

ATTEMPT TO IDENTIFY AND CHARACTERIZE A LEAD USING SEISMIC ATTRIBUTES

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ABSTRACT

The Nganzi Block, located in the coastal basin of the Democratic Republic of Congo, is an area of petroleum interest whose appraisal depends largely on the ability to identify, from the available data, geological objects that are sufficiently coherent to be considered as leads and, eventually, as prospects. However, in a context where exploration data are sometimes limited, fragmentary, or difficult to interpret, the reliable recognition of these objects remains a real scientific and methodological challenge. The central issue of this study is therefore to determine the extent to which instantaneous seismic attributes can contribute to the identification and characterization of a lead from a restricted seismic window.

This study aims mainly to analyze an isolated seismic window, referred to as Window A, extracted from an anonymized 2D seismic line of the Nganzi Block, to highlight seismic signatures that may indicate the presence of a lead. This window lies between 770 ms and 928 ms two-way time, over a trace interval extending approximately from trace 125 to trace 280.

The adopted methodology is based on an integrated approach combining documentary analysis, interpretation of 2D seismic data, use of well data, VSP/checkshot information, surface geochemical indices, and calculation of instantaneous seismic attributes. The attributes considered are mainly reflectivity, envelope or instantaneous amplitude, instantaneous frequency, instantaneous phase, and polarity. This combination makes it possible to go beyond a simple visual reading of the seismic image and to access more detailed information on the geometry, continuity, impedance contrasts, and internal organization of the object studied.

The results obtained show that Window A presents several indicators compatible with a structured lead. These include the presence of seismic interfaces H1, H2, H3, and H4; compartmentalization controlled by reverse faults; amplitude anomalies; polarity variations; low-frequency zones located beneath the levels of interest; and phase continuities and discontinuities that may be interpreted in terms of structural closure. The integration of these results with well data suggests that the identified lead could be associated with the extension of the Lower Bucomazi Formation, which may contain several reservoir levels.

The originality of this work lies in the proposal of a clear approach for upgrading leads from available information, even when such information remains limited. The study is not restricted to a conventional interpretation of the seismic image; it also highlights the value of a multi-

attribute approach for improving interpretation reliability. It does not yet perform a machine-learning classification; however, it establishes a solid geoscientific basis for a future extension toward unsupervised or self-supervised learning models by showing how seismic attributes can be transformed into exploitable quantitative variables.

Ultimately, the lead identified in Window A may be considered a potential prospect, subject to further work involving geochemistry, well-to-seismic calibration, 2D/3D delineation seismic acquisition, and volumetric assessment. The scientific value of this study therefore lies in demonstrating that a restricted seismic window, when analyzed using several complementary attributes, can provide relevant geological indicators to guide petroleum exploration decisions.

Keywords: Nganzi Block, coastal basin, lead characterization, seismic attributes, seismic window, Lower Bucomazi.

INTRODUCTION

Modern petroleum exploration increasingly relies on the combination of several types of data to better understand the subsurface and reduce uncertainties related to hydrocarbon exploration. Regional geological data, seismic profiles, well information, geochemical indices, stratigraphic knowledge, and structural models are therefore analyzed in a complementary manner to build a more reliable interpretation of a basin's petroleum potential [1],[2]. In areas that remain underexplored, or in blocks where drilling has not yet led to commercial discoveries, the challenge often consists of giving geological meaning to anomalies observed on seismic data. These anomalies must progressively be transformed into well-supported leads and, eventually, into prospects that are sufficiently constrained to justify further investigations or additional investment [3],[4]. The present study falls within this perspective and focuses on the identification and characterization of a lead in the Nganzi Block using instantaneous seismic attributes.

The Nganzi Block belongs to the Congolese coastal basin, which is itself related to the Lower Congo Basin system and to the West African passive margin. This basin represents the main sedimentary domain of the Democratic Republic of the Congo where hydrocarbon exploration and production have actually been developed, particularly in the onshore and offshore sectors of the Atlantic coast. Studies carried out in the Lower Congo Basin have highlighted the existence of petroleum systems associated with pre-salt series, among which the Bucomazi Formation is generally recognized as a major source rock in several sectors of the West African margin [5],[6]. It is essentially argillaceous, with sandy interbeds in some areas. The proximity of the petroleum basins of Cabinda and the Republic of the Congo therefore reinforces the interest in the Nganzi Block, insofar as some regional petroleum structures or trends could extend into the Congolese sector.

The position of the study area, close to recognized petroleum sectors and within the axis of the Lemba Trough, gives the block particular interest for the search for structural and stratigraphic traps. Exploration works already carried out in this area includes gravity, magnetic, geochemical, and 2D seismic surveys, including seismic acquisitions in 2008 and 2011. These data provide an important basis for re-examining the petroleum potential of the block, especially when analyzed using attributes capable of better revealing amplitude variations, phase changes, discontinuities, and certain frequency anomalies.

Despite its geological and petroleum interest, the Nganzi Block has not yet led to a commercial hydrocarbon discovery. According to information from the Sonahydroc S.A. database, wells drilled in this area by SOCO E&P did not yield the expected results. However, the occurrence of gaseous hydrocarbons reported in the Bayingu-1 well is an important indicator. It supports the idea that the block could contain the elements required for a functioning petroleum system, including source rocks, reservoir levels, seals, migration pathways, and possible trapping configurations. This situation shows that the petroleum potential of the Nganzi Block cannot be assessed solely from the regional context. It requires a more precise analysis of geological structures, considering their geometry, continuity, structural organization, and possible relationship with stratigraphic levels of interest.

Thus, the central research question of this study can be formulated as follows: can instantaneous seismic attributes, applied to a localized seismic window of the Nganzi Block, reveal signatures compatible with the existence of a petroleum lead that could be upgraded into a prospect?

This question must be approached with caution, because seismic attributes do not, by themselves, constitute direct proof of the presence of hydrocarbons. Rather, they provide geophysical indicators that must be interpreted within a coherent geological framework and compared with well data, VSP/checkshot information, structural observations, and available geochemical indices. Instantaneous attributes, particularly instantaneous amplitude, instantaneous phase, and instantaneous frequency, derived from complex seismic trace analysis, are especially useful for assessing signal-energy variations, reflector continuity, polarity changes, and certain effects related to lithological or structural contrasts [7],[8],[4].

The main objective of this work is therefore to identify and characterize a potential lead within a restricted seismic window of the Nganzi Block by combining the analysis of instantaneous seismic attributes with the available geological information. More specifically, the aim is to delineate the seismic window of interest, analyze the observable interfaces and discontinuities, calculate the main instantaneous attributes, and then interpret their significance in terms of geometry, structural compartmentalization, polarity variation, amplitude anomalies, and stratigraphic continuity. This approach seeks to provide a coherent geoscientific basis for maturing the studied lead and for its possible future upgrading into a prospect.

GEOGRAPHICAL AND GEOLOGICAL SETTING OF THE STUDY AREA

From a geographical point of view, the Nganzi Block is located in Kongo Central Province (Figure 1) and covers an area of approximately 800 km². It is bounded to the east by the Mavuma Block, to the west by Central Cabinda, to the north by Northern Cabinda, and to the south by the Lotshi Block.

Geologically, the Nganzi Block is part of the Congolese coastal basin, with which it shares the main structural and stratigraphic characteristics. Its evolution is related to the opening of the South Atlantic, which progressively organized the West African margin into a succession of pre-salt, salt, and post-salt deposits [5],[6]. Within this tectono-sedimentary context, several formations favorable to the functioning of a petroleum system were able to develop, including organic-rich intervals, sandstone or carbonate reservoirs, and clayey, marly, or evaporitic seals. The location map and the stratigraphic log of the study area are shown in Figure 1 and Figure 2, respectively.

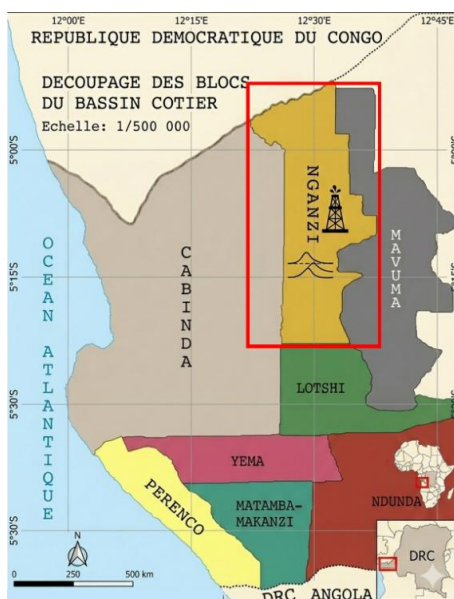


Figure 1. Location of the Nganzi Block.

