Petroleum Res. J. Vol. 19 (2006); P. 61–70, 9 Figs.

Attributes and the Enhancement of Seismic Data Interpretation: An Nafurah-Awjilah Oil Field, Sirt Basin, Libya

Mohamed M. Elazezi*

مميّزات وتعزيز تفسير المعطيات السيزمية: حقل النافورة – أوجلة، حوض سرت، ليبيا

محمد العزيزي

تم استعمال المعطيات السيزمية التي تمثل صخور المكمن القاعية الجرانينية التابعة لعصر ما قبل الكامبري وصخور عصر الطباشيري العلوي الفتاتية والجيرية لحقل النافورة – أوجلة بحوض سرت بليبيا لدراسة تجاوب المميزات السيزمية. كما تم حساب هذه المميزات السيزمية التطبيقية من خلال تحليل إشارات مركبة تمثل المقاومة الصوتية وسعة الذبذبة والطور وشدة الانعكاس.

توضح النتائج المتحصل عليها أن تجاوبات جيدة ممثلة للمميزات تعتمد بدرجة كبيرة على نوعية المعطيات السيزمية المتوفرة، كما تبين تأثير الضوضاء والمضاعفات في حجب تجاوب المميزات نتيجة لتداخلهم مع أحداث الانعكاسات الرئيسية. تشير مجموعتي البيانات المستعملة أن تجاوب المميزات قد يكون مفيداً للتفسير ومقارنة البيانات. إن عروض سعة الذبذبة وشدة الانعكاس والتذبذب الفوري كلها مؤشرات جيدة لصدع ما ولغياب وحدة طبقية، ومثل هذه المؤشرات غير منظورة بالمقاطع المسجلة ومن ثم لا يمكن تتبعها. يعطي ضم مجموعتي البيانات فرصة للمقارنة والاستقصاء وتحسين دقة التفسير السيزمي.

Abstract: *Seismic data representing the reservoir rocks of Precambrian granitic basement, and Upper-Cretaceous clastic and carbonate rocks of the An Nafurah-Awjilah oil field, Sirt Basin, Libya were used to study the seismic attributes response. These applied seismic attributes were computed from complex signal analysis which consisted of acoustic impedance, amplitude, phase, and reflection strength.*

The obtained results show that good and representative responses of attributes rely very heavily on the quality of seismic data available. They also show the effect of noise and multiples in obscuring the attributes response due to their interference with the main reflection events. The two used data sets have shown that the attributes response can be useful for the interpretation and correlation of seismic data. The displays of amplitude, reflection strength and instantaneous frequency show good indications of fault and stratigraphic unit pinchout. Such indications are not visible in the recorded sections and therefore can not be followed. Combination of the two data sets gives an opportunity for comparison to investigate and improve the accuracy of seismic interpretation.

* Libyan Petroleum Institute

INTRODUCTION AND OVERVIEW

Seismic attributes computed from complex signal analysis are used as a tool to aid in the interpretation of seismic data. The complex analytic signal and its application to seismic data has been described by several authors such as Balch (1971), Farnbach (1975), Sheriff (1976), Taner and Sheriff (1977), Taner, *et al*. (1979), Robertson and Nogami (1984), Bodine (1984), Sicking (1978), Ren, *et al*. (1986), and Yilmaz (1987). They have also discussed the methodology of computing complex trace attributes and the apparent relationships between features of attribute displays and physical properties of subsurface sequences and also the involved constrains.

The seismic data were collected from the An Nafurah-Awjilah oil field, Sirt Basin. Geologically the field is situated over the crestal area of the Rakb high (Fig. 1). It is considered as one of the major oil fields in the world which produce from basement reservoir and represents a typical example of this type of oil fields as shown in Figure 2 (Elazezi, 1992, Elazezi and Ashcroft, 1996, Belazi, 1986, 1989, and Williams, 1968, 1972).

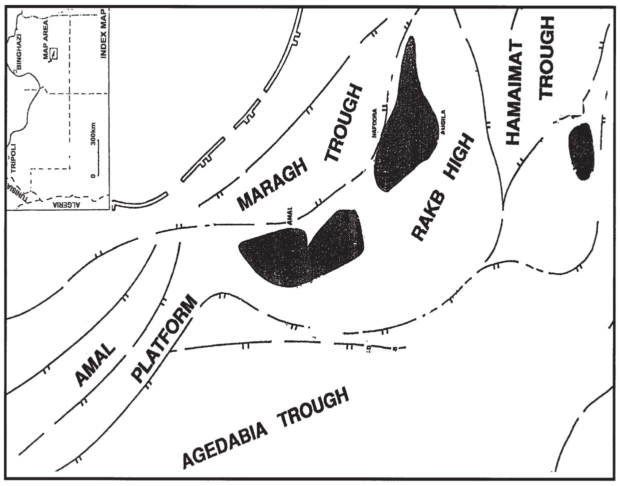

Fig. 1. An Nafurah-Awjilah oil field, and the tectonic elements of the eastern Sirt Basin.

The used seismic data (Fig. 3) is consisted of synthetic and recorded seismic sections representing reservoir rocks of Precambrian granitic basement, and Upper Cretaceous clastic and carbonate rocks. The aim of computing seismic attributes is to enhance

