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CHARACTERIZATION OF A RESERVOIR IN A SOUTH ALGERIAN PROSPECT USING THE INSTANTANEOUS SEISMIC ATTRIBUTES : EFFICIENCY AND RELIABILITY OF THE INSTANTANEOUS FREQUENCY PARAMETER USING THE JOINT TIME-FREQUENCY ANALYSIS

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ABSTRACT

Present day, exploration for oil and gas requires a combined effort based on the successful integration of the most part of geophysical methods for optimizing the location of data acquisition, identifying and evaluating the productive potential of unexplored regions or extending existing productive traps.

Exploration seismology has been focussed on imaging the structural features of the Earth's subsurface. This approach is now commonplace in most seismic evaluation project due to the ability of this technique under favorable hypothesis to predict reservoirs properties (depth, lateral extension, discrimination between reservoir fluids...). However, after the fantastic software improvement, new robust processing tools (principally in signal processing techniques) have been developed for extracting indirect information provided by structure imaging. These new tools can significantly increase the probability of success associated with a given project.

In this context, the success of direct hydrocarbons detection is primary due to the identification of large negative amplitudes known as bright spot which can define a necessary but not sufficient condition for identifying oil and gas pitfalls. Robust methods involve computed and correlated sesimic attributes such as the instantaneous ones (intantaneous phase, instantaneous frequency, instantaneous amplitude, inversion polarity...) have enjoyed in many cases considerable success for characterizing potential hydrocarbon traps. In the present work, we have precisely used a set of instantaneous attributes to characterize a reservoir located in a permit of the South Algerian Sahara.

However, we take the following question : how about the efficiency and the reliability of each instantaneous seismic attribute ?

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To do this, the instantaneous frequency parameter has been selected because it provides a power indicator of the variations in the energy distribution of the seismic signal, principally in a noisy environment. More recently, adapted signal processing tools are performed ; one can cite the joint time-frequency analysis and its corollaries the Wigner-Ville Distribution, the Wigner bispectrum and the Pseudo-Wigner-Ville representation which are simultaneously tested in the present work on a noisy hyperbolic swept frequency signal.

Keywords - Reservoir- bright spot - Seismic attributes – Instantaneous phase - Instantaneous frequency - Instantaneous amplitude - Apparent polarity - Wigner-Ville Distribution

CARACTERISATION D'UN RESERVOIR DU SUD ALGERIEN PAR APPLICATIONS DES ATTRIBUTS SISMIQUES INSTANTANES : EFFICACITE ET FIABILITE DU PARAMETRE DE FREQUENCE INSTANTANEE PAR L'ANALYSE CONJOINTE TEMPS-FREQUENCE

RESUME

Les techniques actuelles d'exploration d'hydrocarbures (huile et gaz) se concentrent sur une intégration, par ailleurs réussie, des diverses méthodes de géophysique dans un objectif d'optimisation des données enregistrées, d'une justification et d'une estimation des potentialités que peuvent offrir soit les zones non encore explorées ou conforter les performances des pièges en cours d'exploitation.

L'exploration sismique s'est longtemps focalisée sur l'image des structures révélatrice d'une géométrie *a priori* de la subsurface. Cette conception, adoptée de manière concluante dans pratiquement l'intégralité des projets de détection d'hydrocarbures, présente l'avantage, sous la contrainte d'hypothèses favorables, permet de prédire certaines propriétés caractérisant les réservoirs (profondeur, extension latérale, séparation des fluides...). Cependant, eu égard au formidable développement du génie logiciel, des instruments de traitement plus performants ont vu le jour (principalement dans les techniques de traitement du signal), permettant un accès et une extraction des informations dites indirectes émanant de l'image des structures. Ces nouveaux outils ont amélioré les probabilités de succès du projet d'exploration.

A cet effet, l'option de la détection directe des hydrocarbures trouve son origine dans la mise en évidence dans un enregistrement de fortes amplitudes négatives ou "bright-spot". Ce dernier est peut-être une condition nécessaire quant à la présence d'hydrocarbures mais en tout cas pas suffisante. Des méthodes de confirmation intégrant le calcul et la corrélation des attributs sismiques tels que ceux dits instantanés (phase instantanée, fréquence instantanée, amplitude instantanée, inversion de polarité...) ont été appliquées avec succès pour caractériser des pièges potentiels d'hydrocarbures. C'est ainsi que l'un des objectifs du présent travail est la caractérisation par les attributs sismiques instantanés d'un réservoir sis dans un permis d'exploration du Sud Sahara Algérien.

Cependant, une question est à poser: qu'en est-il de l'efficacité et de la précision de chaque attribut sismique instantané? Pour ce faire, nous avons donné une préférence au paramètre de fréquence instantané, sachant que ce dernier constitue un indicateur certain de la nature de la distribution de l'énergie du signal sismique, principalement dans un environnement «bruité». Les approches de calcul et de modélisation emprunté les techniques de l'analyse conjointe temps-fréquence et leurs corollaires la Distribution de Wigner-Ville, le bispectre de Wigner, la Pseudo-Représentation de Wigner-Ville. Ces dernières ont été appliquées dans le présent travail sur un modèle de signal sismique modulé hyperboliquement en fréquence en présence de bruit.

Mots-clé - Réservoir- Bright spot - Attributs sismiques - Phase instantanée - Fréquence instantanée - Amplitude instantanée - Polarité apparente - Distribution de Wigner-Ville.

INTRODUCTION

An instantaneous seismic attribute or simply attribute is defined as all qualitative or quantitative characteristics which «cloth» a variety of sequences derived from seismic traces. The seismic attributes analysis, viewed as another way in the processing of seismic data, involves computing and the description of some features which are not, generally, easy to get within the conventional sequences of processing (Taner, 1977, 2000). We distinguish a large variety of seismic attributes not only in their nature but also in their interpretation. That is, an argued classification of the seismic attributes is proposed : physical and geometric for the wellknown of them.

Regarding this classification, the objectives of the interpretation may be differ and cover a large spectrum of attributes including for example the lithological informations, the geological structure of the subsurface, the hydrocarbon detection through direct hydrocarbon indicators, the reservoir characterization ... (Taner, 2000; and Ferrahtia, 2001).

The principle of the seismic interpretation using the seismic attributes is based on the concept of the attribute anomaly for the geometric approach or the computing and the measuring of the instantaneous parameters variations like the instantaneous frequency, the instantaneous phase, the instantaneous envelope, the inversion of polarity and many others.

Among the most requirements of the seismic attribute analysis, we privilege the search of a good graphical resolution within the seismic sections. Therefore, the use of a wheel of standard or combination colours implies an aesthetic representation and an easier interpretation of the seismic maps (Ferrahtia, 2001).

The aim of this paper involves four main parts :

- A modelling of some instantaneous seismic attributes according to their mathematic compute and their properties.

- An application of the seismic attributes on real data from a seismic reflection survey in the South Algerian Sahara.

- The use of the time-frequency analysis of non-stationary signals for a computing accuracy of the classical seismic attributes.

- The concept integration of the weighted average instantaneous frequency law which will show the «fragility» of this parameter in the multi-component signal processing.

ABOUT THE SEISMIC ATTRIBUTES

Two wide families of seismic attributes are usually adopted for their classification : the instantaneous attibutes class and the geometrical attibutes group. Although this classification seems to be a logical or natural discrimination between the most known seismic attributes, one can add to these two categories any judicious other parameters carring suitable seismic information, like the high order of the instantaneous envelope, the instantaneous quality factor or the instantaneous acceleration. According to the classification drawn by M. T. Taner (2000), the physical attributes are subdivised into three subclasses :

- the attributes deduced from the analytic trace for computing the instantaneous attributes;

- the attributes describing the seismic events;

- the attributes related to the geometrical scheme of the subsurface.

The instantaneous attributes

Another approach for the implementation of the analytical signal

These attributes derive from the analytical trace which is built by using the Hilbert Transform (HT) of the recorded one. Given a causal signal *s(t)*, its spectrum *S(v)* calculated via the Fourier Transform (FT) is generally a complex expression, so that:

$$S(v) = A(v) + jB(v) \quad (1)$$

The real part of *S(v)* i.e *A(v)* and the imaginary part i.e *B(v)* are related to each other by a biunivoque mathematical correspondence (the Hilbert Transform) such as :

$$A(v) \xrightarrow{TH} Bv) \Leftrightarrow B(v) = -\frac{1}{\pi} V_p \frac{1}{v} * A(v) \quad (2)$$

where V_p denotes the *principal Value integral* and the symbol " * " the convolution operation. Since the signal *s(t)* is real, its spectrum *S(v)* is characterizesd by hermytian symetry such as:

$$S(-v) = S^*(v), \quad v \geq 0 \quad (3)$$

((*) denotes the complex conjugate). Then the negative frequential components don't carry any additional information; therefore the useful information is completely contained in the positive side of the spectrum. An immediate consequence of the previous observation allows to define a signal noted *z(t)* such as its frequency complex spectrum *Z(v)* must verify the following relation:

$$Z(v) = \begin{cases} 2S(v) & if\, v > 0 \\ S(v) & if\ v = 0 \\ 0 & otherwise \end{cases} \quad (4)$$

By taking the inverse Fourier transform, one can obtain the time equation of the analytical signal *z(t)* associated to the real and causal signal *s(t)* such as :

$$z(t) = s(t) + j\left[-\frac{1}{\pi} V_p \frac{1}{t}\right] * s(t) \quad (5)$$

The imaginary part of the analytic signal *z(t)* is known as the quadrature signal of *s(t)* and defines its Hilbert Transform (Barry *and al.*, 1990; Chahraborty *and al.*, 1995). For a discrete sequence $\{s_n\}_{n \in N}$ an accurate relation may be found for the implementation of the discrete analytical signal by the discrete Hilbert Transform:

$$z(n) = s(n) + j[s(n) * h(n)] \quad (6)$$

where the term *h(n)* represents the impulsional response of the quadrature filter such as :

$$z(n) = \begin{cases} \frac{2}{\pi n} \sin^2\left(\frac{\pi n}{2}\right) & if\ n \neq 0 \\ 0 & if\ \ n = 0 \end{cases} \quad (7)$$

This impulsional response is generally non causal and infinite. In practice the sequence is limited towards the low frequencies by applaying a suitable window.