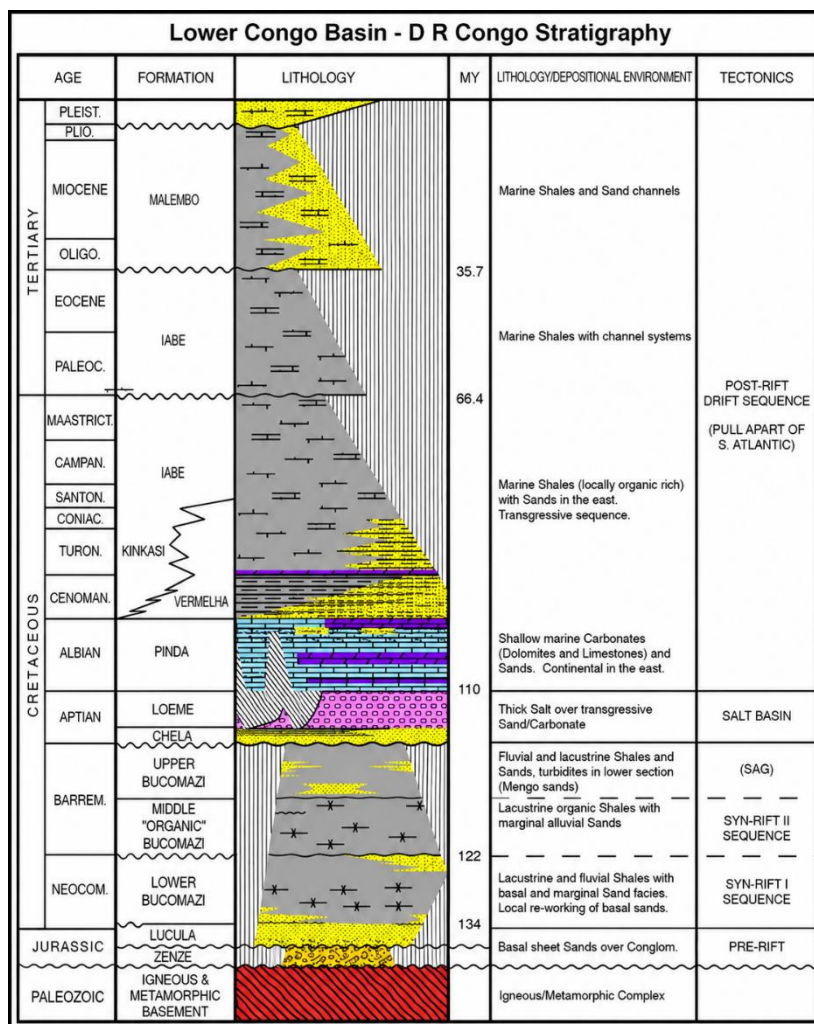


Figure 2. Stratigraphic column of the Lower Congo Basin.

The Nganzi Block is of particular interest because of its position within the Lemba Trough, an area where tectonic structures may have favored hydrocarbon migration and trap development. At the regional scale, petroleum systems in the Congo-Cuanza domain show that basin structural organization, the presence of reservoirs, and the development of structural or mixed traps play an important role in hydrocarbon accumulation [9]. At the local scale, older exploration data, particularly the 1990 Conoco report preserved in the Sonahydroc S.A. database, also provide a useful source for better understanding the geological interest of the sector [10]. Within this framework, several investigations have been carried out in the Nganzi Block. Without listing all of them, the main works retained for this study include the geochemical study conducted by Geo Microbial Technologies International (GMTI), as well as gravity, magnetic, and 2D seismic surveys carried out in the area. These data, illustrated in Figure 3, make it possible to place the studied seismic window within its geological, structural, and petroleum context.

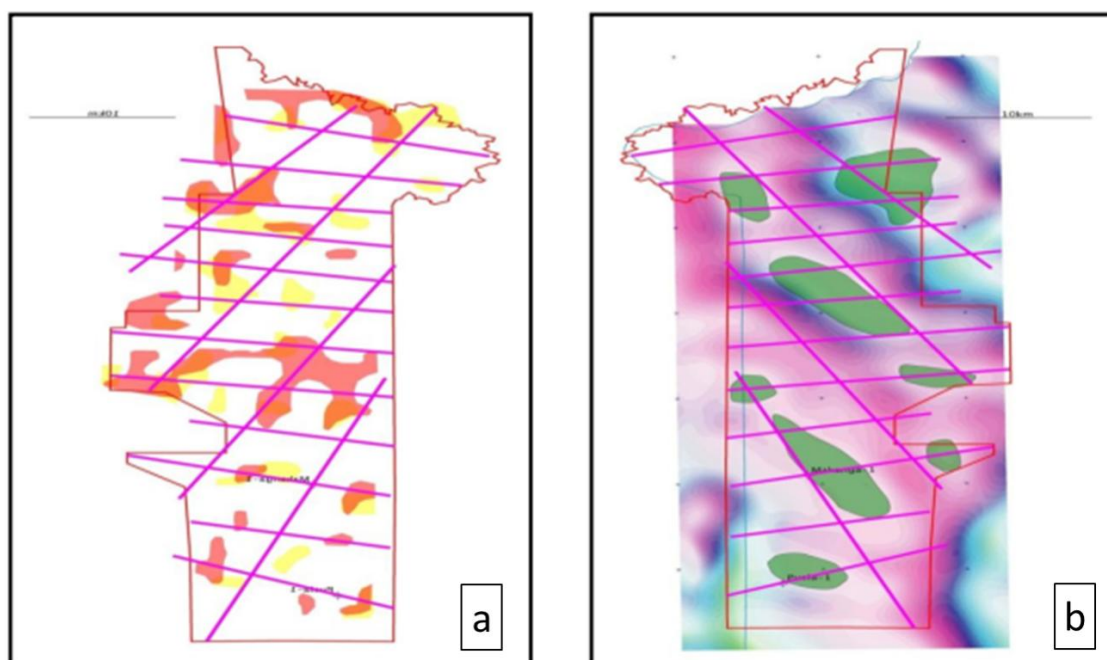


Figure 3. 2D seismic survey layout by BGP with (a) geochemical survey by Gore and (b) prospects [11].

MATERIALS AND METHODS

The materials used and the methodological approach adopted in this article, as shown in Figure 4, are based on an integrated and multi-model approach. This approach combines documentary analysis, critical review, and the numerical use of well data, relying on specialized analysis and processing software, namely:

- SMT Kingdom, for delineating Window A and processing certain seismic attributes;
- Seisee, for extracting seismic traces as amplitude values with a 2 ms sampling interval;
- MATLAB, for calculating instantaneous seismic attributes and determining the characteristic energy of wavelets;
- CorelDRAW, for presenting and formatting graphical data;
- Microsoft Office 2020, for writing, processing, and organizing the study data.

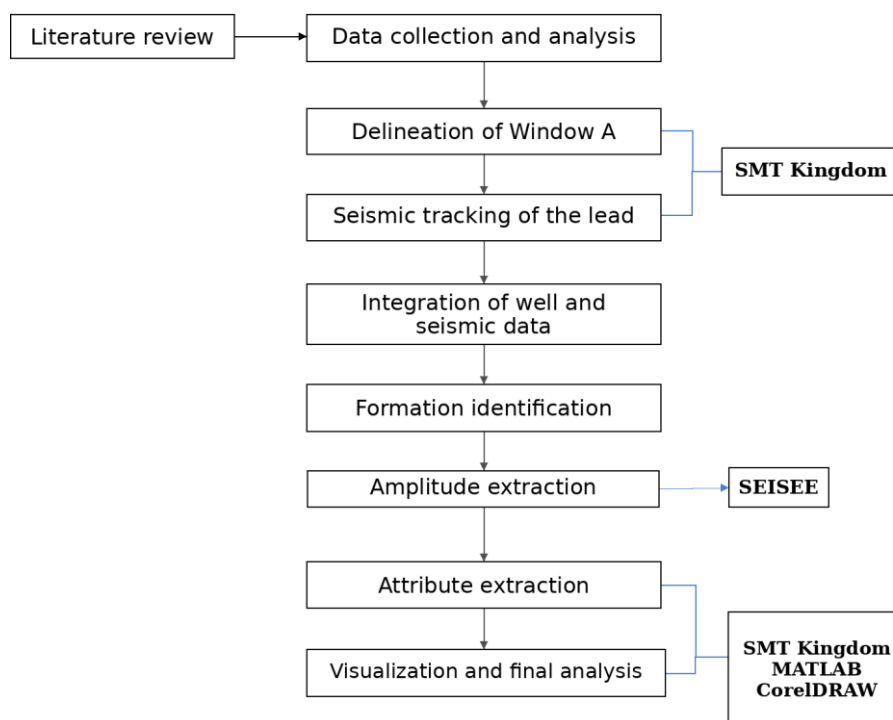


Figure 4. Synthetic methodological workflow.