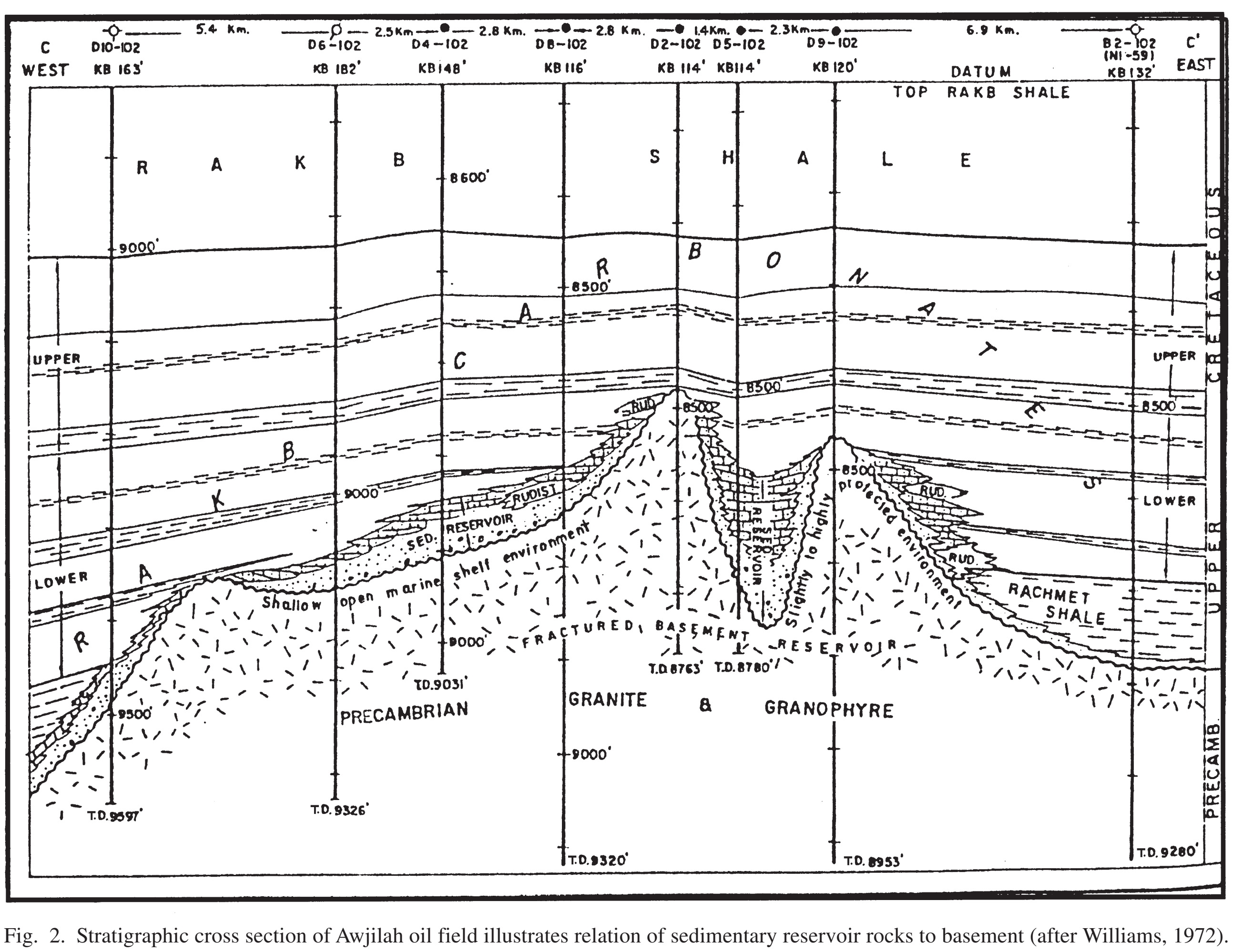

Fig. 2. Stratigraphic cross section of Awjilah oil field illustrates relation of sedimentary reservoir rocks to basement (after Williams, 1972).