Using analytical traces in the seismic modelling

The analytic approach leads to hold three simultaneous representations :

1 - The real part of *z(x,t)* which is in fact the given real input trace (Ferrahtia, 2001; James *and al.*, 1984). Therefore one can built a synthetic seismic

section by adding an offset variation and this for a chosen geological model (fig.1 (a)).

2 - The use of the imaginary part of *z(x,t)* which defines its quadrature component, enables to obtain another seismic section (fig. 1(b)). Note that no significative differencies may be distinguished between the two sections (a) and (b).

3 - The modulus of the input analytical trace *z(x,t)* or its square, represents the envelope *e(x,t)* computed as :

$$e^2(x,t) = Re^2[z(x,t)] + \mathrm{Im}^2[z(x,t)] \qquad (8)$$

An example of a seismic section in terms of trace envelope is shown in (fig. 1 (c)). Notice the sharp character of the peaks. This means that the envelope reflects in the same time the distribution of the instantaneous energy of the analytical trace and the range of the impedance constrasts directly in relation with :

- the possible changes of lithology;

- the local uncomformities like faults, or discordances;

- the bright spots interpreted as probable gas accumulation;

- the thin bed effects.

4 - Generally speaking, the time derivative of the instantaneous envelope may be interpretated as a ratio of the variation of the energy versus time. This last effect is simply the absorption phenomenon due to :

- the interface events like sharp interfaces;

- attenuation or dispersial phenomena;

- local discontinuities.

The following synthetic seismic section (fig.2) illustrates the behaviour of the instantaneous envelope in the case of a pinch -out. Notice the character of the concentration of the energy around the end of this synthetic structure.

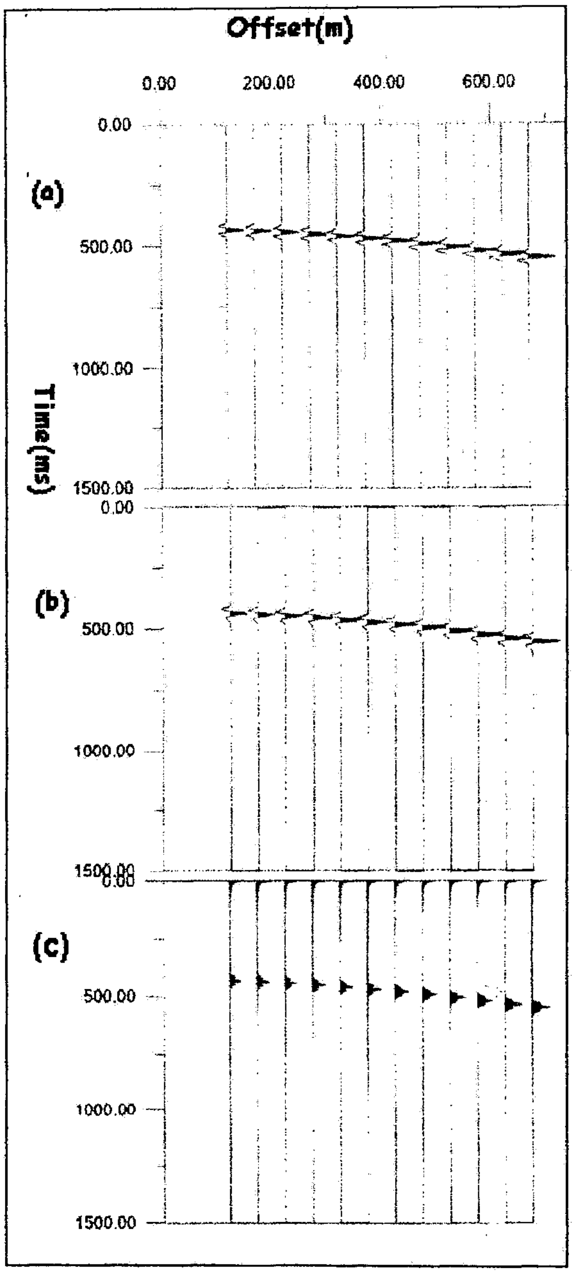


Fig. 1 - Analytical seismic sections in terms :
a - real part, **b** - imaginary part and **c** - envelope

Section sismique en mode analytique en terme de :
a - partie réelle, b - partie imaginaire et c- d'enveloppe

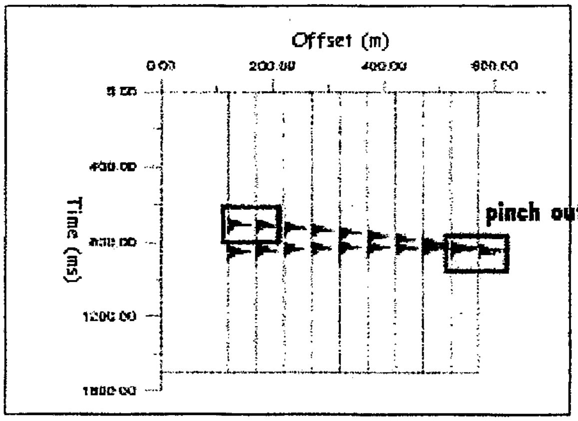


Fig. 2 - Sismic section with pinch-out

Section sismique exhibant en biseau

5 - The analytical input trace exhibits also another instantaneous attribute defined as its argument like:

$$\varphi(x,t) = Arg\left[z(x,t)\right] = arctg\left\{ \frac{\mathrm{Im}\left[z(x,t)\right]}{Re\left[z(x,t)\right]} \right\} \quad (9)$$

Before studying the instantaneous phase as a seismic attribute, a synthetic section was built using the argument $\varphi(x,t)$ (fig3. and fig.4). This synthetic seismic section highlights an evident delay of the traces according to the following property: from equation (11), the relation between the spectrum of the real signal i.e. $S(\nu)$ and the quadrature spectrum i.e. $S_Q(\nu)$ is expressed as:

$$S_Q(\nu) = \left[-j\,sgn(\nu)\right].S(\nu) \quad (10)$$

So the argument of $S_Q(\nu)$ is obtained as :

$$Arg\left[S_Q(\nu)\right] = Arg\left[S(\nu)\right] - \frac{\pi}{2} \quad (11)$$

The phase displacement appears now as a polarity inversion of the traces at the same location compared to the previous section.

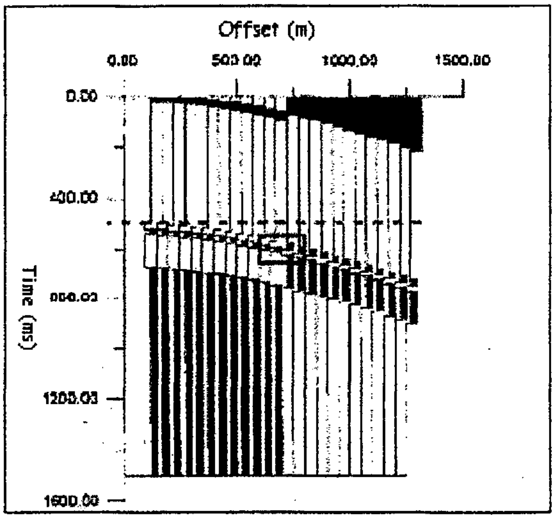


Fig. 3 - Instantaneous phase section

Section sismique en phase instantanée

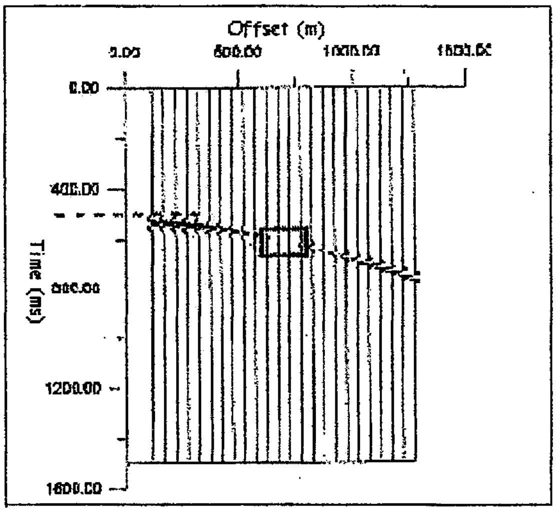


Fig. 4 - Instantaneous phase section in CMP group

Section sismique en phase instantanée et en groupe CMP

SEISMIC ANALYSIS USING TIME-FREQUENCY DISTRIBUTION

The Fourier Transform between efficiency and inadequacy

All the instantaneous seismic attributes applied previously, were expressed exclusively in the time domain. It is known that the reflection seismic data also involve a frequency content which is itself related to the seismic event. Furthermore, it becomes most important to integrate the frequency component to the time behaviour of the seismic data. That is, for example, the energy spectrum belongs to the instantaneous attributes class.

