UNIVERSIDADE FEDERAL FLUMINENSE
INSTITUTO DE GEOCIÊNCIAS
DEPARTAMENTO DE GEOLOGIA E GEOFÍSICA
PROGRAMA DE PÓS-GRADUAÇÃO EM DINÂMICA DOS OCEANOS E DA TERRA

IGOR DE ANDRADE NEVES

A NEW GEOLOGICAL MODEL BASED ON A SEISMIC-STRATIGRAPHIC ANALYSIS OF THE EASTERN INHAMBÚ OIL FIELD, ONSHORE ESPÍRITO SANTO BASIN, BRAZIL

NITERÓI
2018

IGOR DE ANDRADE NEVES

A NEW GEOLOGICAL MODEL BASED ON A SEISMIC-STRATIGRAPHIC ANALYSIS OF THE EASTERN INHAMBÚ OIL FIELD, ONSHORE ESPÍRITO SANTO BASIN, BRAZIL

Dissertation submitted to the Programa de Pós-Graduação em Dinâmica dos Oceanos e da Terra of Universidade Federal Fluminense in partial fulfillment of the requirements for the degree of Master in Geology and Geophysics.

PhD. Wagner Moreira Lupinacci (Principal Adviser)

NITERÓI - RJ
2018

A NEW GEOLOGICAL MODEL BASED ON A SEISMIC-STRATIGRAPHIC ANALYSIS OF THE EASTERN INHAMBÚ OIL FIELD, ONSHORE ESPÍRITO SANTO BASIN, BRAZIL

IGOR DE ANDRADE NEVES

Dissertation submitted to the Programa de Pós-Graduação em Dinâmica dos Oceanos e da Terra of Universidade Federal Fluminense in partial fulfillment of the requirements for the degree of Master in Geology and Geophysics.

Approved for the Committee in May 29th, 2018.

Committee:

____

PhD. Luís Otávio Aguiar Oliveira (PANGEA – Consultorias em Geociências)

____

PhD. Luiz Alberto Santos (Petrobras and UFF)

____

PhD. Cleverson Guizan Silva (LAGEMAR/UFF)

____

PhD. Wagner Moreira Lupinacci (GIECAR/GGO/UFF) (Principal Adviser)

Abstract

The onshore Espirito Santo basin is an important hydrocarbon province on the east margin of Brazil, accounting for almost 9% of Brazil's onshore oil production. The objective of the present work was to understand the stratigraphy and the evolutionary history, from the post-rift section (Cricaré Formation, Mucuri Member), to the drift section (Rio Doce Formation), from an area east of the Inhambú Field, in Espírito Santo, onshore. In this study, the main stratigraphic surfaces that were interpreted were: Basement, Intra-Mucuri unconformity, post-rift unconformity, anhydrite (Itaúnas Member), Fazenda Cedro Canyon, Inhambú Canyon (Pre-Urucuruca unconformity - DPU) and Upper Pre-Eocene Unconformity (DPES). Four seismofacies were identified, from the basement to the Upper Pre-Eocene unconformity. As a result, a chart of events was made in the area studied. Additionally, the interpretation of the wells allowed for the recognition of six cycles of 3rd order, where it was possible to identify 4 events with regressive character, including the surface of maximum regression and two of transgressive character. Finally the update of the conceptual geological model for the area to the East of Inhambú oil field of was carried out.

Palavras-chave: Seismistratigraphy, chart of events, sismofacies, Fazenda Cedro Canyon, Espirito Santo Basin.

Resumo

A bacia terrestre do Espírito Santo é uma importante província de hidrocarbonetos na margem leste do Brasil, respondendo por quase 9% da produção brasileira de petróleo em terra. O presente trabalho teve como objetivo entender a estratigrafia e a história evolutiva, desde a seção pós-rifte (Formação Cricaré, Membro Mucuri), até a seção drifte (Formação Rio Doce), de uma área a leste ao Campo de Inhambú, da Bacia do Espírito Santo, onshore. Neste estudo, foi interpretado as principais superfícies estratigráficas: Embasamento, discordância Intra-Mucuri, discordância pos-rifte, anidrita (Membro Itaúnas), Cânion de Fazenda Cedro, Cânion de Inhambú (Discordância Pré-Urucuruca – DPU) e Discordância Pré-Eoceno Superior (DPES). Quatro sismofácies foram identificadas, desde o embasamento até a discordância do Pré-Eoceno Superior. Como resultado obtido foi confeccionado uma carta de eventos na área estudada. Adicionalmente, a interpretação dos poços permitiu o reconhecimento de seis ciclos de 3ª ordem, onde foi possível identificar 4 eventos com carter regressivo, incluindo a superfície de máxima regressão e dois de caráter transgressivo. Como resultado final foi realizado a atualização do modelo geológico conceitual para a área a Leste ao campo petrolífero de inhambu

Palavras-chave: sismoestratigrafia, carta de eventos, sismofácies, Cânion de Fazenda Cedro, Bacia do Espirito Santo.

Acknowledgements

The thanks that I have given here will never be enough, due to the countless help I received during my post-graduation.

Initially, I thank God for sustaining me here and for always being on my side in this daily struggle, which we call life.

To my parents and my brothers, who have always supported me and motivated me further and being responsible for the development of my character.

My wife Geisa, for the enormous motivational force, advice and total support, during the postgraduate period.

My daughters Livia Maria and Valentina, because they always impel me to improve as a person and as a professional.

To my supervisor, Prof. Dr. Wagner Moreira Lupinacci, who guided me and dedicated hours to the development of the ideas presented here and for always having encouraging me and believing in my work.

To the reviewers of these works, mainly Professor Cleverson and the geophysicist Luís Otávio, for always making constructive and pertinent criticism to the work in order to improve it.

To my friends João Zambrini, Danilo Jotta, Rafael Cherene, Lívia Spagnuolo, Ingra Martins, Suelen Gouvea and Marta Gomez, who were present with me during the whole journey.

To the institution ANP, for making the necessary data available for the accomplishment of this work.

To the companies, Schlumberger and Emerson-Paradigm, for giving me the opportunity to carry out this work and for making the licenses available for this work.

To the Fluminense Federal University, where I had the privilege of taking my postgraduate course.

“Antes de se entregar à derrota, levante a cabeça, se dê a oportunidade, vá à luta e coragem para enfrentar o desconhecido, com o pensamento: EU QUERO, PORTANTO EU FAÇO! E VOCÊ?”

Bento Augusto.

Contents

List of figures

Chapter 1

Presentation

This dissertation was developed from the results of the critical analysis of the processes of seismic interpretation on the sedimentary package from the Cretaceous to the Paleogene of an area located on the São Mateus platform, close to the Fazenda Alegre and Inhambu fields. This dissertation is presented in the form of a scientific article. This article will be submitted to BRAZILIAN JOURNAL OF GEOPHYSICS magazine, after all the reviews requested by the bank are met.

The stages carried out for the development of the dissertation were organized in six chapters: presentation, introduction, geological context, materials and methods, results and discussions and conclusion.

1.1. Dissertation Structure

This dissertation was developed from the results of the critical analysis of the processes of seismic interpretation on the sedimentary package from the Cretaceous to the Paleogene of an area located on the São Mateus platform, close to the Fazenda Alegre and Inhambu fields. This dissertation is presented in the form of a scientific article. This article will be submitted to BRAZILIAN JOURNAL OF GEOPHYSICS magazine, after all the reviews requested by the bank are met.

The stages carried out for the development of the dissertation were organized in six chapters: presentation, introduction, geological context, materials and methods, results and discussions and conclusion.

The second chapter presents the initial studies that motivated the proposed work. In the third chapter a bibliographical review is carried out on the sedimentary filling, structuring and petroleum system of Espírito Santo, more specifically on the onshore part of the Basin, focusing on turbidite reservoirs, associated with canals analogous to the Inhambú and Native West fields.

The fourth chapter details the seismic interpretation process, the seismic units individualization, seismic units, the creation of event charts and the individualization of the main work area Shallowing / drowning cycles.

The fifth chapter presents the results of the seismostratigraphic interpretation of the mapped units, the chart of events and the updating of the conceptual geological model. Finally, in the last chapter the conclusions obtained through the critical analysis of the results are presented.

Chapter 2

Introduction

Hydrocarbon exploration in the onshore portion of the Espírito Santo Basin began in the 1950s with the drilling of the first stratigraphic well (2-CB-1-ES). However, the first commercial oil well was drilled almost two decades later in 1969 and resulted in the discovery of the São Mateus field. With continuous exploration in the 1970s, the Fazenda Cedro (1972) and Lagoa Parda (1979) fields were also discovered.

In January 2018, the production from the basin was 35,051 barrels per day (bbl/d). The onshore part of the Espírito Santo Basin contains approximately 55.7 million barrels of total reserves and 23.9 million barrels of proven reserves. Currently, the most important fields are the Fazenda Cedro (25.5%) and Inhambú (25.6%) fields, which account for 50% of the total onshore production (Figures 1 and 2).

The initial studies identified the sandstones of the Urucutuca Formation as the main reservoir rocks in the area. The petroleum accumulations are located in stratigraphic traps that are similar to the Fazenda Cedro and Fazenda Alegre fields. The main reservoir of the São Mateus Platform is the Mucuri Member of the Mariricu Formation, which consists of Neo-Aptian fluvial-deltaic sandstones that were deposited during a marine transgression that culminated with the deposition of the evaporites of the Itaúnas Member (França et al., 2007) (Figure 3).