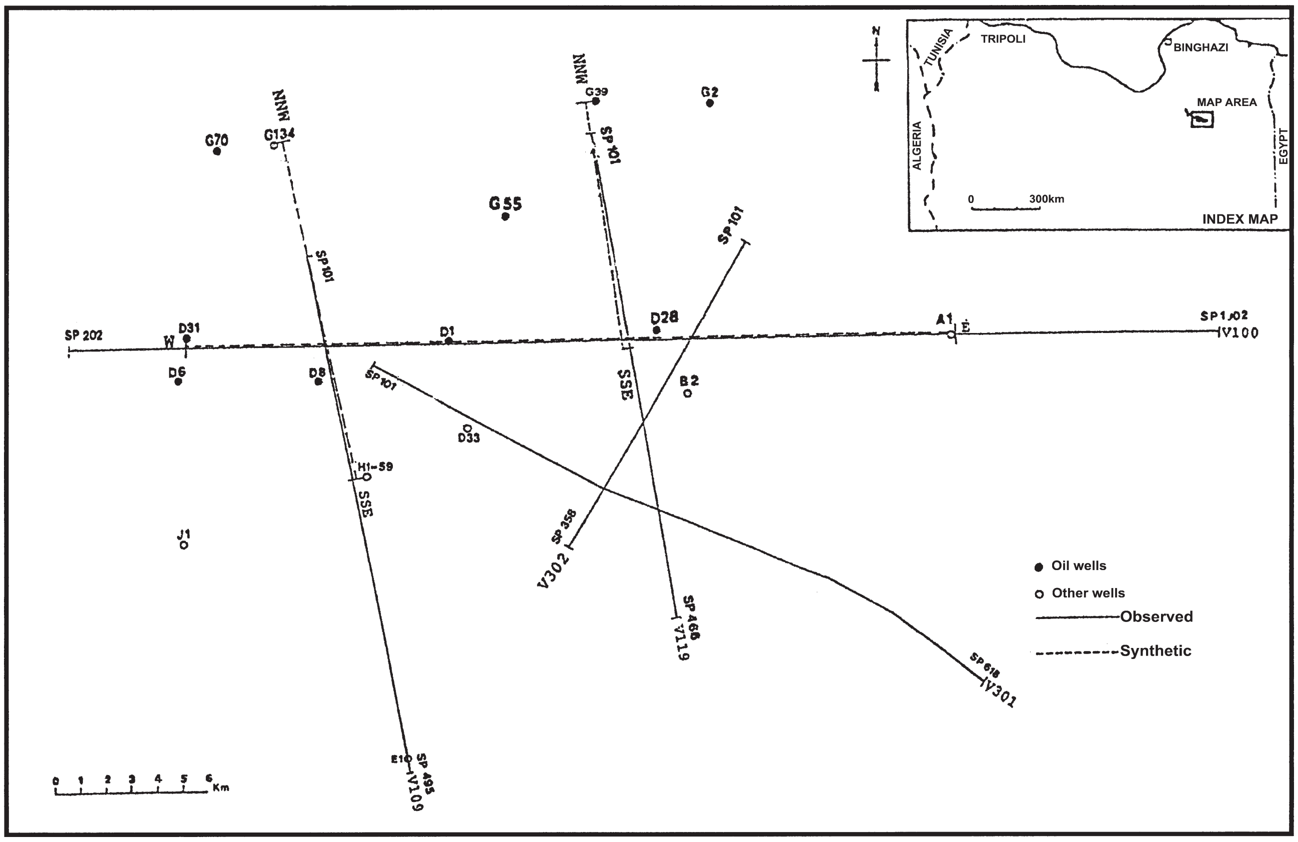

Fig. 3. Location map of the study area

the interpretability of the seismic data. The interpretation of attributes is expected to contribute in showing any lateral variations along the bedding which indicate stratigraphic change resulted from thickness and lithological variations. Such a change could be used to locate pinching out of thin beds and hydrocarbon accumulations. It also expected to define the continuity of the main seismic reflection events and locate any abrupt change which might result from structural features such as faults.

COMPUTATION OF THE ANALYTIC SIGNAL

The seismic trace with its real and imaginary parts, as shown in Figure 4, can be considered as being generated by a vector rotating as a function of time, with the length varying with time. The projection of this rotating vector onto the real plane gives the conventional seismic trace, where the observed seismic trace, g(t), is expressed by:

$$g(t) = R(t) \cos\theta(t),$$

where R(t) is the envelope of the seismic trace and $\theta(t)$ is the phase. Projection onto the imaginary plane produces the quadrature trace, h(t), which is expressed as

$$h(t) = R(t) \sin\theta(t),$$

where R(t) is termed the reflection strength and $\theta(t)$ is the instantaneous phase. The total signal can be written as

$$R(t)e^{i\theta(t)} = R(t)\cos\theta(t) + R(t)\sin\theta(t)$$
$$= g(t) + h(t)$$

After obtaining the complex seismic trace four seismic attributes associated with the seismic signal can be computed.

i. Reflection strength,
$R(t) = \{ [g(t)]^2 + [h(t)]^2 \}^{1/2}$

ii. Phase angle,
$\theta(t) = \arctan [h(t) / g(t)]$

iii. Instantaneous frequency,
$d\theta(t) / dt$

iv. Polarity, defined as the sign of the seismic signal at maximum R(t).

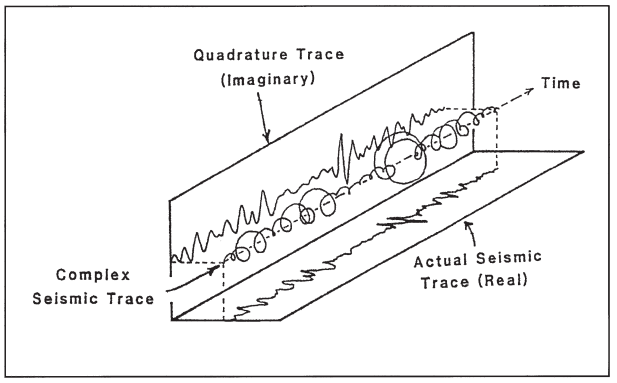

Fig. 4. Complex seismic trace as generated by a vector whose length varies with time, (rotating as a function of time).

THE SIGNIFICANCE OF ATTRIBUTE ANALYSIS

Reflection Strength

Reflection strength is known also as instantaneous amplitude and can be used to distinguish between reflections from massive reflectors which tend to remain constant over large regions and interference from a composite of reflections. High reflection strength is often associated with major lithological changes between adjacent rock layers and also is often associated with gas accumulations. Reflection strength may aid in lithological identification of subcropping beds associated with unconformities which may vary as the subcropping beds change. Sharp local changes in reflection strength may indicate faulting or hydrocarbon accumulations where trapping conditions are favorable.

Instantaneous Phase

Phase emphasizes the continuity of events and because of its independence of reflection strength it often makes weak coherent events clearer. In phase display each peak, trough and zero crossing can be picked and assigned the same colour so that any phase angle can be followed from trace to trace. Therefore, the displays are effective in showing discontinuities, pinchouts, angularities, faults, and the interference of events with different dip attitudes.

Instantaneous Frequency

Instantaneous frequency is the time derivative of instantaneous phase and is a very useful tool in investigating reflection events composed of individual reflections from a number of very closely spaced reflectors. Change in the composite reflection tends to change the instantaneous frequency more rapidly such as at pinchouts and at the edge of hydrocarbon-water contacts. Drop in frequency (low frequency shadow) often occurs only on reflections from reflectors immediately below gas sand, condensate and oil reservoir. Such a high degree of variation in the instantaneous frequency, which may be related to the nature of the interface between two stratigraphic sequences, make it a useful attribute.

Apparent Polarity

The analysis of apparent polarity assumes a single reflector, a zero phase wavelet, and no ambiguity due to phase inversion. However, since most reflection events are a composite of several reflections, polarity lacks a clear comparison with reflection coefficient and hence it is qualified as apparent polarity. It is used for distinguishing between different types of bright spots. Clastic sediments containing gas accumulations usually have lower acoustic impedance than surrounding beds and hence show negative polarity for reservoir top reflections and positive polarity for reflections from gas-oil or gas-water interfaces.

PROCEDURES

The application of seismic attributes was started by the selection of parts of synthetic and recorded seismic sections which cover areas of productive and non productive reservoir units of interest, and areas where stratigraphic units pinched out. The aim of using two sets of data was to compare the response of attributes in each set. The obtained results can then be used to investigate the similarities and differences for possible data improvement.

Colour is one of the display parameters which has proven to be especially effective in complex trace analysis and has been used as an interpretation aid for seismic sections. The visual impact of the attribute displays is sensitive to colour scaling. However, the presence of noise and multiples, and also colour range have affected response from the main reflection events.

