American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Offshore Stratigraphic Architecture of the Miocene to Actual Deposits in the Southern Margin of Rio-Del-Rey (South Cameroon)

Arnold louvier Noudjo Djeudjam[a]*, François Mvondo Owono[b], Marie-Joseph Ntamack-Nida[c], Raphael Belinga[d], Stephane Koum[e], François Guillocheau[f]

[a,b,c,d,e]*Department of earth science, University of Douala BP 24157 Douala, Cameroon*
[d]*Minpromalo*
[f]*UMR-CNRS6118 GeosciencesRenes, Université de Rennes 1, 35042 Rennes Cedex, France.*
[a]*Email : arnoldnoudjo@yahoo.fr*
[b]*Email : francois-mvondo@hotmail.com*

Abstract

The study of the geometric deposits in a basin allows the reconstitution of its tectonic and eustatic history. The Rio-del Rey basin, upon which this study is being carried out, constitutes one of the two Cameroon margin basins located North of the Cameroon volcanic line. To study the stratigraphic architecture of the Miocene deposits consists in characterizing the deposits geometry by discriminating the controlling factors. This study is based on data, made up of 13 seismic lines and 07 wells and then on various methods related on seismostratigraphy and diagraphies. The obtained lithologies in the study area constituted essentially of sandy and clayey deposits from Paleocene to Recent. They are grouped differently in to Akata, Agbada and Benin Formations, and the Isongo Member. These deposits are set up in marines (bathyal and neritic), deltaics, turbiditic cones slope and fluvial channels environments. Three second-orders sequences were identified (S1, S2 and S3), they are made up of deposits presenting variable geometries along the basin. They are prograding, aggrading, in domes and synclinal. The disposition of the deposits was influenced by tectonic structures such as folds and faults. The isochronal map allows understand the sedimentary flow impact on topographic evolution of the basin in the upper- Miocene. It turns out that, deposits of this basin present various geometric tectonics control (subsidence and uplift) that constitute a major influential factor, being marked by the presence of synclines (gravity tectonics), domes (argilocinesis) and syn-sedimentary faults. The fall in marine level eustatism gives rise to progradations, whereas, a rise in marine level is responsible for retrogradations and aggradations. Thus, the sedimentary flow exerts a secondary control. It is related to the above two major factors.

Key Words: Rio-Del Rey; architecture; seismic stratigraphy; diagraphy; isochronal.

---

* Corresponding author.

1. Introduction

In a sedimentary basin, the deposits geometry is conditioned by the combined influences of tectonics, eustatism and sedimentary flow. Eustatism and sedimentary flow are themselves closely related to tectonics and climate [1]. The geometric study of the sedimentary bodies in a basin is necessary because it provides informations not only on the tectonic history of the basin but also on the variations of the accommodation potential in relation to tectonics or eustatism. The Rio-Del Rey (RDR) basin by its geologic framework is a good choice for such a study. Indeed, located at the heart of the Gulf of Guinea, the RDR is one of the two main basins of the Cameroon margin affected by the activity of Mount Cameroon along the Cameroon volcanic line in which Mount Cameroon, one of the very significant active stratovolcano (Figure 1). Some works contributed to the knowledge of the geology of this basin. Reference [6], highlighted three structural provinces in the RDR and showed that the productive reservoirs are excellent and not very deep, located less than 2000 meters. They are identified by good quality bed rocks corresponding to Paleocene-Eocene marine clays. Reference [13] showed from an analysis of seismic data and well, a clear succession between two great sedimentary systems: lower Miocene turbiditic channels and the middle Miocene-Actual prograding delta.

These deposits were affected by the taking down deformation followed by the rocking of the upper Miocene margin [11], highlighted the Plio-Pleistocene relative uplift of the southern coastal surface margin of the RDR through the measurement of fluvial incision. This uplift is attached to the Pliocene activity of the Cameroon volcanic line and the many reactivations of the post Pan-African faults. Recently, Reference [14] constructed environments in the basin by integrating palaeontological, granulometric and petrographic data. The interpretation of these data implied major marine environments, middle neritic then transitions between the coastal and intertidal environments where there were Cretaceous sediment deposits. Other works were realized in this basin but remained unpublished, for example, we have [3], who realized a synthesis of old works carried out on the basin.

This internal unpublished report entitled ‘’kinematic synthesis, tectonic, sedimentary and petroleum of the RDR basin’’ presents ideas on the geology of the basin. The Rio-Del Rey basin never has been the subject of a true study in seismic and/or sequential stratigraphy. The geometry of the sedimentary bodies in relation to Cretaceous tectonic inheritance or their developments in relation with Tertiary to Actual neotectonic, the gravitating and argilocinesis phenomenon are all issues that deserve to be highlighted in this study of the basin.

The purpose of this work is to characterize the geometry of the Miocene sedimentary deposits in the RDR basin by discriminating the controlling factors. It is precisely a question of the determination of the mode and the nature of the filling basin, the geometry of deposits and their evolution in the course of time (Miocene). This study based on the analysis of seismic profiles and diagraphic signal aimed at: (1) identifying and analyzing the facies, in order to determine the lithology of the Miocene formations; (2) to reconstruct the systems and the sequences of deposit; (3) to identify and characterize great tectonic phases that affected the deposits; and (4) to characterize the topographic evolution of the basin from the isochronals and isopach maps and finally to discuss the evolution of the controlling factors.

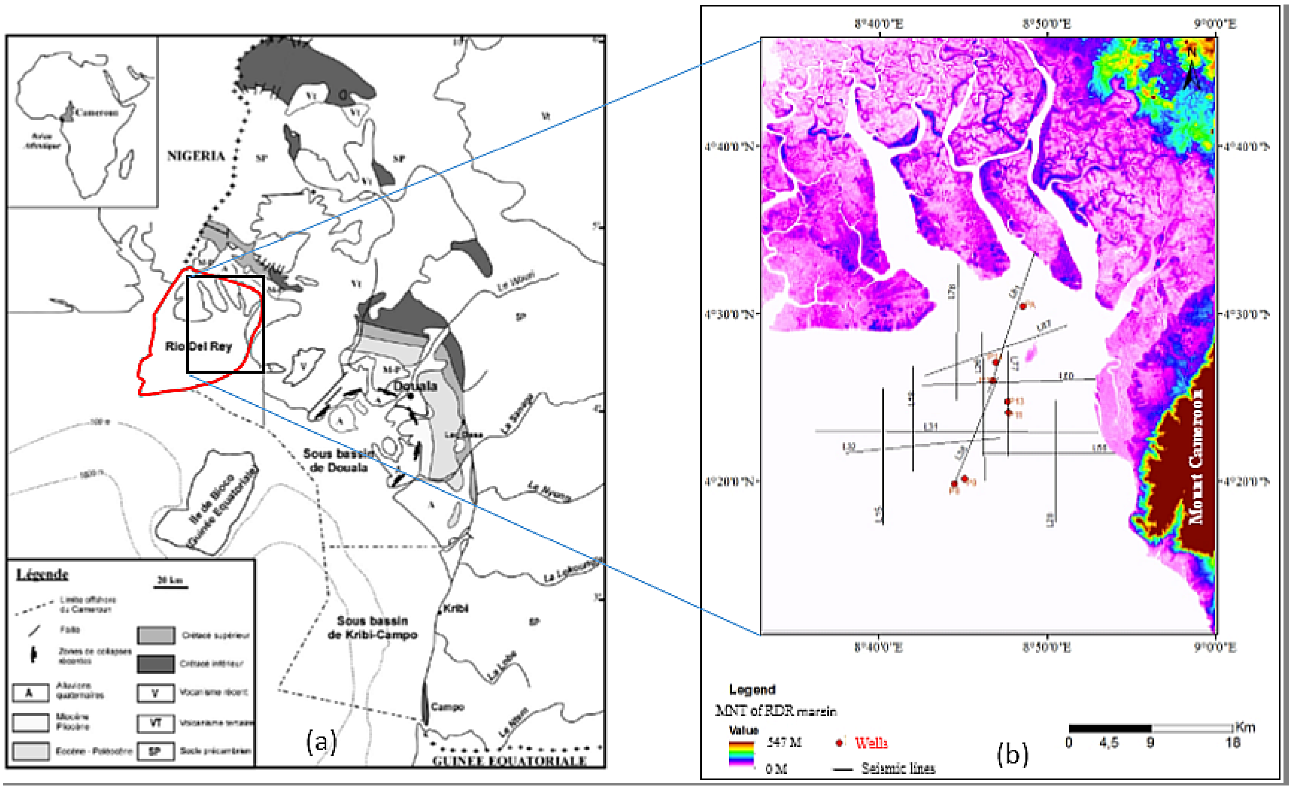


Figure 1: Geological map of the Cameroon coastal basins [19].In red locating the RDR basin (a) and presenting on background of Digital Elevation Model (Southern RDR), the positioning Plan of the seismic lines and wells (b).

2. Geological setting

Located in the Gulf of Guinea between 2°10' and 5°00' north, 8°30' and 10°20' east, the Cameroonian coastal basins are passive margin type basins. They can be subdivided into three sections: a Northern section represented by the Rio Del Rey basin, a central section represented by the Douala sub-basin and a southern section represented by the Kribi-Campo sub-basin (Figure 1).The Northern and central portion are separated by the Cameroon volcanic line and the southern portion extends to the Rio Muni basin in Equatorial Guinea [13]. The formation and tectonic evolution of this basin like the other basins bordering the West African coast are closely related to the rifting process which allowed or gave way to the opening of the South Atlantic, the separation of the African and South American continents and the formation of the Gulf of Guinea during the Albo-Aptian. This rifting process was marked by an extensive basement fracturing, followed by a rifting phase dominated mainly by growth faults. Three structural provinces each associated with a tectonic domain have been highlighted in the RDR [3,6]: in the North, a province of growth faults, associated with a domain in extension and characterized by an East-West succession of syn-sédimentary faults; at the center, an intermediate province characterized by North-South clay ripples and ending in the South by reverse faults and; to the South, a compressive province South-East of the basin, marked by folds and overlaps and juxtaposed to the Cameroon volcanic line.

The RDR is composed of Neocomien to Recent Formations from with clastic and biogenic sediments making approximately 6000 m thickness [17]. Three diachronal Formations (Figure 2) are well documented: (1) the Paleocene-Recent Akata Formation is a prodeltaïc marine clay unit overlying the cretaceous sediments; (2) the Oligocene-Miocene to Recent Agbada Formation overlying the Akata Formation and is made up of delta front alternating sand and clay; (3) the Pliocene-Recent Benin Formation is the superficial unit made up of continental sandstones and coastal plain sandstone.

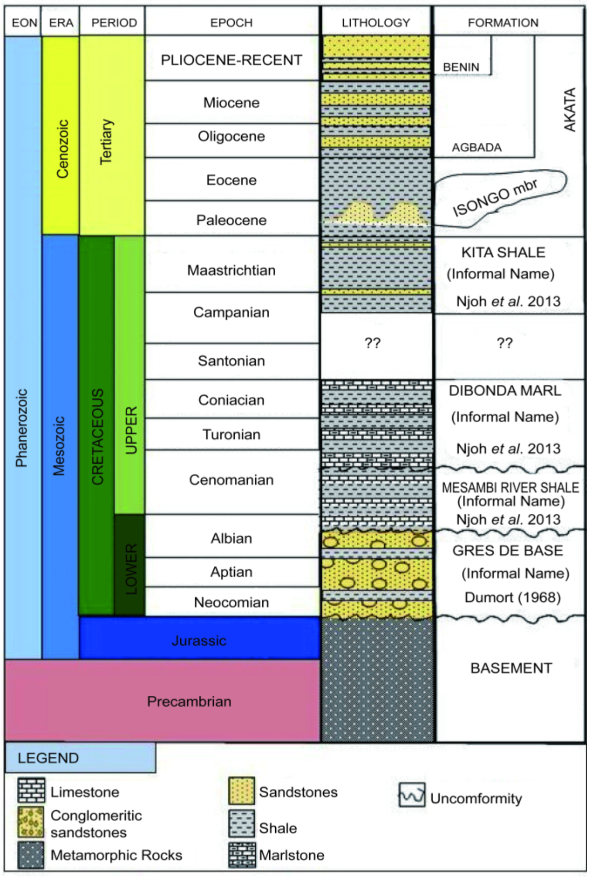


Figure 2: Stratigraphy of the RDR basin [14].