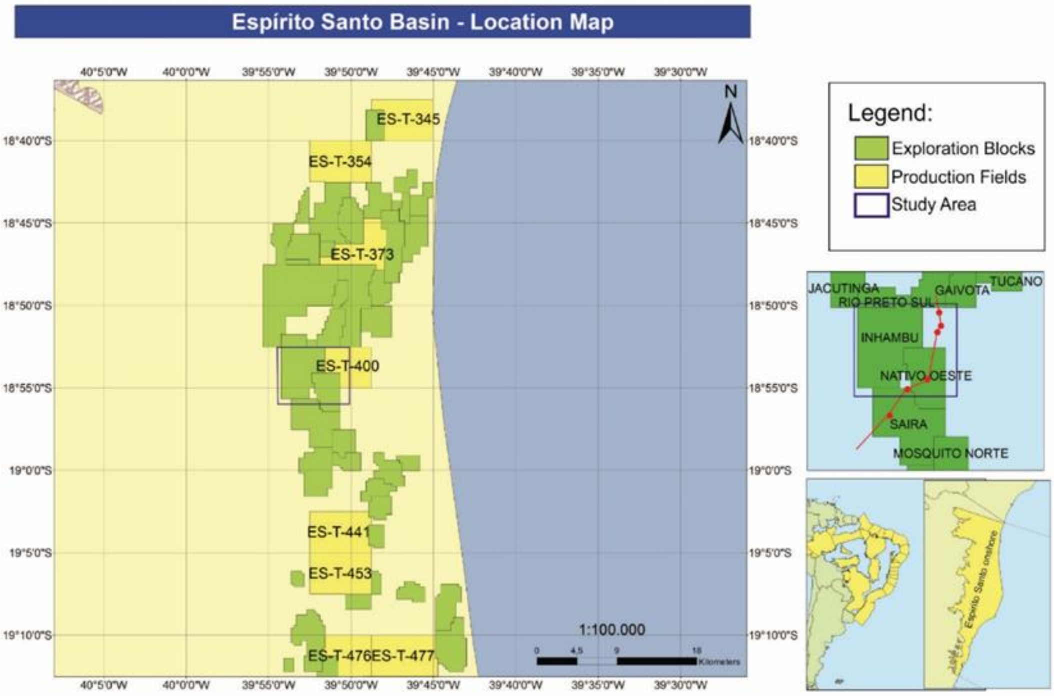


Figure 1: Location map of the study area, onshore Espírito Santo Basin, Brazil.

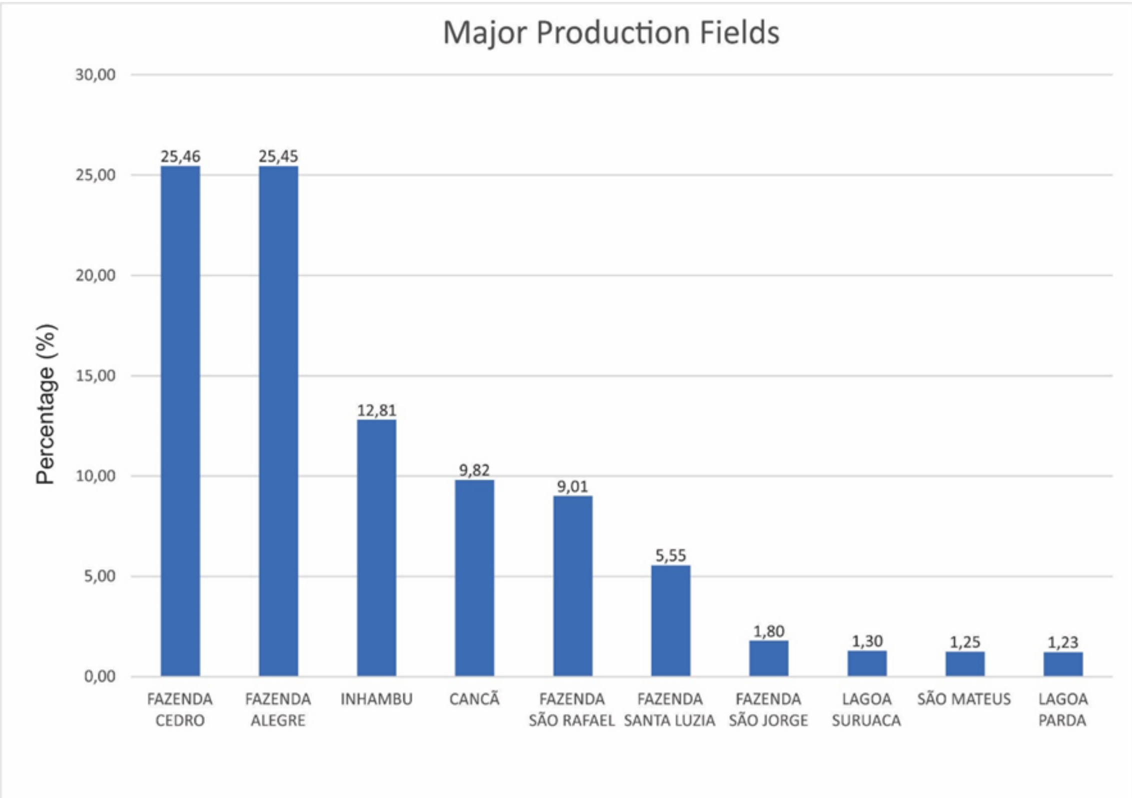


Figure 2: Hydrocarbon production percentages of the main fields in the onshore Espírito Santos Basin in 2018 (BDEP, ANP).

New wells drilled in the area (see Figure 3 for locations) showed the absence of the Urucutuca Formation reservoirs at these locations (Neves *et al*., 2017). Because these were considered to be the main reservoirs in this part of the basin, in this study, we re-interpreted seismic and well data from the Inhambú oil field to define the main seismic units and stratigraphic surfaces with the intention of constructing a geological model that describes the distribution of the Inhambú Field reservoirs. We followed the definitions of Mitchum Jr. et al. (1977) to determine the sequence boundaries, which are considered to be stratigraphic units of genetically related sequences with relatively concordant strata that are limited at their tops and bottoms by unconformities and their conformable equivalents.

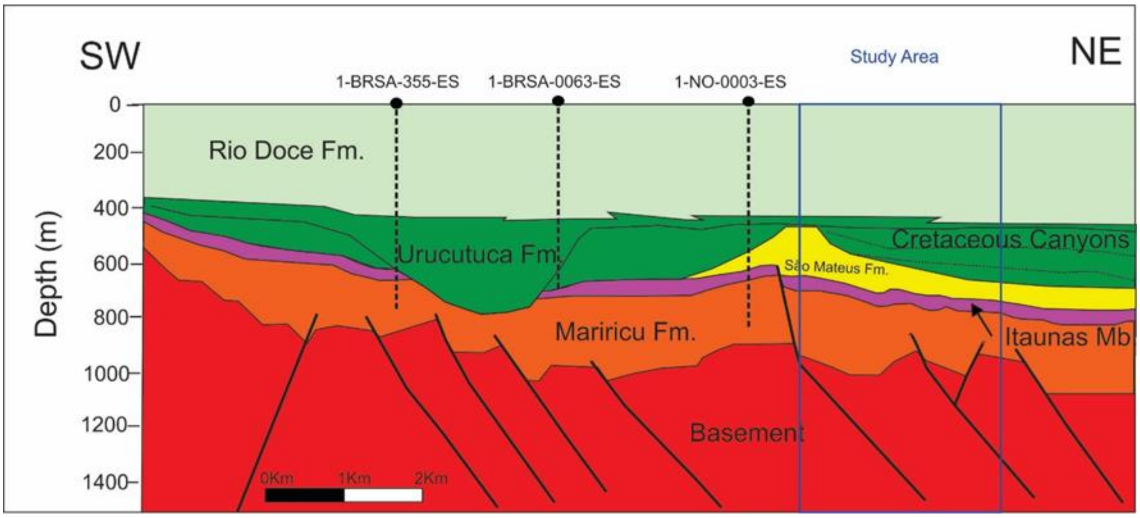


Figure 3: Cross section showing the interpreted stratigraphy based on three industry wells and the literature (Neves et al., 2017). See Figure 1 for the location.

Chapter 3

Historical Context

The Espírito Santo Basin is located on the eastern Brazilian margin and is limited to the south by the Vitória structural high, to the north by the Mucuri paleo-canyon, to the west by crystalline basement and to the east by the Abrolhos volcanic complex (Carvalho, 1965). It covers an area of approximately 41,500 km², of which 3,000 km² is onshore. The basin stratigraphy was reviewed by França et al. (2007) and includes sedimentary rocks from the early Cretaceous to the Neogene that deposited over the Pre-Cambrian crystalline basement (Figure 4).

The oldest sediments belonging to the Mariricu Formation and the Mucuri Member of the Cricaré Formation were deposited from the Valanginian to the lower Aptian during the rift phase of the basin, and they include lake deposits with fluvial and alluvial contributions near fault borders. The upper limit of the rift sequence is the pre-Alagoas regional unconformity at the top of the Mucuri Member (Dias, 2005). The Cabiúnas Formation represents a volcanic event during the Eo-Cretaceous and is composed of basalts and diabases within the lacustrine sediments of the Mariricu Formation (Gomes and Suita, 2010) (Figure 4).

The post-rift interval consists of a single Aptian sequence (Cricaré Formation) that was deposited during quiescent tectonic conditions; it begins with sediments from fluvio-deltaic to sabka environments of the Mucuri Member and ends with evaporites (mostly halite and anhydrite) deposited in a restricted environment that correspond to the Itaúnas Member.

The drift sequence is represented by the Albian São Mateus Formation sandstones and by the Regência Formation carbonates, which were deposited in shallow marine environments. At the end of the Albian, a regional unconformity (pre-Urucutuca unconformity- PUU) eroded the Regência and Fazenda Cedro paleocanyons. A rapid subsidence and drowning of the Regência carbonate platform began in the Cenomanian and peaked during the Turonian with the deposition of the deep-water shales and turbidites of the basal Urucutuca Formation. In the onshore portion of the basin, the basal Urucutuca Formation shales are restricted to the intervening canyons. The Regência carbonates are partially preserved on two platforms, the São Mateus Platform and the Regência Platform, which were continuously covered by the Urucutuca shales (Figure 3). The study area is located on the São Mateus Platform at the northern edge of the Fazenda Cedro Canyon (Figure 5).

During the Paleogene, the Espírito Santo Basin experienced increased siliciclastic and carbonate sedimentation rates following the tectonic reactivation of the southeastern Brazilian margin. This reactivation resulted in the formation of the southeastern Brazil coastal ranges (Serra do Mar) and was followed by expressive volcanic events. The Abrolhos Volcanic Complex in the Espírito Santo Basin (Figure 5) is the expression of this regional reactivation, which has been dated at 62 to 37 Ma (França et al., 2007). A mixed siliciclastic-carbonate shelf developed on the shallow margin starting in the Meso-Eocene, which is represented by the Rio Doce Formation (proximal shelf siliciclastics) and the Caravelas Formation (distal shelf carbonates).

