Petroleum and Coal

Article **Open Access**

Multiple Point Statistics Carbonate Facies Modelling Workflow Using Core Data and Spectral Decomposition Attributes: A Case Study from Jintan Field in Central Luconia Province, Malaysia

Grisel Jiménez Soto[1], Mirza Arshad Beg[1], Michael C. Pöppelreiter[2], Khaidir Rahmatsyah[3]*

[1] South East Asia Carbonate Research Laboratory, Department of Geosciences, Universiti Teknologi PETRONAS
[2] Shell Kuwait
[3] Baker Hughes Netherlands

Received May 6, 2020, Accepted August 6, 2020

Abstract

Building static models in carbonate environments proved to be complex due to the multi-dimensional nature of poro- perm-systems (karst to microporosity) and biological growth architecture complex geometries imprint at a different scale from um to km. In addition, the presence of multiple erosions or lack of deposition the interpretation in the stratigraphic columns makes the development of a modelling workflow challenging using the traditional method as variogram-based algorithms that mostly ignore important geological information.

A 100 km^2 of 3D seismic data, 3 wells logs, 2 core well logs, and selective modern carbonate analog were integrated to define a set of carbonate geological "shapes" calibrated with core linked with facies to bring sedimentary facies architectural realism using Multiple Point Statistics geomodelling technique. This methodology, a good first pass approximation to build a meaningful facies model where depositional facies can be mapped and captured at various scales both vertically and laterally using the input data with relevant contribution and weight.

***Keywords**: Central Luconia; Middle Miocene; Carbonates;Spectral Decomposition; Carbonate facies; Reef rim; Karst; 3D seismic geobodies extraction; Multiple-point statistics.*

1. Introduction

In the past 25 years, there has been a significant development in the computing power and software capability which has led to progressively improve a range of modelling techniques, however, despite all these efforts facies architecture and its distribution is often poorly understood and hence its representation in 3D digital models can be related to large uncertainties.

Isolated carbonate platforms are common carbonate environments of deposition throughout the Phanerozoic. They were especially abundant during the Palaeozoic. Our present understanding of build-up distribution, and the ability to better predict their location, is hampered by the fact that maps of build-ups rarely show evidence of spatial organization of petrophysical properties, at the contrary, they often appear chaotic [1].

Typically, in Luconia carbonate reservoirs, the reservoir heterogeneity arises from differences in porosity/permeability, which are marked by diagenetic overprint and/or meteoric dissolution resulting in Reservoir Rock Types (RRTs) with different petrophysical properties, therefore one of the first challenges for property modelling is to identify the depositional facies.

This study proposes an integrated modelling workflow divided into four steps and using a wide range of data from core to satellite image scale. Seismic attributes interpretation, geomorphology and core-facies seismic analysis were carried out to produce a depositional seismic model using Multiple Point Statistics method in a heterogeneous reservoir in Jintan platform in offshore Luconia province, Malaysia, a unique geologically location where facies and depositional facies are still visually distinct in the core.

2. Geological background

Central Luconia province is located in offshore Sarawak, Northwest Borneo, Malaysia, with an aerial extent of 45, 000 km², over 250 isolated carbonate build ups have aggraded mainly from a Middle Miocene substrate [2]. Global and regional Middle Miocene events provide an imprint to internal facies distribution, lateral and vertical heterogeneity in porosity type and distribution.

The Central Luconia province is a relative paleo high which dips gentle NW ward towards a regional lineament, the West Baram line. The province is subdivided structurally into a number of regional highs and lows that are further partitioned into localized extensional horsts and grabens trending systematically SSW-NNE, while compressional structures mostly trend WSW-ENE [3].

The overall architecture of build-ups seems to be determined by four major processes: the rate of skeletal carbonate production, subsidence, sea-level fluctuations, and the supply of clastic material from the Borneo deltas [4]. Observed trends, in general revealed that carbonate build-ups seem to have died earlier and are thinner (<500m) in the south, while they lived gradually longer, are thicker (up to 3000m) and reached higher in the stratigraphy towards the north [5-9].