Unfortunately, the most popular tool used in many arrays of the signal processing application is based on the spectral analysis personified by the Fourier Transform which requires a fundamental condition : the stationarity of the analyzed signal (Barry *and al.*, 1990; Chahraborty *and al.*, 1995). Then the Fourier Transform is confronted with the case of processing signals where the spectral behaviour is varying with the time. Among the other criticsconcerning the efficiency of the classical spectral analysis, we have the following objection : it has found that two distinct signals might present a same spectral representation. Therefore, the power discrimation of the Fourier Transform is not always reliable (Djeddi *and al.*, 1994).

THE INSTANTANEOUS FREQUENCY COMPUTED VIA THE TIME-FREQUENCY DISTRIBUTION

A short review on the time-frequency representation

As we have seen in the previous case, the most used Fourier Transform presents some disavantages in the practice according to the hypothesis that the signal is stationary. The Short Fourier Transform may give an alternative solution to this condition but the choice of the analysing window becomes an another problem. So, for such non stationary signals, the concept of time-frequency analysis is defined in an attempt to provide a suitable tool for their spectral representation and the computing of their intrinsic parameters like the instantaneous frequency, the group delay, the distribution of the energy ... (Cohen *and al.*, 1990; Boashash *and al.*, 1987).

In the most popular Time-Frequency Distribution known as the Wigner-Ville Representation, a kernel function $K(t,\tau)$ is fixed as a basis of the decomposition. To explicit the form of the kernel, two similar expression may be used :

- $K(t,\tau)$ expressed directly from the given real signal so that :

$$K_s(t,\tau)=s(t+\frac{\tau}{2})\,s(t-\frac{\tau}{2}) \qquad (12)$$

- The analytical form of the real signal is currently used for reducing the interferences due to the non-linearity of this time-frequency representation so that:

$$K_z(t,\tau)=z(t+\frac{\tau}{2})\;z^*(t-\frac{\tau}{2}) \qquad (13)$$

(z^*, t and τ denote respectively the conjugate of the analytic signal z, t the time variable and τ the time-lag)

The Wigner-Ville Distribution (WVD) defines the Fourier Transform of the kernel $Z(k,\tau)$ in relation to the time-lag τ as :

$$WVD_z(t,\nu)=\int_{-\infty}^{+\infty} K_z(t,\tau)\exp(-2\pi j\nu\tau)\,d\tau \qquad (14)$$

In practice, the bi-dimensional function $WVD_z(t,\nu)$ describes the distribution of the signal energy in the time-frequency domain. In fact it is considered as a pseudo-energy density from. Which the law of the energy variation may be analyzed jointly in the two directions: time and frequency.

Figure 5 is an illustration of the time-frequency distribution of an hyperbolic frequency decreasing modulation signal s(t) so that :

$$s(t)=\prod_T(t-\frac{T}{2})\cos[\varphi(t)] \qquad (15)$$

with :

$$\varphi(t)=\frac{2\pi\nu_0}{\alpha}\log|1+\alpha t| \qquad (16)$$

where α and ν_0 are fixed parametres and $\prod_T(t)$ the natural rectangular window related to the duration T of the real signal. The analytic signal associated with s(t) is computed as [15]:

$$z(t)=\prod_T(t-\frac{T}{2})\exp(2\pi j\nu_0)\log|1+\alpha t| \qquad (17)$$

The integration (14) yields the *WVD* of the previous signal :

$$WVD_z(t,\nu)=\prod_T(t-\frac{T}{2})\frac{\sin[\psi(t,\nu)]}{\pi\left(\nu-\frac{\nu_0}{1+\alpha t}\right)} \qquad (18)$$

with :

$$\psi(t,\nu)=\sin\left[2\pi(T-2\left|t-\frac{T}{2}\right|(\nu-\frac{\nu_0}{1+\alpha t})\right] \qquad (19)$$

For a decreasing law modulation, we take $\alpha<0$.

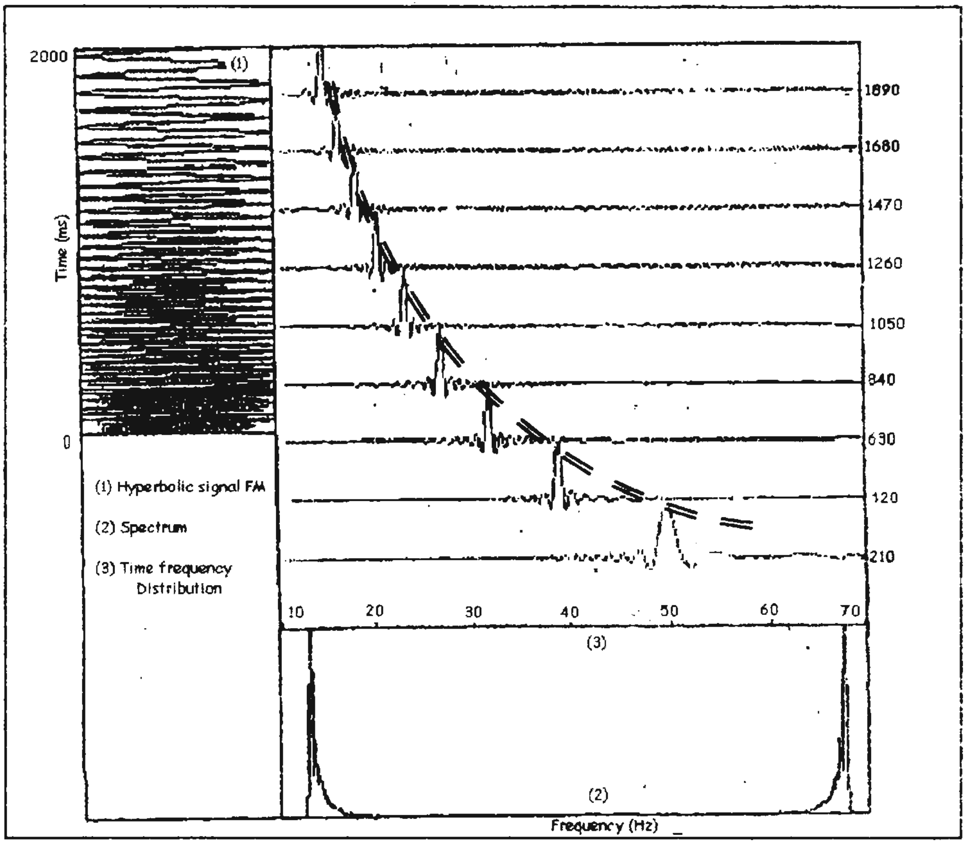


Fig. 5 - WVD Hyperbolique Frequency Modulation Signal

Distribution de Wigner-Ville d'un signal Modulé Hyperboliquement en Fréquence

The curve which joins the peaks of the prevoius time-frequency distribution highlights the nature of the instantaneous frequency law (fig. 5) (here a decreasing hyperbolic frequency law).

The interpretation of WVD

The major disavantage of the WVD is its non-positivity and consequently it does not define an energy density or an instantaneous energy distribution in the time-frequency domain. However, the WVD presents many other performances in the signal processing; the time-frequency analysis allows at least two objectives: a local variation of intrinsic parameters like dispersion or attenuation phenomenon depicted by the deviation of the instantaneous frequency curve and a panoramic view of the signal behaviour in the time-frequency space. Therefore, the total energy E_t of the sequence may be calculated using the following integral (Djeddi *and al.*, 1994):

$$E_t = \int_{-\infty}^{+\infty} WVD_z(t,\nu)\,d\nu \qquad (20)$$

Graphically, the energy E_t is related to the area involved in the each lobe of the WV distribution. However, for elucidating and extracting with accuracy the salient characteristics of the signal, the use of the WVD seems more adapted than the classical method based on the analytical representation.