Modeled Seismic Data

Synthetic seismic sections were generated using the available well data along the recorded seismic sections V100, V109 and V119 (Fig. 3). The modeled data were used to study the response of the seismic attributes. Figure 5a shows the amplitude display of part of the E-W synthetic seismic section along the recorded seismic section V100. A number of wells are located on or near the section such as well D1–102 which are producing from the Upper Cretaceous and Precambrian Basement reservoirs. The Bahi and Rachmat Formations unconformably overlying the basement reservoir and pinch out against the basement high. The technique used to analyze the response of seismic attributes is similar to that described by Robertson and Nogami (1984) and Taner, *et al.* (1979).

The instantaneous phase plot (Fig. 5b) emphasizes the continuity of the reflection interfaces of the stratigraphic units. The primary reflection interfaces are surrounded by an area of random interfaces resulting from the added noise. At CMPs 450-500, and time of about 340 msec there are indications of thinning (yellow to reddish yellow) of the Bahi stratigraphic unit. This is confirmed by colour changes in the frequency and reflection strength plots (Figs 5c,d).

The display of reflection strength (Fig. 5c) shows that half period tuning clearly stands out as red and reddish yellow colours at offset intervals between CMPs 310-330 and 370-460, and around 320 msec time interval. These represent intervals where the Bahi Formation is thinning in both directions, and Rachmat Formation is thickening towards the east between CMPs 380-500 and pinching out at about CMP 300 towards the west as shown in Figure 6a.

The instantaneous frequency plot (Fig. 5d) shows the reflection from the base Kalash Limestone and top Sirte Shale at 200 msec is overlain by a low frequency (red). The green colour interval between about CMPs 300-330 to the west and 370-440 to the east, and time interval between 300-350 msec might indicate thinning of both the Bahi and Rachmat Formations which corresponds well with change in reflection strength mentioned above. From CMP 330 towards the west the change in colour could be evidence of thinning of the Bahi Formation to quarter period as shown by the decrease in reflection strength (blue) and increase in instantaneous frequency (green)

At CMPs 480-500 and about 325-335 msec high frequency (blue) is visible. The increase of instantaneous frequency indicates that the thickness of the Bahi Formation approaches one period. The increase is followed by a clear and abrupt transition

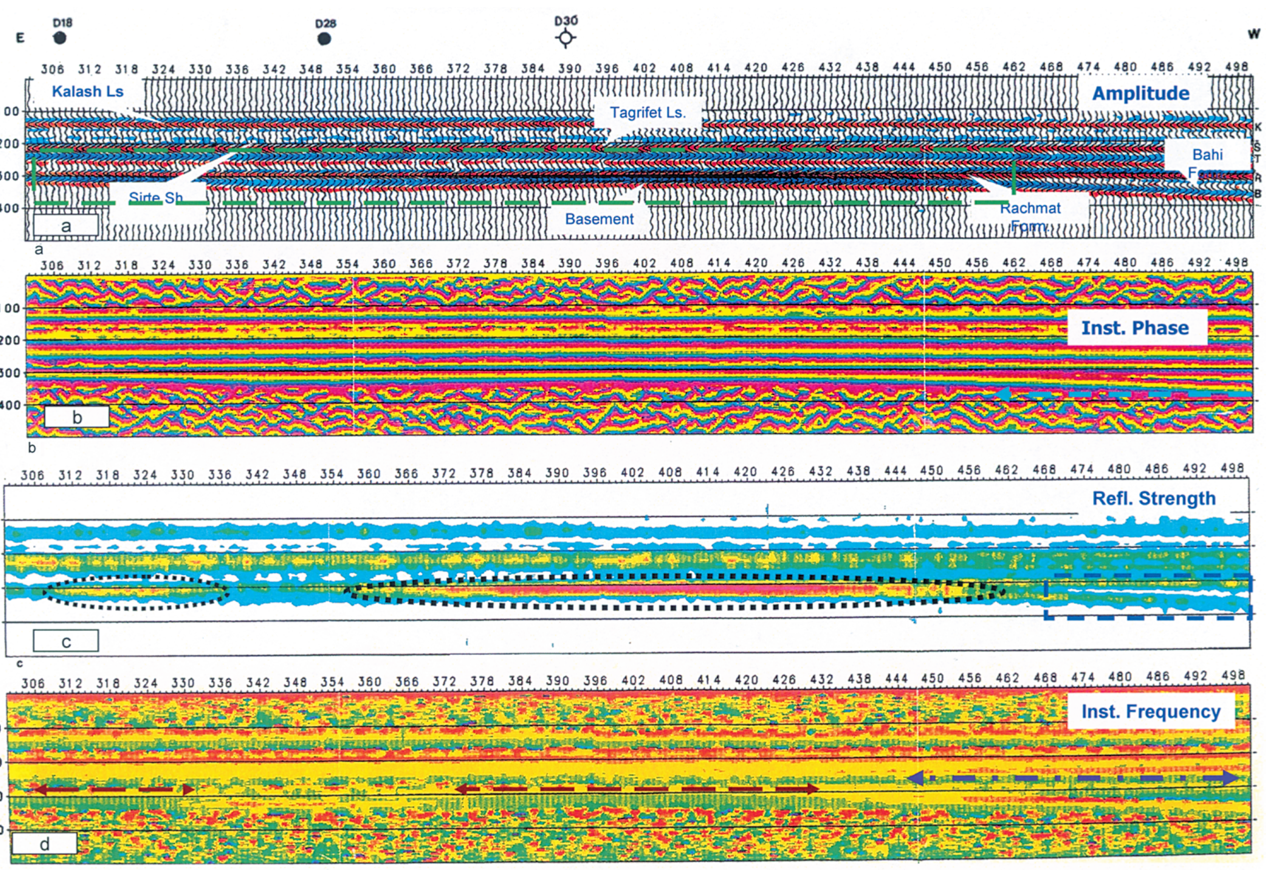

Fig. 5. Portion of the E-W synthetic seismic section between CMPs 300-500 along seismic section V100.

to low frequency (red) and then from a half to a quarter period, the frequency increases again (yellow). These changes in colour indicate the thinning of the stratigraphic unit and reaches the tunning effect followed by the thinning beyond the seismic resolution limit.