3. Data set and methods

3.1. Data set

To extract quantitative and qualitative information to discuss the stratigraphic architecture of the deposits in the basin, we use 2D seismic data and wells. They consist of thirteen seismic lines including three dips, five strikes and five random obtained in the offshore part. Six wells containing Logs and a synthetic film (PA) are analyzed in this work (Figure 1.b). The Logging set consists of Gamma Ray (GR), spontaneous potential (PS), caliper (CALI), neutron porosity (Nphi), electron density formation (RhoB), sonic and resistivity. The biostratigraphic data we have are recorded in an end-of-survey report carried out in 1970 by the ELF SEREPCA Company. It condenses informations on micropalaeontology, palynology and lithology which allow seismic temporal calibration and correlations.

3.2. Methods

In order to achieve our goal, we use two approaches: seismic stratigraphy and "Quick Look" method. Seismic stratigraphy makes it possible to determine the geometry of the sedimentary formations and to define seismic facies. This method provides information on seismic facies, sedimentary filling mode and deposit sequences. The geophysics characteristics are the continuity, frequency and amplitude. The analysis of the external configurations allows to define the installation model of sedimentary strata, deposits processes, erosion and paleotopography [12, 17].

There are parallel, divergent and prograding reflections; reflection-free and chaotic, etc. The determination of the deposit sequences requires a seismic temporal calibration and the identification of discontinuities which delimits these sequences and can be reinforced by the sequential analysis of the well Logs. There exist four types of reflectors termination to recognize these discontinuities on a seismic profile. They are onlap, downlap and erosional truncation. A deposit sequence corresponds to a set of strata set up during a sedimentary cycle. According to the duration of the cycle, one will have according to [20]: first-order sequences, of duration greater than 50 Ma, related to the first-order cycle, controlled by the formation and separation of super continents; second-order sequences, of duration between 3 Ma and 50 Ma, related to the second-order cycles and controlled by the variations in marine level related to tectonic phenomenon; the third-order sequences are in relation with the third-order cycles, of duration varying between 0.5 Ma and 3 Ma, they are controlled by eustatism; the fourth and fifth-order sequences are related to the fourth (between 0.08 and 0.5 Ma) and fifth-order cycles (lesser than 0.08 Ma), they are under eustatic control.

The ‘' Quick look " method is a fast well Log interpretation developed by [18]. It integrates several stages, including : (1) determination of lithology which consists in drawing on the GR Log, the base line of sands and that of clays to have an idea on the lithology.

These lithologies are often confirmed by the PS Log and the evolution of the bore hole (CALI); (2) determination of electrofacies which is done while following the joint evolution of the RhoB and Nphi Logs which makes it possible to determine the positive polarity electrofacies, negative polarity electrofacies and nul polarity electrfacies.

The identification of structural features on the seismic lines is based on the behavior of the reflectors. Thus, a fault is identified by the shift of a series of seismic reflectors, a fold by the more or less marked presence of the synclinal or anticlinal forms and a dome by an anticlinal-shaped bulge overhung by faults.

Isochronal and isopach maps are the result of the correlation of the double seismic time coming from the same interpreted horizon, the time here are those covered by seismic waves [10].

The realization of isochronal and isopach maps is done after the temporal wedging of seimic profile that resulted in the significant dating surfaces. The following interpretation of these significant fault surfaces and on the whole of seismic volume which allowed the transfer of the double time of the surface considered on Petrel software and the construction of curves of equal time course (isochronal).

The realization of isopach maps of a given formation are made from two isochronal maps (at the base and at the top) using a time law provided by the software.

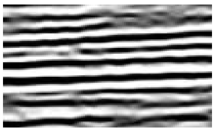
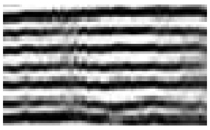
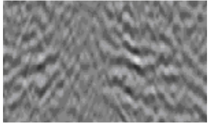
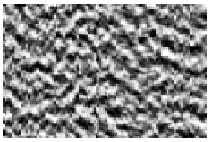
4. Results and interpretation

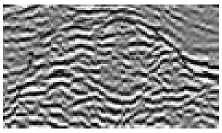
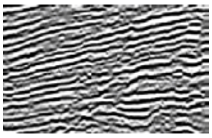
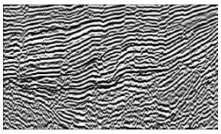
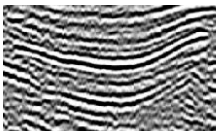
The results obtained mainly concern lithology, environmental and depositional sequences and deposits geometry, tectonics, isochronal and isopach maps.

4.1. Filling of the basin

The analysis of seismic profiles reveals the existence of eight seismic facies marked F1 to F8 (Table 1): facies with parallel tendency (F1, F2) (Figures 8, 9), facies with prograding tendency (F6, F7) (Figure 9), free-reflection facies (F3) (Figure 8), chaotic-reflection facies (F4) (Figures 6, 13), channel facies (F8) (Fig. 6) and mounded facies (F5) (fig. 4). Well-Logs (Figure 12) have shown that these facies are sands (fine to coarse) and clays (Fig. 3).

Table 1: Characteristics of seismic facies

Seismic facies 	Description	Energy of the environment	Lithology	Lateral relations	Nature of boundaries	Depositional environment
F1 : sub-parallel 	Sub-parallel reflector with variable amplitude , low frequency, with average to high continuity	Low, uniform deposit rate	Sandy clays	Spread towards the basin (uniform rate of sedimentation)	More or less concordant at the top and the base	marine
F2 : Parallel 	Reflectors with tabular geometry, average amplitude, high frequency and high continuity	Low, uniform deposit rate	Dominant sands and clays	Spread towards the basin (uniform rate of sedimentation)	Concordant to the top and base	deltaic Plain
F3 : complex 	Free-reflection, low amplitude, uniform frequency and average continuity	Low	clays	Complex	complex, uniform sedimentation	Deep marine
F4 : chaotic 	Irregular geometry, average to strong amplitude, variable frequency and low continuity	Low	Sands and clays	Spread over all directions	Irregulars	Deep marine

F5 : mound 	cone geometry with average to low amplitude and variable to low frequency	high to variable	Sands and clays	Chaotic internal Reflections ,spread to the deep basin	Irregular base, top receives onlap	submarine canyon/ Slope
F6 : Oblique clinoforms 	Prograding reflectors, average amplitude, high to average frequency and average continuity	High, steady sea level	Clays, silts and sands	Prograde to the open sea	Ends in toplap at the top and downlap at the base	Pro delta
F7 : Sigmoidal clionoforms 	Reflectors with prograding geometry , average amplitude, high frequency and good continuity	Low, rise of sea level	Clays, silts and sands	Prograde to the deep basin	Downlap base and discordant top	Slope
F8 : Channel fill 	Recessed reflectors with Onlap filling, low amplitude, high to average frequency, average to good continuity	Fall followed by the rise in sea level	Sands and clays	laterally discordant with other reflectors	Concordance at to the upper limit	Submarine environment (canyon filling/channels)

The lithological logs obtained make it possible to group them in to four units. From the base to the top:

- a unit essentially sandy (Esub) consisting of fine to medium sands , visible between 2478.2 m and 2703.9 m of depth only on well 13 (Figure 3). Its lithological characteristics are similar to those of the Isongo;
- an argillaceous unit (Au) with some intercalations of coarse, medium to fine sands observed in all wells but at variable depths and thicknesses depending on the position and depth of wells. Its characteristics are similar to those of the Paleocene-Recent Akata Formation;
- a unit made up of a sandy succession and clayey layers (SCu) of variable thicknesses according to wells, the lithological characteristics are identical to those of Oligocene-Miocene to Recent Agbada Formation,
- an unit essentially sandy (ESu) with medium fine to coarse sands and some few clay intercalations, it is visible only on well 15, extending from the top to 300 m, either 200 m thick, its characteristics correspond to those of the Benin Formation.

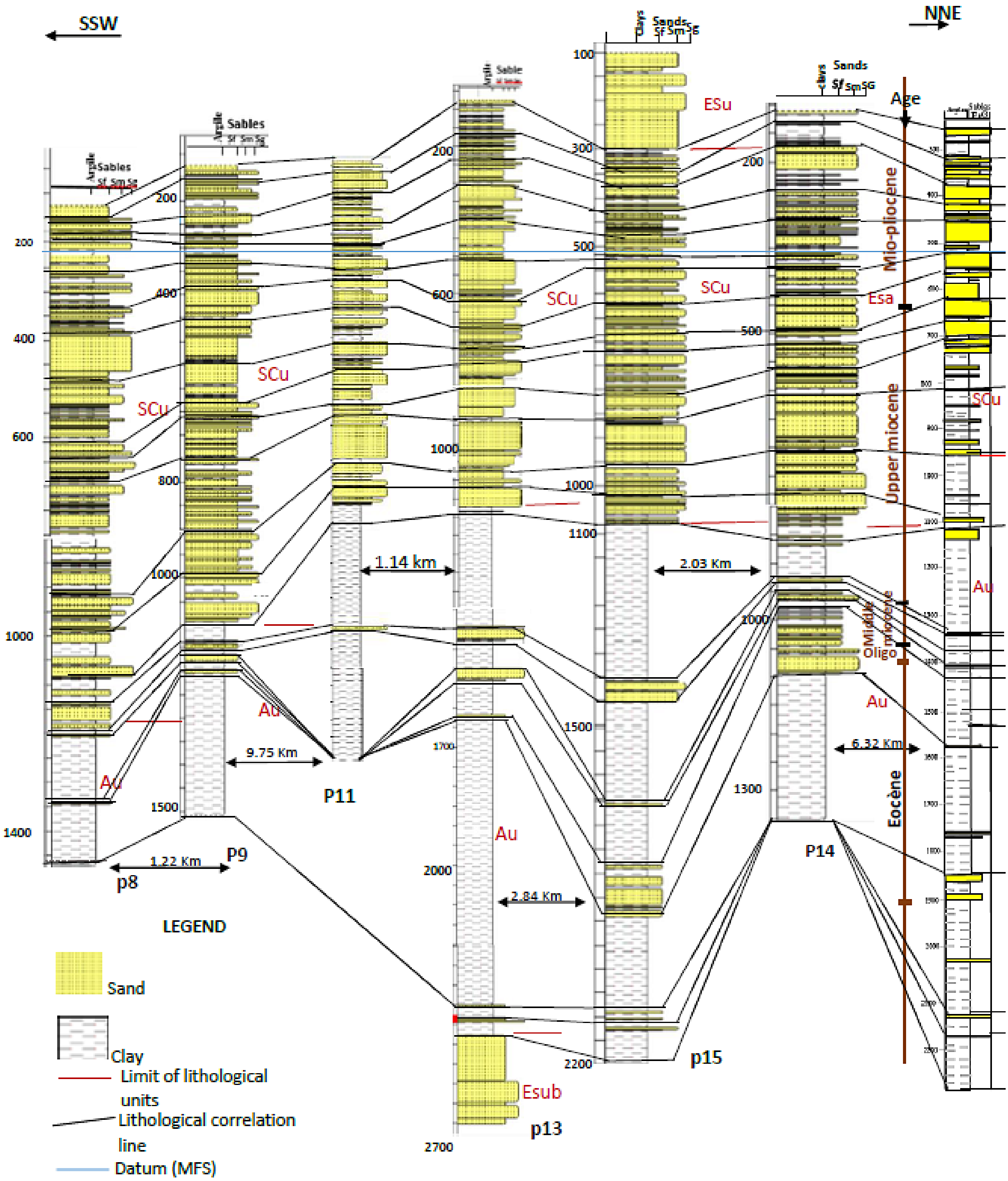


Figure 3: Lithological correlation and wells temporal calibration. Note the subdivision of the lithological units by horizontal lines in red color. Au: argillaceous unit with some coarse, medium and fine sand intercalations, ESub: essentially sandy unit at the base, ACu: succession of sandy and clayey layers, Ess: essentially sandy unit at the top.