Computing the instantaneous frequency from the time-frequency distribution

To estimate the instantaneous frequency law from the Wigner-Ville Distribution, we take the first time moment of the WVD with the normalization by the temporal energy previously expressed like :

$$\nu_i(t) = \frac{\int_{-\infty}^{+\infty} \nu\, WVD_z(t,\nu)\,d\nu}{E_t} \qquad (21)$$

THE WIGNER-VILLE BISPECTRUM

It easy to generalize the concept of the Wigner-Ville spectrum to formulate the WV bispectrum . The first step consists in defining an appropriate kernel $K_3(t,\tau_1,\tau_2)$ which is widely similar to the previous products :

$$K_{3s}(t,\tau_1,\tau_2) = s(t)s(t+\tau_1)s(t+\tau_2) \qquad (22)$$

This kernel may be writen under the form:

$$K_{3s}(t,\tau_1,\tau_2) = \alpha(t)\beta(t)\gamma(t) \qquad (23)$$

with :

$$\begin{cases} \alpha(t) = s\left[t - \frac{1}{3}(\tau_1+\tau_2)\right] \\ \beta(t) = s\left[t - \frac{1}{3}(-2\tau_1+\tau_2)\right] \\ \gamma(t) = s\left[t - \frac{1}{3}(\tau_1-2\tau_2)\right] \end{cases} \qquad (24)$$

The simplest form of the WV bispectrum $WVD_{3s}(t,\nu_1,\nu_2)$ is obtained by taking the bidimensional Fourier transform of the kernel $K_{3s}(t,\tau_1,\tau_2)$ like :

$$WVD_{3s}(t,\nu_1,\nu_2) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} K_{3s}(t,\tau_1,\tau_2).\exp\left[-2\pi j(\nu_1\tau_1+\nu_2\tau_2)\right] d\tau_1\, d\tau_2 \qquad (25)$$

Figure 8, shows the Wigner-Ville bispectrum of the previous Hyperbolic FM signal .

A simple comparison between the two representations Wigner-Ville spectrum (fig.6) and bispectrum (fig.8) highlights at the same time an evident attenuation of the greatest part of the interference terms , a better identification of the frequential bandwidth and a fair authentification of the of the instantaneous frequency law. In the case of a multicomponent record $s(t)$, oscillating terms between the components of the signal appear: then if :

$$s(t)=\sum_i s_i(t) \qquad (26)$$

The Wigner-Ville Distribution of $s(t)$, is obtained under the following form :

$$WVD_{\sum_i s_i(t)}(t,\nu)=\sum_i WVD_{s_i}(t,\nu)+I(t,\nu) \qquad (27)$$

where :

$$I(t,\nu)=2Re\left[\sum_{\substack{i,j\\ i\neq j}} WVD_{s_i,s_j}(t,\nu)\right] \qquad (28)$$

$Re[.]$ represents the real part of the expression written between bracksets.

The time-frequency function $I(t,\nu)$ is the cross-term interference which damages the resolution of the WV energy distribution and consequently its interpretation. The filtering of the cross-terms can be done by a smoothing operation of the WVD, using a smoothing function.

THE PSEUDO WIGNER-VILLE DISTRIBUTION (PWVD) [15]

Basic formulation

Since the WVD is often a non-causal transform, in practice the duration of the signal to be analyzed is shorter than the theoretical time observation. So, it may be localized in a specified interval by using an chosen observation window $w(t)$ submitted to a translation:

$$z_w(t)=z(t).w(t-t_0) \qquad (29)$$

In this case, the WVD becomes a localized time-frequency distribution known as the Pseudo-Wigner-Ville Distribution (PWVD) so that:

$$PWVD_{z_w}(t,\nu)=WVD_z(t,\nu)\overset{\nu}{*}WVD_w(t,\nu) \qquad (30)$$

($\overset{\nu}{*}$ denotes the convolution product versus the frequency). Thus the PWVD improves the frequency resolution without any effect in the time direction.

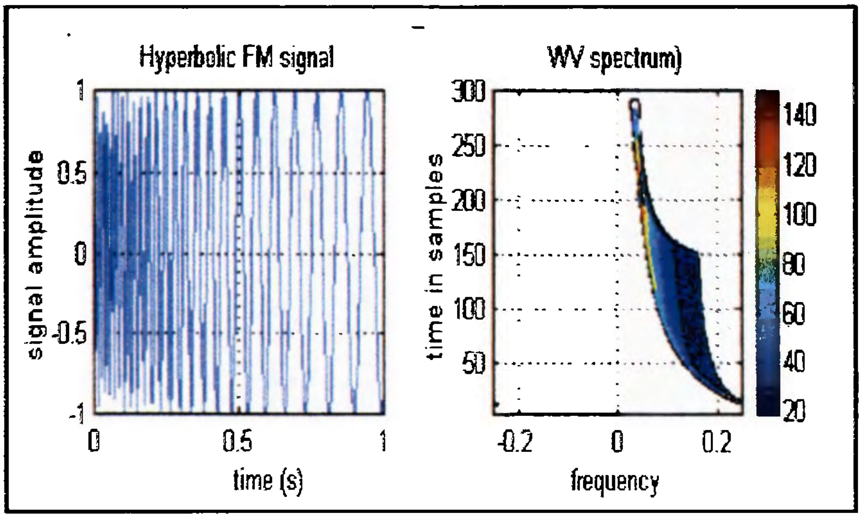


Fig. 6 - WVD of noiseless HFM Signal

Distribution de Wigner-Ville d'un signal MHF en absence de bruit

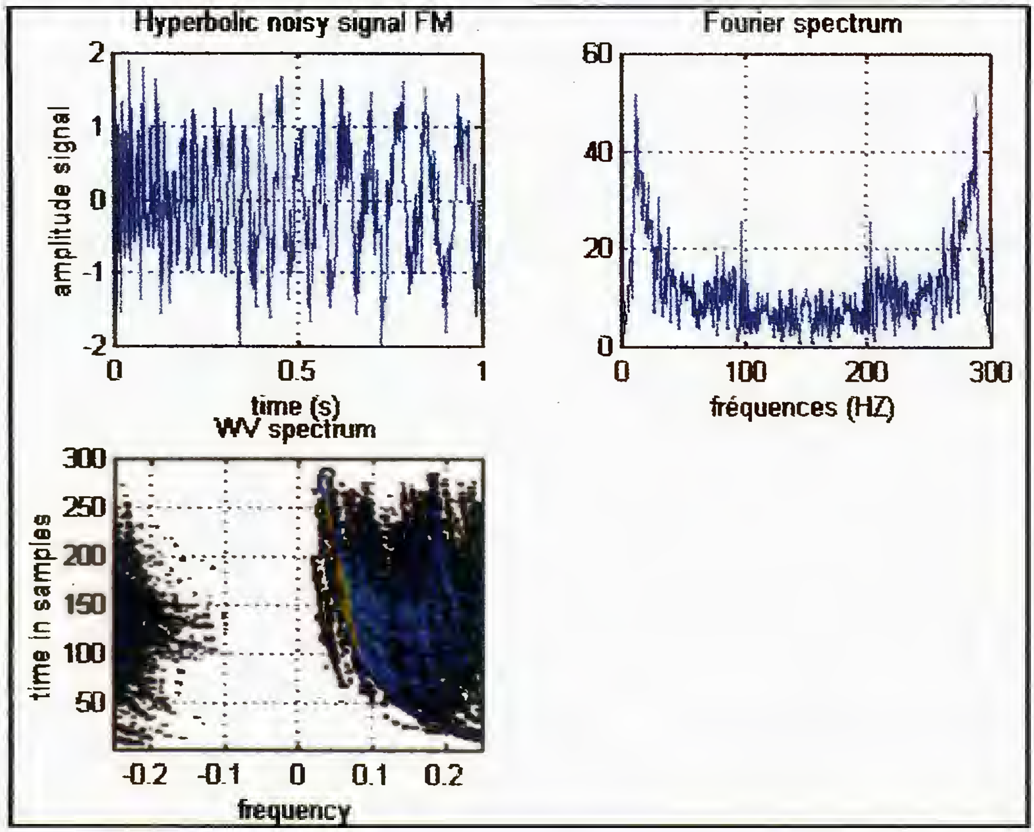


Fig. 7 - Spectrum and WVD of a noisy HFM signal

Spectre et Distribution de Wigner-Ville d'un signal MHF en présence de bruit

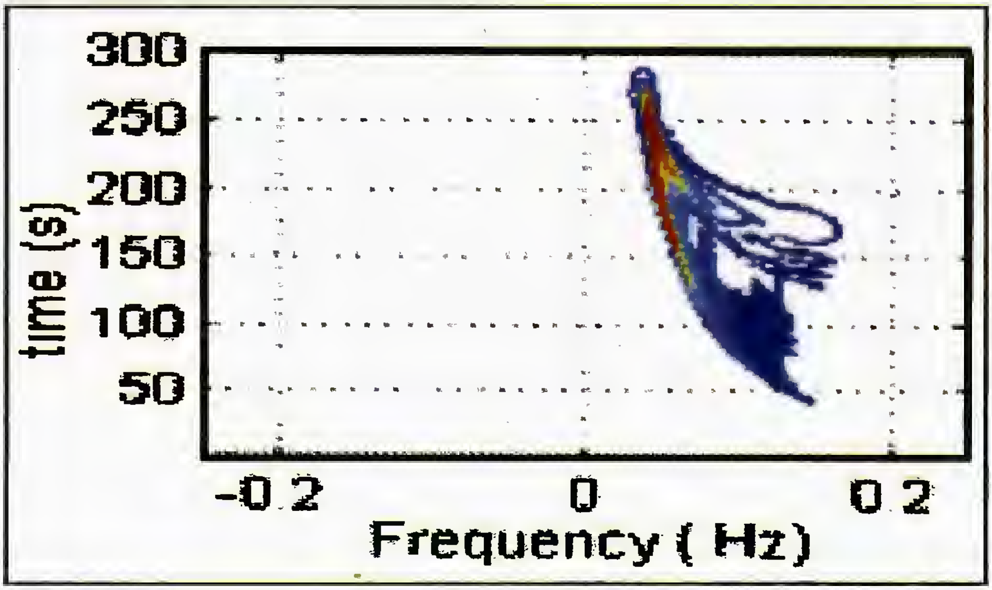


Fig. 8 - Wigner-Ville Bispectrum of the HFM signal

Bispectre de Wigner-Ville d'un signal MHF

The instantaneous frequency law through the PWVD

Since the instantaneous frequency represents a measure of the distribution of energy, the limitation an analysing window which length equals the duration of the signal, does not affect this intrinsic parameters; so the same expressions used in the calculus of the instantaneous frequency previously showed may be reproduced relatively to the PWVD (Velez *and al.*, 1990). Therefore the normalized first moment of the PWVD is another possibility to obtain the instantaneous frequency law :

