Seismic interpretation of the north proximal Jequitinhonha Basin

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Abstract

This paper presents an interpretation of 2D seismic data from the north proximal portion of Jequitinhonha Basin, located in the South Bahia coast, Brazil. Sequence Stratigraphy concepts and Salt Tectonics mechanisms were the base to approach the complexity of this basin. The post-salt sequence was characterized in eight sequences of third order discussed in terms of the dominance of transgression or regression in the filling history of this basin. Structural characterization of the post-salt sequence occurred in terms of the prevalence of gravity spreading or gravity gliding. The methodology of interpretation includes the use of instantaneous seismic attributes and TecVA to map faults and horizons in seismic sections.

Introduction

Seismic interpretation requires a junction of good models to rebuild the geological history of the subsurface and good tools to extract the maximum information from available data. Sequence stratigraphy is a powerful methodology of interpretation, that gives more than lithostratigraphic units, but allows us to infer about the genesis, spatial and temporal succession of units called depositional sequences (Holz, 2012). A depositional sequence forms during a full cycle of change in accommodation (Catuneanu *et al.* 2011). Accommodation is the space available to fill with sediments controlled by tectonism and eustasy and it is limited by the base-level. For passive margin basins, base-level corresponds to relative sea level. When the base-level drops and exposures the continental platform, erosion generates an unconformity that is the boundary surface of a depositional sequence. At this moment, the shoreline advances toward the sea, forming a progradational stacking pattern. It always happens when the accommodation rate is lower than the sedimentation rate. The opposite happens, when the accommodation rate exceeds the sedimentation rate, a retrogradational stacking pattern is formed, with shoreline advancing toward the continent. When the accommodation and sedimentation rates are equivalent, the stacking pattern formed is aggradational with no movement of shoreline. Stratigraphic sequences can be classified according to the magnitude that the base-level changes in a specific basin. The first order sequence is relative to tectonic event that formed the basin. The second order represents the basic division of the first order, in successions that reflects great changes in accommodation and sedimentation balance. The third order sequence is equivalent to a typical depositional sequence, recording smaller tectonic/eustatic variations than the second order sequences. It can be more expressive in some basin portions than others and it comprises system tracts characterized by their stacking pattern, aggradational, progradational or retrogradational, that reflect the conditions between accommodation and sedimentation rates. This study recognized depositional sequences until third order by mapping unconformities in seismic sections.

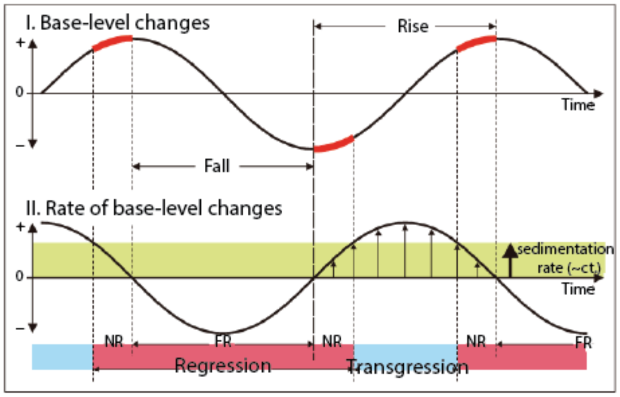

Figure 1 - *Top sine curve shows the magnitude of base-level changes through time. The thicker portions on this curve indicate early and late stages of base-level rise, when the rates of base-level rise (increasing from zero and decreasing to zero, respectively) are outpaced by sedimentation rates. At these moments, Normal Regression (NR) occurs with a progradational pattern of sedimentary succession. Note that the rates of base-level change are zero at the end of base-level rise and base-level fall stages (the change from rise to fall and from fall to rise requires the motion to cease). Forced Regression (FR) occurs when base-level falls with a progradational pattern of sedimentation and shoreline go toward sea. Transgressions occur when the rates of base-level rise outpace the sedimentation rates. Adapted from Catuneanu (2006).*

Structural geology of post-salt section of Jequitinhonha basin is strongly controlled by adiastrophic tectonics. Evaporitic basins are characterized by thin-skinned deformation driven by gravitational force on salt-sediments system, where salt acts as a ductile substrate to brittle sediments package. Under these conditions, the basin have two main domains of deformation: a landward extensional domain and seaward contractional domain separated by a transitional domain (Vendeville 2005, Rowan *et al.*, 2012, Adam *et al.*, 2012a). The major mechanisms of thin-skinned deformation are gravity gliding and gravity spreading, due to the decrease of potential gravitational energy (Rowan *et al.*, 2012). Gravity gliding is caused by a slope in the salt layer, while gravity spreading occurs due to differential sedimentary load over viscous salt (Figure 2).