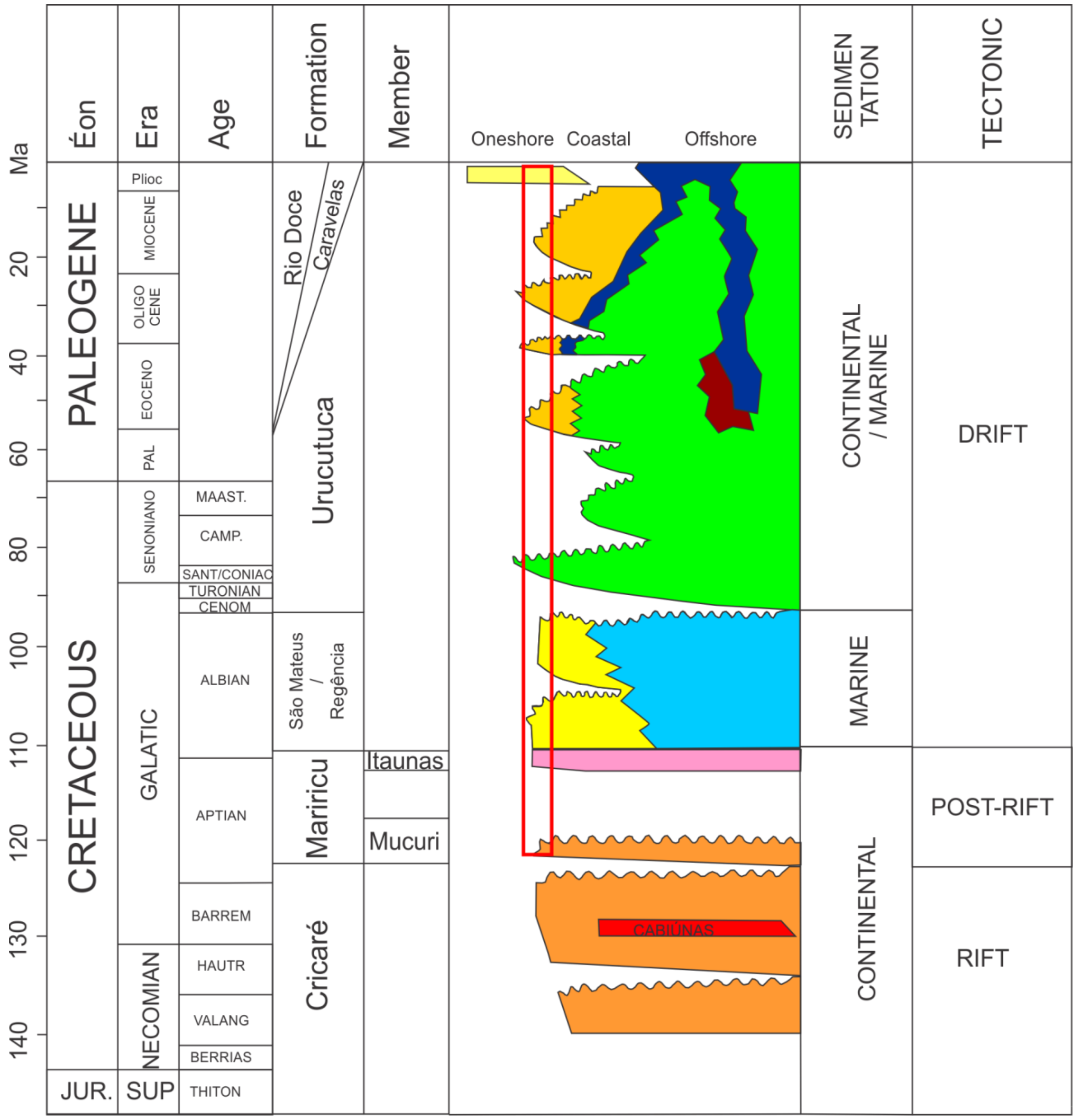


Figure 4: Stratigraphic chart of the Espírito Santo Basin.

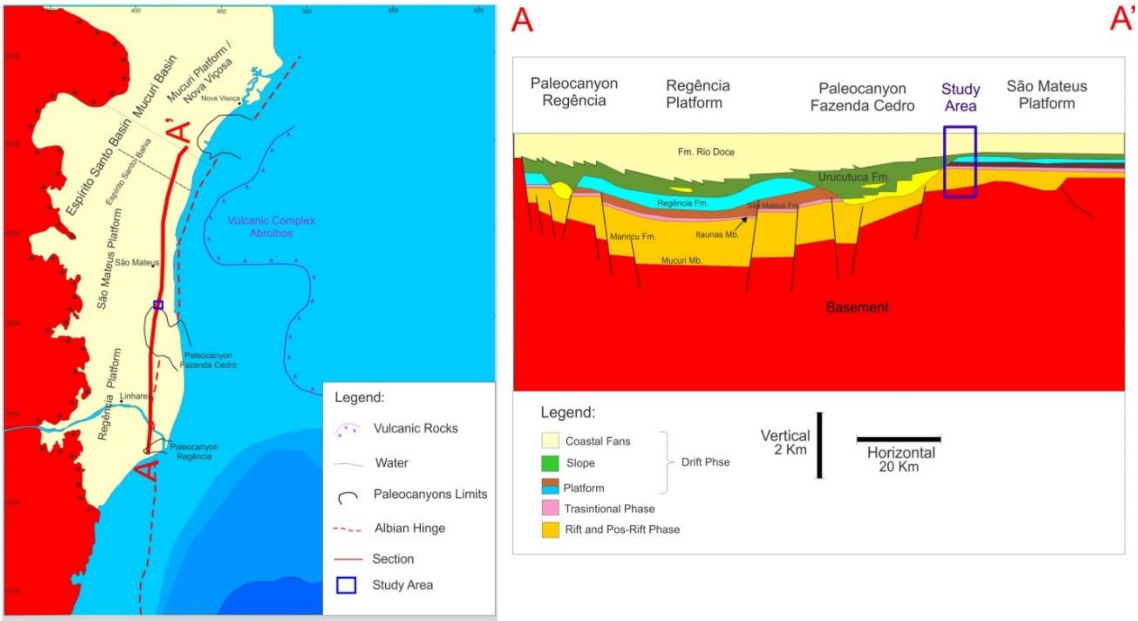


Figure 5: A) Location map of the study area; B) geological cross section showing the main rift structures, sedimentary units and morpho-sedimentary provinces.

The main source rocks in the onshore portion of the Espírito Santo Basin are the lacustrine shales of the upper rift sequence (Sernambi Member of the Cricaré Formation). Other potential source rocks are the black shale layers associated with the evaporites of the Mariricu Formation. Migration may have occurred along fault planes in the rift section, along unconformity surfaces or by direct contact between the source rocks and the reservoirs. The reservoir rocks are located in the rift phase (Mucuri Formation), post-rift phase (Mariricu Member) and drift phase (Urucutuca Formation) sediments and are widely distributed throughout the basin.

The traps identified on the onshore Espírito Santo Basin are diverse. Horsts, grabens and tilted blocks are common in the rift section and form structural traps on the São Mateus Platform. Structural, stratigraphic and combination traps are present in the drift section. Structural and combination traps related to rollovers and listric faults are located in the Regência platform.

Stratigraphic traps and reservoirs related to turbidites that are truncated against canyon walls are the main traps and reservoirs in the onshore basin (Figure 6).

The evaporites of the Itaúnas Member (Mariricu Formation) are the seals of the oldest reservoirs. The shales of the Urucutuca Formation are the main seal in the basin, especially for the drift section reservoirs.

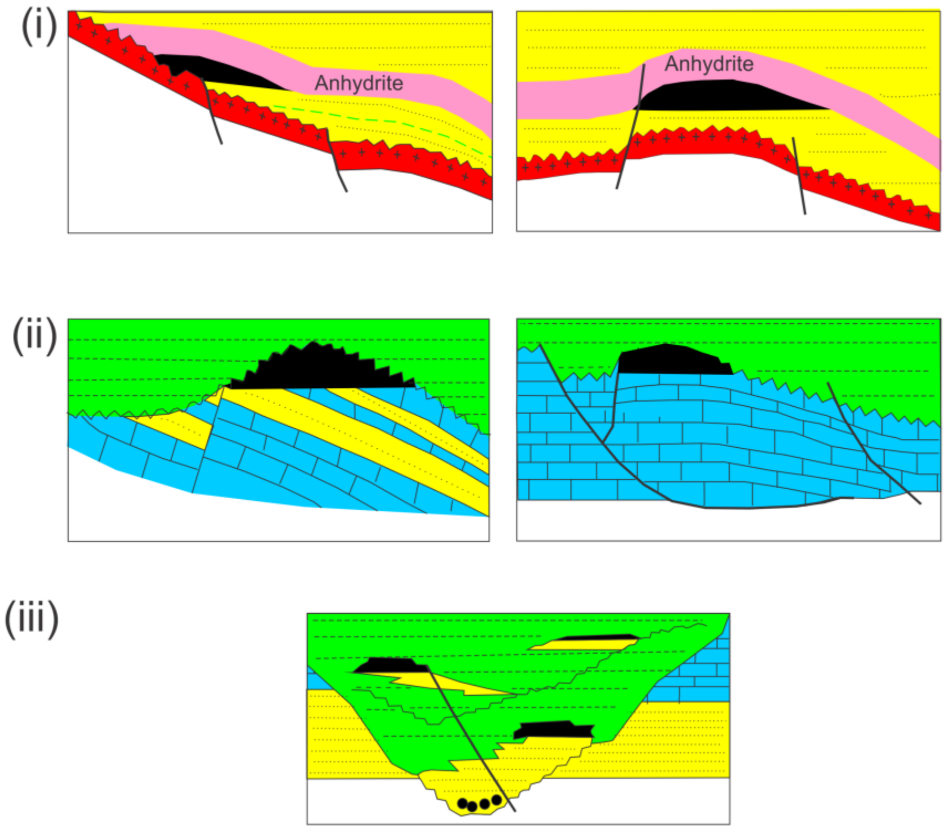


Figure 6: Common hydrocarbon traps in the Espírito Santo Basin. (i) Structural traps within the rift section that are sealed by evaporites; (ii) combination structural and stratigraphic traps in carbonate reservoirs that are in erosional contact with shales; (iii) turbidite reservoirs that are erosionally truncated by canyons.