Thus, the methodological approach adopted in this article can be summarized as follows:

- *Document collection and analysis:* first, we collected bibliographic data (official reports related to work carried out in the study area, scientific articles, theses, dissertations, and other essential sources consulted on websites related to our research) in digital format. These data were then analyzed.
- *Lead detection and delineation:* the documentary analysis, as mentioned previously, made it possible to detect and delineate the studied lead, referred to in this research as Window A. It was identified from a strong concentration of surface geochemical anomalies, which served as the starting point for guiding the seismic analysis.
- *Tracking of the top and base of the lead:* after delineating Window A, the top and base of the lead were tracked on the available seismic lines, particularly those crossing or located near drilled wells. This step made it possible to better constrain the interval of interest on the different seismic sections.
- *Integration of well and seismic data:* well data, VSP/checkshot information, lithological logs, and seismic data were integrated in order to place the lead within its stratigraphic and lithological context.
- *Formation and lithology identification:* through the calibration between well data, VSP/checkshot information, and seismic data, the studied interval was assigned to the Lower Bucomazi Formation, characterized by an alternation of clayey and sandy levels.
- *Seismic amplitude extraction:* the amplitude values of the seismic traces were extracted using Seisee software, providing the data required for calculating instantaneous seismic attributes.

- *Calculation of instantaneous attributes using MATLAB:* The instantaneous seismic attributes - amplitude envelope, instantaneous phase, and instantaneous frequency - were calculated using MATLAB, following the methodological principles described in the relevant sections of the work.
- *Calculation and visualization using SMT Kingdom:* Some complementary attributes were calculated and visualized using SMT Kingdom software. These results provided additional support for analyzing and comparing the observed seismic responses.
- *Results analysis:* Finally, the results derived from the different attributes were analyzed by considering the seismic interfaces and the amplitude, polarity, frequency, and phase variations observed within the studied window.

RESULTS

Presentation of the Study Data

The data used in this study consists of three seismic traces from three different wells in the Nganzi Block, namely:

- Trace 1: "ORIGINAL-F-2008-21TR745", extracted from the Bayingu-1 well;
- Trace 2: "ORIGINAL-F-2008-13TR255", extracted from the Nganga-1 well;
- Trace 3: "ORIGINAL-F-2008-01TR592", extracted from the Kinganga Nyanya-1 well.

Thus, based on surface geochemical anomalies detected from the studies of Geo Microbial Technologies International (GMTI) [12], we selected a seismic profile that we named "Sensor Line-2008-K1". On this line, we identified a lead and then isolated the seismic data of Window A, shown in Figure 5 around this lead, bounded by TWT1 = 770 ms and TWT2 = 928 ms, over seismic traces ranging from the 125th to the 280th trace. All seismic data were organized in a database (text format) and processed using MATLAB software for seismic trace analysis.

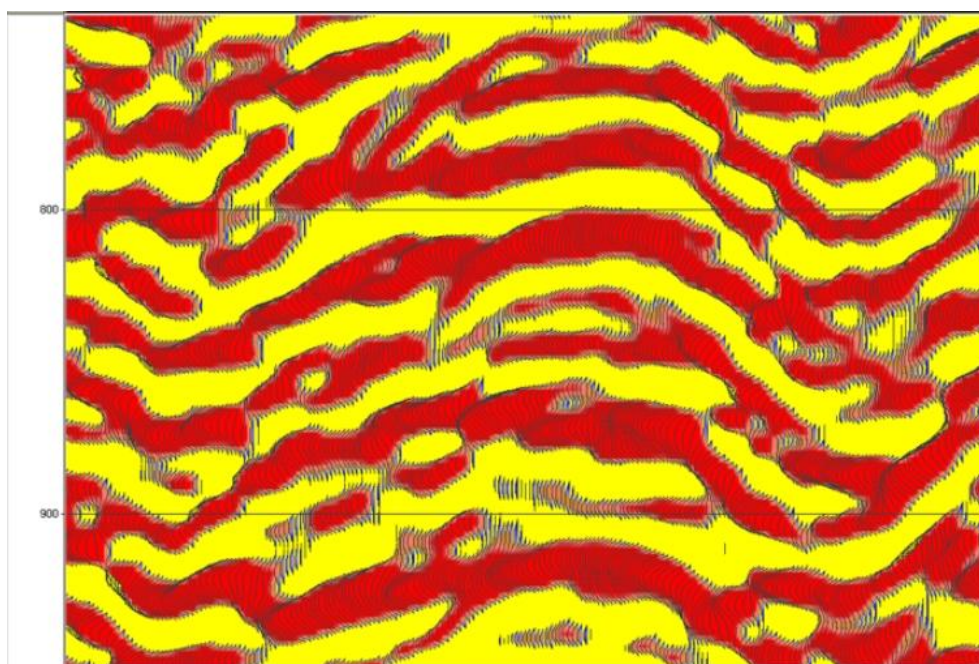


Figure 5. Window A of the lead identified on seismic profile Line-2008-K1.

We also used lithological log data from the BYU-1, NGA-1, and KNY-1 wells, as well as the results of the geomicrobial study carried out by Geo Microbial Technologies International (GMTI), as shown in Figure 6.

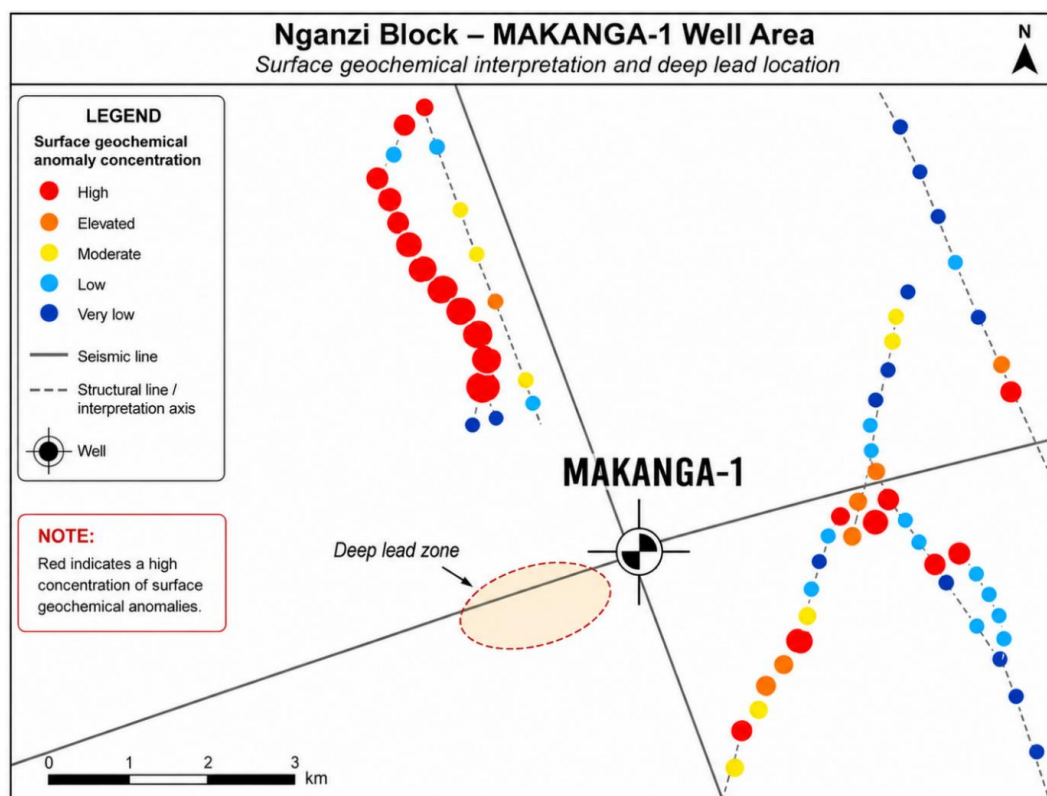


Figure 6. Presence of a significant surface geochemical anomaly [12].