4.2. Cutting in to depositional sequences

Three depositional sequences were defined on the basis of the well-wedge seismic data, and Well Logging signal. These are the second-order sequences named S1, S2 and S3. From the base to top, we have:

- Sequence S1

It is an Oligocene - upper Miocene (approximately 15.8 Ma) sequence included in the Paleocene- Recent Akata Formation.Visible on all wells with variable depths and thicknesses (Figure 12), it is bounded at the base by SB 1 identified by erosional truncatons, onlap and downlap, and at the top by the MFS discontinuity North of the study area.The seismic profiles show a progradational geometry upstream characterized by oblique and sigmoidal clinoforms (Figures 6, 7).This sector is dominated by deltaic deposit systems essentially progradational (L78, L81, L60) (Table 1) crossed by listric faults. East of the study area, this sequence presents a synclinal geometry (Figure 8), characterizing subsidence sediments. These sediments originate from the significant erosion of the western flanc of Mount Cameroun (Figure 1.b), the significant sedimentary strength causes a collapse of deposits under the influence of their weight, it is gravity subsidence.

South-West of the study area (downstream), it presents a dome geometry. These deposits geometry result from diapirism resulting from the plastic deformation of clays by uplift under the effect of pressure generated by the weight of the overlying clastic sediments. The uplift of clay in the form of a dome deforms the above deposits,thus, causing the appearance of vertical to sub-vertical faults (apex faults) (Figure 9).

- S2 sequence

S2 is an upper-Miocene sequence (approximately 1.9 Ma), it extends over the Miocene-Actual Agbada Formation. It is observed only on wells P13 and P15 (Figure 12), its basal boundary is the MFS 1and its summital boundary is MFS 2 (Figure 6). This sequence is less thick (300 ms). North of the study area, it presents a prograding geometry marked by oblique clinoforms (Figures 6, 7) and becomes aggrading to the open sea characterized by more or less horizontal reflectors parallel to sub-parallel and continuous (Figure 9). Like the S1 sequence, it presents a synclinal form in the East of the study area (Figure8).

- Sequence S3

It is a Pliocene-Recent sequence (approximately 5.3 Ma) (Figure 6). It extends on the Pliocene-Recent Benin Formation. It is observable on all wells except well P15 (Figure 12). It is bounded at the base by MFS 2. Deposits situated upstream of this sequence have the same geometries as those of the previous sequence located in the same area. Downstream, they become aggrading marked by sub-horizontal and parallel seismic reflectors (Figure 9). They characterize sediments set up in a marine environment by aggradation when the marine level is upwards. Eastward of the study area, this sequence shows deposits moving from a synclinal form into upstream to the dome shape towards the downstream (Figure 8). This geometry transition is explained by the processes of diapirism previously explained.

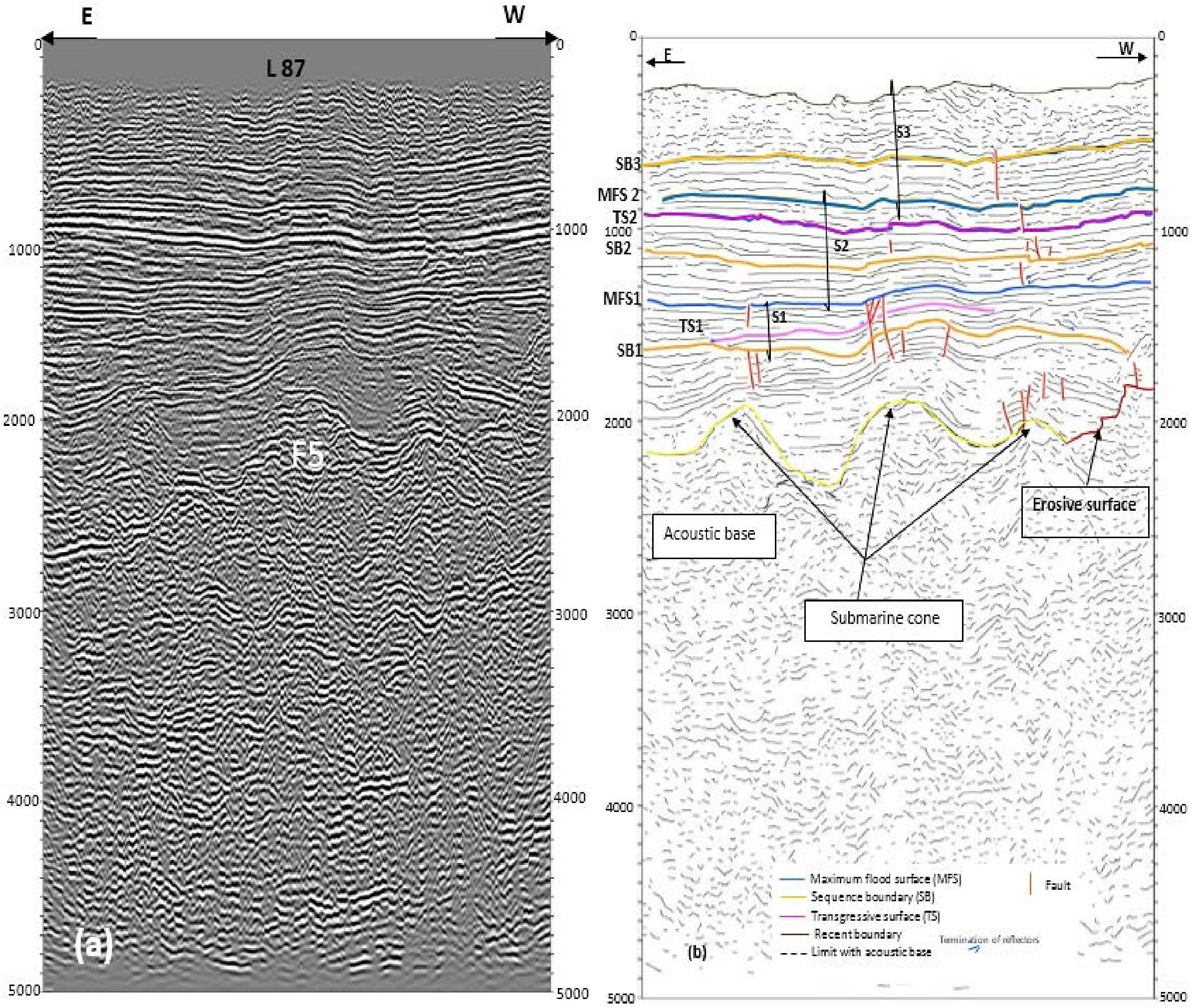


Figure 4: Seismic lines showing the system of turbiditic deposits materialized by submarine cones. To note the presence of the erosive zones generated by turbidity currents.

4.3. Structural analyze

Two tectonic styles were developed during the Miocene interval: folds and faults

- Folds

Folds are mainly observed in the South of the study area. Four types were identified:

- folds produced by phenomenon of diapirism: in fact anticlines with average side which gradually attenuate towards the vertical, they are recurrent to the South (Figures 8, 9);
- compensation anticlines or roll-over where sediments come to fit the geometry of the fault (Figure 10);
- a syn-sedimentary fold on thrust: represented by syncline and anticline related to a series of faults expressing a thrust (Figure 11);
- folds locating the channels: they present a great horizontal extension, wavelengths making about 5.9 km, amplitude varying between -200 ms and -300 ms (Figure 5).

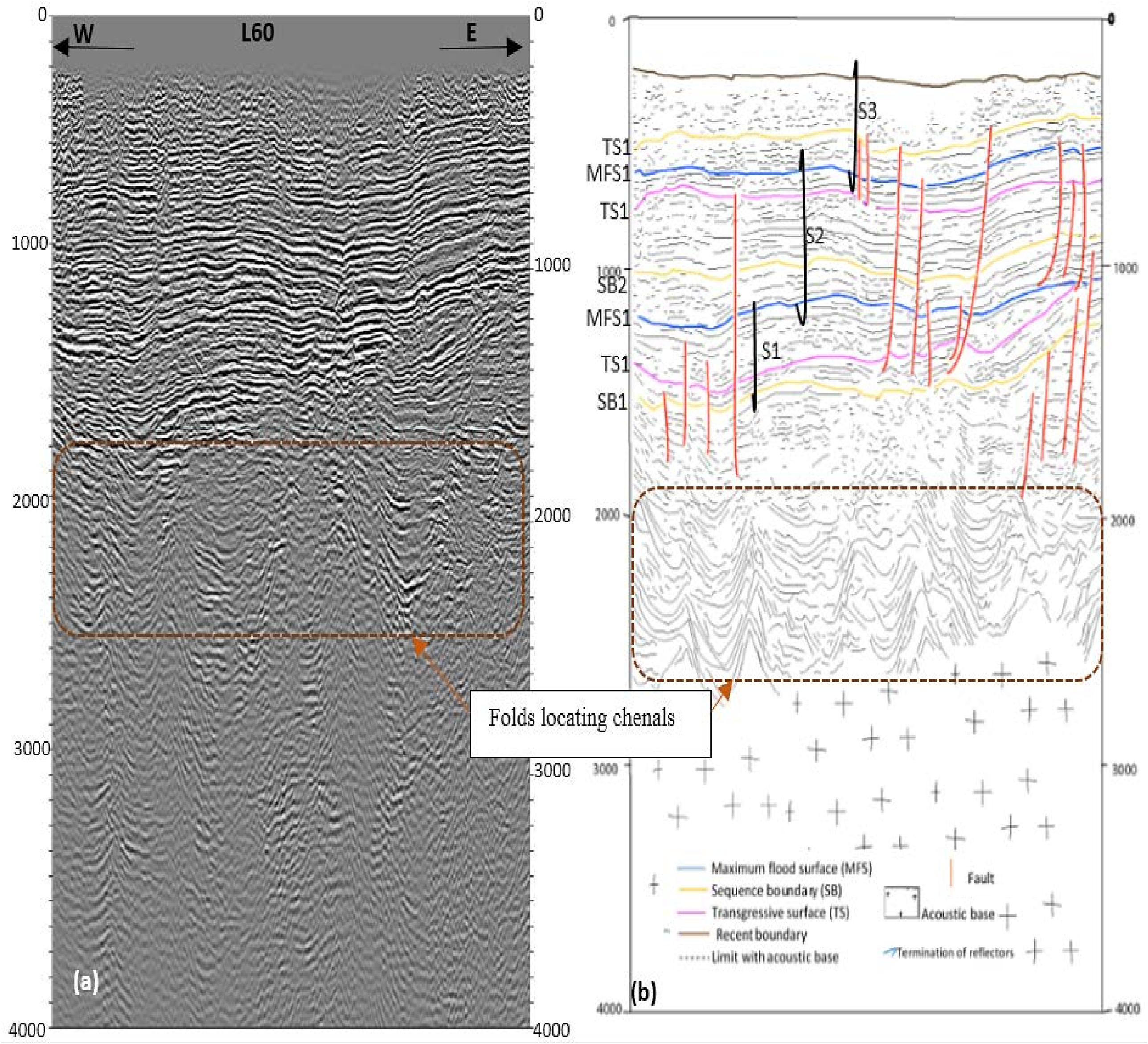


Figure 5: Seismic line, showing meandriform channels Systems (a:original line L60, b:interpreted line)

➢ Faults

Two types of faults are observed in the study area: vertical faults with sub-vertical and listric faults.

- Vertical to sub-vertical faults is visible all over of study area, but appears with a significant recurrence in the south. They have a global N-S orientation. A significant part of these faults is generated by the diapirism phenomenon and is located at the top of the shale domes (Figures 8, 9).
- listric faults are mainly observed in the north, where they present two main directions NE-SW and N-S. In the East, they are not very abundant and are directed E-W affecting deposits from the erosion on the western flank of Mount Cameroon (see L56 on Figure 3). They are syn-sedimentary growth faults involving gravity subsidence caused by the weight of sediments from the continent (Figure 6).