Chapter 4

Methods

This study is based on the interpretation of 3D seismic data, well logs and descriptions from three wells drilled in the vicinity of the Inhambú Field. The seismic reflection survey covers an area of approximately 50 km^2, has a maximum penetration of 5 seconds two-way travel time (TWTT), and covers all of the Inhambú and Nativo Oeste oil fields (Figure 7). The inline and crossline spacings are 12.5m and 50m, respectively; the inlines are oriented north-south, and the crosslines are oriented east-west. In both fields, the main Cretaceous reservoir rocks are located in channels sealed by shales of the Urucutuca Formation. Wells 1-CW-1-ES, 1CW-2-ES and 1-CW-3-ES are located on the northeastern corner of the 3D block, approximately 1.1 km from the limits of the Inhambú Field. Wells 1-CW-1-ES and 1CW-2-ES reached the crystalline basement at depths of 1300 m and 1396.8 m, respectively.

The interpretation of the seismic data initially consisted of the identification of the main depositional sequences related to the evolutionary stages established in the stratigraphic chart of França et al. (2007). The main horizons mapped correspond to the top of the basement; the intra-Mucuri unconformity; the post-rift unconformity (end of the post-rift phase); the base and top of the evaporites (Itaúnas Member); the pre-Urucutuca unconformity (Albian-Cenomanian); and the upper Eocene unconformity (base of the Rio Doce Formation). Structural maps were generated in TWTT for each of these horizons.

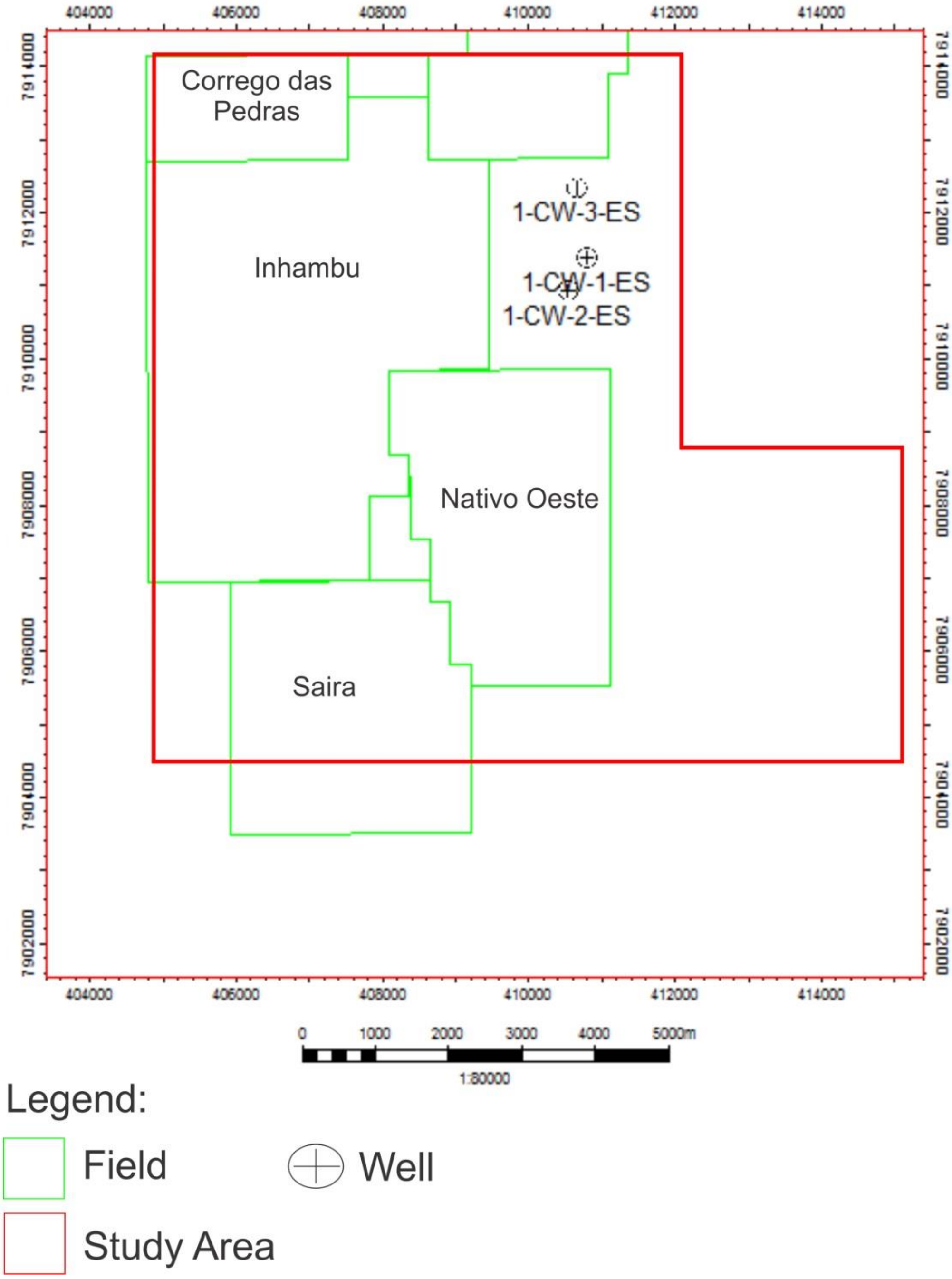


Figure 7: Data used in this study. The seismic survey is represented by the red polygon, and the wells are represented by circles.

After detailed analyses of the lithologies and gamma-ray logs, the main 3rd-order depositional sequences were identified and tied to the seismic data. These sequences were separated by erosion and/or exposure surfaces, maximum flooding surfaces (MFS) and maximum regressive surfaces (MRS).

The internal seismic facies were used regionally to aid in the seismic interpretation. This information was used to update the final geological model and to generate a chart of events indicating the critical times of the petroleum system elements and processes in the Inhambú oil field. Figure 8 shows a detailed flowchart of the work.

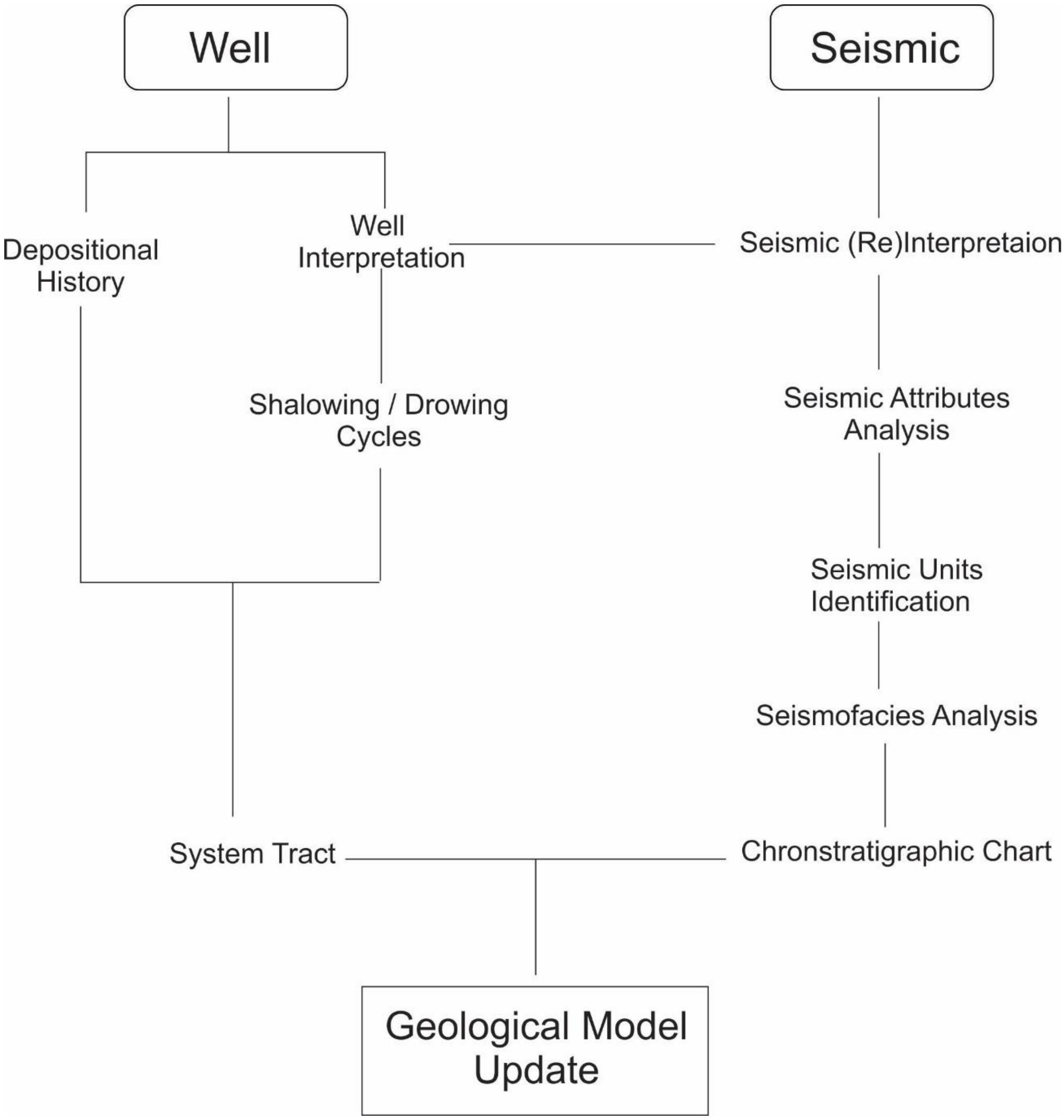


Figure 8: Flow chart of the work.