Attribute Calculation using MATLAB: Analysis of Seismic Traces along Wells

The analysis of seismic traces along wells, combined with the calculation of seismic attributes in MATLAB, is an important step in petroleum exploration. It helps to better understand the relationship between the response recorded in seismic data and the geological characteristics of the subsurface. By studying traces located near wells, it becomes possible to identify the most significant seismic events, verify their polarity, observe their continuity, and follow their evolution with depth or two-way time. This approach also helps to better correlate seismic horizons with the levels actually penetrated by the wells, as well as with possible lithological or stratigraphic variations. It is therefore part of an integrated interpretation approach in which seismic data, well information, and calculated attributes are compared to better characterize the subsurface and reduce uncertainties related to the identification of petroleum-interest zones [13-15].

In this research, this analysis provided information on the amplitude, phase, frequency, continuity, and polarity of seismic events. These results are presented in Tables 1, 2, and 3, which summarize the characteristics of the different seismic attributes observed on the traces associated with the Bayingu-1, Nganga-1, and Kinganga Nyanya-1 wells.

Table 1. Trace 1: ORIGINAL-F-2008-21TR745, extracted from the Bayingu-1 well.

LOWER BUCOMAZI					
Top	1498 m MDBRT = 1006,9Ms		Thickness	1498	696
Base	2194 m MDBRT = 1369,2Ms			2194	
Events	Amplitudes	Time	Instantaneous phase	Frequencies	Polarities
EV1	8097	1006	4,541	12,9	(+)
EV2	8222	1044	103,4	10,58	(-)
EV3	3280	1066	-113,1	5,348	(-)
EV4	7511	1092	58,08	13,07	(+)
EV5	10430	1136	106,6	13,38	(-)
EV6	5998	1170	-8,845	13,81	(+)
EV7	5631	1222	130,5	12,89	(-)
EV8	6875	1260	-5,194	11,68	(+)
EV9	2200	1288	-156,7	11,4	(-)
EV10	2638	1324	153,1	10,65	(-)
EV11	4805	1352	-63,35	10,34	(+)

Table 2. Trace 2: ORIGINAL-F-2008-13TR255, extracted from the Nganga-1 well.

LOWER BUCOMAZI					
Top	1271 m MDBRT = 923,3Ms		Thickness	1271	429
Base	1700 m MDBRT = 1155,5Ms			1700	
Events	Amplitudes	Time	Instantaneous phase	Frequencies	Polarities
EV1	8068	910	132,7	14,68	(-)
EV2	3313	948	152,9	13,08	(-)
EV3	4102	966	-97,11	11,39	(-)
EV4	6058	986	-10,02	12,63	(+)
EV5	5737	1010	100,7	13,78	(-)
EV6	3117	1032	-168,6	15,06	(-)
EV7	2646	1050	-145,2	14,79	(-)
EV8	2288	1072	-36,41	16,44	(+)
EV9	4821	1094	25,63	15,06	(+)
EV10	4613	1116	63,14	14,25	(+)
EV11	7906	1158	112,6	13,67	(-)

Table 3. Trace 3: ORIGINAL-F-2008-01TR592, extracted from the Kinganga Nyanya-1 well.

LOWER BUCOMAZI					
Top	670 m MDBRT = 623,6Ms		Thickness	670	54
Base	724 m MDBRT = 666,3Ms			724	
Events	Amplitudes	Time	Instantaneous phase	Frequencies	Polarities
EV1	2910	618	-127,6	11,68	(-)
EV2	4944	634	-22,84	10,86	(+)
EV3	5182	650	102,5	13,76	(-)

To analyze the seismic traces more effectively and derive the relevant attributes, we applied the Hilbert transform and the complex trace approach. The main mathematical formulas used are summarized in Table 4, and the diagram resulting from the calculation of these seismic attributes is presented in Figure 7.

Table 4. Summary of the main mathematical formulas of the Hilbert transform and the complex trace.

Attribute / operation	Main formula	Geophysical meaning
Hilbert transform	$\tilde{s}(t) = H[s(t)] = \frac{1}{\pi} \text{P. V.} \int_{-\infty}^{+\infty} \frac{s(\tau)}{t - \tau} d\tau$	It expresses the phase-shifted component required for the complex trace.
Complex seismic trace	$z(t) = s(t) + i\tilde{s}(t) = A(t)e^{i\varphi(t)}$	It corresponds to the analytic signal used as the basis for calculating instantaneous attributes.
Instantaneous amplitude	$A(t) = z(t) = \sqrt{s^2(t) + \tilde{s}^2(t)}$	It represents the signal envelope and highlights its local energy as well as the main amplitude variations.
Instantaneous phase	$\varphi(t) = \arg[z(t)] = \tan^{-1} \left(\frac{\tilde{s}(t)}{s(t)} \right)$	It helps track reflector continuity and polarity variations without depending on signal amplitude.
Instantaneous frequency	$f_i(t) = \frac{1}{2\pi} \frac{d\varphi(t)}{dt}$	It expresses phase variations over time and helps identify frequency changes related to texture, thickness, or lithology.
Discrete approximation in MATLAB	$f_i[n] = \frac{1}{2\pi} \frac{\varphi[n] - \varphi[n-1]}{\Delta t}$	It makes it possible to calculate instantaneous frequency from the unwrapped phase, generally obtained in MATLAB with <code>unwrap(angle(z))</code> before differentiation.

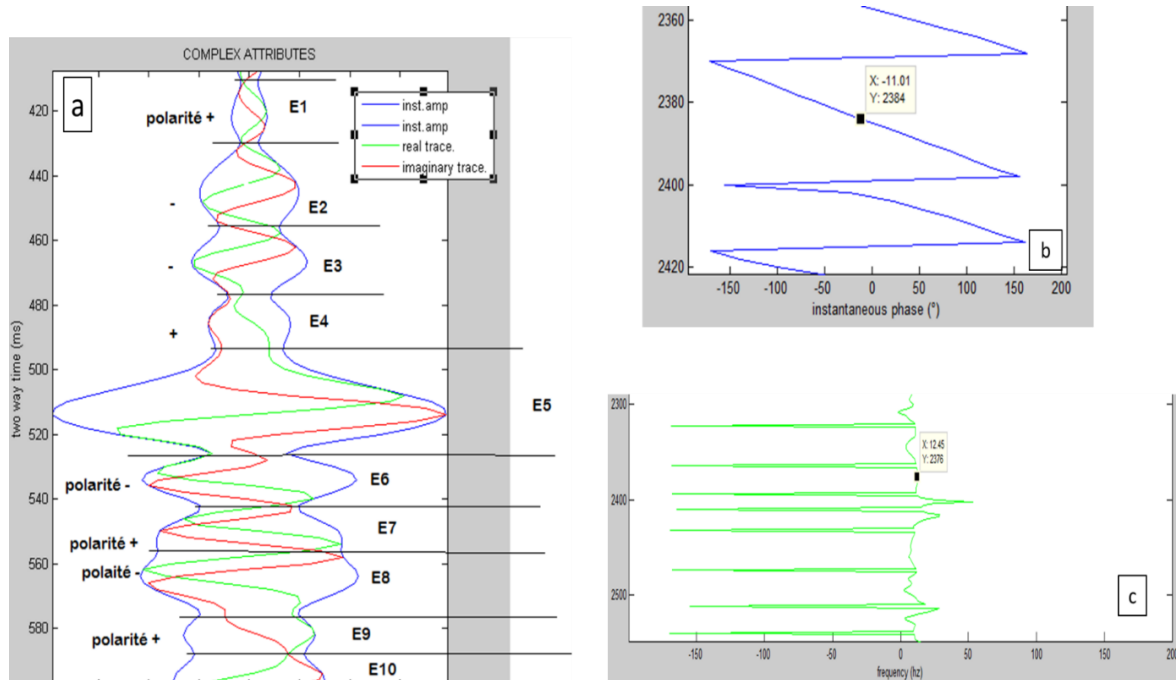


Figure 7. Complex seismic trace diagram: (a) polarities of the complex trace from an arbitrary seismic line of the Nganzi Block; (b) instantaneous phase diagram of a trace from an arbitrary seismic line of the Nganzi Block; (c) instantaneous frequency diagram of a trace from an arbitrary seismic profile of the Nganzi Block.