The platforms experienced several phases of evolution in response growth and architecture of the platforms were controlled by a relative constant subsidence rate over the province (based on relatively uniform platform thicknesses of about 1200 m), and the interplay with eustatic sea-level fluctuations and the monsoonal wind system of the middle Miocene affecting the area [9].

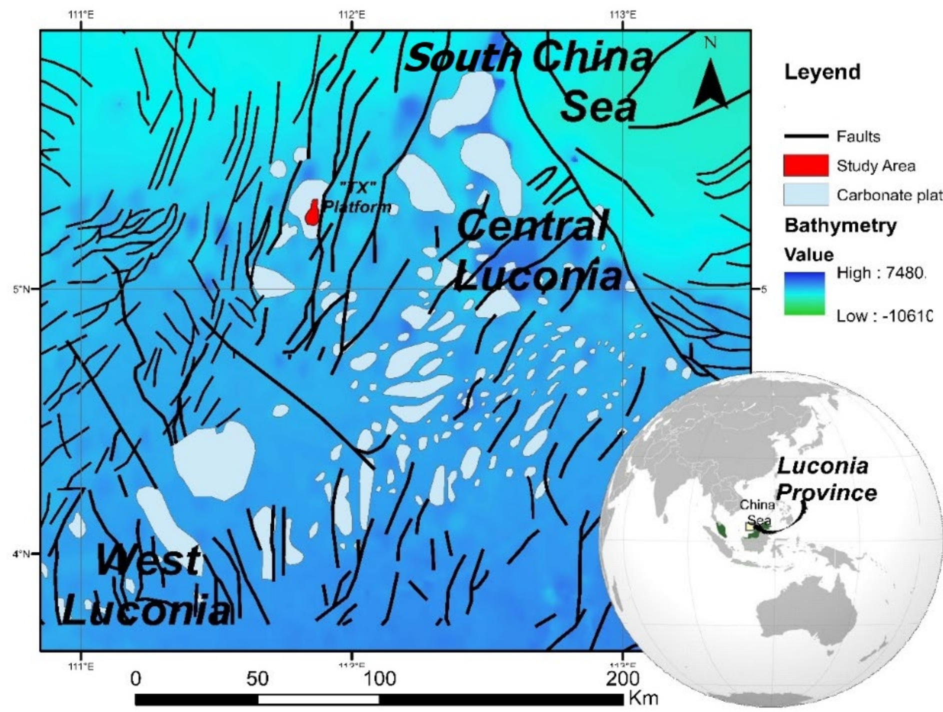

Figure 1. Bathymetric map of the South China Sea, with major structural lineaments (black lines), superimposed with the Miocene carbonate build-ups distributed in Luconia Province. The red polygon shows the location of the Jintan platform

The study field is located in the Northwestern Luconia province and is one of the seven stratigraphic culminations on a major mega platform (30 km x 50 km large). The Jintan platform is approximately 280 km NNW of Bintulu. The carbonate build-up has experienced an aggradation phase followed by a backstepping phase during a series of third-order sea-level cyclicity in the middle Miocene [9].

3. Dataset and methodology

The subsurface data used for this study comprises three pre-stack time migrated 3D seismic surveys tied to 3 wells that cover an area of approximately 96 km^2. The well data accessed included wireline logs which include core description information from TX-2 (1713 MD) and TX-3 (1875MD). TX-3 core data was used for calibrating the stratigraphic markers with the seismic stratigraphy. Google Earth satellite images of a modern carbonate build-up located in Tun Sakaran Marine Park, Malaysia were used to develop the conceptual model and training image for MPS simulation. The proposed workflow methodology using MPS includes the following four steps.

3.1. Integrated seismic-core log calibrated geocellular grid

3.1.1. Seismic geomorphology and seismic attributes

The seismic data consist of a pre-stack time cube covering the entire Jintan platform. The data comprise two surveys acquired in 1991 and 1992 for a total of 245 km, the grid spacing is 300 m. The dominant frequency in the carbonate platform averages around 30 Hz, average acoustic velocity averages around 2900 m/s.