Chapter 5

Results and Discussions

The top of basement was encountered in wells 1-CW-1-ES e 1-CW-2-ES and is represented by undefined metamorphic rocks. Above the basement, the post-rift sandstones and shales of the Mariricu Formation are the deepest sedimentary units drilled. The Mucuri Member lithologies are 314 to 342 m thick. The top of the Mariricu Formation is well defined in all three wells and is represented by the Itaúnas Member anhydrites, which are an average of 40 m thick. These evaporites are clearly recognized in the seismic reflection data due to their high acoustic impedance contrast. Above the salt, the São Mateus Formation is represented by thick sandstone layers that are covered by thin intervals of the Urucutuca Formation shales, which decrease in thickness from SW to NE; this makes them difficult to identify in wells and seismic data (Figure 9).

Figure 10 shows a seismic section oriented in the dip direction (W to E). The interpreted seismic section illustrates the main horizons and depositional sequences identified in this study. The basement dips to the east from 600 ms to 1200 ms (two-way travel time) and is cut by normal faults that also affect the post-rift sequence. Most of the normal faults were active only in the initial post-rift phase and do not offset the intra-Mucuri unconformity, which was regionally mapped inside the post-rift sequence.

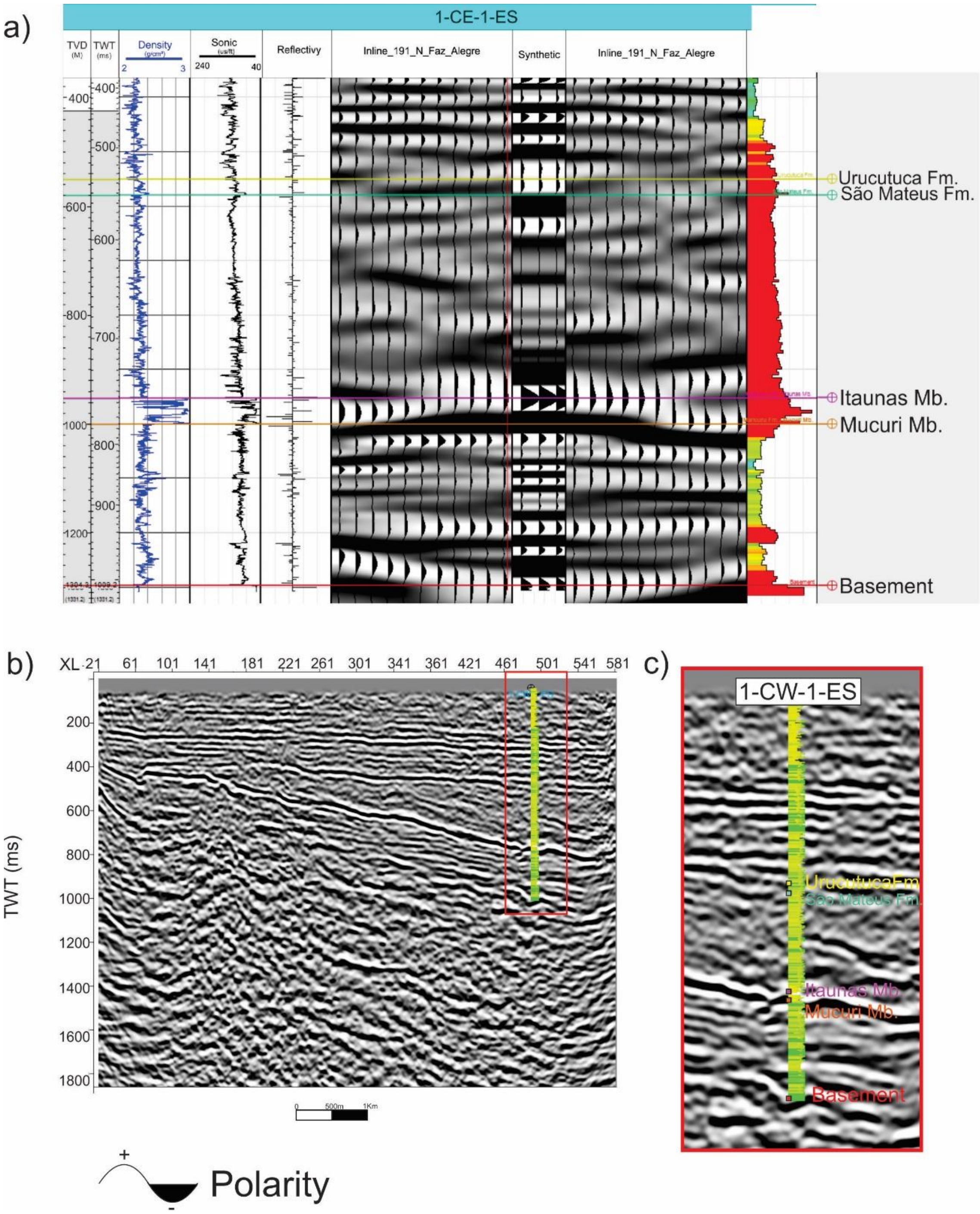


Figure 9: A) Synthetic seismogram of well 1-CW-1-ES and well tops; B) inline 191 in time and well 1-CW-1-ES; C) expanded area of the well showing the well ties and seismic with well picks.

A basement high, which is controlled by normal faults, is located near the center of the seismic section, and the seismic reflectors pinch out against this basement high. The pre-Urucutuca unconformity (PUU) is a prominent erosional surface that dissects two deep canyons with nearly 200 ms of local relief. From west to east, these canyons are the Inhambú and Fazenda Cedro Canyons, which are separated by the basement high. The sedimentary infilling of the canyons was followed by another erosional phase that is represented by the upper Eocene unconformity (UEU) (Figure 10).

These horizons and erosional unconformities bound six seismic-stratigraphic units: I) the initial post-rift unit from the basement to the intra-Mucuri unconformity, II) the lower transitional unit from the intra-Mucuri unconformity to the top of the post-rift sediments (base of the Itaúnas Member), III) the upper transitional unit, which corresponds to the Itaúnas Member evaporites, IV) the lower drift unit, which extends from the top of the Itaúnas Member to the pre-Urucutuca unconformity, V) the intermediate drift unit between the pre-Urucutuca and the upper pre-Eocene unconformities, and VI) the unit above the upper pre-Eocene unconformity (Figure 10). These units generally correspond to depositional sequences related to the evolutionary stages established in the stratigraphic chart of França et al. (2007).

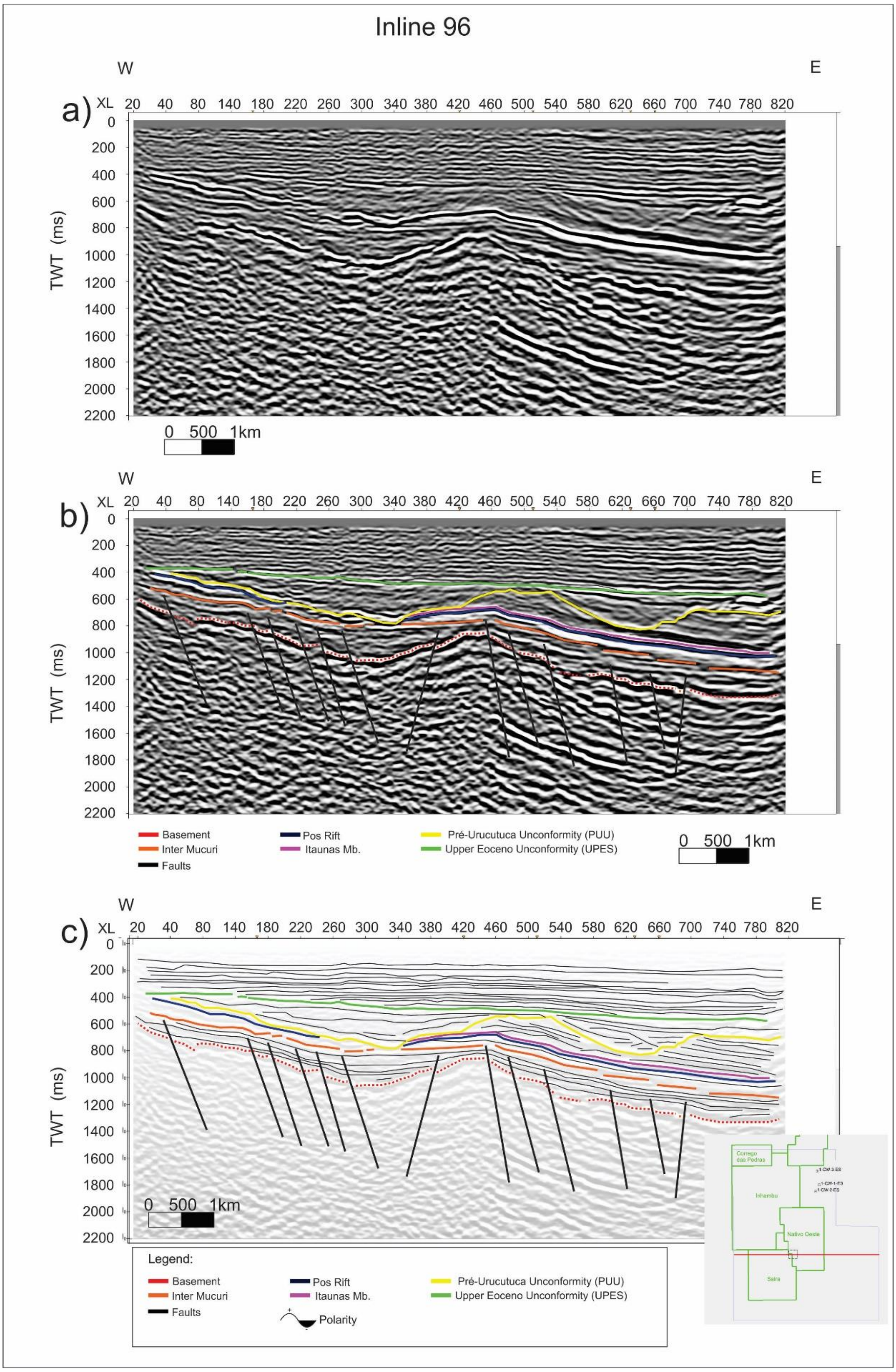


Figure 10: A) Seismic inline (96) oriented in the dip direction (E-W); B) interpreted seismic section; C) interpretation of seismic units.