Attribute Calculation Using SMT Kingdom Software

After processing Window A using SMT Kingdom software, the different seismic attributes were calculated, and the resulting outputs are presented in Figure 8.

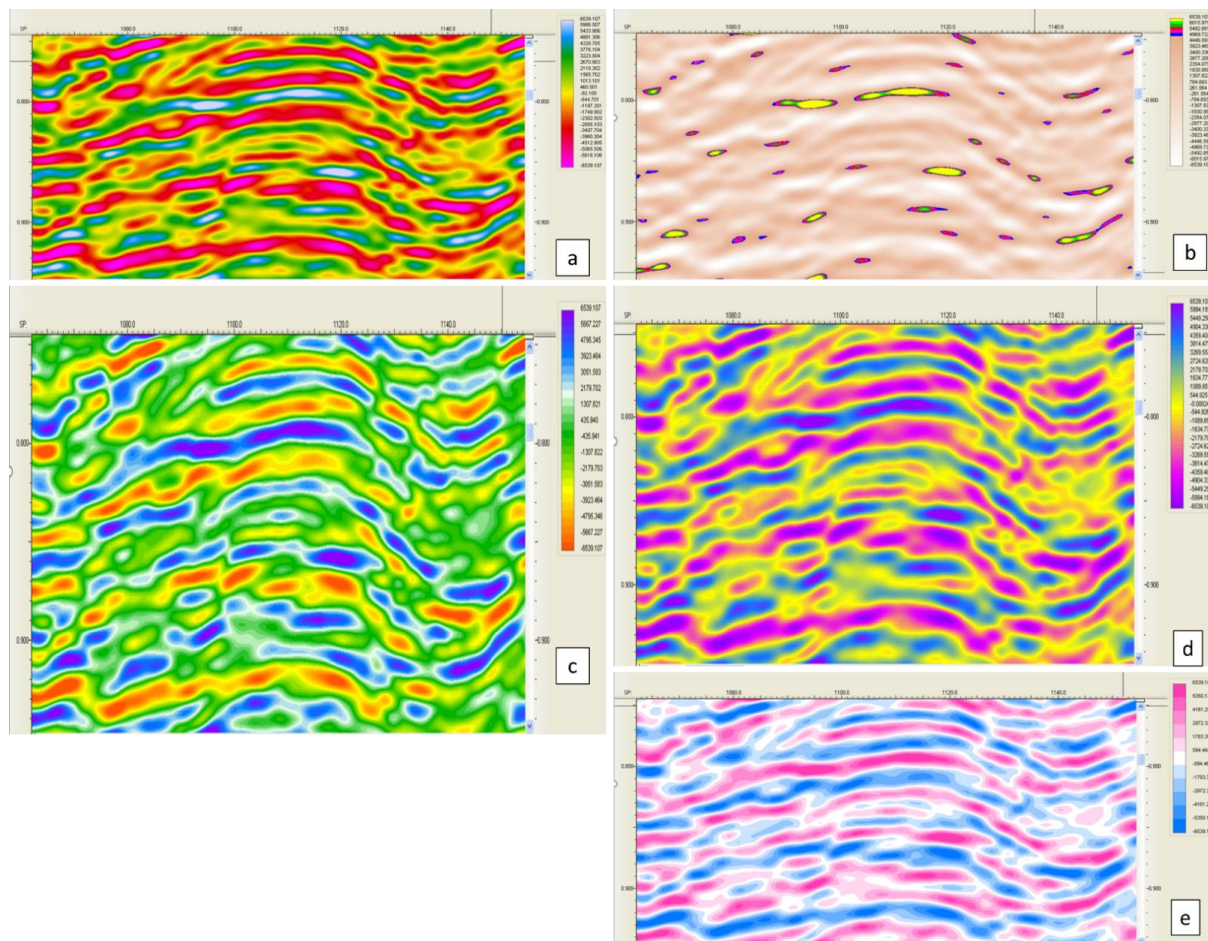


Figure 8. (a) Reflectivity; (b) envelope or instantaneous amplitude; (c) instantaneous frequency; (d) instantaneous phase; (e) polarity.

Interpretations

The interpretation is mainly based on four seismic attributes defined previous: envelope, instantaneous frequency, instantaneous phase, and polarity. These attributes make it possible to analyze the seismic response from several complementary perspectives. The envelope provides information on the local energy of the signal and can highlight certain marked reflectors. Instantaneous phase and polarity help to track the continuity of seismic events and recognize possible changes in impedance contrast. Instantaneous frequency, for its part, may reflect variations related to the texture, thickness, or lithology of the levels crossed [16-18]. Thus, the combined analysis of these attributes does not directly confirm the presence of hydrocarbons, but it can reveal indicators favorable to the existence of a petroleum lead and help to better assess its potential. Figure 9 and Figure10 respectively, relating to reflectivity and polarity, are interpreted as follows.

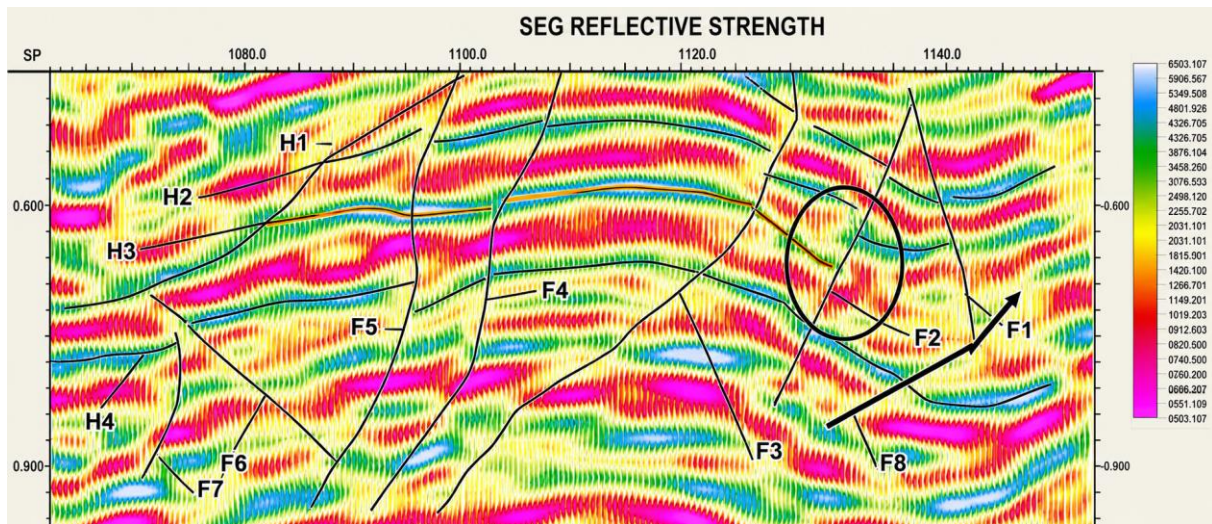


Figure 9. Interpretation of the reflectivity attribute.

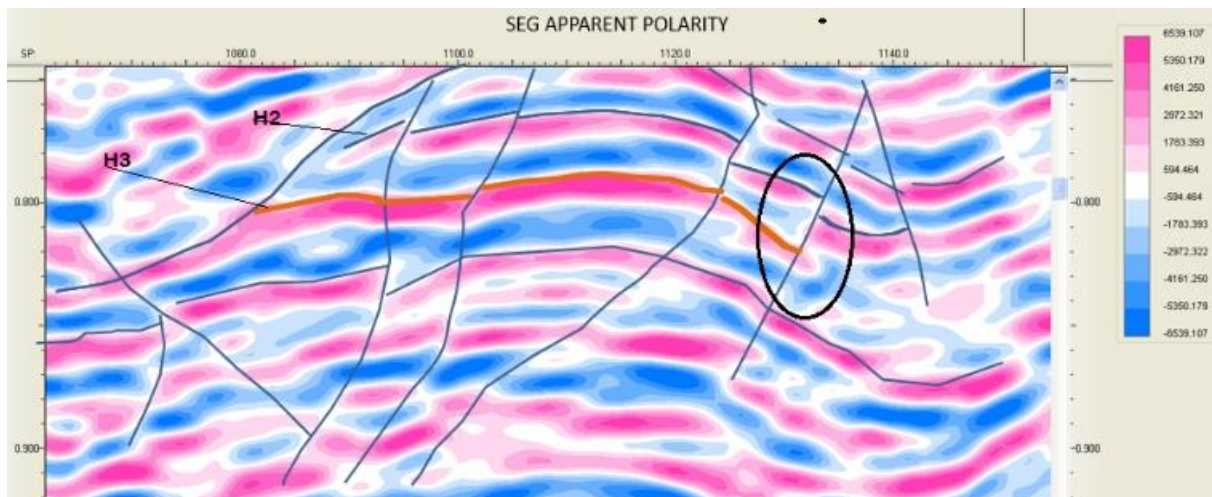


Figure 10. Interpretation of the polarity attribute.