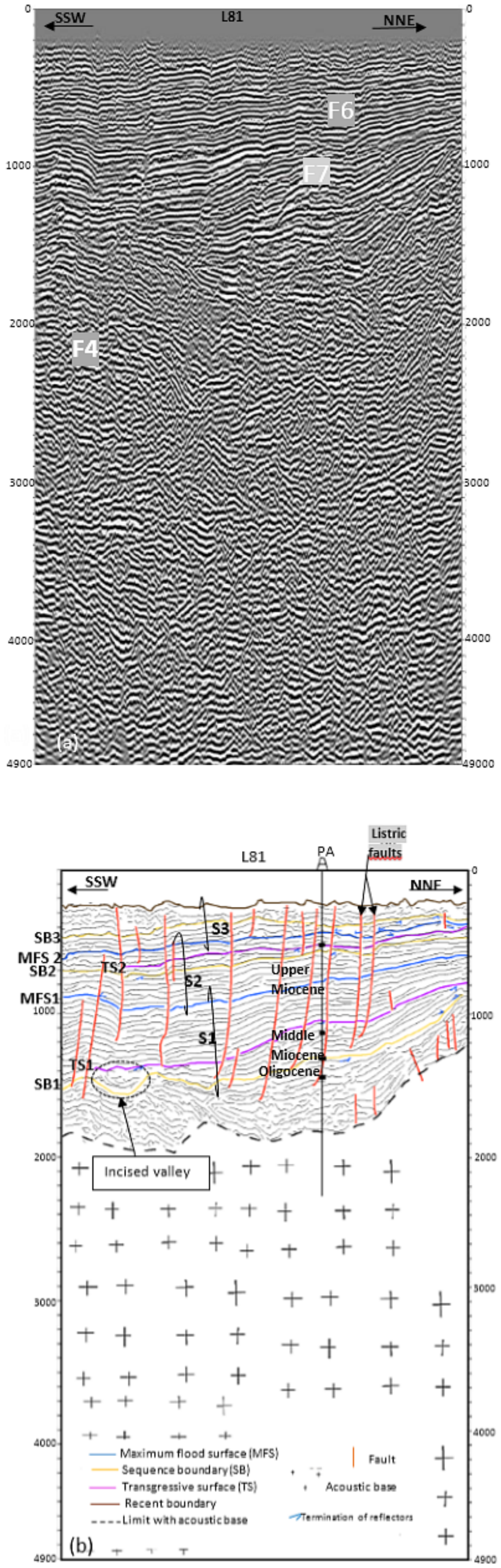


Figure 6: Seismic interpretation of the L81 line showing discontinuities, seismic sequences and tectonic structures. (a): original line, (b): interpreted line. Pa: well a allowing to tie the biostratigraphy.

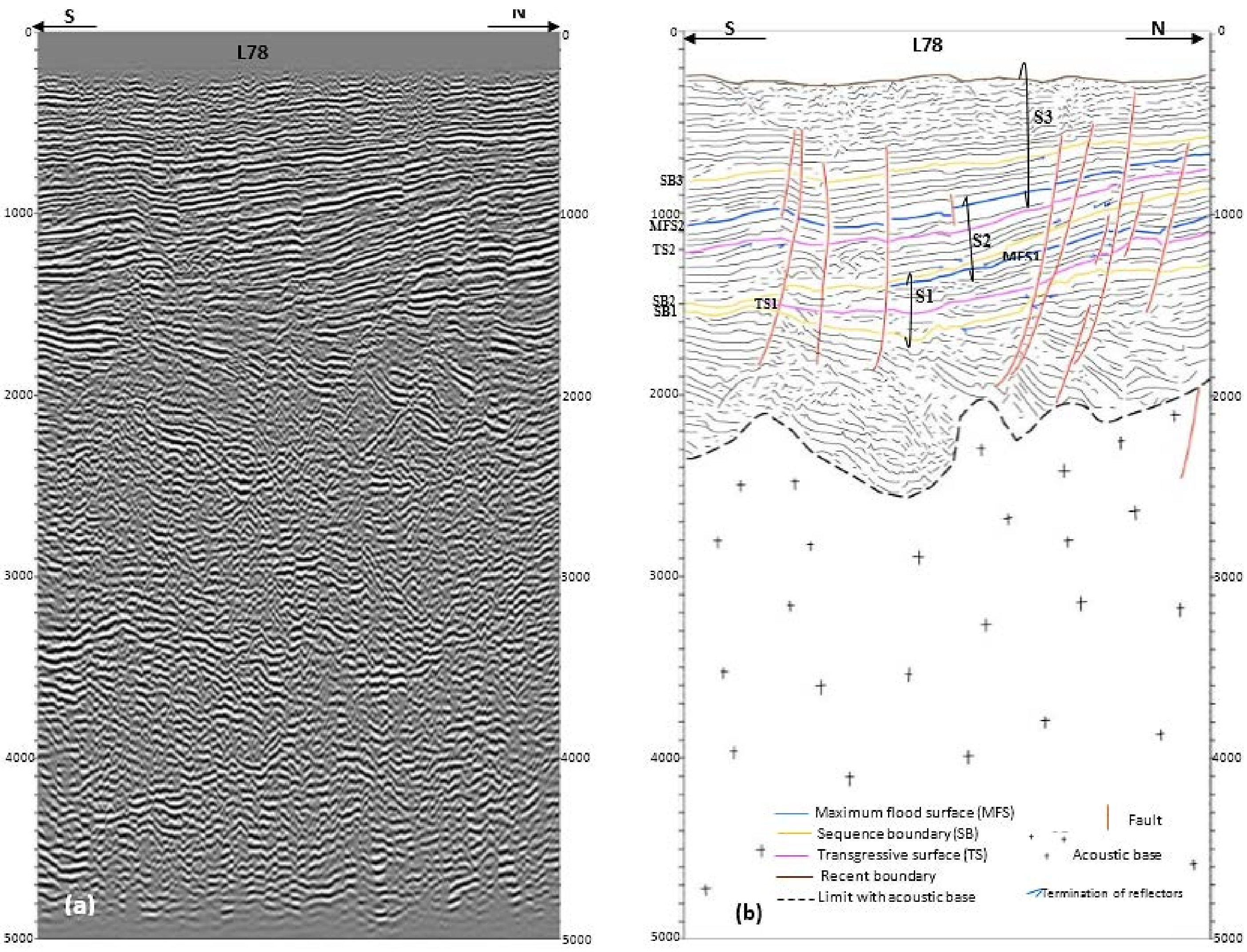


Figure 7: Seismic interpretation of the L78 line showing discontinuities, seismic sequences and faults.(a):original line, (b): interpreted line. Pa: well A allowing to tie the biostratigraphy.

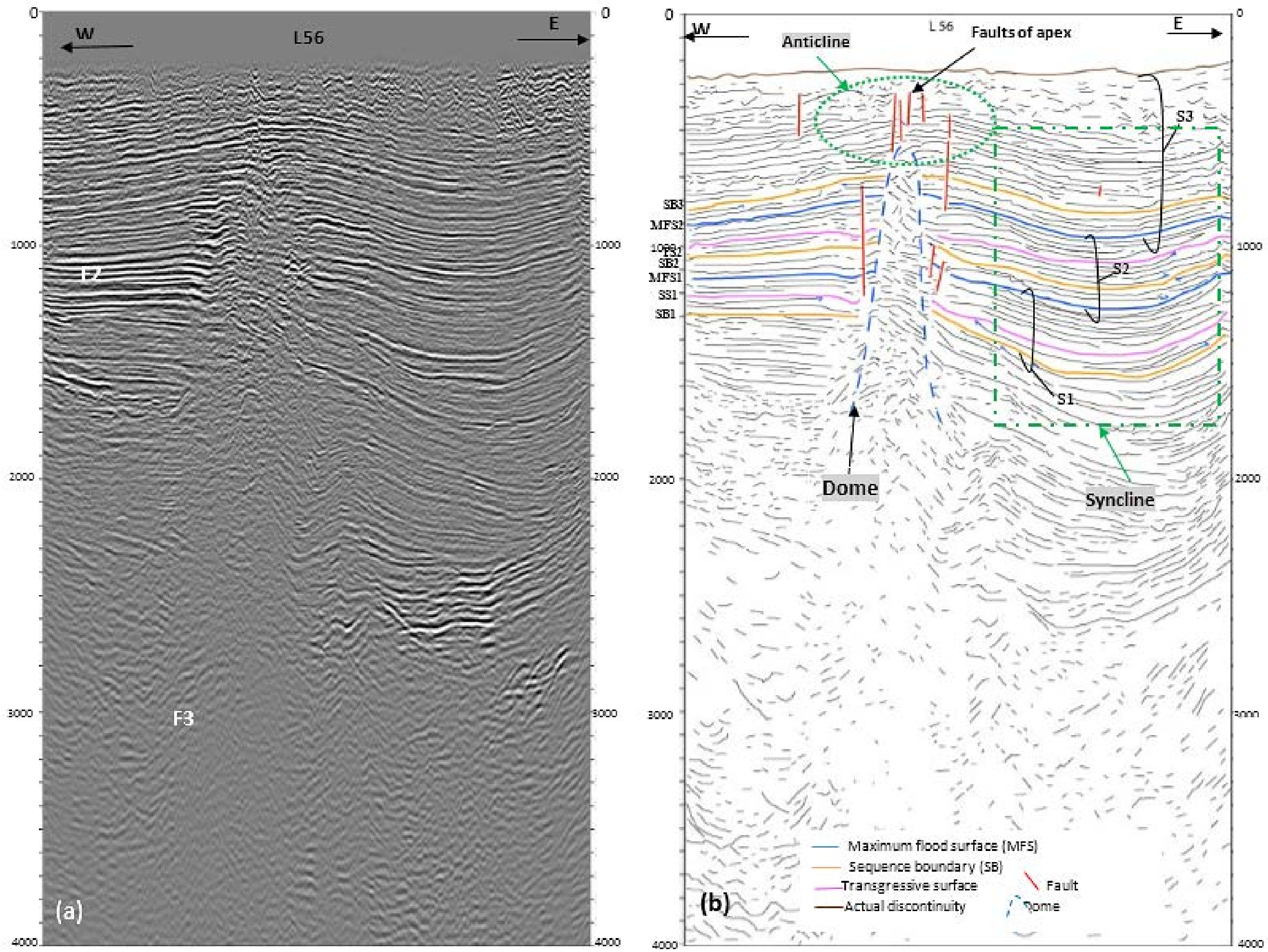


Figure 8: Seismic interpretation of the L56 lines showing discontinuities,sequences and tectonic structures.(a):original line, (b): interpreted line.

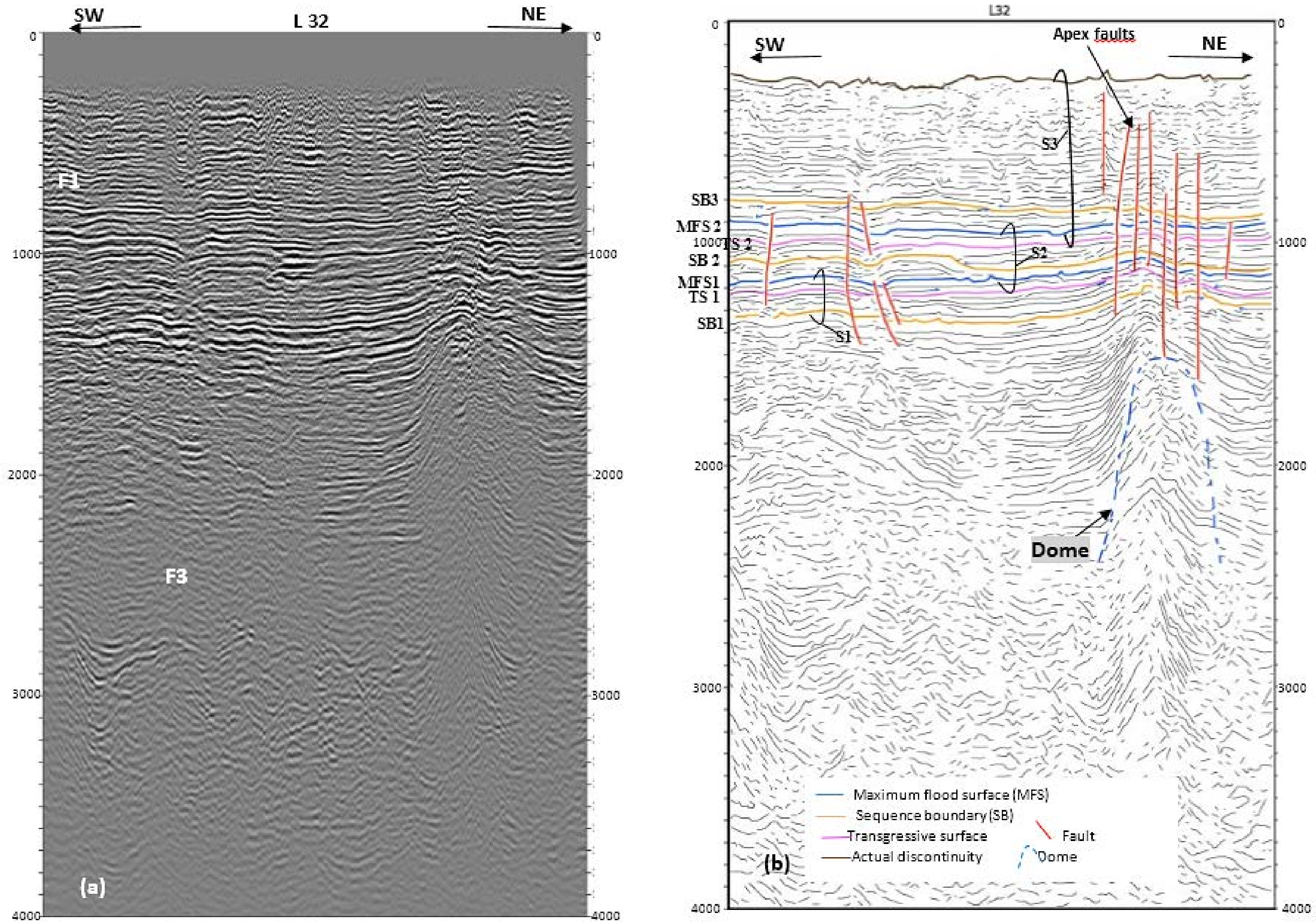


Figure 9: Seismic interpretation of the L32 line showing discontinuities, sequences and tectonic structures. (a):original line, (b): interpreted line.