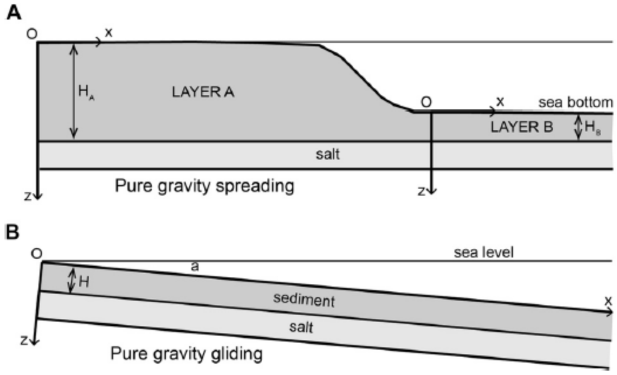

Figure 2 - *End-members of thin-skinned deformation. A-gravity-gliding above basinward-dipping detachment; B-Gravity spreading due to differential sediment loading; Adapted from Rowan et al., (2012).*

In gravity gliding, the movement of sediments package is parallel and downward along the displacement surface, which have some dip in movement direction. The top surface of sediments is not a gravity gliding evidence and there is no deformation inside the body translated. Gravity spreading is characterized by deformation inside body translated and the top surface of sediments package has some dip in the movement direction. The movement of sedimentary load is toward the base surface and the displacement surface can be even in counter direction of the movement of the sedimentary load (Figure 3). Both mechanisms occur along the basin, but the dominance of one may be recognized.

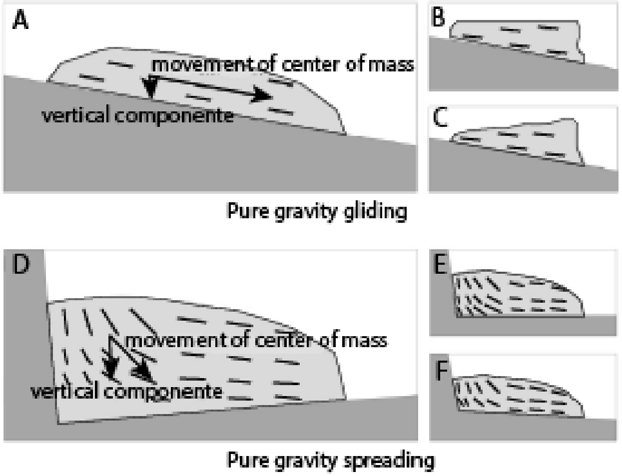

Figure 3 – *In pure gravity gliding there is no internal deformation of the translating body. The bottom surface must have a component of dip in the movement direction, whereas the dip of the top surface is not diagnostic of gliding (B and C). Pure gravity spreading characters: Motion of the material toward the basal surface (D). Spreading require deformation of the spreading body. Parts of the upper surface must have components of dip in the movement direction. The bottom surface may be opposite to motion (D), horizontal (E) or in the same direction of motion (F). Adapted from Rowan et al., (2012).*

Besides these stratigraphic and structural models of the passive margin basin, artifices in seismic reflection method can be used to improve visualization. A seismic attribute is any measure of seismic data that helps us to visually enhance or quantify features of interpretation interest (Chopra and Marfut, 2005). Instantaneous attributes besides TecVA were used in this work.

Geology of Study Area

Jequitinhonha basin has a typical East Brazilian margin sedimentary succession with a continental syn-rift section, transitional clastic-evaporitic section, a shallow-marine carbonate section, a transgressive and regressive sections (Chang *et al.*, 1992). Syn-rift section comprises sandstones, shales and coquinas of Cricaré Formation, inferred by seismic data in this basin. The Transitional section was formed during the Aptian, with deposition of evaporites of Itaúnas member that were greatly deformed and modeled the basin architecture and controled the deposition of upper sediments. The carbonate section was formed in the Albian during the thermic subsidence, and it is formed by deltaic fan deposits of São Mateus Formation in margin becoming high to low energy carbonates of Regência Formation. Transgressive section with Siliciclastic sediments of São Mateus Formation and shales of Urucutuca Formation going towards platform with the increase of base-level. Some turbidites are present in distal basin since Turonian, conditioned by haloknetic structures. The upper regressive section was formed during the Late Cretaceous to Neogene with shales, marls and turbiditic sandstones of Urucutuca in distal basin and the progradational siliciclastics of Rio Doce Formation in basin margin.