The interpretation of the well logs allowed the identification of 3rd-order cycles and system tracts (Figure 11). Four regressive and two transgressive 3rd-order cycles were identified above the basement. The first regressive to transgressive system tract is located in the Mariricu Formation and is limited by a maximum flooding surface inside the Mucuri Member (Figure 11). The Itaúnas Member anhydrites are a distinct stratigraphic marker in wells 1-CW-1-ES, 1CW-2-ES and 1-CW-3-ES, which records deposition during the transitional phase in a quiescent tectonic environment. During the deposition of the Itaúnas Member, an arid climate and excessive evaporation caused the deposition of the anhydrites in a very shallow lake, which characterizes a second regressive system tract ending at a maximum regressive surface (MRS) on top of the Itaúnas Member (Figure 11). This surface corresponds to the climax of arid conditions. The third regressive to transgressive third-order cycle includes all of the São Mateus and Urucutuca formations and most of the Rio Doce Formation. The Urucutuca Formation is very thin in wells 1-CW-1-ES and 1-CW-2-ES and is absent in well 1-CW-3-ES. The transition from regressive to transgressive conditions is indicated by the increasing gamma-ray values (Figure 11). The fourth and last regressive sequence is located at the tops of the wells within the Rio Doce Formation, and it is clearly recognized by the decreasing gamma-ray counts (Figure 11).

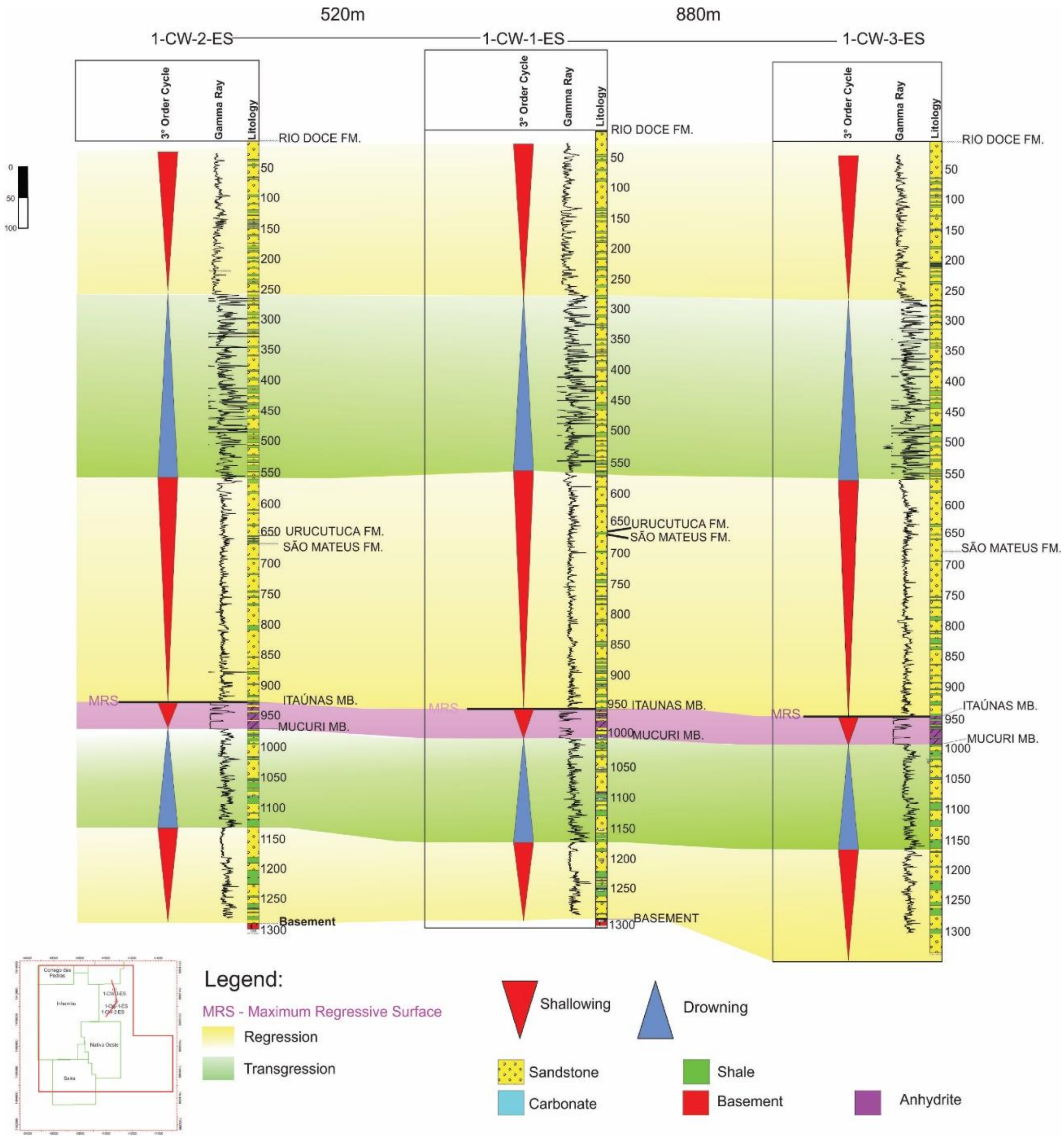


Figure 11: Third-order cycles showing the system tracts based on the shallowing/drowning cycles in wells 1-CW-1-ES, 1-CW-2-ES, 1-CW-3-ES, onshore Espírito Santo Basin.

The structural maps in Figure 12 show the two-way travel times (TWTTs) to the main horizons and unconformities. The upper Eocene unconformity (UEU) structural map reveals a homoclinal slope dipping gently to the southeast (Figure 12 a). The pre-Urucutuca unconformity (PUU) isochron grid reveals the Inhambú (Figure 12 b) and Fazenda Cedro (Figure 12 c) canyons with well-defined N-S-oriented thalwegs. The isochron maps to the top of the Itaúnas Member and to the post-rift unconformity are slightly different (Figures 12 d and e). The Itaúnas Member was eroded away by PUU in the Inhambú Canyon area, but it is still present under Fazenda Cedro Canyon (Figure 12 d). The top of the intra-Mucuri unconformity was also partially eroded by Fazenda Cedro Canyon (Figure 12 f) and has a NE-SW hinge at greater depths (from -900 to -1100 ms). The isochron map to the top of the basement reveals the same NE-SW structural hinge at greater depths (Figure 12 g), which is controlled by the basement high shown in the seismic sections (Figures 10 and 13). Only small normal faults displace the intra-Mariricu unconformity (Figure 13), which indicates a relative quiescent tectonic environment that is analogous to the SAG phase of the Campos and Santos Basins, which culminated with the deposition of evaporites (Itaúnas Member).

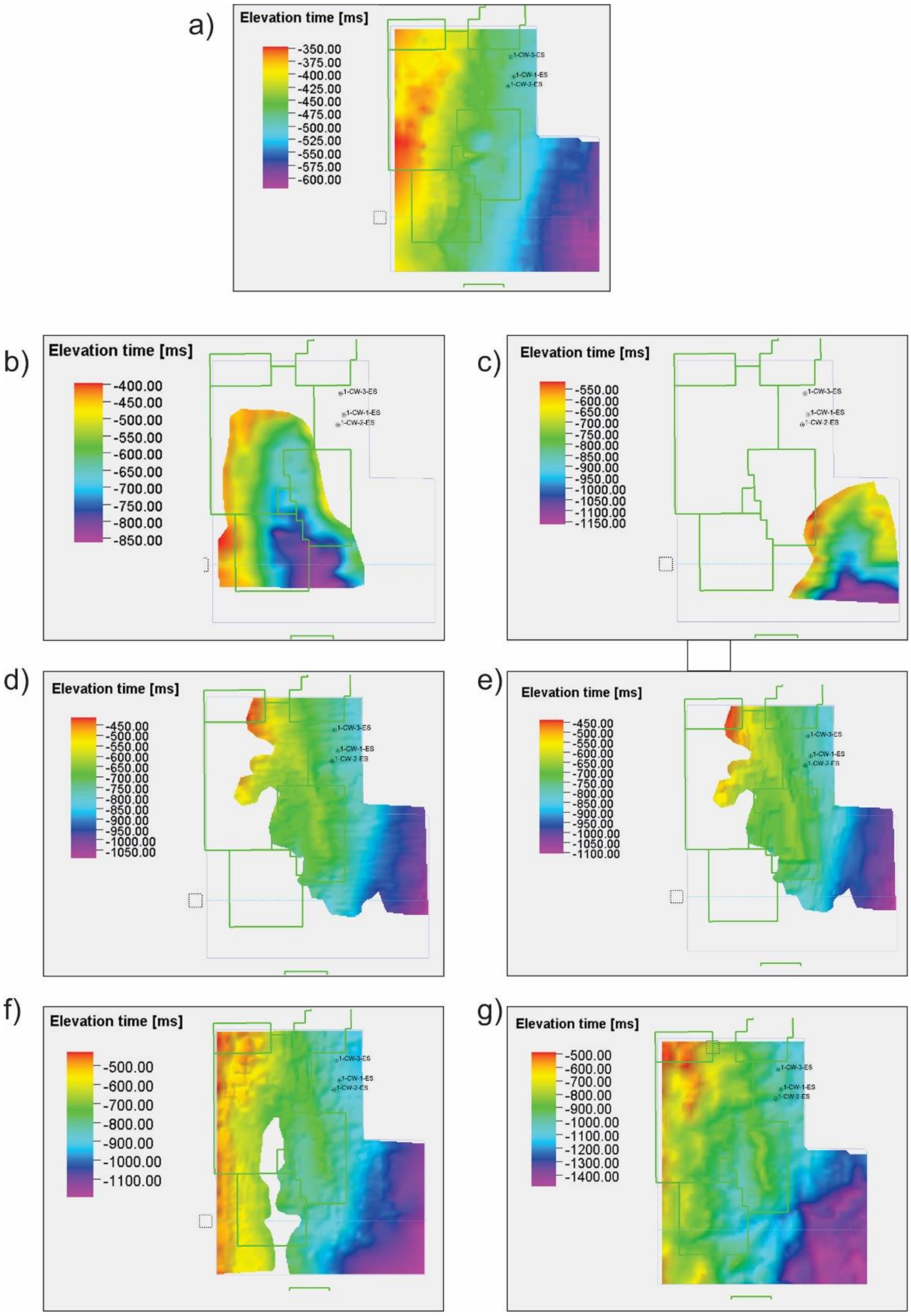


Figure 12: Structural isochron maps (TWTT) of the main interpreted horizons and unconformities. A) Upper pre-Eocene unconformity; B) pre-Urucutuca unconformity in the Inhambú Canyon area; C) pre-Urucutuca unconformity in Fazenda Cedro Canyon; D) top of the Itaúnas Member evaporites.; E) post-rift unconformity; F) intra-Mucuri unconformity; G) basement.