Well to seismic ties were completed by establishing a reasonable correlation between the seismic and synthetic seismograms by adjusting T-D functions through stretch and squeeze. In both wells the top of the carbonate sequence is associated with an apparent decrease in density. Also in both wells, the first noticeable reflector of the reverse polarity synthetic originates near the top of the carbonate.

A neural network methodology is applied for seismic interpretation in PaleoscanTM [10] in order to create a number of stratigraphy consistent horizon slices through the Jintan platform. This methodology created a node network for every peak, trough, and zero-crossing. It then calculates the best correlation coefficients between two seismic traces, which results in the minimization of the 'time' of correlation. This correlation was modified and calibrated with nine manually interpreted horizons in the Jintan platform. Then a calculation of a 3D Relative Geological Time model (RGT) was applied using an intra - and extrapolated version of the correlation cube.

To extract the geobodies and define thin horizon stack layers, spectral decomposition (SD) with short-time Fourier transform (STFT) method attribute was applied to 'decompose' the original seismic wavelet into its individual low (Hz 16), mid (33 Hz), and high (46 Hz) frequency components. We use the blending of the red-green-blue (RGB) colour model to identify the delineate the geobodies and seismic facies.

3.1.2. Core and well logs data

Wireline logs are available from three vertical wells: density, porosity, permeability and, lithofacies logs were used for log correlation to identify lateral variations, vertical facies distribution and establish a comprehensive correlation of cross-sections along with the dip and strike directions of the platform. Furthermore, the correlation was used to create a depositional trend map to run MPS simulation. Core data and well data description is used to create upscaled facies logs for MPS simulation.

3.2. Training image

A training image (TI) is a 3D conceptual model that provides a representation of the full range of shapes and dimensions expected in the modeled platform. The properties in the TI grid can be facies properties, porosity, grain size, or other reservoir properties. It is under the assumption that the TI has the same multiple-point statistics and contains the same complexity of the geological features of the area of interest, or in other words, assumed stationary [11].

Google Earth provided high-resolution image input to develop Tis from modern carbonates build-ups [12-13] a selected modern analog satellite image was used for the comparative metric analysis of main depositional facies environments. These interpreted images were processed and converted into a 3D grid by defining the number of cells in JewelSuite™.

3.3. Auxiliary variable or trend map

The objective to generate a 3D auxiliary variable is to create a trend containing information about facies dimensions and relationships among facies. In this step, horizons and seismic facies, seismic attributes were used to delineate the geobodies of seven 3D depositional facies: Deep Lagoon, Shallow Lagoon, Proximal Reef (Lagoon), Reef Rim, Upper Talus, and Lower Talus.