Figure 10 highlights a seismic lead that could be interpreted as a probable stratified, compartmentalized, and potentially oil-impregnated prospect developed within an anticlinal-type structure. This configuration is of particular interest in petroleum exploration, because anticline structures are among the most classic and most sought-after structural traps in sedimentary basins. Indeed, when an anticline is associated with a porous and permeable reservoir rock, an impermeable cap rock, and an effective structural closure, it can promote the accumulation and preservation of hydrocarbons [19-21].

Observation of the reflectivity makes it possible to distinguish eight reverse faults, named F1, F2, F3, F4, F5, F6, F7, and F8. These faults could be related to basement uplift, which caused compressional deformation of the overlying sedimentary layers. Their presence gives the lead a more complex structural organization, as they appear to compartmentalize it into several blocks. This compartmentalization may play an important role in hydrocarbon distribution,

insofar as faults can either facilitate fluid migration or, conversely, form barriers and contribute to trapping, depending on their nature, continuity, and sealing capacity [4],[22],[23].

In this context, the observed reverse faults may be considered favorable elements for the development of structural traps with fault closure. After migrating from the source rock to the reservoir, hydrocarbons may accumulate against these fault planes if they provide sufficient lateral closure. This arrangement is common in several petroleum systems where compressional tectonics or structural inversion has allowed the formation of traps associated with folds and reverse faults [19],[24],[25].

Moreover, four main seismic interfaces were individualized and designated H1, H2, H3, and H4. Interface H1 may be interpreted as the top of the lead, probably corresponding to the boundary between the reservoir and the cap rock. This cap rock, probably clayey, is an essential element of the petroleum system because it prevents vertical hydrocarbon leakage and allows hydrocarbons to be preserved in the reservoir. Without an effective seal, even in the presence of a favorable structure, hydrocarbon accumulation may be compromised [1],[20],[21].

Interfaces H2, H3, and H4 may be interpreted as internal boundaries marking lithological changes or acoustic-impedance contrast variations within the lead. They could correspond to alternations between potentially reservoir levels, possibly hydrocarbon-impregnated, and more impermeable clayey levels. In seismic interpretation, these contrasts are often expressed by variations in reflectivity, amplitude, continuity, and frequency, which can provide information on facies changes, stratigraphic boundaries, or fluid variations within rock pores [4],[26],[27].

Interface H4 is considered the base of the lead, that is, the lower boundary of the interval of interest. Thus, the interval between H1 and H4 could represent a stratified reservoir zone in which hydrocarbons would be trapped through the combination of several factors: anticlinal geometry, the presence of compartmentalizing reverse faults, fault closures, and clayey levels acting as internal barriers. This interpretation remains consistent with the principles of seismic stratigraphy, according to which reflector geometry, continuity, terminations, and amplitude contrasts make it possible to infer the organization of geological units and their petroleum potential [4],[26],[28].

It should nevertheless be emphasized that the identification of a lead on a seismic section does not automatically mean confirmed hydrocarbon presence. It is rather a favorable geological hypothesis that must be verified by other analyses. The interpretation must therefore remain cautious and be strengthened by the study of seismic attributes, particularly envelope, instantaneous phase, instantaneous frequency, and polarity. These attributes make it possible to better assess variations in energy, continuity, frequency, and seismic contrast, which may be associated with lithological changes, layer boundaries, or the possible presence of fluids in the reservoir [7],[18],[29],[39].

Thus, the observed structure presents several encouraging elements for petroleum exploration. It combines an anticlinal form, structural compartmentalization by reverse faults, well-individualized seismic interfaces, and a possible reservoir-seal organization. All of these elements make it possible to consider this lead as a potential prospect, but its truly petroleum-bearing character will have to be confirmed by complementary analyses, particularly detailed interpretation of seismic attributes, trap evaluation, seal characterization, study of hydrocarbon migration, and, ideally, calibration with well data [1],[4],[21]. Considering the result of the envelope attribute illustrated in Figure 11 and Figure 12 respectively.

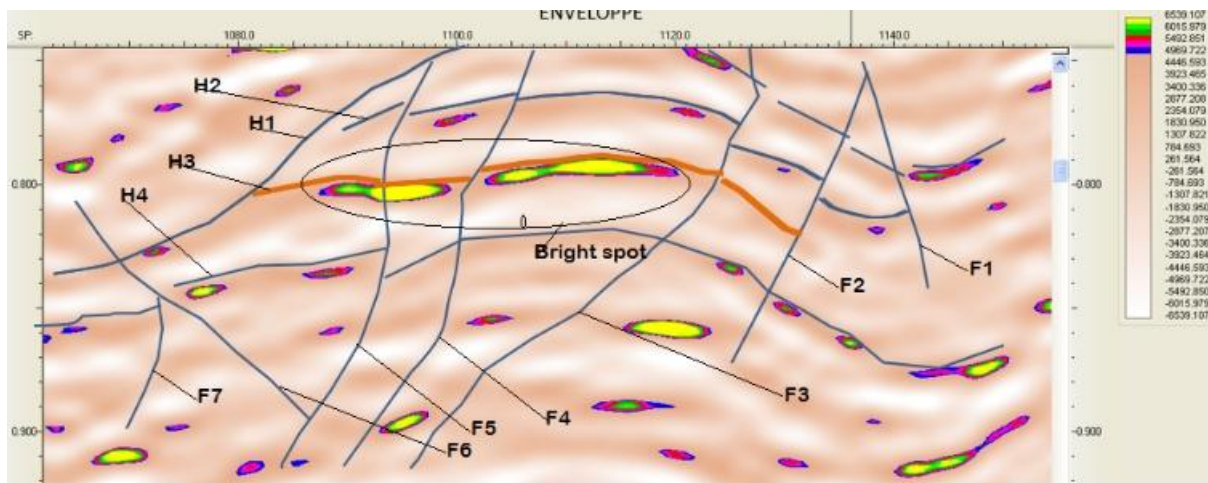


Figure 11. Interpretation of the envelope showing a bright spot.

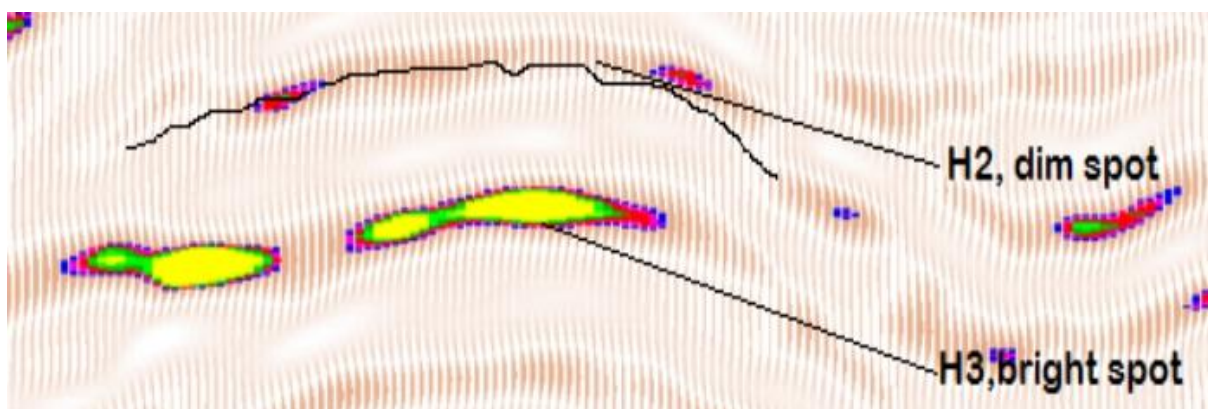


Figure 12. Observation of a dim spot.

A bright spot is observed between 790 ms and 810 ms, more precisely at interface H3. This anomaly is expressed by strong reflectivity and a marked increase in the amplitude of the seismic envelope. In petroleum interpretation, this type of response is often considered a direct hydrocarbon indicator, because it may result from a significant acoustic-impedance contrast between a hydrocarbon-impregnated reservoir rock and the surrounding formations. In principle, when a reservoir contains oil or gas, its acoustic impedance may decrease, generally producing a strong amplitude anomaly, sometimes accompanied by negative polarity depending on the seismic convention used [7],[14],[27],[29].