$$v_i(t) = \frac{\int_{-\infty}^{+\infty} v PWVD(t,v)dv}{\int_{-\infty}^{+\infty} PWVD(t,v)dv} = \frac{\int_{-\infty}^{+\infty} v WVD(t,v)dv}{\int_{-\infty}^{+\infty} WVD(t,v)dv} \quad (31)$$

Another way to characterize the nature of the energy distribution consists in calculating the high order moments of WVD or PWVD; for exemple the second order allows to obtain the standard deviation function.

THE WEIGHTED AVERAGE INSTANTANEOUS FREQUENCY LAW

The estimation of the instantaneous frequency law is not easy in many cases because of the interference terms contained in the multicomponent signals. However, the wieghted average instantaneous frequency may be a useful tool for analysing this class of signals (Jons *and al.*, 1990).

Let $z_m(t)$ a multicomponent signal such as :

$$z_m(t) = \sum_i z_i(t) \quad (32)$$

where $z_i(t) = a_i(t)\exp[-j\varphi_i(t)]$ represents the ith component. We take the correspondant WVD of (25):

$$WVD_{z_m}(t,v) = \sum_k WVD_{z_k}(t,v) + Q(t,v) \quad (33)$$

with :

$$Q(t,v) = \sum_{\substack{k,l \\ k\neq l}} XWVD_{z_k,z_l}(t,v) \quad (34)$$

The two variables additive function $Q(t,v)$ exhibits the cross-WVD ($XWVD$) distorsions that are characteristic of the interferences implying an oscillatory pattern or noisy effect. By taking the normalized first moment of the $WVD_{z_m}(t,v)$, we obtain the instantaneous frequency law $v_i(t,v)$ so that:

$$v_i(t) = \frac{\int_{-\infty}^{+\infty} v\, WVD_{z_m}(t,v)dv}{\int_{-\infty}^{+\infty} WVD_{z_m}(t,v)dv} \quad (35)$$

Therefore two components occur in the global instantaneous law : a fundmental component $v_{i1}(t)$ highlighting the real character of the energy distribution and an hybrid component $v_{i2}(t)$ which appears as a ghost intantaneous frequency law; these two laws are expressed as (Djeddi *and al.*, 1994):

$$v_{i1}(t,v) = \frac{\sum_k \int_{-\infty}^{+\infty} v\, WVD_{z_k}(t,v)dv}{\sum_k \int_{-\infty}^{+\infty} WVD_{z_k}(t,v)dv + \int_{-\infty}^{+\infty} Q(t,v)dv} \quad (36)$$

and

$$v_{i2}(t,v) = \frac{\int_{-\infty}^{+\infty} v\, Q(t,v)dv}{\sum_k \int_{-\infty}^{+\infty} WVD_{z_k}(t,v)dv + \int_{-\infty}^{+\infty} Q(t,v)dv} \quad (37)$$

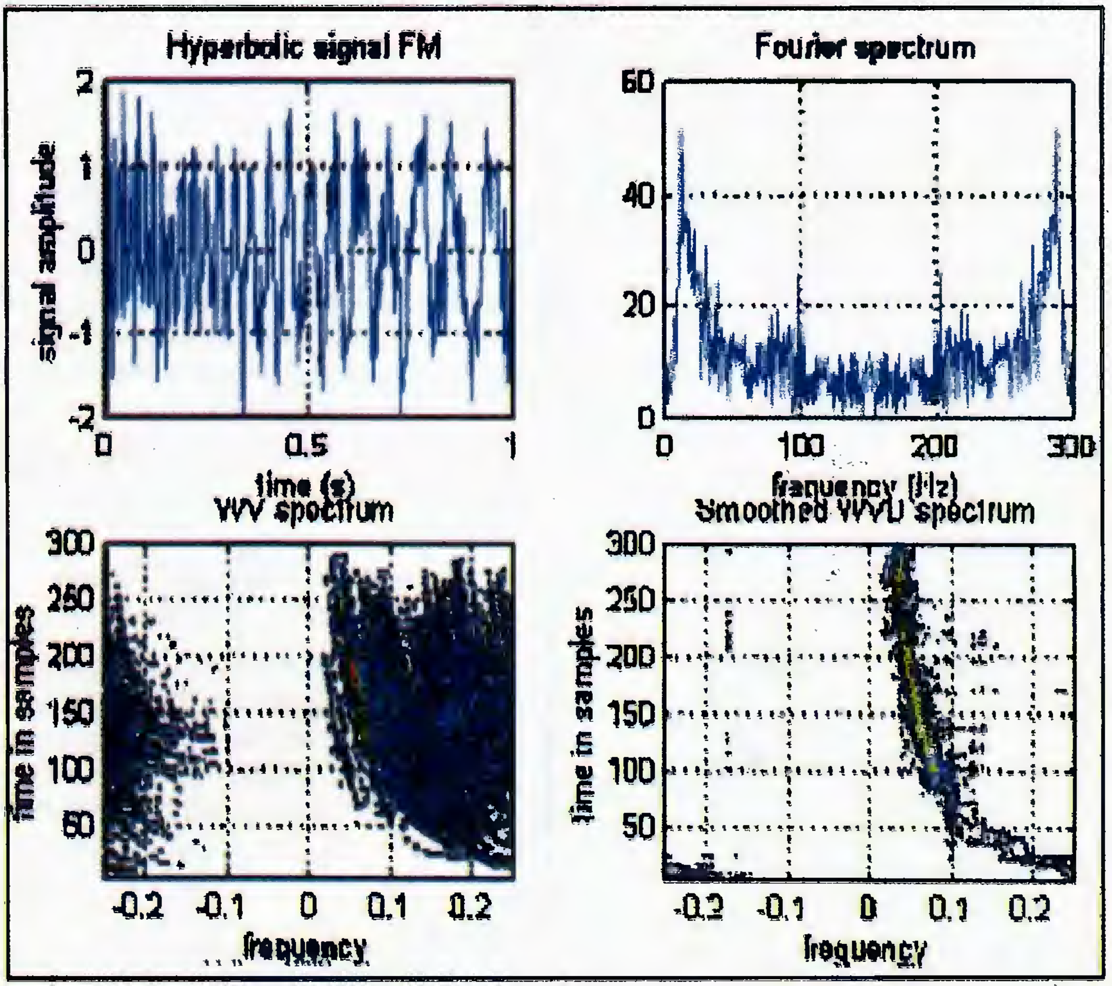


Fig. 9 - PWVD of a noisy HFM signal

Pseudo-Distribution de Wigner-Ville d'un signal MHF en présence de bruit

The objective is to avoid the distorsion effects by filtering the ghost term $v_{i2}(t)$. For any component $z_k(t)$, we can see that :

$$\int_{-\infty}^{+\infty} v\, WVD_{z_k}(t,v)dv = v_{i_k}(t)\left|z_k(t)\right|^2 = v_{i_k}(t).a_k^{\,2}(t) \qquad (38)$$

By tayking only the real parts of the calculated integrals, the integral of the XWVD may be written under the form:

$$\int_{-\infty}^{+\infty} XWVD_{z_k,z_l}(t,v)dv = a_k(t)a_l(t).C(t) \qquad (39)$$

In the same way:

$$\int_{-\infty}^{+\infty} vXWVD_{z_k,z_l}(t,v)dv = v_{ik}(t).a_k(t)a_l(t).C(t) \qquad (40)$$

$$\int_{-\infty}^{+\infty} vXWVD_{z_k,z_l}(t,v)dv = v_{il}(t).a_k(t)a_l(t).C(t) \qquad (41)$$

with : $C(t) = \cos[\varphi_k(t) - \varphi_l(t)]$

Finally the instantaneous frequency law of the multicomponent signal$z_m(t)$?is expressed as follow:

$$v_i(t) = \frac{\sum_k a_k^2(t) v_{ik}(t) + \sum_{\substack{k,l \\ k \neq l}} N_{k,l}(t)\left[v_{ik}(t) - v_{il}(t)\right]}{\sum_k a_k^2(t) + \sum_{\substack{k,l \\ k \neq l}} N_{k,l}(t)} \qquad (42)$$

with :

$$N_{k,l}(t) = a_k(t).a_l(t)\cos\left[\varphi_k(t) - \varphi_l(t)\right] \qquad (35)$$

Thus the instantaneous frequency law is formulated as a sum of two factors which are:

- a normalized linear combination of the partial instantaneous frequency laws;

- a normalized oscillatory factor defining the interference effects.