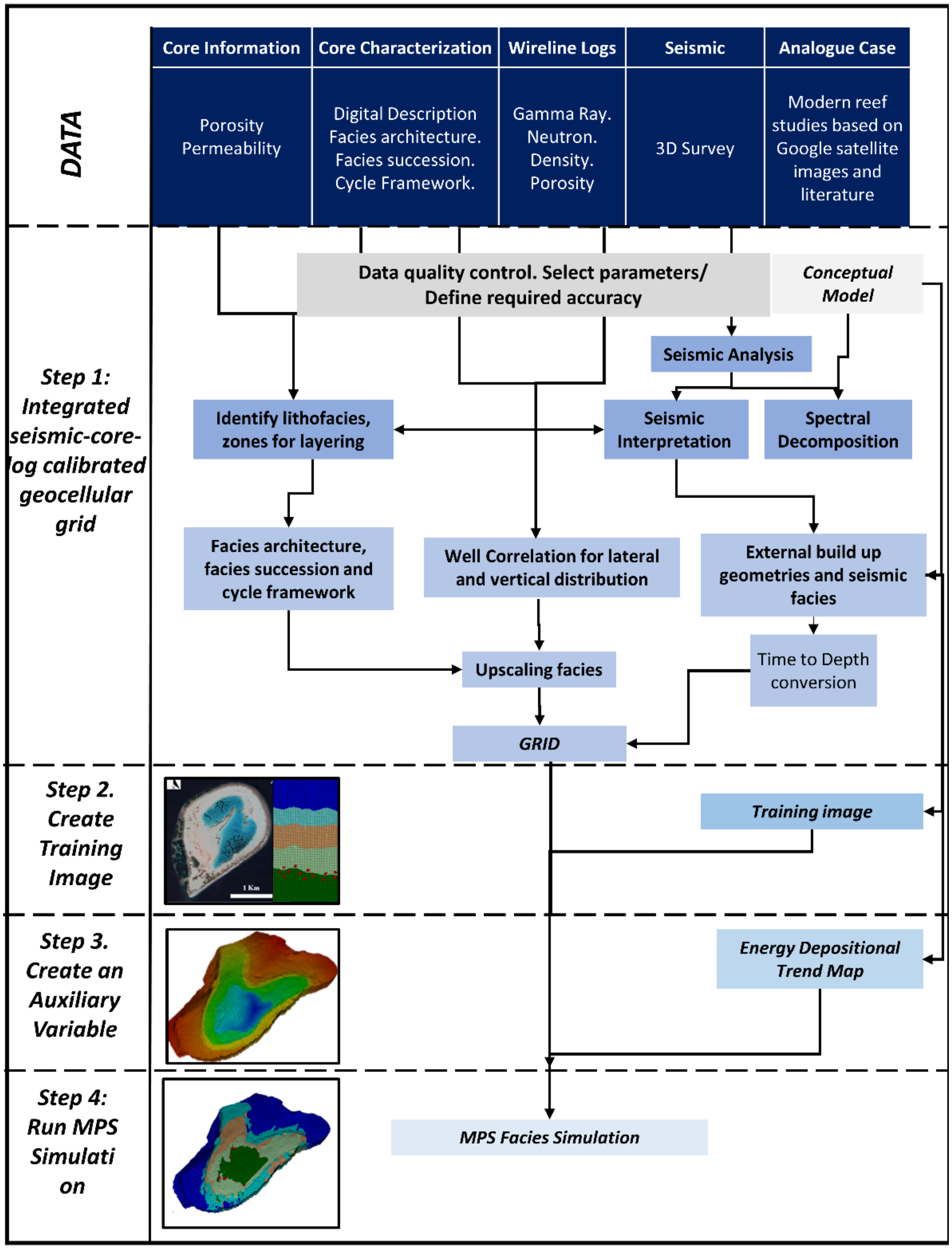

Figure 2. Proposed workflow methodology using MPS facies modelling. The basic data include geological information, seismic survey, well data and satellite images

3.4. Simulate depositional depositional facies population using the trend map and training image

An MPS simulation using the TI and auxiliary variable run at this late stage. This technique is inspired by the object-based modelling method. The resulting continuous training image was eventually transformed to match a target property histogram to generate an MPS Simulation in cross-section and maps and to match facies regions.

4. Results and discussion

4.1 Integrated seismic-core-log calibrated geocellular grid

4.1.1. Seismic expression

The seismic interpretation of site survey data demonstrates the Jintan platform comprises parallel-layered stratigraphy. The eastern margin is rimmed by a high energy organic reef non -continuous and often chaotic reflectors. Erosion and faulting, combined with depositional thinning, limit the buildup to the west and north.