However, in the present case, the observed bright spot has positive polarity, which may be explained by the influence of a strong negative-reflectivity event located immediately above interface H3. This superposition may modify the seismic expression of the anomaly and produce a more complex response than that of a classic bright spot. Caution is therefore required, because amplitude anomalies may also be influenced by lithology, layer thickness, tuning effects, signal phase, or seismic-data processing [4],[18], [30].

In addition to the established interpretative model, the bright spot identified on interface H3 may also be considered a potential flat spot. A flat spot generally corresponds to a relatively horizontal reflection, sometimes independent of stratification, and may indicate the presence of

a fluid contact within the reservoir. In this case, the anomaly observed at H3 could indicate an oil-water contact, or WOC – Water-Oil Contact, which would strengthen the hypothesis of hydrocarbon accumulation within the lead. Thus, this anomaly located between 790 ms and 810 ms could be interpreted either as a bright spot related to hydrocarbon impregnation, as a flat spot marking a fluid boundary, or as a combination of both phenomena. This dual possibility gives interface H3 particular importance in lead characterization, because it suggests not only a potential reservoir zone but also a possible vertical organization of fluids. Nevertheless, this interpretation should not be considered definitive proof of oil presence; it must be compared with the other seismic attributes, particularly envelope, instantaneous phase, instantaneous frequency, and polarity, in order to distinguish a fluid-related anomaly from a simple lithological or stratigraphic variation [7],[18],[27],[29],[30].

Focusing on the instantaneous-frequency result illustrated in Figure 13. The low-frequency zone observed immediately beneath interfaces H2 and H3, shown in orange in the figure 13, is of particular interest. In seismic interpretation, this type of anomaly is often described as a low-frequency shadow and may be associated with the possible presence of hydrocarbons in a reservoir [31-33]. In the present case, the contrast between the relatively high frequencies along interfaces H2 and H3 and the low frequencies located in Figure 13 seems to support the hypothesis that the lead is hydrocarbon-impregnated. This observation becomes even more significant when it is related to the anomalies already identified on the amplitude envelope, because the association between strong amplitudes and low frequencies often constitutes a favorable indicator in petroleum reservoir characterization [7],[29]. However, this interpretation must remain cautious, because a frequency decrease may also be caused by other factors, including lithological variations, layer thickness, seismic-signal absorption, or certain effects related to data processing [18],[27],[30].

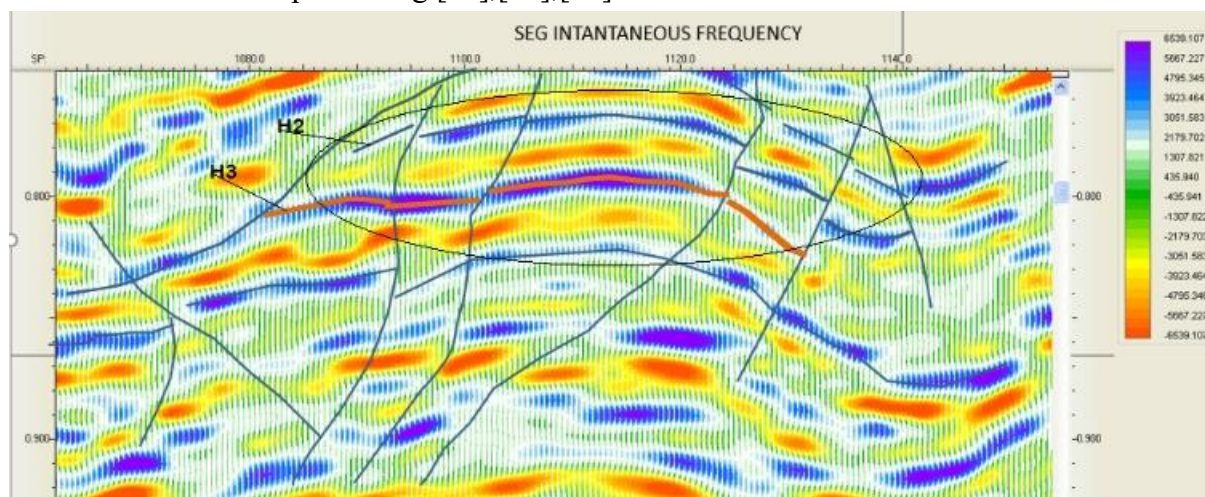


Figure 13. Interpretation of the instantaneous-frequency attribute: frequency variation between interfaces H2 and H3.

Instantaneous amplitude, also called envelope, better highlights important seismic reflectors because it expresses the energy of the reflected signal. Instantaneous phase, for its part, mainly helps to track reflector continuity without taking the strength of their amplitude into account. Indeed, when a reflector belongs to the same geological surface, it generally has a relatively constant phase. For this reason, instantaneous phase is often used as a good indicator of

continuity or breaks in sedimentary layers [7],[27],[34]. Some phase variations may also indicate lithological changes, structural discontinuities, or, in some cases, be associated with the possible presence of hydrocarbons, especially when analyzed with other attributes such as envelope, instantaneous frequency, and polarity [18],[29],[35],[36]. In the same approach, Stark [37] proposed unwrapping instantaneous phase in order to better individualize reflectors, detect discontinuities, and separate stratigraphic units, as also noted by Labrunye [38].

In the Figure 14, clear variations in instantaneous phase are observed at interfaces H2 and H3, as well as on another interface located below H3. These variations appear to indicate breaks in reflector continuity, probably related to the effect of tectonics on the sedimentary layers. The identified discontinuities, named PCF1, PCF2, PCF3, and PCF4, illustrated in Figures 15, can therefore be interpreted as structural zones favorable to hydrocarbon accumulation. They could correspond to fault-bounded traps, that is, traps in which hydrocarbons accumulate against a fault plane when that plane provides sufficient lateral closure. This interpretation remains consistent with the principles of structural and seismic-stratigraphic analysis, according to which breaks in continuity, reflector offsets, phase changes, and seismic terminations can reveal tectonic accidents, reservoir compartments, or zones favorable to hydrocarbon trapping [4],[19],[21],[26].

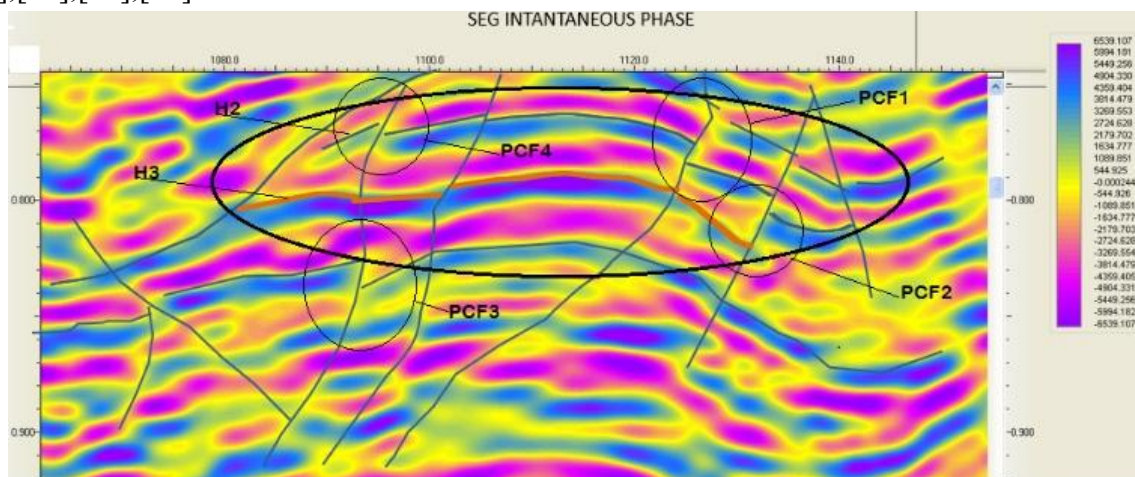


Figure 14. Interpretation of the instantaneous-phase attribute.