Recorded Seismic Data

Selected parts of the recorded seismic sections which cover the same intervals of synthetic sections were used to analyze the attribute response. Figure 6 shows parts of seismic sections V100 and time interval 1000-2000 msec respectively. The section is displayed as an example from the observed data and was converted to amplitude and instantaneous phase (Figs. 6b-c), reflection strength, and instantaneous frequency (Figs. 7b-c).

The vertical zone of interest is marked on Figure 6 and extends about 300 msec of TWT (1400-1700). The reflection events of interest exhibit lateral variations in character, amplitude, and arrival time. These variations might be related to the presence of shale and sandstone beds and also variation due to the effect of weathering and fracture on the basement reflector especially in the high areas.

Figures 6b and 8b show plots of amplitude display of parts of seismic sections V100 and V109. The change in colour (red/blue) according to the wavelet shape at the reflection coefficients of each interface make it much easier for tracing the continuity of reflection events in comparison with black and white sections.

Figure 8c shows instantaneous phase display of the main reflection events of interest at the time interval between 1400-1600 msec TWT, seismic section V100. Reflectors are also seen within the interval and below the Basement reflector at around 1600 msec. The spurious interfaces are the result of remnant noise and long period multiples. Therefore, such noise effect have to be considered during the assessment of attributes response from the observed seismic data. The phase plot emphasizes the continuity of the main reflectors.

Comparison between the phase plot, black and white section (Fig. 6a), and amplitude plot (Fig. 6b) shows that the top Kalash Limestone is just below the 1400 msec time line and is slightly dipping downwards to the east. The Sirte Shale reflector is at about 1500 msec with slight dip similar to the Kalash reflector. The Tagrifet Limestone interface is just below the Sirte Shale interface at about 1520 msec.

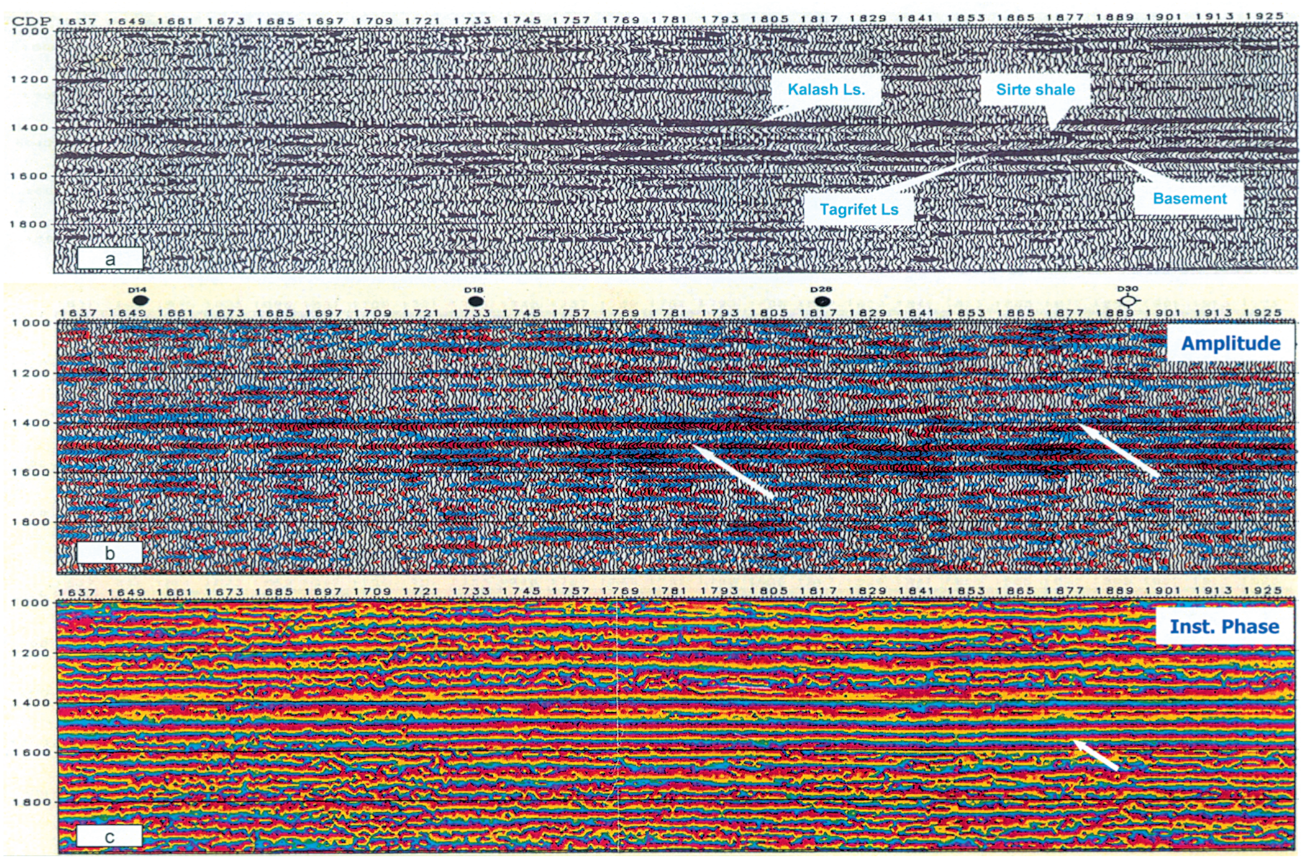

Fig. 6. Portion of seismic section V100 between CMPs 1632-1932: Amplitude and Inst. phase.