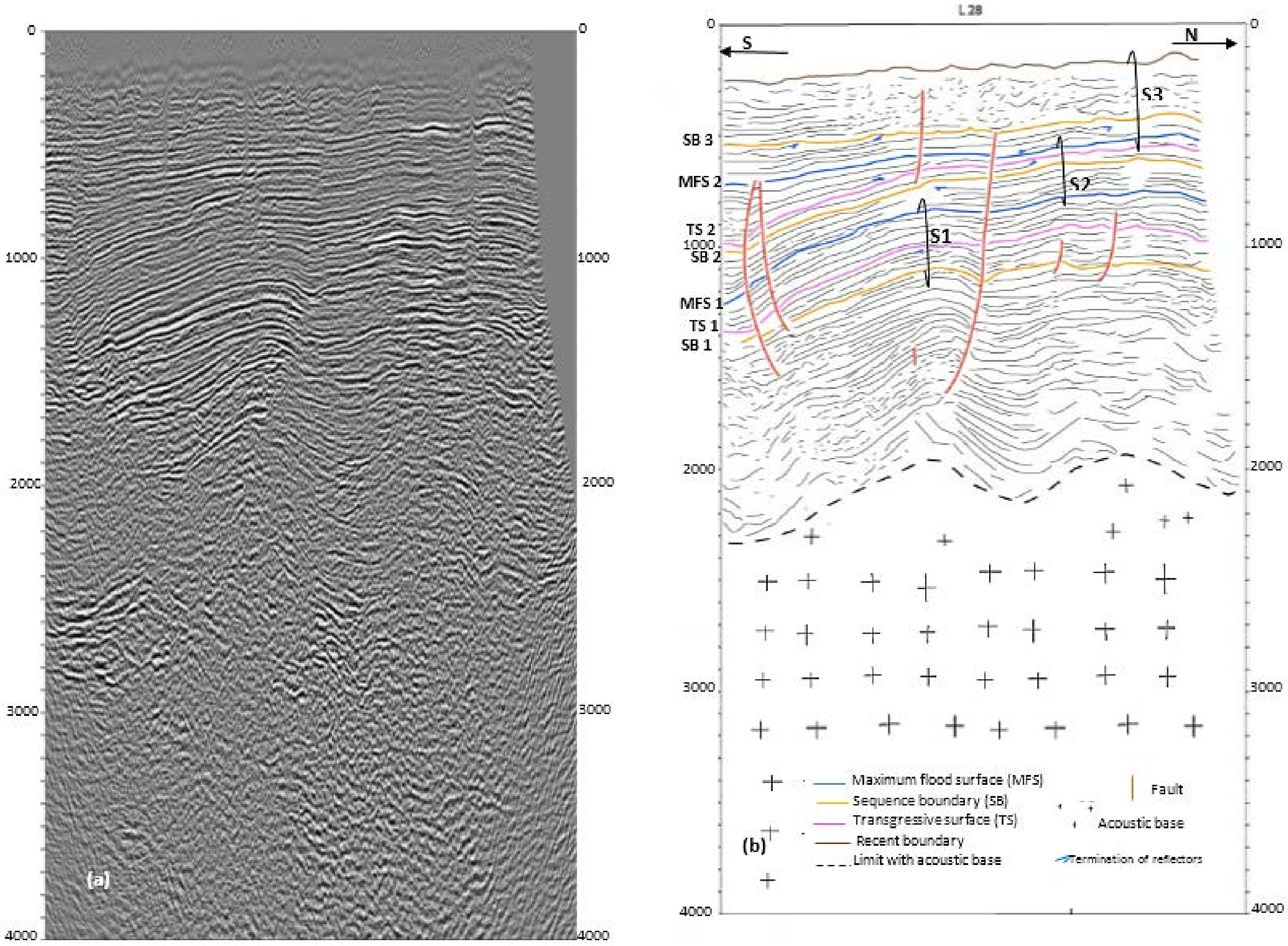


Figure 10: Structural interpretation of the seismic line L28 locating a roll over structure.(a):original line, (b): interpreted line.

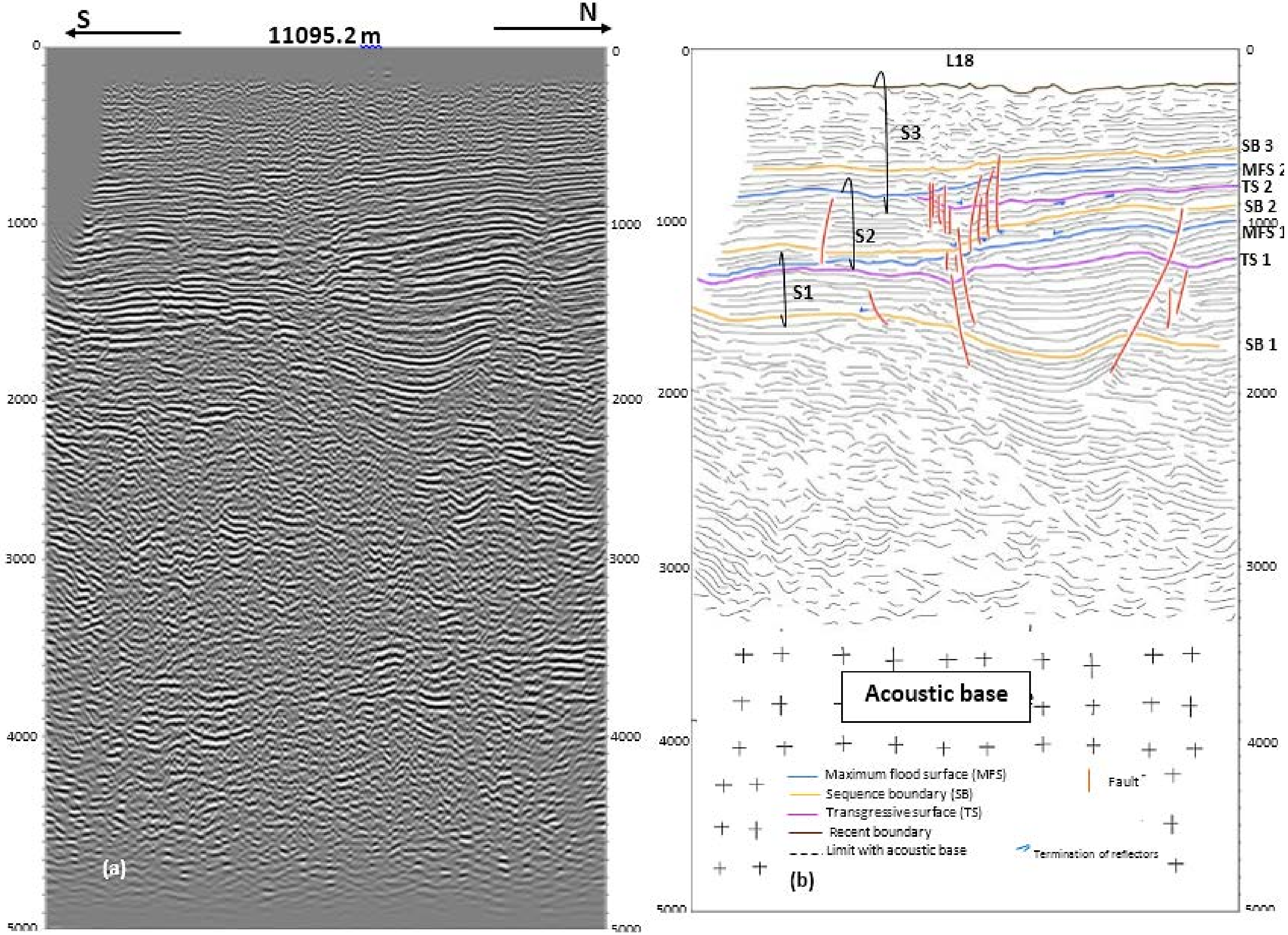
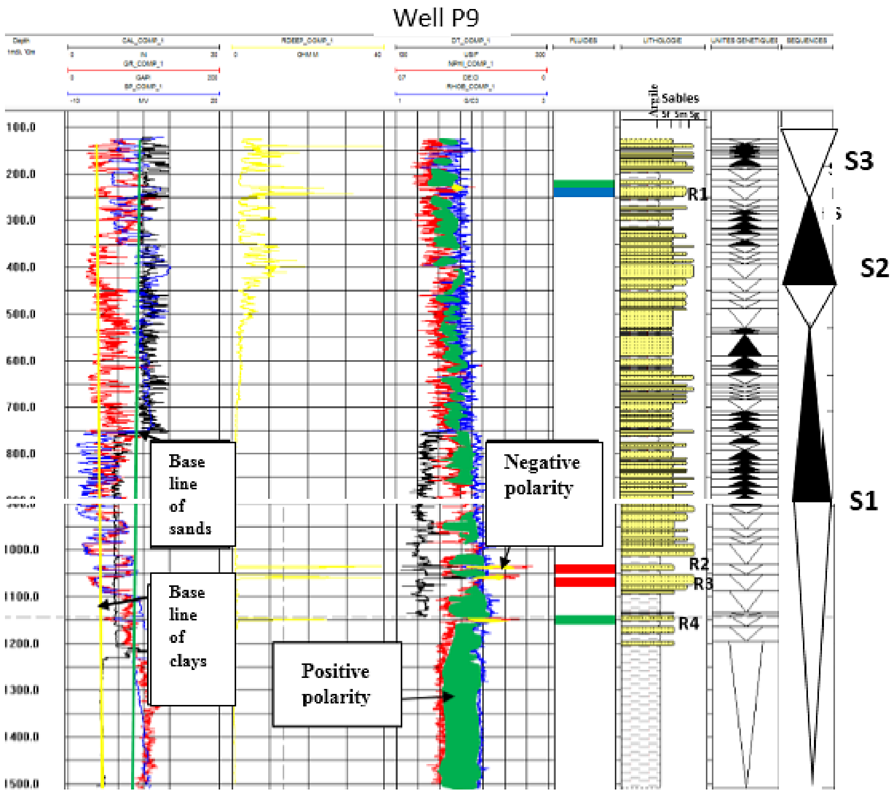
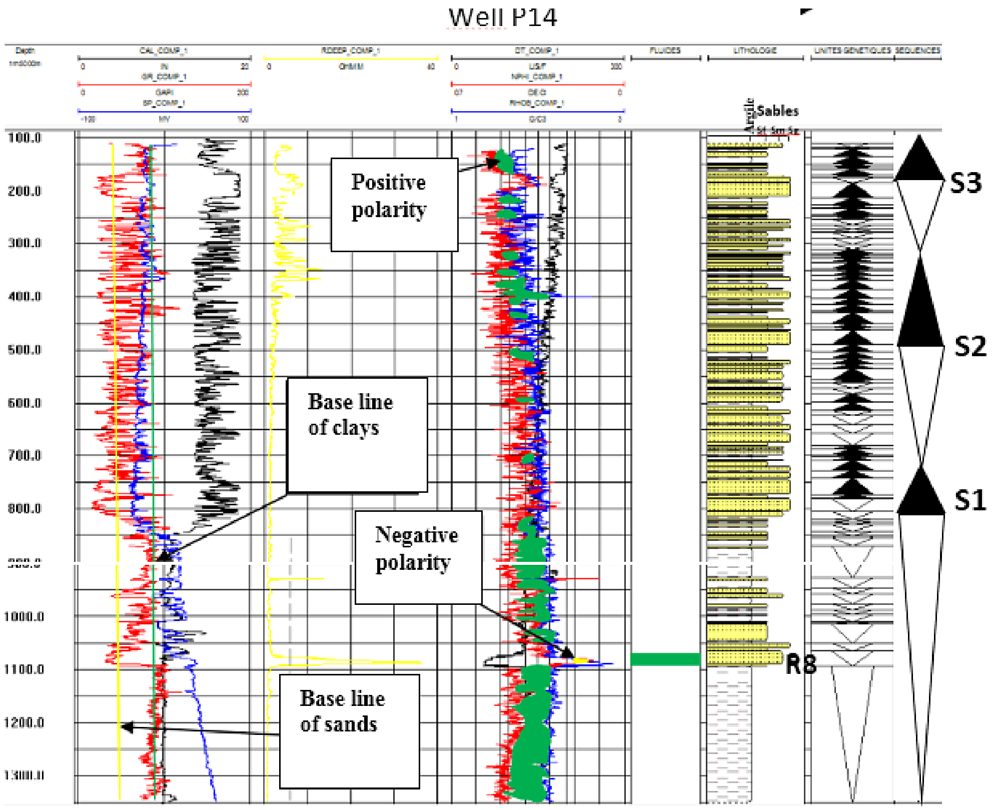
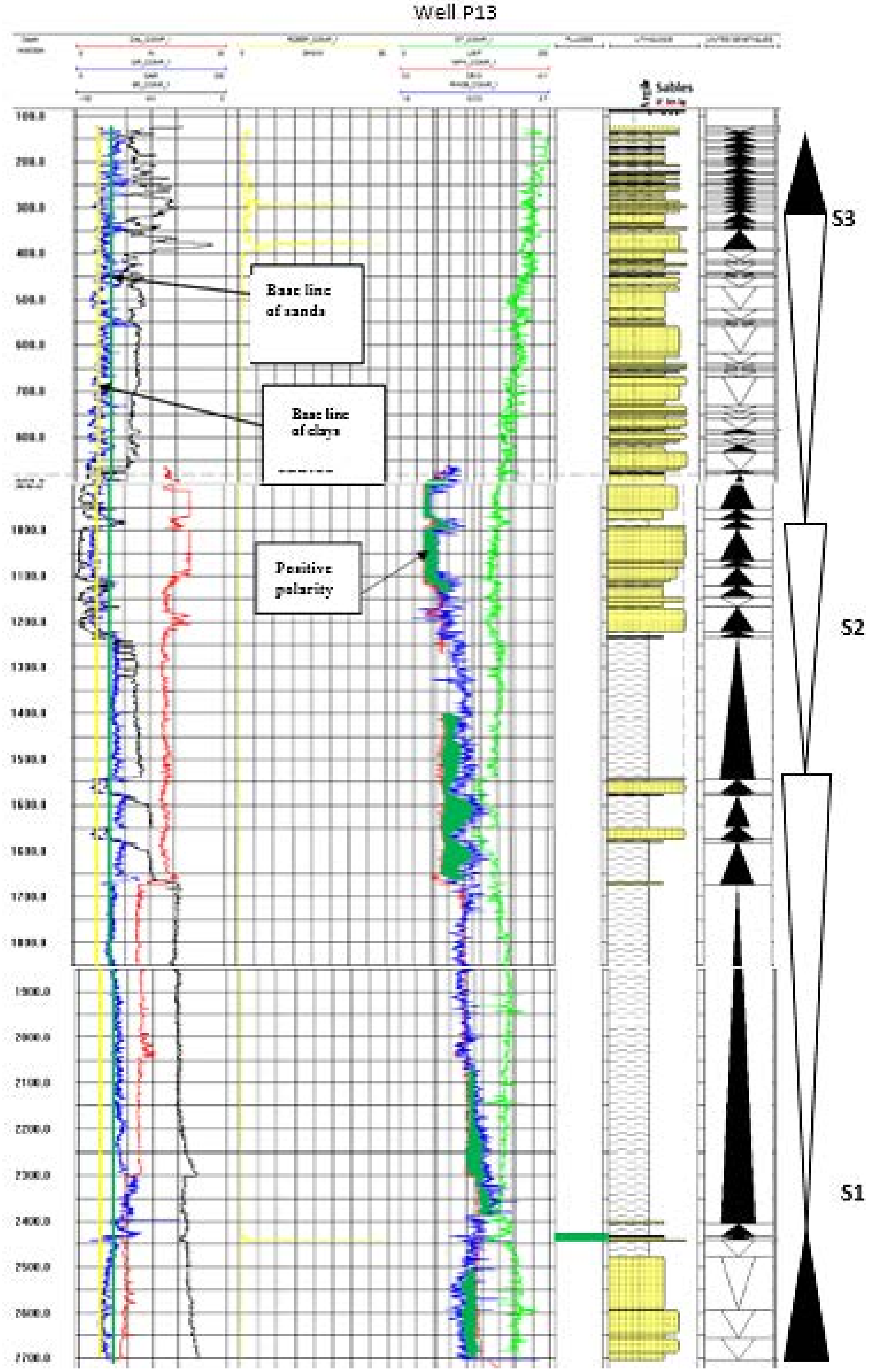