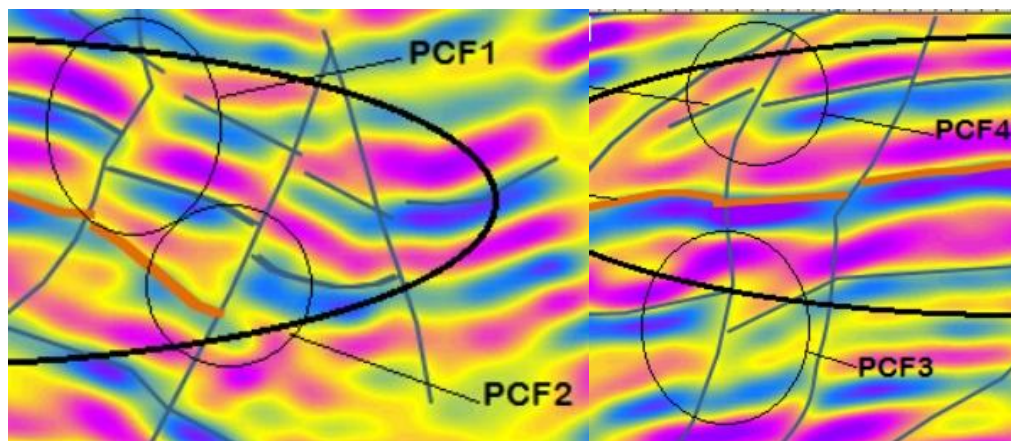


Figure 15. Fault-bounded traps acting as closures.

In accordance with the established principle and with information from the wells and VSP/checkshot data, which indicate that the studied interval belongs to the Lower Bucomazi Formation, characterized by an alternation of clayey and sandy levels, the polarity changes observed at interfaces H2, H3, and H4 are thought to be related to the alternation between sandstone levels, probably containing hydrocarbons, and clayey levels. This is illustrated in Figure 16. From all these interpretations, several direct indicators of hydrocarbon accumulation emerge, including:

1. the presence of strong negative-polarity reflectivity, identified at the troughs of the real traces and at the interface between clay and the reservoir at the top;
2. the presence of a positive-polarity bright spot at the reservoir-clay interface;
3. the presence of low-frequency zones just beneath the reservoir levels;
4. the presence of structural closures at certain reservoir levels.

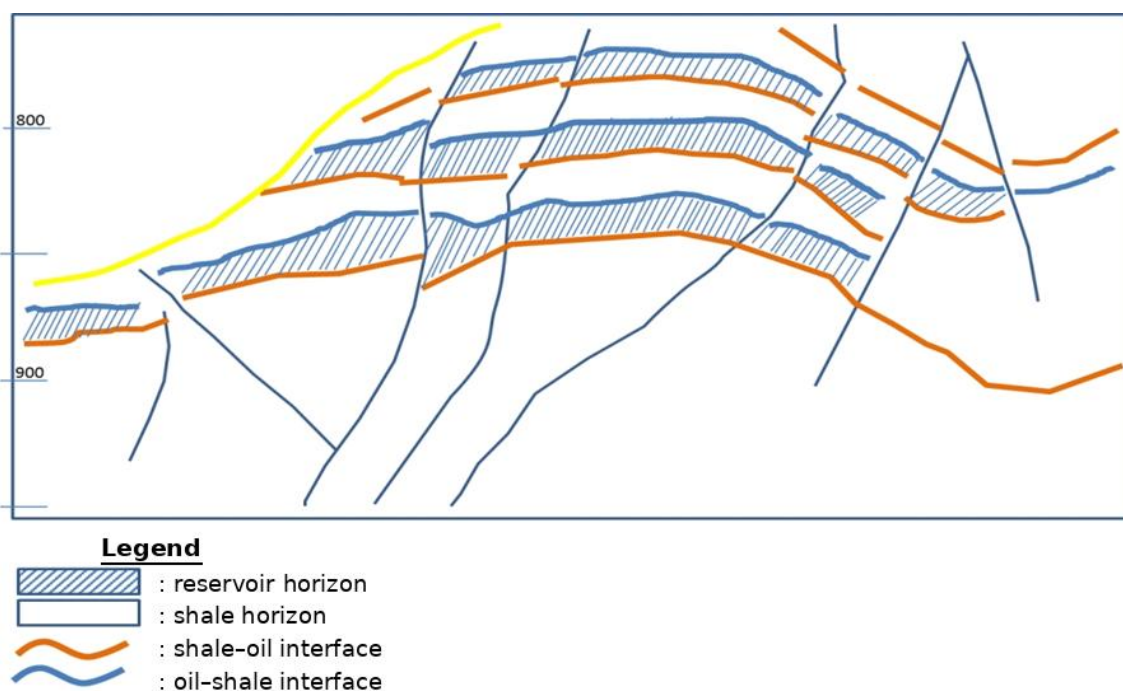


Figure 16. Interpretative model of Window A lead as a probable prospect.

DISCUSSIONS

The results presented in Tables 1, 2, and 3, derived from the calibration of well data with seismic data and from the analysis of instantaneous attributes of traces passing through the wells, indicate that the studied interval belongs to the Lower Bucomazi Formation. This formation occurs at variable depths and displays different thicknesses depending on the points considered. It is known for its alternation of clayey and sandy levels, which may explain part of the variations observed in the seismic attributes. In this context, the combined interpretation of reflectivity, polarity, and amplitude envelope suggests that the studied lead could correspond to a stratified and compartmentalized reservoir. However, the amplitude envelope alone does not allow a definite conclusion. It mainly highlights a positive-polarity bright spot, whose origin

may be related to hydrocarbons but also to other factors such as lithology, layer thickness, or seismic-signal effects. By contrast, when this anomaly is compared with the reflectivity attribute, it shows a more interesting response, marked by strong negative-polarity reflectivity, which reinforces the idea of possible hydrocarbon impregnation of the lead.

However, these initial indicators are not sufficient, by themselves, to confirm the presence of hydrocarbons or to clearly delineate all the interfaces H1, H2, H3, and H4. For this reason, the analysis was completed with other attributes, particularly instantaneous frequency and instantaneous phase. Instantaneous frequency shows, especially at interfaces H2 and H3, low-frequency zones located just beneath the reservoir levels, which provides an additional argument in favor of possible hydrocarbon accumulation. Instantaneous phase, for its part, makes it possible to better track breaks in reflector continuity and highlights four fault-bounded traps that may act as structural closures. All these observations therefore support the hypothesis of a potentially interesting lead, stratified, compartmentalized, and probably oil-impregnated. This hypothesis is even more plausible because the lead lies in the extension of a structure already recognized in an area where strong surface geochemical anomalies were reported by GMTI-Sonahydroc S.A. Nevertheless, caution is required: these results are favorable geophysical indicators, but they should ideally be confirmed by complementary data, particularly petrophysical, geochemical, or drilling data.

CONCLUSIONS

This study has shown that the combined use of instantaneous seismic attributes, particularly reflectivity, amplitude envelope, instantaneous phase, instantaneous frequency, and polarity, can constitute an interesting approach for identifying and characterizing a lead with a view to upgrading it into a prospect. Applied to the lead identified on seismic line Line-2008-K1, in the Nganzi Block, this method highlighted a structure that can be interpreted as a stratified and compartmentalized reservoir, presenting several indicators favorable to possible hydrocarbon accumulation.

The integration of well data, particularly VSP/checkshot data and lithological logs, as well as the analysis of instantaneous attributes of seismic traces passing through the wells, made it possible to place the studied lead within the Lower Bucomazi Formation. This formation, characterized by an alternation of clayey and sandy levels, provides a geological context favorable to the presence of reservoir levels. The observed anomalies, such as strong reflectivities, polarity variations, the bright spot, low-frequency zones, and fault-bounded structural closures, reinforce the hypothesis of a lead potentially impregnated with hydrocarbons.

However, caution is required when interpreting these results. The elements highlighted in this work are favorable geophysical indicators, but they cannot, by themselves, definitively confirm the presence of oil. This hypothesis is nevertheless supported by the significant geochemical anomalies reported in the lead area by the geomicrobial study. Thus, to better define the spatial extent of the prospect and evaluate the volumes of hydrocarbons in place, further investigations remain necessary, including a more detailed geochemical study, better-coverage 2D or 3D seismic acquisition, volumetric assessment, and eventually exploration drilling.

Ultimately, this study is not an end in itself but rather a step in the progressive upgrading strategy of the Nganzi Block. It demonstrates the value of searching for, identifying, and characterizing leads from one seismic profile to another in order to better guide future

exploration operations and increase the chances of success of future drilling. It also opens an interesting perspective toward the application of machine learning, using seismic attributes as input variables in a neural network, in order to improve reservoir characterization and the prediction of zones favorable to hydrocarbon accumulation.

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