Structural framework of North Jequitinhonha Basin is composed by synthetic normal faults N-S and NE-SW of rifted basement locally interrupted by transfer faults. Structures resulted from salt tectonics can be grouped in some compartments as in Figure 4. The high extension taxes in proximal portion caused a big translation of a sedimentary block about 10 km eastward, forming the Jequitinhonha Trench, a major basinward dipping growth fault and related rollover anticline, that marks the landward limit of thin-skinned extension (Davison, 2007). Besides it, there is a province of structures due to salt movement towards basin, with salt pillows, listric faults and rafts of carbonate section. These features denote the translation of packages over the evaporitic layer. Thick salt layer and big domes are in distal portion of basin, where the sedimentary overburden is in contractional deformation domain. South Jequitinhonha basin has two submarine canyons in proximal portion, Canavieiras e Belmont, and the Royal Charlotte volcanic complex on distal basin. The study area of this work is restricted to north proximal portion of the basin, into the extensional to translational deformation zones resulting from halokinesis.

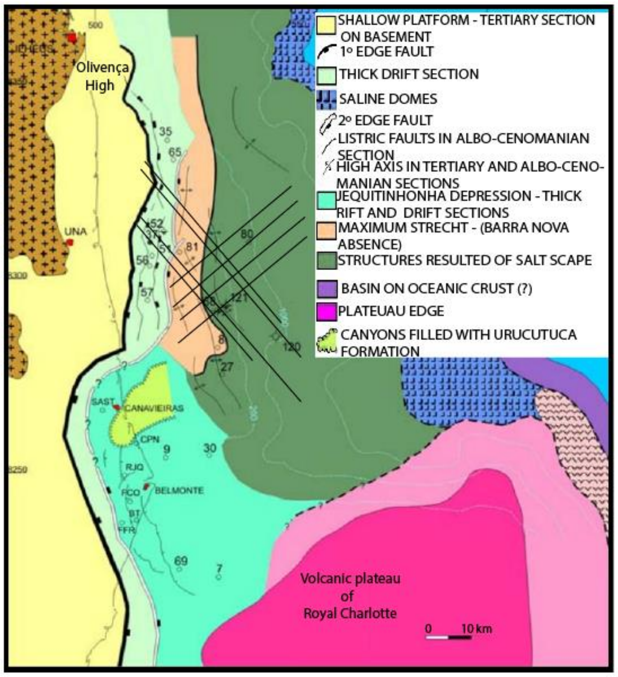

Figure 4 – *Structural framework of Jequitinhonha Basin. Straight lines correspond to interpreted seismic lines.*

Methodology

The available data for this interpretation work were 8 stacked migrated seismic sections and two wells, all given from ANP (Nacional Petroleum Agency), and the interpretation were made with OpendTect software of dGB Earth Sciences.

The methodology for seismstratigraphy characterization followed the next items:

1. Quality data analysis
2. Mapping reflector terminations (toplaps, onlaps, downlaps, offlaps and truncations) with instantaneous attributes help;
3. Mark stratigraphy surfaces;
4. Interpret geophysical gamma ray log to infer lithology and stacking pattern of stratigraphy succession;
5. Make seismic-well correlation, building synthetic seismograms;
6. Interpret depositional sequences;
7. Mapping faults and salt structures with tecVA attribute help;
8. Interpret the dominance of salt tectonics mechanisms.

Instantaneous attributes used to enhance seismic sections were instantaneous amplitude and instantaneous phase, defined from analytical sign as follows

$$a(t) = \sqrt{x^2(t) + H^2[x(t)}$$

$$\theta(t) = arctan\left[\frac{H[x(t)]}{x(t)}\right]$$

where, $H[x(t)]$ is the imaginary part of the trace $x(t)$, obtained from Hilbert transform, $a(t)$ is the instantaneous amplitude and $\theta(t)$is the instantaneous phase of $x(t)$.