A best approximation is obtained by a time filtering using a windowed instantaneous frequency law, in fact by the interference suppression. The terms of the XWVD become substantially reduced and the resultant instantaneous frequency law is performed as the weighted average instantaneous frequency law v_{wai} formulated as follow:

$$v_{wai}(t) = \frac{\sum_k a_k^2(t) v_{ik}(t)}{\sum_k a_k^2(t)} \qquad (43)$$

INSTANTANEOUS SEISMIC ATTRIBUTES FOR RESERVOIR CHARACTERIZATION : A CASE IN A PROSPECT OF SOUTH ALGERIA

Objective of the present seismic study (seismic section n° 3)

The first aim of the present seismic study involves the detection and the identification of a gas accumulation according to the seismic survey. The study has been done using a profile crossing a productive well; it turns out to justify the efficiency of the seismic attributes analysis and the direct detection of hydrocarbons. The processed file belongs to a gas region while the geological objectives are the low Devonian and the Ordovician with structural traps. However, in the lower Devonian, the reservoirs are located in the Givitian and may contain potential stratigraphic traps. Notice that the seismic data were recorded with a poor resolution regarding to the level of the coverage (4800 %) and the value of the inter-trace equals to 70 m (seismic sections n° 1 and 2).

Interpretation using the seismic attributes analysis

The analysis of the different seismic sections relatively to each seismic attribute is based on the preserved amplitudes map. Thus four seismic attributes have been displayed in order to highlight a seismic event which will be viewed as a seismic anomaly in the subsurface.

Using the preserved amplitudes section (seismic section n° 4)

This section shows a high negative peak amplitude which is detected around the CDP n° 70 at 850 ms in the double time scaling. More than a seismic event, the bright spot exhibited by the preserved amplitudes section becomes a prior hypothesis before beginning the seismic attributes analysis. In order to obtain valid arguments to justify the effective position of the bright spot, a combination of three attributes was displayed.

Using the apparent polarity attribute (seismic section n° 5)

This section shows clearly an inverse or a negative polarity descripted in blue color around the previously CDP. It is known that the apparent polarity gives the sign and the value of the real amplitude when the envelope reaches its maximum.

Using instantaneous frequency attribute (seismic section n° 6)

This section highlights a yellow band characterizing a low frequency content according to colorbar as it can be seen around the same CDP n° 70 at the same previous time near 890 ms. This low frequency behaviour results from the decreasing of the seismic velocities which is a highest possibility of gas occurence.

Using instantaneous phase attribute (seismic section n° 7) and the normalized amplitudes (seismic section n° 8)

The interpretation of the previous seismic sections constitute convincing arguments to confirm the existence of the hydrocarbon reservoir. Now, using the two seismic sections, in instantaneous phase and in normalized amplitudes, allows to reach its geometrical properties like the lateral extension.

The continuity of the seismic events is clearly defined and the reservoir extension goes from the CDP 725 (890 ms) to CDP 905 (900 ms) accrossing the CDP 771. This closure may be constitute the lateral extension of the confirmed the hydrocarbon reservoir .

CONCLUSION

The previous work involves two parts whitch are substantially related under their instantaneous character.

We have outlined the interest of the instantaneous seismic attributes and of their combined interpretation for a comprehensive procedure applicable to the direct hydrocarbon detection and the characterization of a given reservoir. As resulte, this approach improve the argumentation based upon the investigation of the existing bright spot. Therefore we have detected and outlined in the same time a gas pittfall as suggested by the existing bright spot and the lateral extension of the correspondant hydorcarbon reservoir.

Aditionally, the instantaneous seismic attribute was extented to instantaneous frequency law defined as a more useful function to aid understanding the energy distribution of the signal.

The use of a Hyperbolic Frequency Modulation signal as a synthetic model allowed us to increase our understanding of the behaviour of the instantaneous law over the a time-frequency analysis method, here the Wigner-Ville Distribution (WVD).

REFERENCES

Barry, D.T., Cole, N.M. and Wood, J.C., 1990. Time-Frequency analysis of resonating biological systems. ISSA90, *Theories, Implementations and Applications Gold-Coast Australia.*

Boashash, B. and White Housse H.J., 1987. High resolution Wigner-Ville analysis. *Onzième Colloque GRETSI Nice France.*

Boashash, B. and Black, 1987. An efficient real time implementation of the Wigner-Ville Distribution. IEEE Transactions on Acoustics, *Speech and Signal Processing* Vol. ASSP-35, No 11.

Chakraborty, A. and Okaya, D., 1995. Frequency-time decomposition of seismic data using wavelet based method, *Geophysics* Vol. 60 No. 6 pp. 1906-1916.

Cohen, L. and Lee, C., 1990. Optimal Windows for the Short Time Fourier Transform. ISSA90, *Theories, Implementations and Applications Gold-Coast Australia.*

Djeddi, Mbrk.Ouahabi, A. et Aïtouche, M. A., 1994. Traitement du signal – Les représentations conjointes temps-fréquence. *Office des Publications Universitaires Alger.*

Ferrahtia, D., 2001. Le domaine des attributs sismiques appliqué à la détection directe des hydrocarbures. Magister thesis – *University of Boumerdes Algeria.*

James, D. R. and Henry, H.N., 1984. Complex seismic trace in thin beds. *Geophysics*, Vol.49, pp. 344-352.

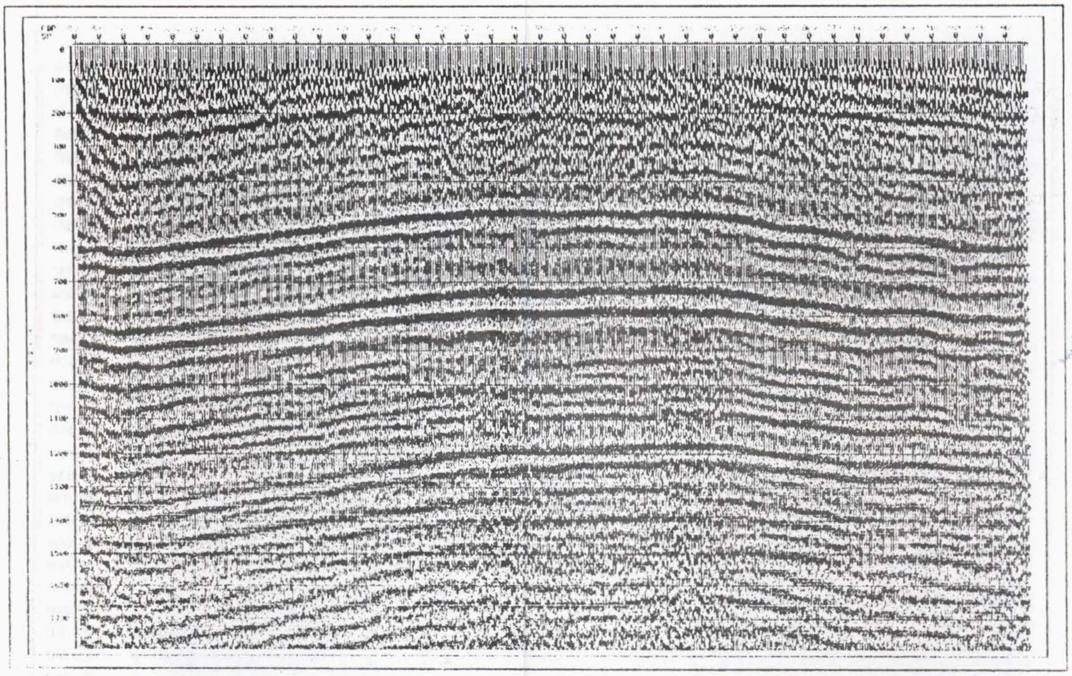
Jones, G. and Boashash, B., 1990. Instantaneous frequency and the analysis of multicomponent signals, ISSA90,*Theories, Implementations and Applications Gold-Coast Australia.*

Speicer, J.M., 1990. functional equations in signal processing.*ISSPA90 Theories, Implementations and Apllications Gold Coast Australia.*

Taner, M. T, 1977. Application of the amplitude, frequency and other attributes to stratigraphic and hydrocarbon determination, *AAPG* n° 23.

