data set for the Exploration Department and later for the Northern Area Reservoir Geology Division. His interests include 3-D seismic workstation interpretation, seismic data processing, and reservoir characterization. Michael is a member of the SEG, DGS and SPE.

Paper presented at the 2nd Middle East Geosciences Conference and Exhibition, GEO’96, Bahrain, 15-17 April, 1996.

Manuscript Received 25 August, 1997
Revised 2 May, 1998
Accepted 9 May, 1998