Volume Amplitude Technical (tecVA) were used in structural interpretation, and is based on Elementar Seismic Layer (SCE) – the minor thickness resolved by seismic data (Bulhões, 1999). The implementation of tecVA follows two steps:

1. Compute RMS amplitude, $\bar{X}_{RMS_i}$, or absolute value trace, $\bar{X}_{ABS_i}$, as follows

$$\bar{X}_{RMS_i} = \sqrt{\frac{1}{M}\sum_{j=i-\frac{M}{2}}^{j=i+\frac{M}{2}} x_j^2}$$

$$\bar{X}_{ABS_i} = \frac{\sum_{j=i-\frac{M}{2}}^{j=i+\frac{M}{2}} |x_j|}{M}$$

   where M is the samples number in the window defined by SCE, j is the sample position and x_j the amplitude sample in position j.

2. Applies rotate phase of – 90° in the result of first step.

Attribute Analysis

Salt and carbonate reflectors were the first features traced in all seismic lines. How the magnitude of the trace envelope is proportional to the acoustic impedance contrast, it was the mainly attribute to highlight these reflectors in sections (Figure 5).

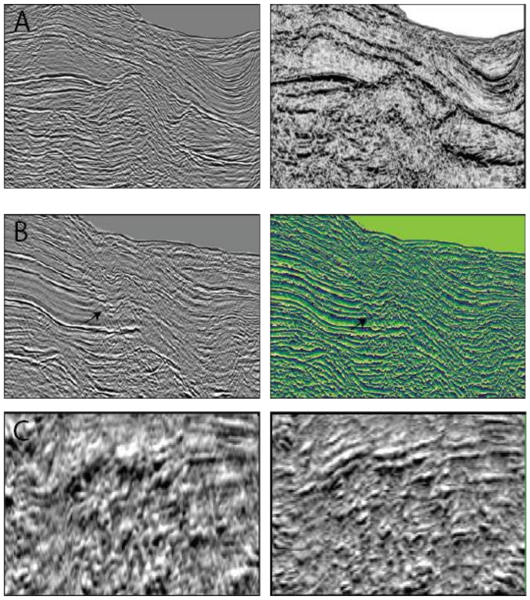

Figure 5 – *In A there is original data and instantaneous amplitude applied data, in B there is original data and instantaneous phase applied data and in C there is envelope with rotated phase on left and absolute value rotated phase on right (TecVA).*

How phase instantaneous attribute is devoid of amplitude information, it highlights all events represented and support visualization of stratigraphic elements giving some texture in images. It helped to trace reflector terminations and thus, highlighted a possible submarine canyon beneath mid-slope (Figure 5). Some attempts were done in OpendTect to implement TecVA attribute. We tried to rotate phase of envelope and absolute value, but the result of absolute value phase rotation was better as implemented by Bulhões (1999). The picture shows how the result of phase rotation of absolute value preserves the high frequencies. The texture in the image seems an outcrop and it is useful to trace faults for structural interpretation.

Seismic Stratigraphic Interpretation

Eight third order depositional sequences, JEQUI-1 to JEQUI-8 were recognized in post-salt section of Jequitinhonha Basin (Figure 7). Unconformity D-0 is the base of JEQUI-1 sequence and it comprises the top of evaporates or salt welds. JEQUI-1 is composed of carbonates mainly, with some intercalations of sand before break slope and its top is limited by the unconformity D-1. The predominance of onlaps in this sequence suggests a rise in base-level during its deposition. In unconformity D-1 there is a strong expression in all seismic sections due to change in lithology between JEQUI-1, carbonates, and JEQUI-2, shales of Urucutuca Formation. It allowed us to see clearly an interruption in this sequence in more proximal portion of data, with younger sediments of the sequences above directly seated on D-1 unconformity, as the description of Jequitinhonha Trench (Figure 6). JEQUI-2 presents the highest gamma radiation values suggesting a rapid rise of base-level. Seismic-facies is characterized by high amplitude parallel reflectors. JEQUI-3, JEQUI-4 and JEQUI-5 sequences are characterized by some mapped downlaps in proximal portion, and medium to high amplitude parallel reflectors in distal portion which suggests that the deposition is still in a transgressive character in these sequences. JEQUI-3 presents a possible canyon feature in distal portion, as depicted in attributes analysis.