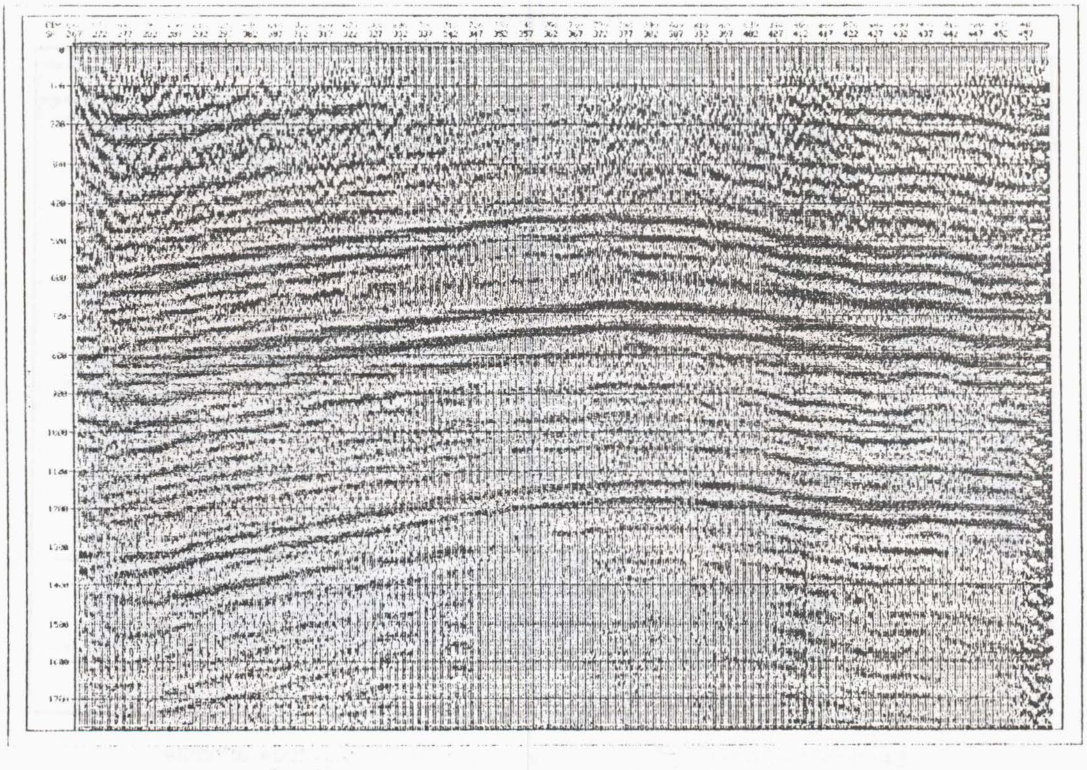
Taner, M. T, 2000. Attributes revisited, *Rock Solid Images* (revised).

Velez, E. and Garudadri, H., 1990. Application of smoothed Wigner Distribution for analyzing transcients in speech. ISSA90, *Theories, Implementations and Applications Gold-Coast Australia.*



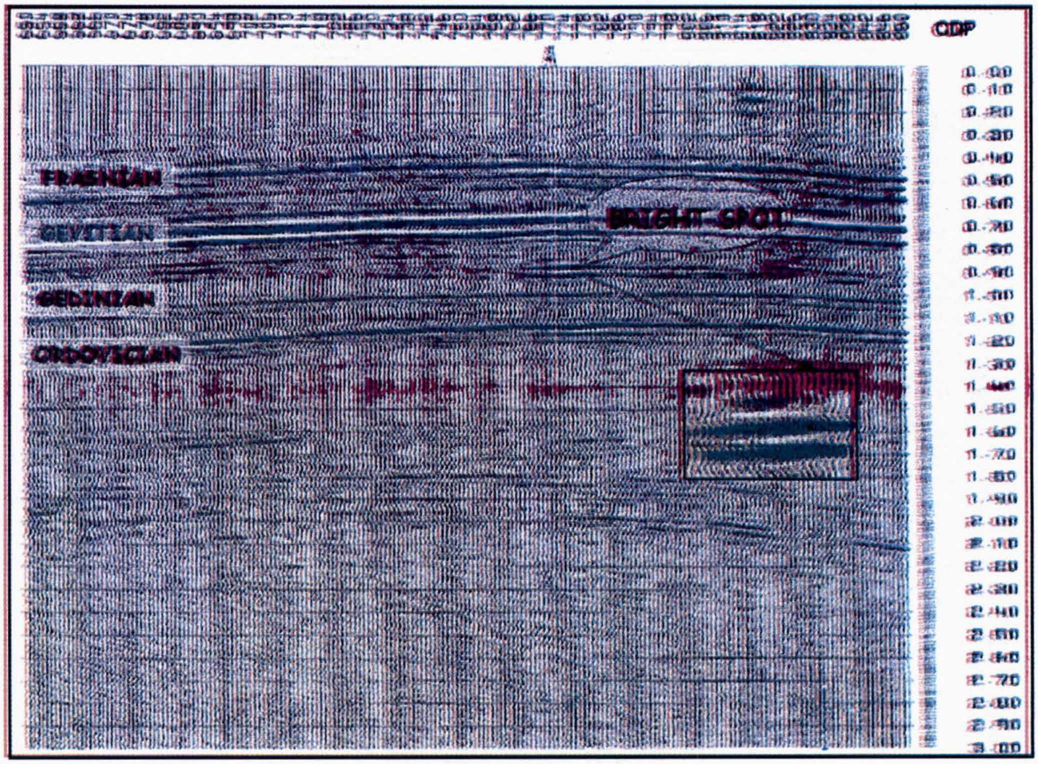
Section 1 - Stacked and migrated seismic section

Section sismique après sommation et migration



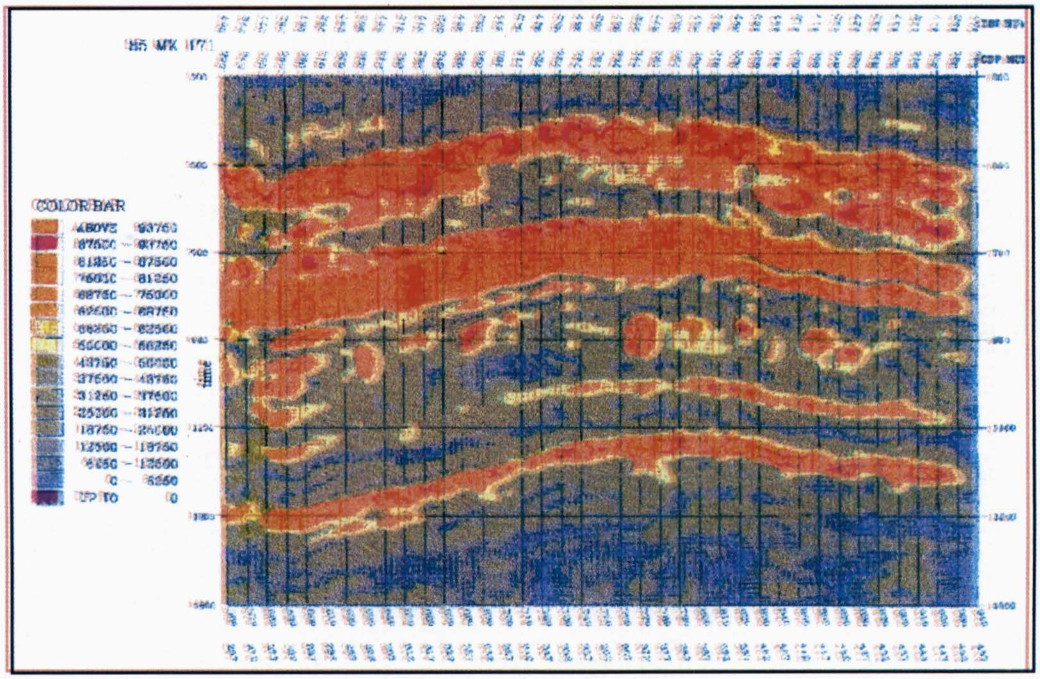
Section 2 - Seismic section before any correction

Section sismique avant tous types de corrections



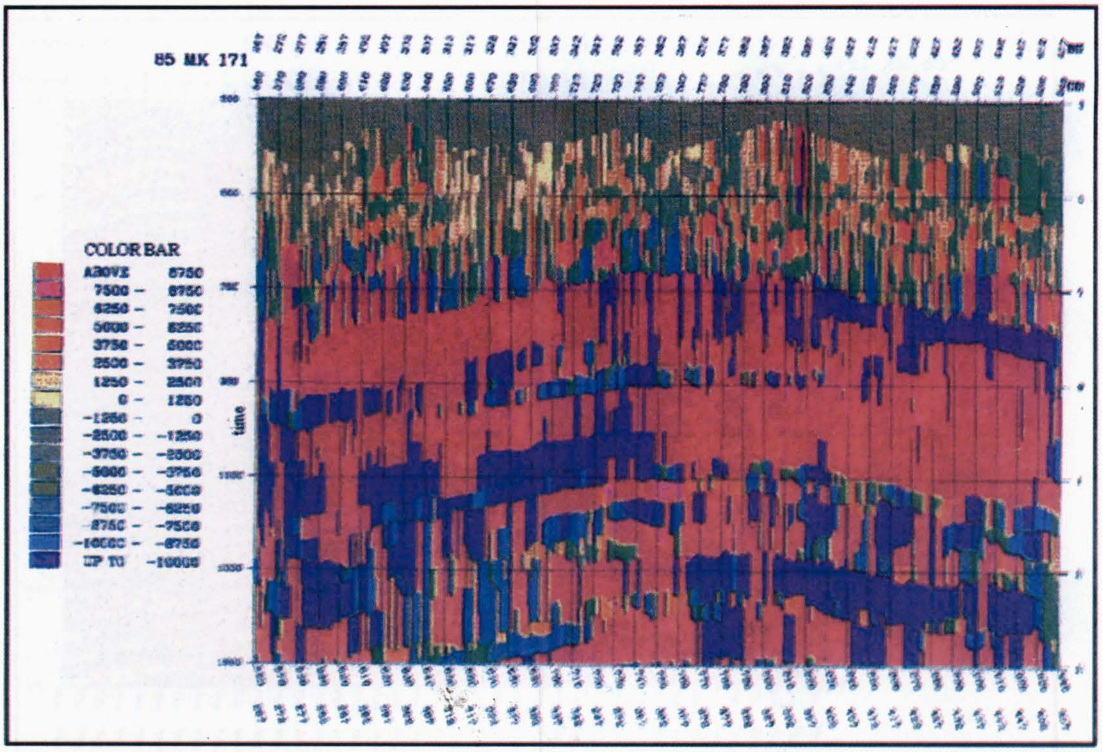
Section 3 - Objectives of the seismic study