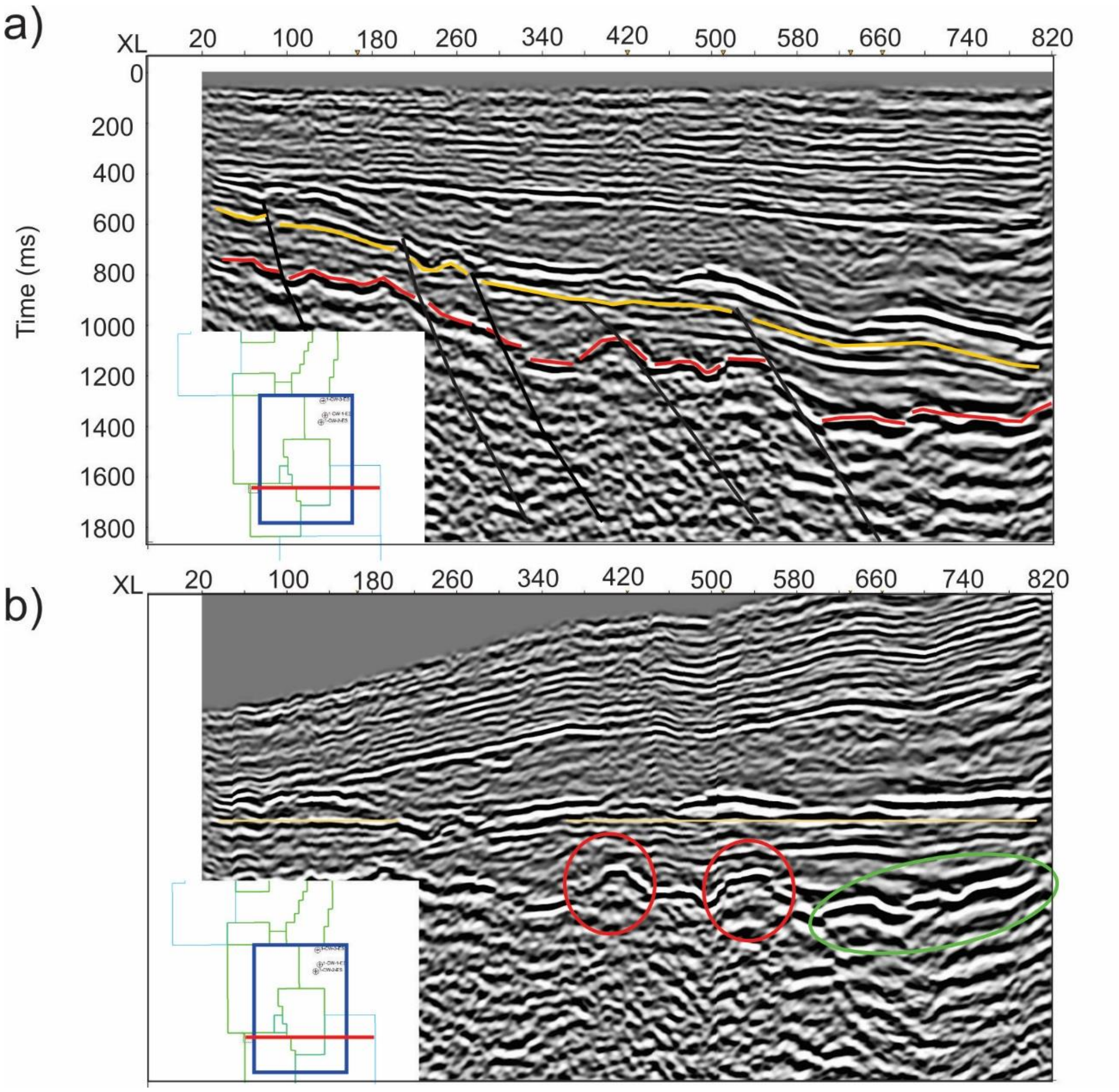


Figure 13: a) Unflattened seismic data; b) seismic data flattened on the intra-Mucuri horizon (depositional lows are highlighted in green, and the structural paleo-highs highlighted in red).

We identified four seismic facies with different seismic patterns (Figure 14). These seismic facies were recognized within the mapped stratigraphic sequences, including the basement (pre-Cambrian), intra-Mucuri, top of the post-rift sequence, base of salt (anhydrite), pre-Urucutuca and upper pre-Eocene unconformity.

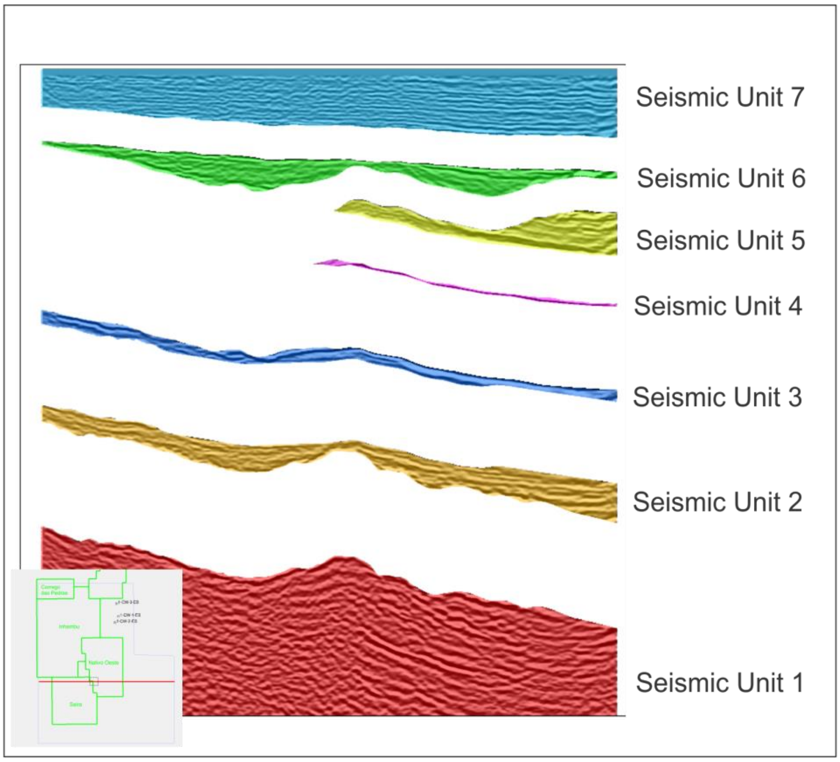
The basement is characterized by chaotic reflections (seismic facies "A"). Seismic facies "B" is located within the post-rift sequence and contains divergent and hummocky reflectors that are semi-continuous with low to medium amplitudes. We interpreted this section to be the result of fan delta progradation.

The upper sequence of the Mariricu Member and the Itaúnas Member anhydrites are characterized by seismic facies “C”, which contains high amplitude, low frequency reflectors with subparallel to parallel configurations and a wedge-shaped geometry. This seismic facies was deposited non-conformably on the underlying strata.

Seismic facies “D” is characterized by sub-parallel, divergent, oblique to tangential and hummocky reflectors with medium to high frequencies and low to high amplitudes. This unit was truncated by the pre-Urucutuca unconformity during the excavation of the early Cretaceous canyons (Figure 14).

The infilling of the canyons above the pre-Urucutuca unconformity is again represented by seismic facies “B”, which contains onlapping and subparallel low to medium amplitude reflectors (Figure 14).

The uppermost seismic units are characterized by parallel to sub-parallel, continuous, high-frequency reflectors with medium to high amplitudes (seismic facies “C”).



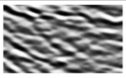
Seismic Unit	Seismic facies	Descrition	Example	Interpretation
1	A	Chaotic configuration and Low Reflectivity, descontinous reflectors		Based on wells, this reflections are assotiated with Basement
2	B	Subparallel to divergent, andhummocky reflection configuration, onlap termination, semi-continous to low reflection		Associated with the Fan Delta System
3	C	Parallel to subparallel, semi-continous good reflections , low frequency		Basin-Drowning event, Sabkha (?)
4	C	High Amplitude and Continuity		Based on wells, this reflections are assotiated with anhydrite, drawing and aridy enviroment
5	D	Parallel and sub-parallel, oblique, with medium and high amplitude, erosive trucation		Initial stage of drift phase, composed predominantly by shallow plataform sandstone of São Mateus Formation
6	B	Mouded onlap to complex, low continuity and amplitude and geometry is filling channel		Filling channel, by the Urucutuca Formation shale
7	C	Parallel configuration reflectors, with good continuity and amplitude, haigh frequency and sheed geometry		Subaqueous enviromenty, quiescence tectonic, with layer geomotry

Figure 14: Correlations between seismic units, seismic facies, descriptions and interpretations.

The chronostratigraphic chart of events (Figure 15) includes 37 relative time events that explain the depositional history of the basin and the tectonic and sedimentary factors that controlled sedimentation. The faults that deform the post-rift section were interpreted as reactivated rift faults because no growth section was observed. The basal section is represented by the Mariricu Formation (Mucuri Member), which was deposited during the Lower and Middle Aptian and reached its maximum extent during relative time T6.

Above the intra-Mucuri unconformity, the absence of faults and the tabular nature of the reflectors with few variations of seismic thickness indicate a calm tectonic environment. A marine transgression was followed by a regression, which culminated with the precipitation of anhydrites in an evaporitic environment (lower Aptian).