Sequences JEQUI-6 and JEQUI-7 are characterized by more progradation of sediments towards the basin, evidenced by downlaps until 1000 m in seismic sections, what demonstrates the regressive character of these sequences. JEQUI-6 presents syn-tectonic deposition evidence, during a possible uplift of evaporitic body in a region out of data. Sequences from JEQUI-1 to JEQUI-7 are strongly affected by structural deformation of basin due to salt tectonics. JEQUI-8 is still in a regressive character of deposition, depicted by progradation of sands and carbonates of Rio Doce and Caravelas formations.

Seismic Structural Interpretation

The study area is in extensional and translational domains of thin-skinned deformation. The slope under JEQUI-1 sequence and the preservation of its seismic facies suggest a dominance of gravity gliding on this sequence (Figure 8). This sequence experimented high rates of extension, that resulted in rafts observed in initial to completely detached stage of model of Duval *et al.* (1992). In this context, Jequitinhonha Trench was formed with gliding of JEQUI-1 sequence big blocks (Figure 6). JEQUI-2 to JEQUI-7 sequences were strongly affected by a combination of gravity gliding and gravity spreading. The proximal portion of these sequences exhibits a complex fault system with no preferential fault orientation, and the top of the sequence has some dip towards the basin what are evidences of spreading dominance. These characters are observed in physical modeling in laboratory (Vendeville, 2005). In the distal portion of the seismic sections, after break slope, we observed that the sequences JEQUI-2 to JEQUI-7 are more preserved from interior deformation and with some slope in their base, what are gliding dominance evidences. A combined deformation model was proposed by Rowan *et al*. (2004) and it is shown in Figure 7. JEQUI-8 sequence is the least affected sequence by extensional deformation in the basin.

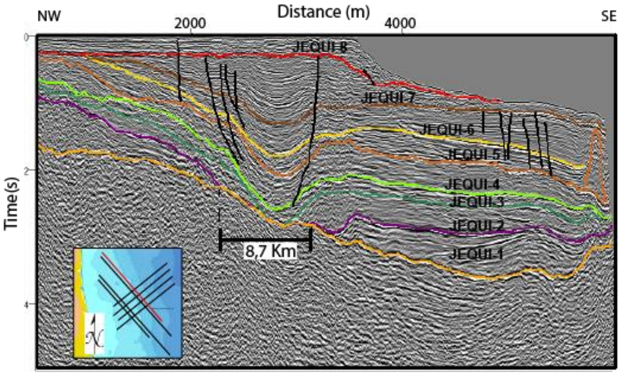

Figure 6: *Glided JEQUI-1 succession over salt layer with younger sediments seated directly on D-0 unconformity.*

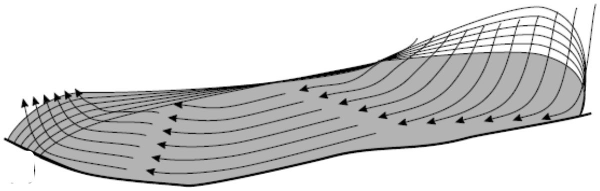

Figure 7- *Mixed-mode deformation. Shaded areas are the final stages and arrows show material movement vectors. Adapted from Rowan et al., (2014).*

Conclusions

Seismic interpretation is as efficient as more different aspects of theories and tools is available to search a geologic site. Sequence stratigraphy demonstrated being a powerful theory and methodology for history of filling of sedimentary basin. Post-salt Jequitinhonha Basin can be divided in two mega sequences, transgressive and regressive. Transgressive facies were characterized by plan-parallel reflector of medium to high amplitudes. Regressive dominance was noted by abundance of daownlaps in seismic sections, denoting progradational pattern. Transgressive mega sequence comprises 5 depositional sequences, JEQUI-1 to JEQUI-5, where the transgression was faster in JEQUI1 to JEQUI-2 sequences, according to highest GR log values. Sequences JEQUI-6 to JEQUI-8 are predominantly regressive.

Structural analysis of Jequitinhonha Basin was made in general terms of thin-skinned deformation. The study area was in extensional to translational domains of deformation. JEQUI-1 sequence experimented highest rates of extension and developed rafts that movement by kilometers. From JEQUI-1 to JEQUI-7 was observed a dominance of gravity spreading in proximal portion of study area and a dominance of gravity gliding in more distal portion of seismic lines, what leads for a combined model of end-members of deformation as the best alternative to contemplate the complexity of the basin.