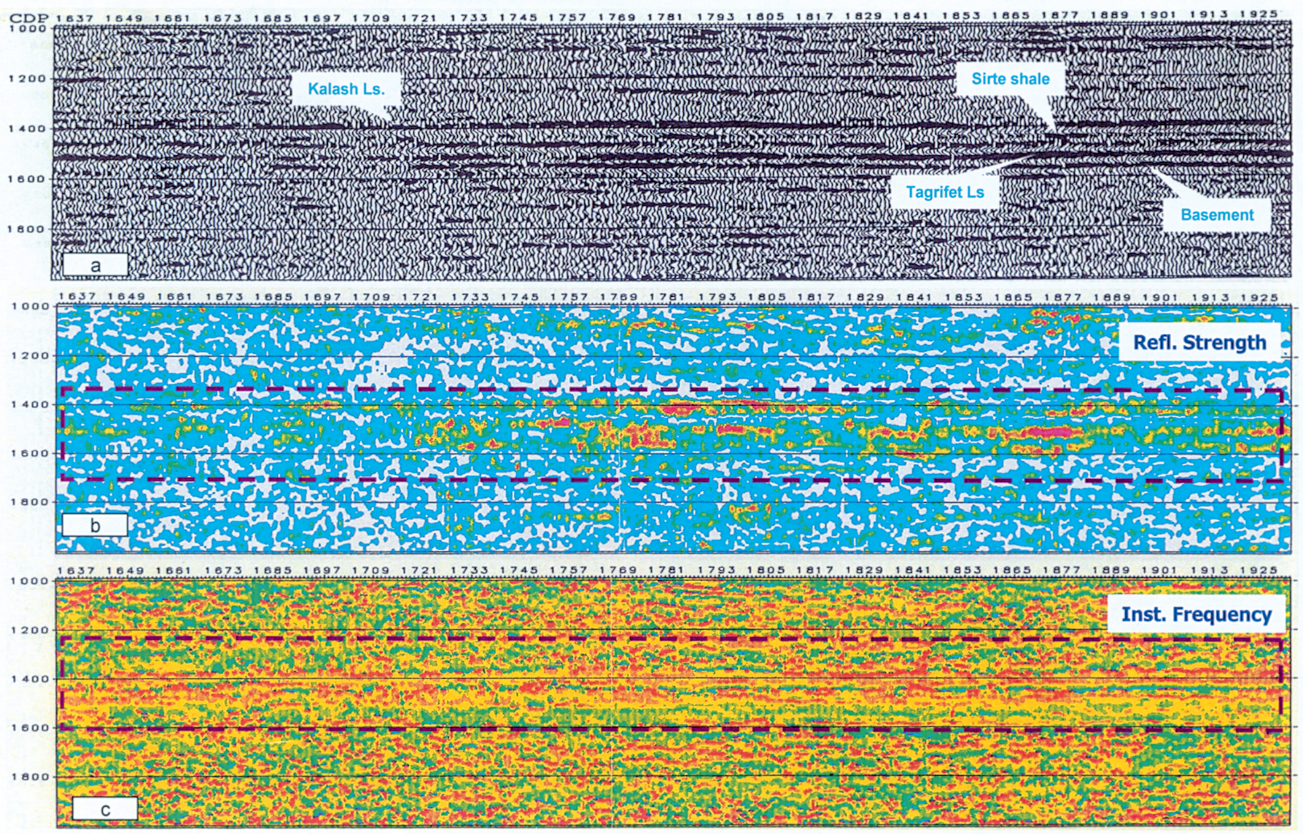

Fig. 7. Portion of seismic section V100 between CMPs 1632-1932: Refl. strength and Inst. frequency.

The basement reflector is between 1600 and 1550 msec from right to left, rising to the west especially at the western end.

Figure 8c shows instantaneous phase of part of seismic section V109. The outstanding feature on this section is the basement fault at CMP 1350 which extends from the basement at 1700 msec to upper sequences at about 1300 msec. The continuity of the reflectors on the upthrown side of the fault can be brought through much further, to the fault plane at CMP 1348, in comparison with the black and white section (Fig. 8a). Another noticeable feature is the pinching out of stratigraphic sequences from right to left at CMPs 1270 and 1290 and time interval between 1600-1700 msec. The main reflectors show continuity on both sides of the fault. The plot also shows coherent energy in the interval below the basement reflector resulting from noise and long period multiples similar to Figure 6c.

Figure 7b shows reflection strength of part of section V100. Reflection events with indication of high strength are mainly confined to the time interval between 1400 and 1600 msec (yellow and red). Figure 9b shows reflection strength response from part of seismic section V109. Reflection interfaces with high reflection strength are indicated by red and yellow colours from right to left just above 1600 and also at 1500 msec time lines. The reflection strength continuity appears to be changing laterally and there are no boundaries of the primary reflection events. The high reflection strength on both sections corresponds to high amplitude as shown in Figures 6b and 8b. Reflectors in both sections are still poorly identified. It appears that reflection strength is of a limited use in this part of the data.

Figures 7c and 9c show instantaneous frequency plots of parts of seismic sections V100 and V109. The plots are of limited use due to the poor definition of reflection interfaces of the main events and the rapid changes in frequency along the sections. Even weighted frequency which has smoothed the instantaneous frequency did not show much improvement regarding the enhancement of reflections continuity.