Figure 11: Structural interpretation of the seismic line L18.(a):original line, (b): interpreted line.


Well P9
Depth
CAL_COMP_1
GR_COMP_1
SP_COMP_1
RDEEP_COMP_1
DT_COMP_1
NPHI_COMP_1
RHOB_COMP_1
FLUIDES
LITHOLOGIE
UNITES GENETIQUES
SEQUENCES
Argile
Sables
Sf Sm Sg
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
1000.0
1100.0
1200.0
1300.0
1400.0
1500.0
Base line of sands
Base line of clays
Negative polarity
Positive polarity
R1
R2
R3
R4
S3
S2
S1


Well P14
Depth
CAL_COMP_1
GR_COMP_1
SP_COMP_1
RDEEP_COMP_1
DT_COMP_1
NPHI_COMP_1
RHOB_COMP_1
FLUIDES
LITHOLOGIE
UNITES GENETIQUES
SEQUENCES
Argile
Sables
Sf Sm Sg
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
1000.0
1100.0
1200.0
1300.0
Positive polarity
Base line of clays
Negative polarity
Base line of sands
R8
S3
S2
S1


Well P13
Sables
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
1000.0
1100.0
1200.0
1300.0
1400.0
1500.0
1600.0
1700.0
1800.0
1900.0
2000.0
2100.0
2200.0
2300.0
2400.0
2500.0
2600.0
2700.0
Base line of sands
Base line of clays
Positive polarity
S3
S2
S1

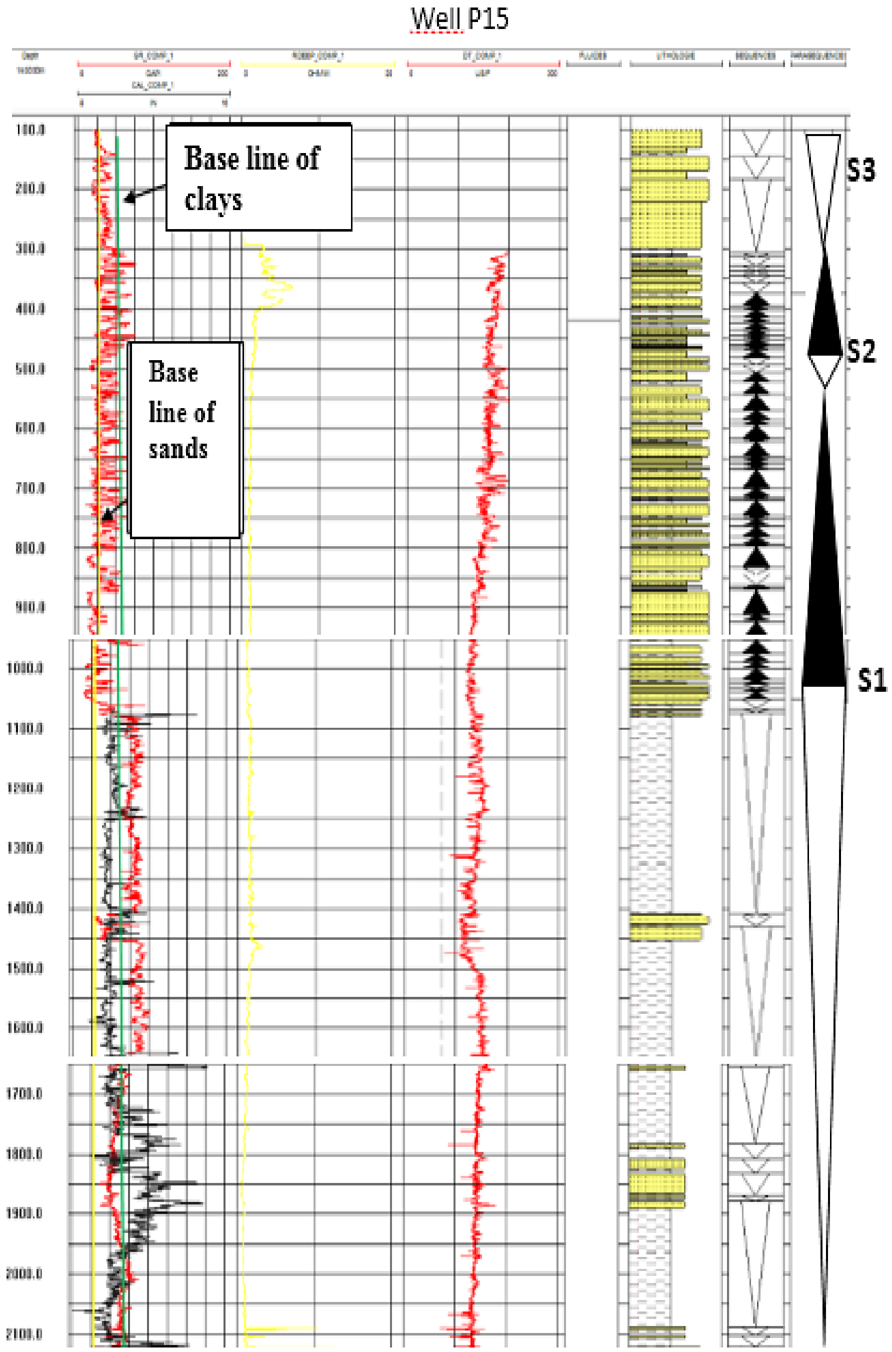


Figure 12: Well- Log interpretation showing the lithological variations, genetic units succession and sequences.

4.4. Evolution of the Miocene topography of RDR

The evolution of paleo-relief in the basin is revealed through the 3D isochronal maps characterizing the Miocene surfaces. The modeled isochronal surfaces are: the base of middle Miocene (upper Oligocene), the summit of middle Miocene and the summit of upper Miocene (Figure 13).The variation of the sedimentary thicknesses over the whole series is revealed through the isopach map (Figure 14).

These isocronal maps allow observing globally a deepening of the basin as we move away from upstream, i.e.

from NE to SW (Figure 13). Thus, following a NE-SW profile of the maps, three morphologic units are observable (Figures 13.a, 13.b, and 13.c):

- a more or less flat raised unit materialized on the map by lower isochrones values would represent the continental shelf ;
- an intermediate unit considerably inclined, constituting a NE-SW oriented slope, with intermediary values of isochronic curves, would represent the slope and;
- an unit of lower elevations deeper at the SW, characterized by higher values of isochronal curves. This area would correspond to the abyssal plain.