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References

Adam, J.; Ge, G. and Sanchez, M. 2012a. Post-rift salt tectonic evolution and key control factors of the Jequitinhonha deepwater fold belt, central Brazil passive margin: Insights from scaled physical experiments. Marine and Petroleum Geology v. 37, 70-100 p.

Bulhões E. M., 1999. Técnica "VOLUME DE AMPLITUDES" para Mapeamento de Feições Estruturais. SBGF, n. 296

Catuneanu, O.; Galloway, W. E.; Kendall, C. G. St. C.; Miall, A. D.; Posamentier, H. W.; Strasser, A.; Tucker, M. E. 2011. Sequence Stratigraphy: Methodology and Nomenclature. Newsletters on Stratigraphy, v. 44, n. 3, 173-245 p.

Catuneanu, O. 2006. Principles of sequence stratigraphy. Elsevier. 375 p.

Chang, H.K.; Kowsmann, R.O.; Figueiredo, A.M.F. and Bender, A.A., 1992. Tectonics and stratigraphy of the East Brazil Rift system: an overview. In: P.A. Ziegler (Ed.), Geodynamics of Rifting, V. II. Case History Studies on Rifts: North and South America and Africa. Tectonophysics, 213: 97-138.

Chopra, S. and Marfut, K. J. 2005. Seismic attributes — A historical perspective. Geophysics, v. 70, n. 5, 3SO-28SO p.

Duval, B., Cramez, C. and Jackson, M. P. A. 1992. Raft tectonics in the Kwanza Basin, Angola. Marine and Petroleum Geology, V. 9, 389-404 p.

Holz, M. 2012. Estratigrafia de Sequências. Interciência. 272 p.

Davison, I. 2007. Geology and Tectonics of the South Atlantic Brazilian Salt Basins. Geological Society, London, Special Publications, v. 272, 345-359.

Rowan, M. G., Peel, F, J., Vendeville, B. C. and Gaullier, V. 2012. Salt tectonics at passive margins: Geology versus models – Discussion. Marine and Petroleum Geology v.37 184-194 p.

Rowan, M. G., Peel, F, J. and Vendeville, B. C., 2004. Gravity-driven fold belts on passive margins, in K. R. McClay, ed., Thrust tectonics and hydrocarbon systems: AAPG Memoir 82, 157– 182 p.

Vendeville, B. C. 2005. Salt Tectonics Driven by Sediment Progradation: Part I. AAPG Bulletin, v. 89, n. 8, 1071–1079 p.