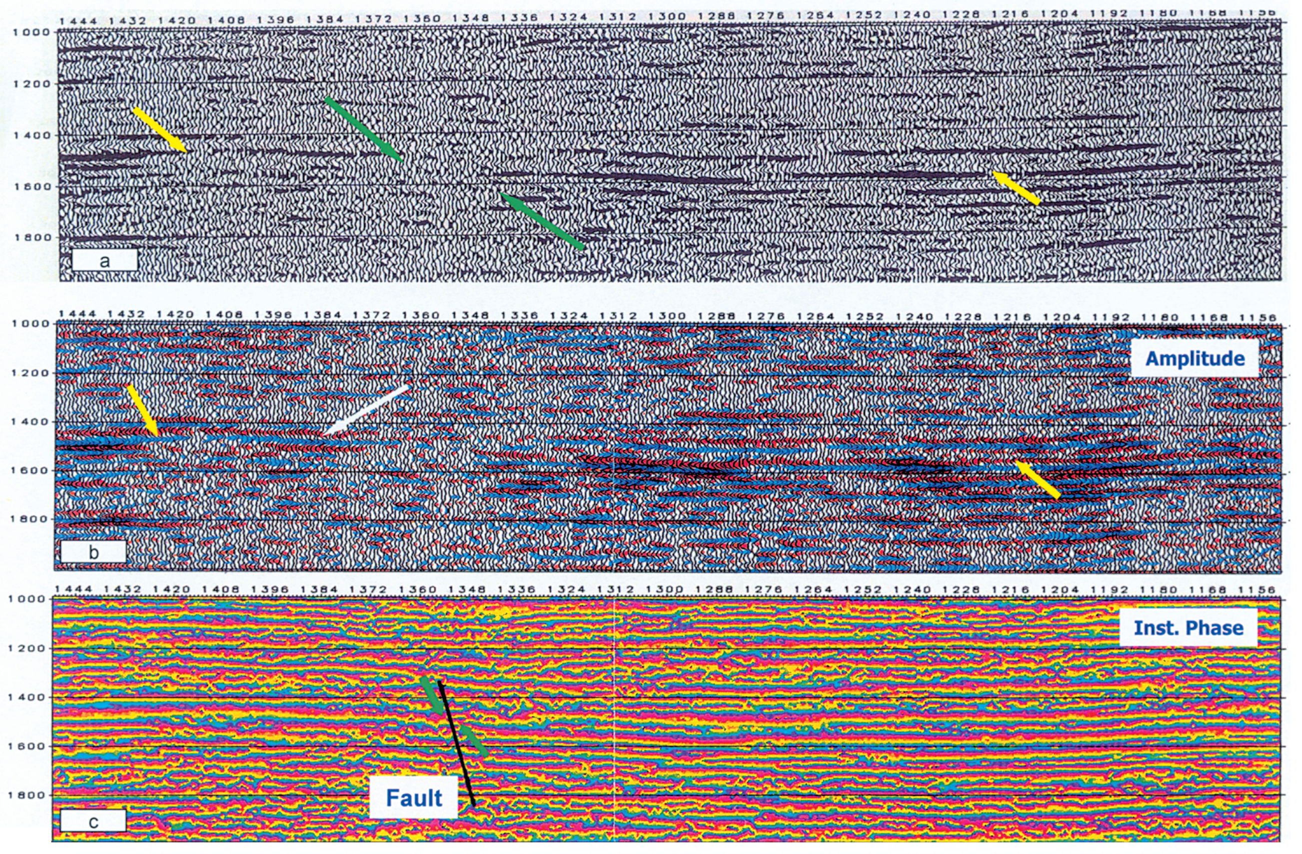

Fig. 8. Portion of seismic section V109 between CMPs 1151-1449: Amplitude and Inst. phase.

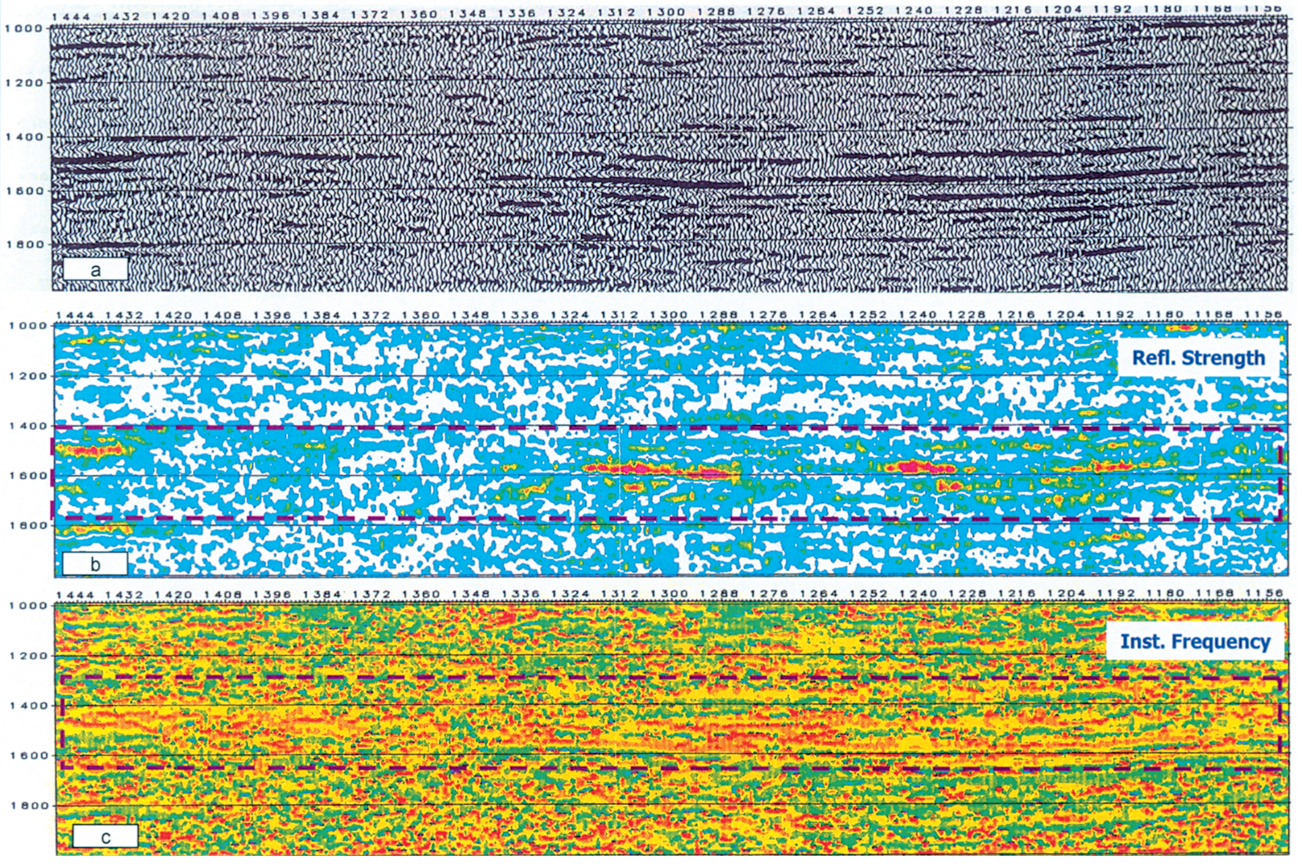

Fig. 9. Portion of seismic section V109 between CMPs 1151-1449: Refl. strength and Inst. frequency.