After the evaporitic phase, the São Mateus platform contains a predominance of sandstones and shales of the São Mateus Formation. These onlap onto the surface of the Itaúnas Member, are thicker to the north, and were completely eroded away to the west by the Inhambú and Fazenda Cedro paleocanyons. The pre-Urucutuca unconformity marks the bases of the canyons that were filled during the basin’s thermal subsidence by shales of the Urucutuca Formation. We interpreted a maximum flooding surface at the top of this section (relative time T27 in Figure 15 C).

The upper pre-Eocene unconformity can be associated with tectonic uplift during the Serra do Mar uplift and Abrolhos volcanism, which controlled the distribution of sands from the northwest during the Lower Oligocene. The Rio Doce Formation was deposited in a predominantly regressive tract starting in the upper Eocene.

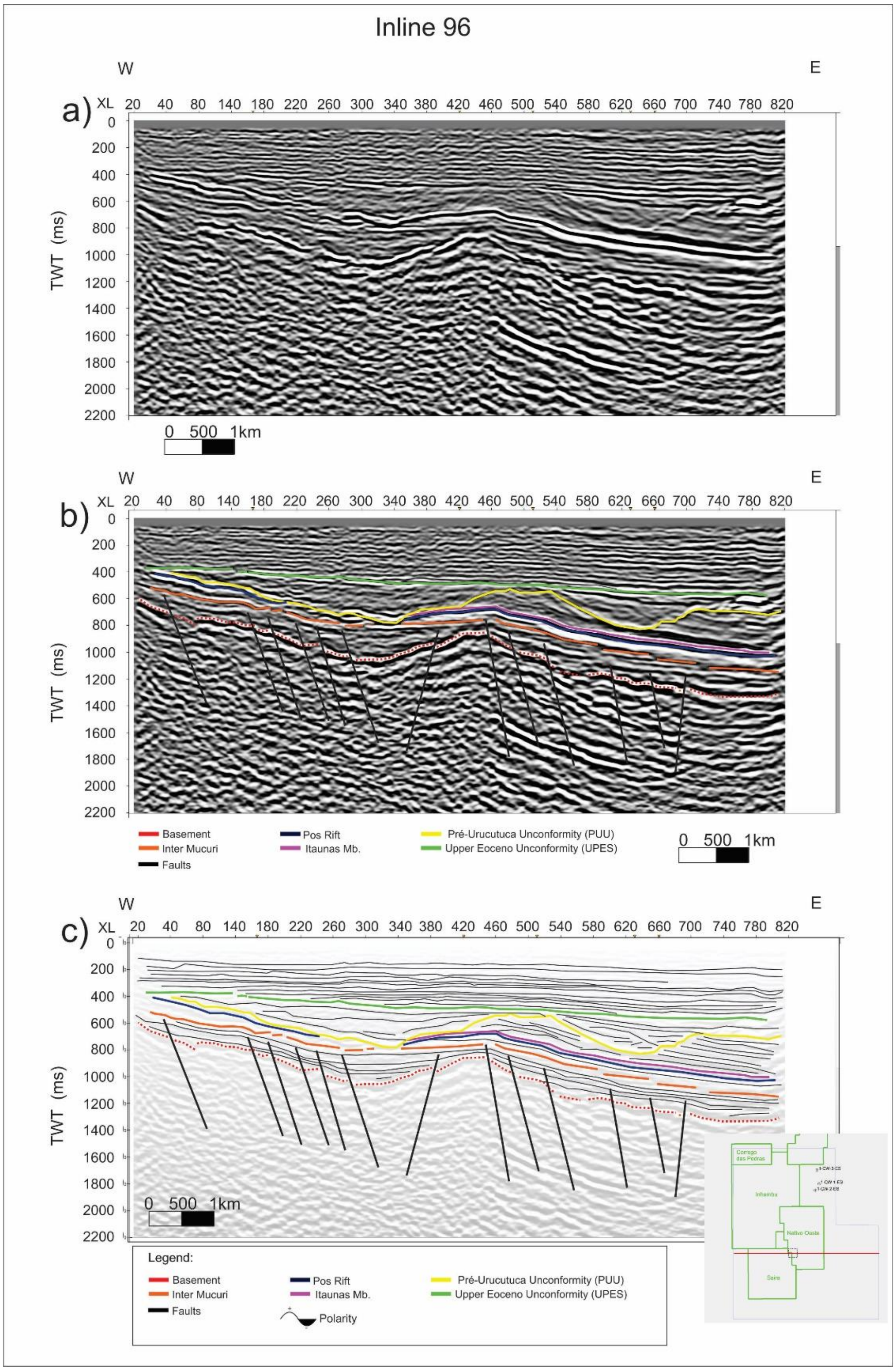


Figure 15: a) Seismic stratigraphic units; b) system tracts interpreted based on the seismic stratigraphic units; c) chart of chronostratigraphic events indicating the main transgressive and regressive events during the deposition of the sequences.

Based on the information from wells 1-CW-1-ES, 1CW-2-ES and 1CW-3-ES and the seismic interpretation, a new geological model is proposed, which shows that the Cretaceous canyons did not exist in the northern part of the study area (Figure 16). This model is different from the previous model (Figure 3) and significantly changes the interpretation of the basin's stratigraphy in the study area. This model will have a significant impact on exploration when considering the importance of the Urucutuca and São Mateus Formation sandstone reservoirs in the Espírito Santo Basin. The main reservoirs on the São Mateus Platform are not the Urucutuca Formation sandstones. In addition, the Mariricu Formation fluvial sandstones may be considered the main reservoirs in the northeastern portion of the Espírito Santo Basin.

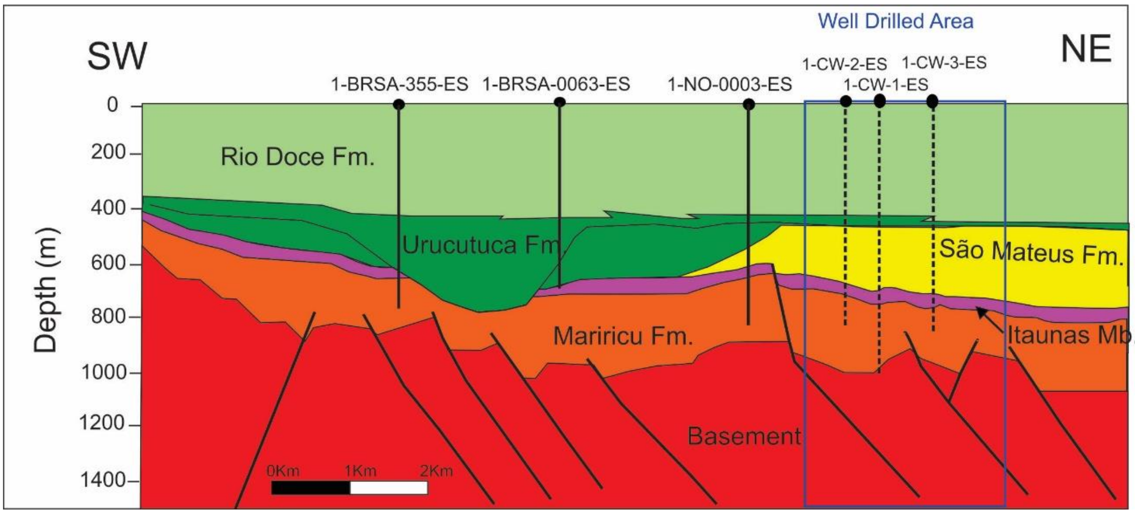


Figure 16: New geological model based on the well and seismostratigraphic studies.

Chapter 6

Conclusions

We developed a regional tectonic-stratigraphic framework in the eastern part of the Inhambú Field, Espírito Santo Basin. The structural contour and isochron maps, which are both in time (TWTT), show significant changes in the basal and intermediate parts of the post-rift section (Mariricu Member) without syntectonic deformation. The Inhambú and Fazenda Cedro canyons did not erode the eastern part of the basin, where the São Mateus sandstones and shales are still preserved. The seismic interpretation allowed the definition of 34 seismic events that are summarized in a chronostratigraphic chart of events. A new geological model is proposed, which reduces exploratory uncertainties for the drilling of new wells. Previous models identified the sandstones of the Urucutuca Formation as the main reservoir rocks and petroleum accumulations in stratigraphic traps, such as the Fazenda Cedro and Fazenda Alegre fields. This study demonstrates that the main reservoir unit on the São Mateus Platform is the Mucuri Member, which consists of neo-Aptian fluvial-deltaic sandstones that were deposited during the marine transgression and subsequent regression that culminated with the deposition of the Itaúnas Member anhydrites.

References

Carvalho, K. W., 1965, Geologia da Bacia Sedimentar do Rio Almada: Boletim Técnico da Petrobras, v. 8, no. 1, 5-55.

Dias, J. L., 2005, Tectônica, estratigrafia e sedimentação no Andar Aptiano da margem leste brasileira: Boletim de Geociências da Petrobras, Rio de Janeiro, v. 13, no. 1, 7-25.

França, R. L., A. C. DelRey,C. V. Tagliari, J. R. Brandão, and P. R. Fontanelli, 2007, Bacia do Espírito Santo: Boletim de Geociências da Petrobras, v. 15, no. 2, 501-509.

Gomes, N.S. and Suita, M.T.F., 2010, Ocorrência de vulcanismo bimodal de idade terciária na Bacia de Mucuri:Boletim de Geociências da Petrobras, v. 18, no.2, 233-248.

Mitchum Jr., R. M., P. R. Vail, J. B. Sangree, 1977, Seismic stratigraphy and global changes of sea level, part 6: Interpretation of seismic reflection patterns in depositional sequences: AAPG Memoir 26 - Seismic stratigraphy – Applications to hydrocarbon exploration. Tulsa, American Association of Petroleum Geologists, 117-133.

Neves, I.A., Lupinacci W. M. and Silva C. G, 2017, Seismostratigraphic analysis in the Inhambú Field, Espírito Santo Basin, Brazil:15th International Congress of the Brazilian Geophysical Society & EXPOGEF, Rio de Janeiro, Brazil, 463-466, doi: 10.1190/sbgf2017-091.