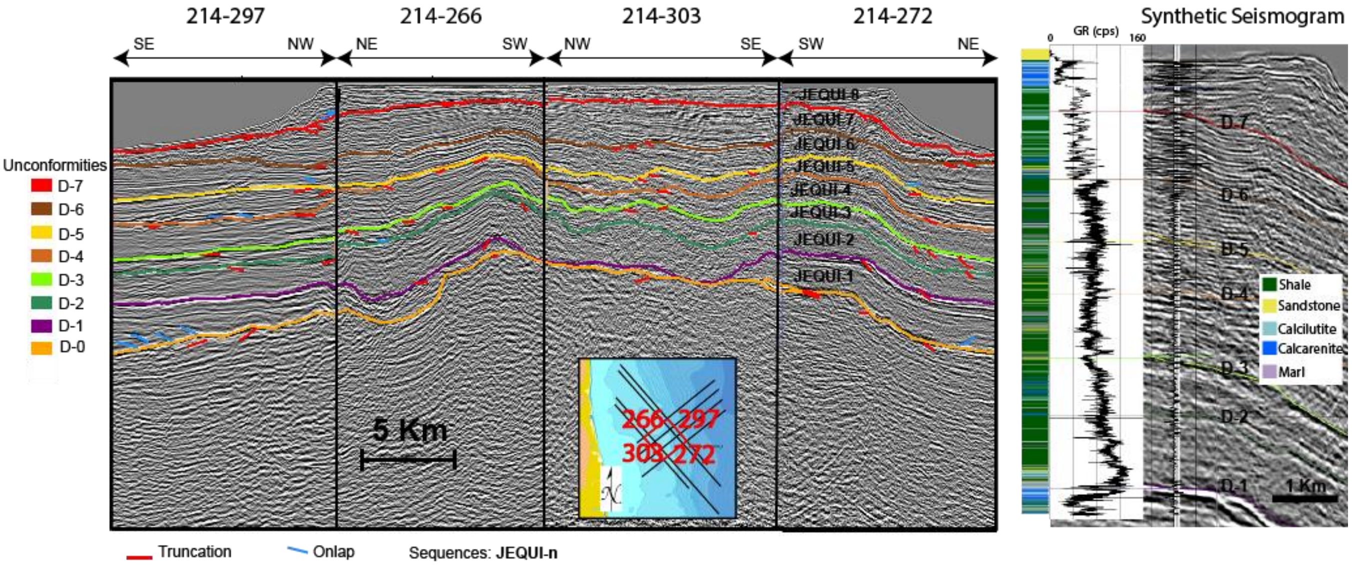

Figure 8: *Composed section of loop seismic lines on right. Synthetic seismogram with lithology interpretation of GR log.*

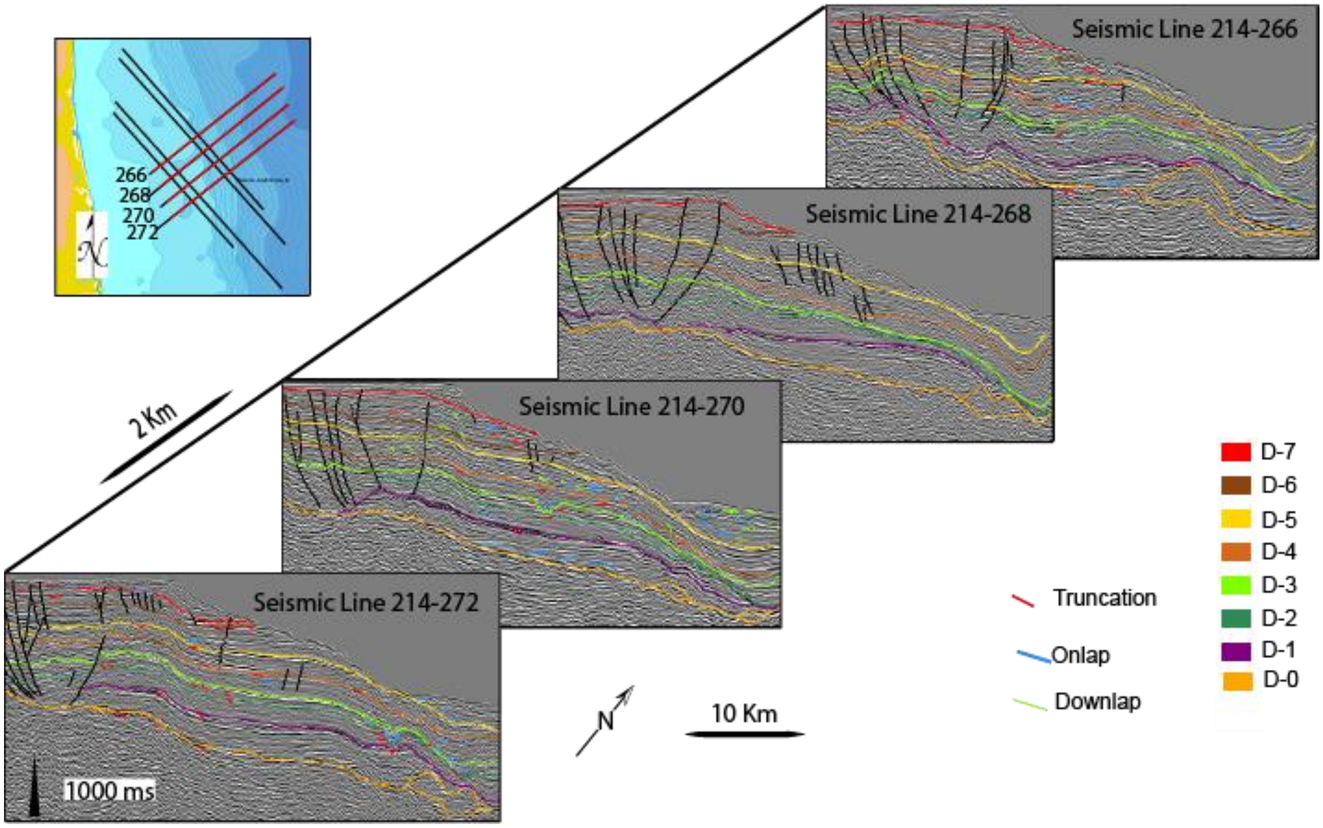

Figure 9: *Dip seismic lines.*