4.4.1. Isochronal map at the middle Miocene (top Oligocene)

The upper area of the map (continental shelf) shows isochronal curves oscillating between -1000 ms and -1500 ms (Fig. 13.a).It is crossed by E-W faults direction which extends to the South. The slope zone is characterized by a series of erosion marks in a N-S direction. The lower Southern area of the map is characterized by synclinal forms with maximum isochronal depths of -2500 ms, probably indicating subsidence (500 ms deep). Erosion surfaces are also present and we can notice anticlinal structures with peaks reaching -1500 ms (elevated over 400 ms).The anticlinal structure is probably due to the phenomenon of diapirism affecting the Southern area, as observed on seismic profiles.

4.4.2. Isochronal map at the middle-Miocene summit

It shows characteristics similar to the map at the base of the middle Miocene. The curves of the elevated area vary between -800 and -1100 ms, the maximum elevation of the area is done on 300ms.

The E-W fault network (West) direction observed at the base of Miocene is still observable and extends to the South. The slope area is always characterized by erosional surfaces which extend southward along a N-S direction. In the South, the curves vary from -1400 to -1800 ms; we always observe synclinal structures, characterizing subsidence with a maximum depth of -1800 ms (major depression of -250 ms deep).

Anticlinal structures are also present with a maximum peak of -1200 ms (raised over 300ms). The summit of the middle Miocene is marked by N-S faults in the South and at the center of the map.

4.4.3. Isochronal map at the summit of upper Miocene

The continental shelf in the elevated area is characterized by variations of curves between -400 and -550 ms (a relief of 150 ms maximum altitude). We notice the appearance of some erosive surfaces. The fault network located to the West, from E-W direction remains present.

The slope is characterized by a steeper slope; some rare erosive surfaces are still present. In the South, the depths have decreased considerably, we notice curves oscillating between -650 and -825 ms. The maximum value of the curves in depth of structures to synclinal decreased to -825 ms (i.e. 125 ms depth of depression).The anticlinal structures present a maximum altitude of -650 ms curves, that is, a rise in -100 ms.Some rare erosional areas are present and we notice in the East a N-S direction of faults development (Figure 13.c).

The evolution of the basin during the Miocene is significant. When we go from the base of middle Miocene to the summit of upper Miocene, the slope becomes steeper. Some erosional surfaces disappear because filled by sedimentary supply attenuating the amplitude of the anticlines which considerably become less pronounced, passing 100 ms (Figure 13.c).

The greatest depth of depression moves from 600 ms to 125 ms.Some low erosive levels appears in the elevated area. Also, we can notice a modification of the altitude of this area which is between 1500 ms and 1000 ms at the base of middle Miocene, between 1250 ms and 800 ms at the top of the middle Miocene (upper Miocene base). While at the top of upper Miocene, it ranges from 500 ms to 375 ms.

These differences in decreasing variations of the values in altitude, amplitude and depth, thus, mark a maximum attenuation of relief in the upper Miocene under the effect of a significant sedimentary flow which gradually fills the depressions thereby reducing their depth, thus, depositing around anticlines. Also, they reduce in their height.

4.5. Isopach map of Miocene (middle-Miocene base – upper-Miocene summit)

The isopach map (Fig. 14) covers the entire Miocene sequence below the Middle-Miocene base surface and above the upper-Miocene top (summit) surface. The spatial distribution of the elevated areas (R1, R2, R3, R4 and R5) with reduced deposits can be distinguished in the North to South and areas of subsidence of the abundant deposit basin (G1, G2) to the North shows a high structure (R1) located towards the continental shelf zone, it gradually decreases towards the SW and becomes very deep in (G1).

Sedimentation in the Northern part is from NNE to SSW with increasing thickness towards the SSW. At the center, the upper structure (R2) is located eastward of the map; this area corresponds to the base of Eastern flank of Mount Cameroon, it drops gradually toward the West materializing the E-W increase deposits thickness.

To the West, there is a deep structure (with thick deposits) corresponding to a subsidence area (G2). In the South, there is a set of structures (R3, R4 and R5) of low deposit depth, which have anticlinal forms generated by diapirism (Figure 14).

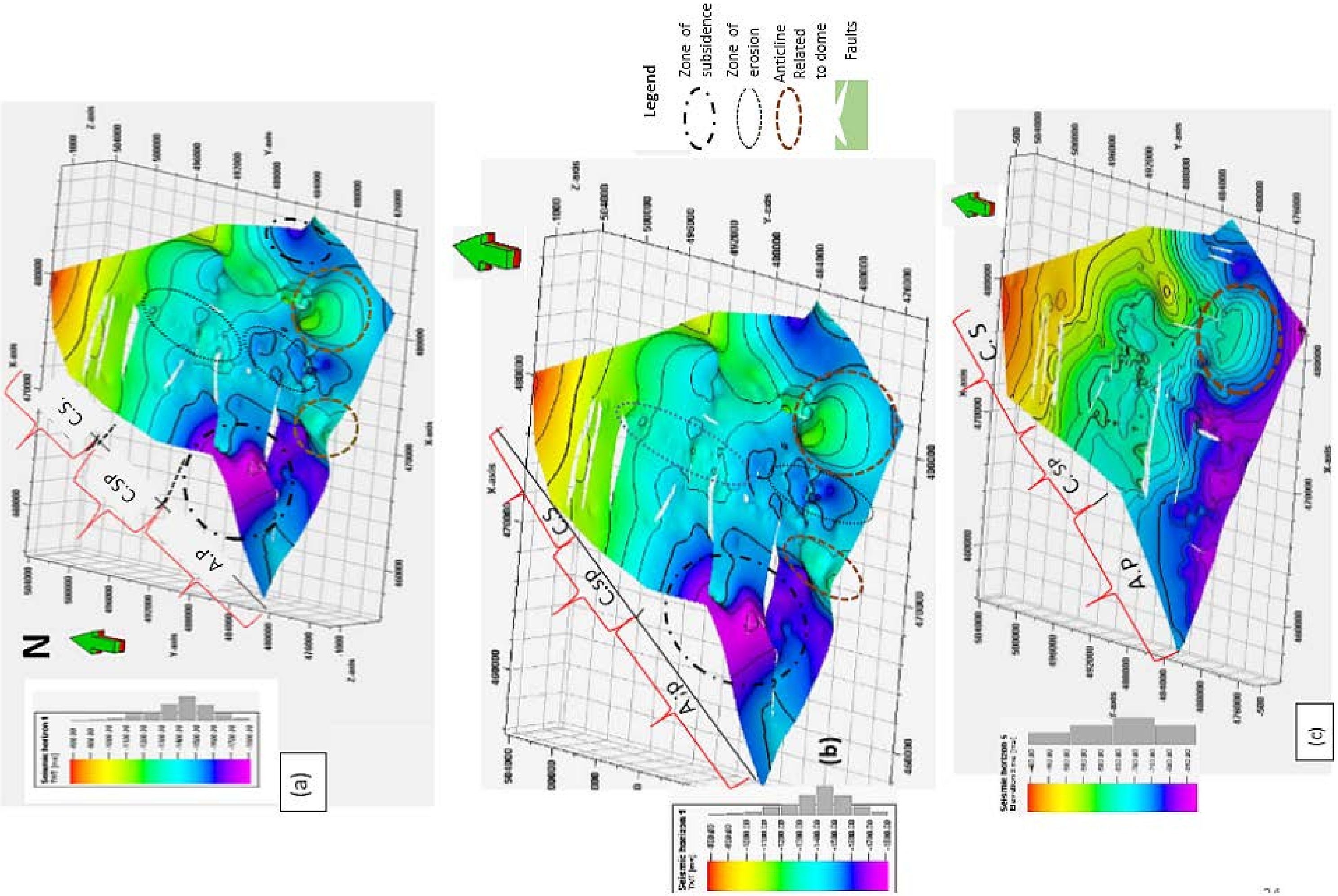


Figure 13: Isochronal maps (3D) of Miocene surfaces. (a) Middle-Miocene base, (b) middle- Miocene summit, (c) Upper-Miocene summit. C.S.: Continental shelf; C. sp: Continental Slope; A.P.: Abyssal plain.

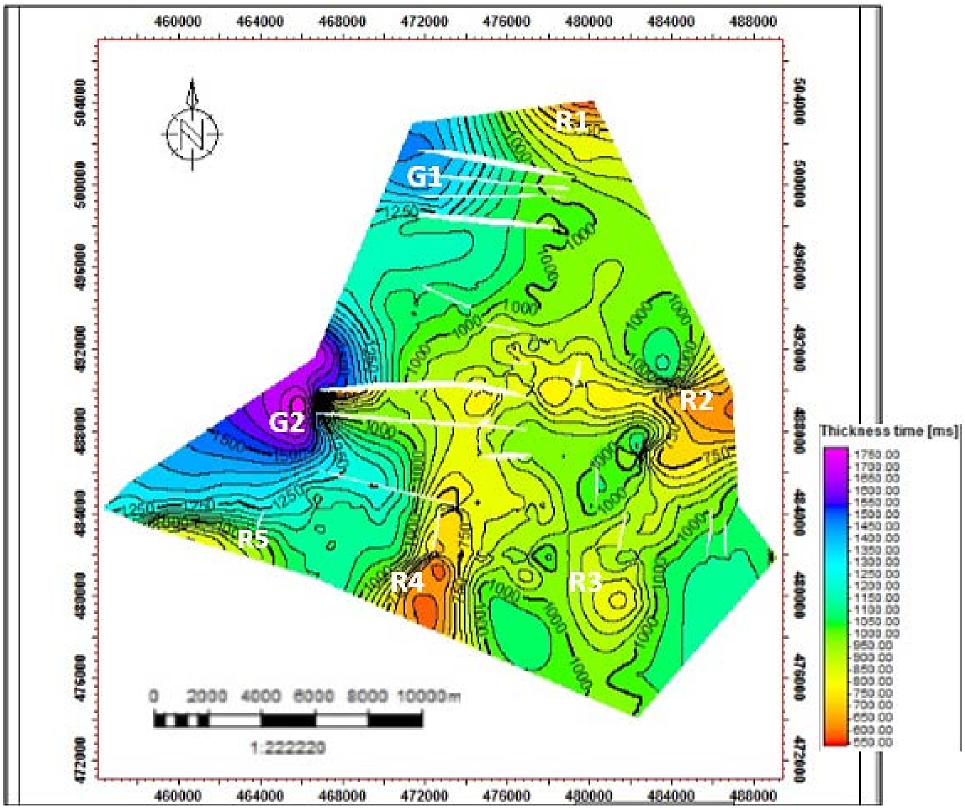


Figure 14: Isopach map of Miocene realized between the middle-Miocene base and upper-Miocene summit, locating the G1 and G2 high sedimentary thickness area in R1, R2, R3, R4 and R5 the one with low sedimentary thickness.

5. Discussion

The aim of this work was to characterize the stratigraphic architecture of the Miocene deposits basin and to discriminate the controlling factors. The results obtained showed that these deposits set up in various environments (marine, deltaic, fluvial channels, etc.) consist essentially of sands and clays. They present prograding and aggrading geometries, dome geometry or synclinal form. What are the factors that control such an organization? What is the control part of each factor? The following discussion will focus manly in response of the above two questions.

5.4. Factors responsible for the basin architecture

The above results presented show that the fluctuations in sea level, tectonics and the amount of sediments arriving in the basin would be responsible for the physiography of the margin.

5.4.2. Eustatic Control

The eustatic variations influence the distribution and the geometry of deposits in the basin [1].

The prograding geometries are usually due either a fall of the sea level, characterized by a migration of deposits from the continent to the ocean [15], or by a regression forced when tectonics mixes. The seismic results allow understanding this fall in sea level movement. The base of middle-Miocene (Oligocene summit) is marked by a sequence boundary (SB) (Fig. 6). The strongly erosive surface present inclined valleys which are generally formed during a relative fall in sea-level [15]. These erosive marks are perceptible on the isochronoal maps at the base and to the summit of the middle-Miocene (Figures 13.a, 13.b). This sea-level fall is followed by the development of submarine canyons by which the sediments transit by eroding to settle on the glacis or the abyssal plain in the form of submarine cone (Figure 4).