DISCUSSION AND CONCLUSIONS

The obtained displays show that good and representative response of seismic attributes rely very heavily on the quality of seismic data available. The displays showed the effect of noise and remnant of multiples in obscuring the attributes response (Sheriff, 1976). They are interfering with the main reflection events and had not been completely removed during the noise filtering and deconvolution processing stages.

The main benefit of the use of attributes in the modeled data is in showing the interval of Bahi Formation which can be detected by the change of attributes such as in the E-W synthetic section. The use of attributes has allowed the comparison between the different responses and gives more details which help the interpretation of the seismic data. The plots of amplitude, reflection strength and instantaneous frequency indicate the presence of the Bahi Formation reservoir interval between CMPs 330-370 (Fig. 5). They also show indications of tuning where the reflection interfaces of the Bahi Formation and Rachmat Formation are thinning and/or pinching out. Such indications are not visible in the observed sections and therefore can not be easily followed (Figs. 6 and 8).

Displays of attributes of the observed seismic data are generally of limited use due to the poor quality of the data. Instantaneous frequency displays (Figs. 7c and 9c) show poor definition of reflection event boundaries, and also variable and rapid changes in frequency. The reflection strength displays (Figs. 7b and 9b) show locations of strong reflections but poorly defined the boundaries. The amplitude and instantaneous phase displays (Figs. 6b-c and 8b-c) show reasonably good response regarding the colour representation of continuity along the boundaries of the reflection events in spite of noise and multiples. They are very useful for showing polarity which helps in tracing reflection interfaces. The amplitude and phase also show good indications of fault and stratigraphic unit pinchout (Fig. 8).

Evaluation of the obtained results demonstrates similar observations made by authors such as Taner, *et al.* (1979) and Robertson and Nogami (1984) regarding the use of attributes to enhance the interpretation of the seismic data. The results suggest that the attributes can be useful for the modeled data. For the observed seismic data, only amplitude and instantaneous phase have shown reasonably good results. The poor results are expected to be due to the obscuring factors previously mentioned and better results can be achieved with good quality data.

The display of the synthetic seismic sections had noise added to give the generated traces a visual nature similar to the traces of the observed data. The attribute displays of instantaneous phase and frequency (Figs. 5b, d) show a spurious response surrounding the area of the reflection events.

The instantaneous phase display of the observed data (Figs. 6c and 8c) shows continuous reflections especially on the interval below the basement reflector. These reflections are mainly the result of multiples and noise and such interference should be considered during seismic data assessment.

The colour spectrum available consists of 12 colour windows. The display of the attributes within this range of colours makes the change from one colour to another too abrupt. Therefore, broader colour spectrum might improve the attribute response and give better displays and more detailed interpretation of the seismic data.

REFERENCES

Balch, A. H., 1971. Colour sonograms: A new dimension in seismic data interpretation. *Geophysics*, **36**, 1074-1098.

Belazi, H. S., 1989. The geology of the Nafoora oil field, Sirte Basin, Libya. *J. Petrol. Geol,*, **12** (3), 353-366.

Belazi, H. S., 1986. *Sedimentology of Middle-Upper Eocene Formations, Nafoora-Augila field*, Libya. Ph.D. thesis (Unpubl), University of London.

Bodine, J. H., 1984. Waveform analysis with seismic attributes. Presented at the 54th Ann. Internat. Mtg. Soc. Explor. Geophys., Atlanta.

Elazezi, M. M. 1992. *Seismic Reflection Characteristics of the Precambrian and Upper Cretaceous reservoirs in Nafoora-Augila oil field, Sirt Basin, Libya*. Ph. D. thesis (unpubl), University of Aberdeen

Elazezi, M. M. and Ashcroft, W. 1996. Modelling of the seismic expression of the Upper Cretaceous and Precambrian Reservoirs in An Nafurah-Awjilah Oil Field, Sirt Basin, Libya. In: M.J. Salem, M. T. Busrewil, A.A. Misallati and M.A. Sola (eds.). *The Geology of the Sirt Basin,* **III,** 267-281, Elsevier Amsterdam.

Farnback, J. S., 1975. The complex envelope in seismic signal analysis. *Bull. Seis. Soc. Am.,* **65**, 951-962.

Robertson, J. D. and Nogami, H. H., 1984. Complex seismic trace analysis of thin beds. *Geophysics*, **49**, 344-352.

Sheriff, R. E., 1976. Inferring stratigraphy from seismic data. *Am. Assn. Petr. Geol*. **60**, 528-542.

Sicking, C. J., 1978. Modeling with complex trace. Presented at the 48th ann. Internat. Mtg. *Soc. Explor. Geophys.,* San Francisco.

Taner, M. T., Koehler, F. and Sheriff, R. E., 1979. Complex seismic trace analysis. *Geophysics*, **44**, 1041-1063.

Taner, M. T. and Sheriff, R. E., 1976. Application of amplitude, frequency, and other attributes to stratigraphic and hydrocarbon determination, in Payton, C. E., Ed., Applications to hydrocarbon exploration: *Am. Assoc. Petr. Geol. Mem.*, **26**, 301-327.

Williams, J. J., 1968. The sedimentary and igneous reservoirs of the Augila oil field, Libya. 10th Annual field conference, *Petrol. Expl. Soc. Libya*.

Williams, J. J., 1972. Augila field, Libya: depositional environment and diagenesis of sedimentary reservoir and description of igneous reservoir. In stratigraphic oil and gas fields - classification, exploration methods and case histories. *Am. Assoc. Petr. Geol. Mem.* **16**, 623-632

Yilmaz, O., 1987. Seismic data processing. In: S.M. Doherty (ed.) *Investigations in Geophysics*, **2**, Soc. Explor. Geoph.