Objectifs de l'étude sismique



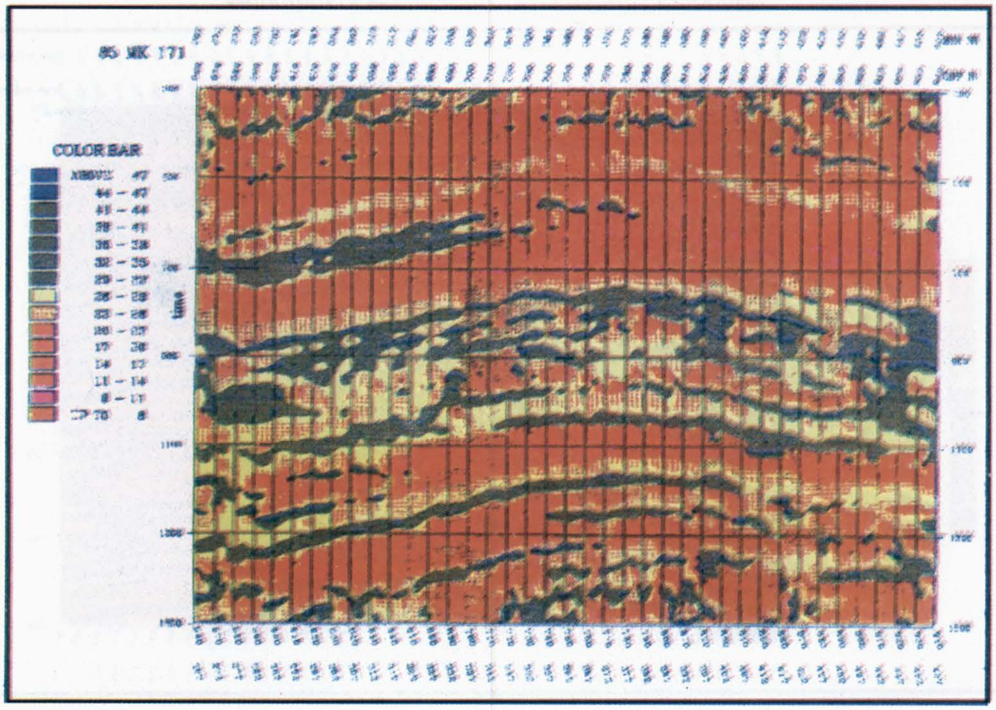
Section 4 - Seismic section vs the instantaneous amplitude attribute

Section sismique en attribut amplitude instantanée



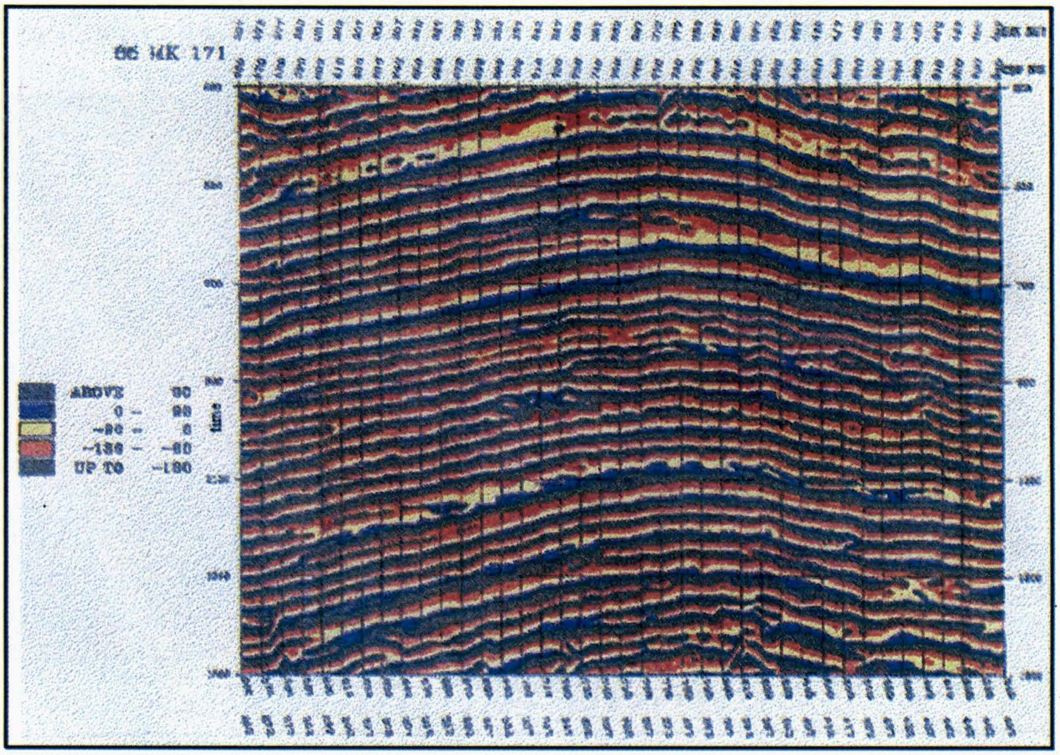
Section 5 - Seismic section vs appareant polarity attribute

Section sismique en attribut polarité apprente



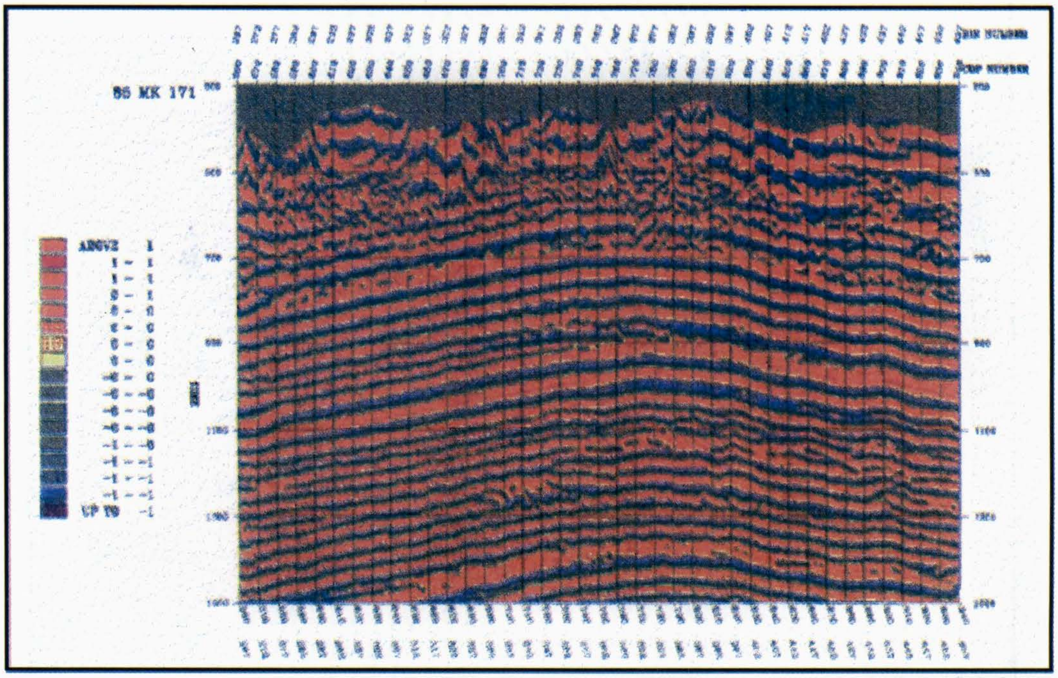
Section 6 - Seismic section vs instantaneous frequency attribute

Section sismique en attribut fréquence instantanée



Section 7 - Seismic vs instantaneous frequency phas attribute

Section sismique en attribut phase instantanée



Section 8 - Seismic section vs normalized amplitudes

Section sismique en amplitude normalisées