At the regional scale, the withdrawal of the sea allowed the African continent to practically regained all territories invaded by the sea during the Cretaceous [16]. The chronostratigraphic chart [9] (Figure 15) shows a significant fall in sea level at the summit of middle-Miocene which would correspond to the SB1. The aggrading deposits are set up during a eustatic rise. Indeed, the beginning of the upper-Miocene is marked by an eustatic level rise (Fig. 15) pronounced by the establishment of the TS1 surface (Figure 6). This rising is follow by the infilling of incised valleys [15]. It is therefore responsible of the deposits migration towards the continent. The transgressive surface TS2 coincides with the summit of the upper-Miocene (Figure 6) and characterizes the beginning of transgression. It is therefore responsible of the deposits migration towards the continent. When the high sea level is stabilized, we attend to a sedimentation by dominant vertical stacking of sediment, deposits stacked one on the others are then parallel. This mode of stacking partern is observed downstream of the basin (Figure 9) implying marine and deltaic plain environments (Table 1) [17]. After the sequence S2 bounded to the summit by MFS 2, a new sequence S3 is set up as a result of eustatic level rise succeeding the sea-level fall observed at the end of Pliocene (Figure 6).

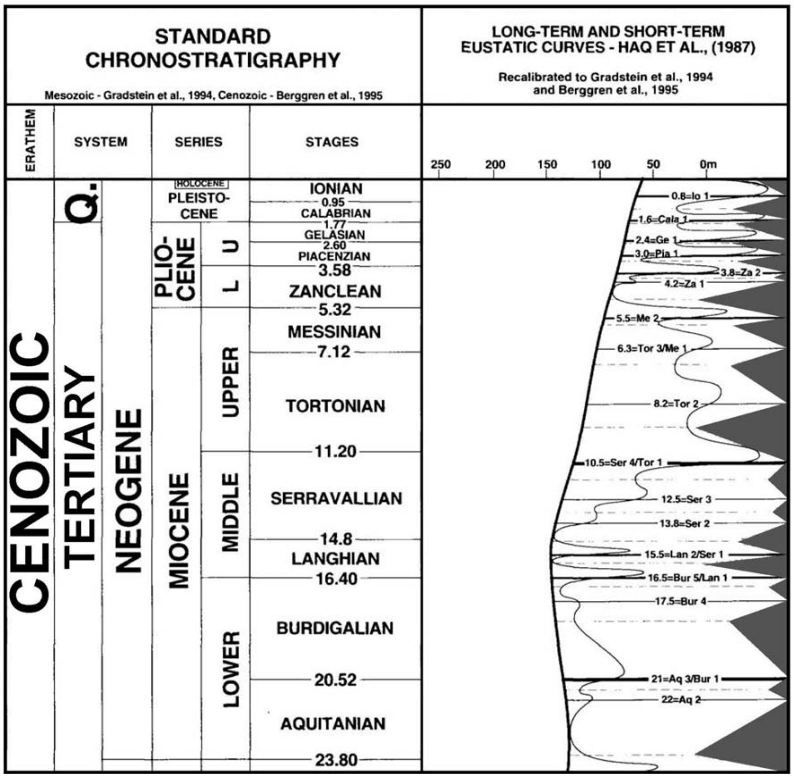


Figure 15: Chronostratigraphic chart highlighting great periods of sea cycle variation [9].

5.4.3. Tectonic control

In addition to the eustatic heritage which determines the morphology of deposits at the beginning, syn or post-sedimentary tectonics can influence the geometry of the sedimentary bodies.

In the study area, we notice the presence of the clay domes which resulted from diapirism [10]. These domes are observed South of the study area through seismic profiles (Figs.8, 9) and the isochronal Miocene maps (Figures 13 a-c). They generated an uplift of Miocene deposits in the swelling form to the summit (anticlinal) and thinning at the domes apex followed by fracturing (Figures 8, 9).This uplift would be responsible for transgressions as described above, which led to the retrogradation of sediments marked by discordances characterized by seismic reflections that ended in onlap on the dome apex.

The synclinal forms also constitute a tectonic geometry origin, they are observed in the South-East and South-West of the study area on the (L56) seismic profile (L56) (Figure 8) and through isochronal maps (Figures 13 a-c). They would have been set up in the course of compressive episode that occurred in the area during the Miocene. Also, the action of tectonic gravity is significant. Indeed, under the effect of the slope imposed by the morphology of the margin and weight of the sediments from erosion of the western flank of Mount Cameroon, some growth faults described above would be related to tectonic gravity. The intense subsidence resulting from these faults replay, would be to the origin of regression which caused a progradation of sediments marked by reflectors ending in downlap (Figure 8).

5.4.4. Sedimentary control

The high quantity of sediments accumulated in the basin shows that it is sufficiently feed. However, there are also periods of low sedimentary input. Indeed, the prograding geometries observed upstream through the seismic profiles especially the prograding sigmoidal prism (middle- Miocene) observed North of the study area (Figure 6) presents a low aggrading component. This interprets a low sedimentary accumulation with a stable and low sea level (Table 1) while the oblique prograding prism (upper Miocene) in the same area represents a heavy sedimentary accumulation [17]. The isopach map of Miocene (Figure 14) allows observing the distribution of sedimentary thicknesses along the study area. It can be observed that the, strongest thicknesses are privileged in areas with synclinal form observed on the isochronal maps (Figure 13).

The isochronal maps between the middle-Miocene base and the summit of the upper-Miocene show a certain evolution of the basin’s physiography. The middle-Miocene presents a well-contrasted relief with a continental platform separated from the abyssal plain by a slope. The abyssal plain is characterized by the presence of the well marked diapiric domes and subsidence and depressions areas. At the end of upper-Miocene, we observed a maximum attenuation of the relief under the action of a significant sediments accumulation [8], as observed on the seismic in this same period. It thus reduces the amplitude of the domes and infills the depressions and erosion area (Figure 13.c). The acceleration of this sedimentary supply would be related to a climatic cause observed in West Africa [8], well studied and characterized. It can be correlated to the central African climate during the same period. This climatic cause can be associated to the large slope result of the central Africa plateau as characterized by [13].

6. Conclusion

From 2D seismic and diagraphic data, thanks to seismic stratigraphy and quick look methods, we characterize the sedimentary architecture deposits in the RDR basin and constraint the factors responsible.

Eight facies mainly made up of sands and clays are distributed from the base at the top in a sandy unit corresponding to Isongo included on the second clayey unit, corresponding to the Akata Formation. Then an alternation of sand and clay unit corresponding to the Agbada Formation and finally a sandy unit with some small clays intercalations, corresponding to the Benin Formation. Deposited in marines, deltaic, fluvial channels, submarine cones slope environments, these deposits are organized in three second-order sequences (S1, S2, S3) affected by folds and faults. They present prograding and aggrading geometries, dome and synclinal geometries. The eustatic control of these geometries was well illustrated through movements of transgression and regression, tectonic control as for it was illustrated through diapiric uplift origin and subsidence. Passive control of sedimentary flow has also been highlighted through seismic profiles, isochronal and isopach maps.

Acknowledgements

The authors are grateful of the National Hydrocarbon company (Cameroon) and Perenco (Cameroon) for the Petromine laboratory and Petrel software 2014 (that helped us during this study) obtained by the convention with the University of Douala. We are indebted to Sebastian Owona (University of Douala) for his fruitful comments. A thank to Valentin Awa Njingun for correcting the English text.

References

[1]. H. Bauer. ‘’Infuence of climate, eustasy and tectonics in the architecture of continental deposits. a case study from the early and middle miocene of the digne-valensole foreland basin (SE France).’’phD. Sciences of the Universe. Ecole Nationale Superieure des Mines de Paris, France, 2006.

[2]. V. Bellec. ‘’Evolution morphostructurale et morphosedimentaire de la plate-forme aquitaine depuis le neogene.’’ phD. Science de la Terre. Université bordeaux I, France , 2003.

[3]. B. Blin. ‘’Synthèse cinématique, sédimentaire et pétrolière du bassin du Rio Del Rey (Cameroun)’’unpublished internal raport, Cameroun, 1999.

[4]. S. Bourquin. ‘’Analyse facio-sequentielle par diagraphies du trias du centre-ouest du bassin de paris: apports a la reconstitution de l'environnement de depot. Science de la Terre.’’ phD. Université Henry poincaré, France , 1991.

[5]. C. Duvail. ‘’Expression des facteurs régionaux et locaux dans l'enregistrement sédimentaire d'une

marge passive. Exemple de la marge du Golfe du Lion étudiée selon un continuum terre-mer. Minéralogie.’’ phD. Université de Montpellier 2, Frances, 2008.

[6]. R. M. Coughlin, W.O. Bement and W.V. Maloney. ‘’Petroleum Geology of the Deltaïc Sequence, Rio Del Rey Basin, offshore Cameroon’’, AAPG International Conference and Exhibition, the Hague, Netherlands, vol. pp 17-20. 1993

[7]. Exxon. ‘’Interprétation stratigraphique des sections sismiques.’’ Mémoire AAPG, n°26, Sneap, 1978.

[8]. J. L. Grimaud ‘’Dynamique long terme de l'érosion en contexte cratonique: l'Afrique de l'Ouest depuis l'Eocène.’’ Géoscience. Université de Toulouse, France, 2014.

[9]. J. Hardenbol , J. Thierry, M. B. Farley, P. C. De Graciansky, and P.R. Vail, ‘’Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins’’ 1998.

[10]. I. Hezzi . ‘’Caractérisation géophysique de la plateforme de Sahel, Tunisie nord-orientale et ses conséquences géodynamiques.’’ PhD. Géophysique, Université Rennes 1, France, 2014.

[11]. S. Koum, F. Mvondo Owono, M.-J. Ntamak-Nida, B. Njom, R. Belinga, E. Boum. ‘’Surrection relative plio-pleistocene de la marge Sud du Rio del Rey (Cameroun) à partir de la géomorphologie quantitative sur Modèle Numérique de Terrain (MNT).’’ Science, Technologie et Devellopement, vol 14, pp 59-69. 2013.

[12]. R. M. Mitchum, P.R. Vail, J.B. Sangree. ‘’Seismic stratigraphy and global changes of sea level, Part 6: Stratigraphic interpretation of seismic reflection patterns in depositional sequences C.E. Payton Ed., Seismic Stratigraphy-Applications to hydrocarbon exploration, AAPG, Mem. 26, 1977. pp 117-133.

[13]. F. Mvondo Owono. ’’Surrection cenozoique de l'Ouest de l'Afrique à partir de deux exemples : Le plateau sud-namibien et la marge nord-camerounaise.’’ PhD. Science de la Terre. Université de Reine1, France, p 327. 2010.

[14]. O. Njoh Anoh and J. Agbor Taku. ‘’Shallow Marine Cretaceous Sequences and Petroleum Geology of the Onshore Portion Rio del Rey Basin, Cameroon, Gulf of Guinea.’’ Journal of Marine Science. vol 6, pp177-192. 2016.

[15]. O. Raynal. ‘’Architecture de dépôts et facteurs de contrôle d’un système côtier à faibles apports sédimentaires - le littoral languedocien (Golfe du Lion, Sud de la France).’’ PhD. Université de montpellier II, France, p187, 2008.

[16]. D. Reyre. ‘’Bassin sédimentaires du littoral africain,’’ Travaux de symposium de New Delhi 1964, Paris. Association des services géologiques africains, 1966.

[17]. J.B Sangree and J. M. Widmier. ‘’Seismic Stratigraphy and Global Changes of Sea Level, Part 9.’’

The American Association of Petroleum Geologists Bulletin V. 62. No. 5 (May 1978), pp752-771, 1977.

[18]. O. ‘’Serra Diagraphies (géophysique).’’ Encyclopedia Universalis, 1990, pp. 348357.

[19]. SNH/UD. ‘’Stratigraphie séquentielle et tectonique des dépôts mésozoïque syn-rift du sous bassin de Kribi-Campo.’’ Rapport non publié, pp134, 2005.

[20]. P.R. Vail, R.M. Mitchum, and S. Thompson. ‘’Seismic stratigraphy and global changes of sea level,’’ in Seismic - application to hydrocarbon exploration, edited by C. E. Payton pp. 49-205, Amer.Assoc.Petrol. Geol. Memoir. 1977 Part 1 to 11.