The identification of major flooding surfaces, sequences boundaries was carried out combining seismic expression, seismic geomorphology, well and core data. Four main zones were identified. Three main reservoir porous zones delimited by two flooding surfaces or tight layers calibrated with the deepest cored and wireline logs well TX-3 (Figure 3)

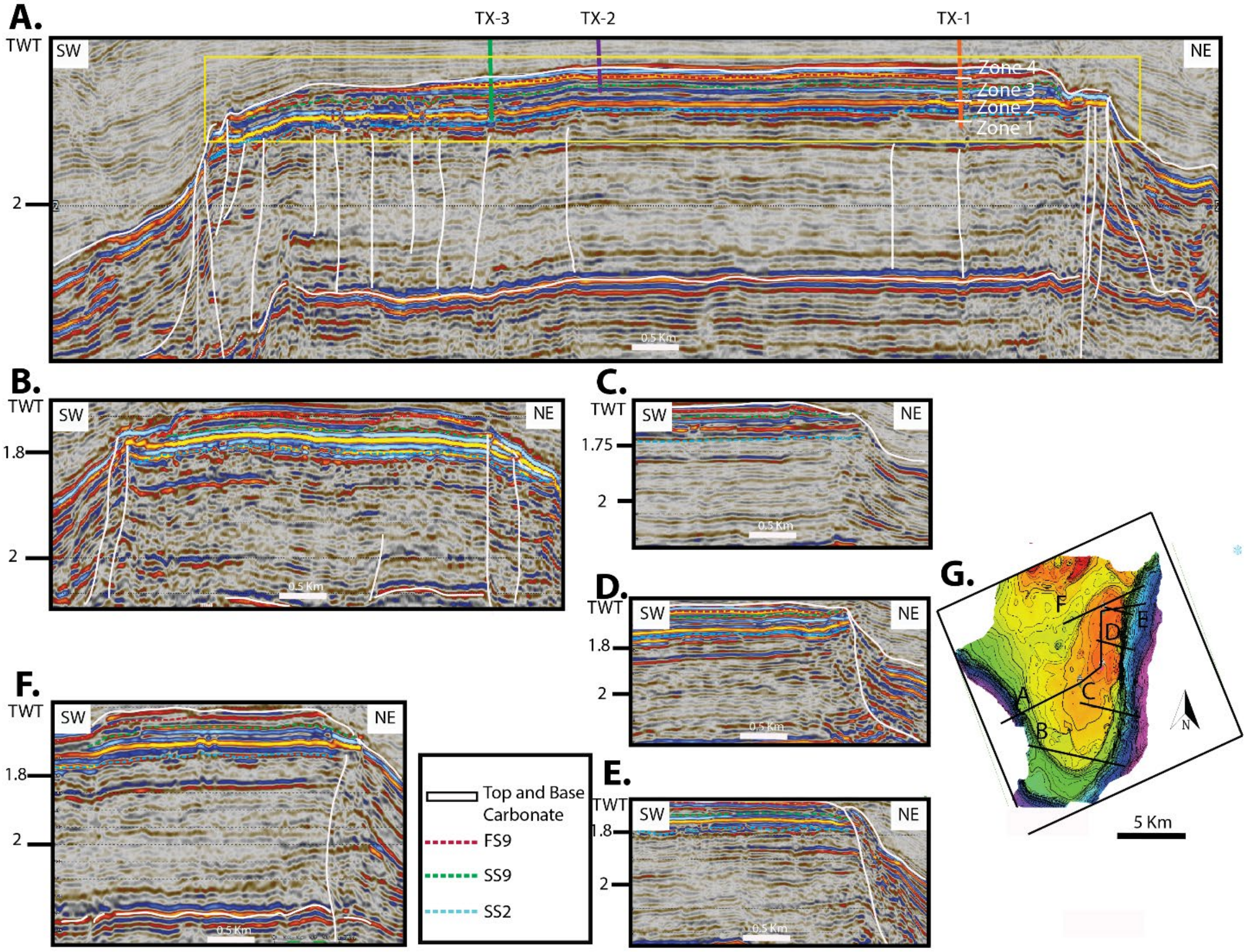

Figure 3. A. Arbitrary multiregional line interpreted northeast to southwest arbitrary covering the 3 study wells. B, C, D, E showing eastern arbitrary seismic lines showing the seismic character of the talus distribution and reef rim geometries. F. Arbitrary line displaying the seismic character of the Northern part of the build-up. G. The insert map shows the locations of the arbitrary lines

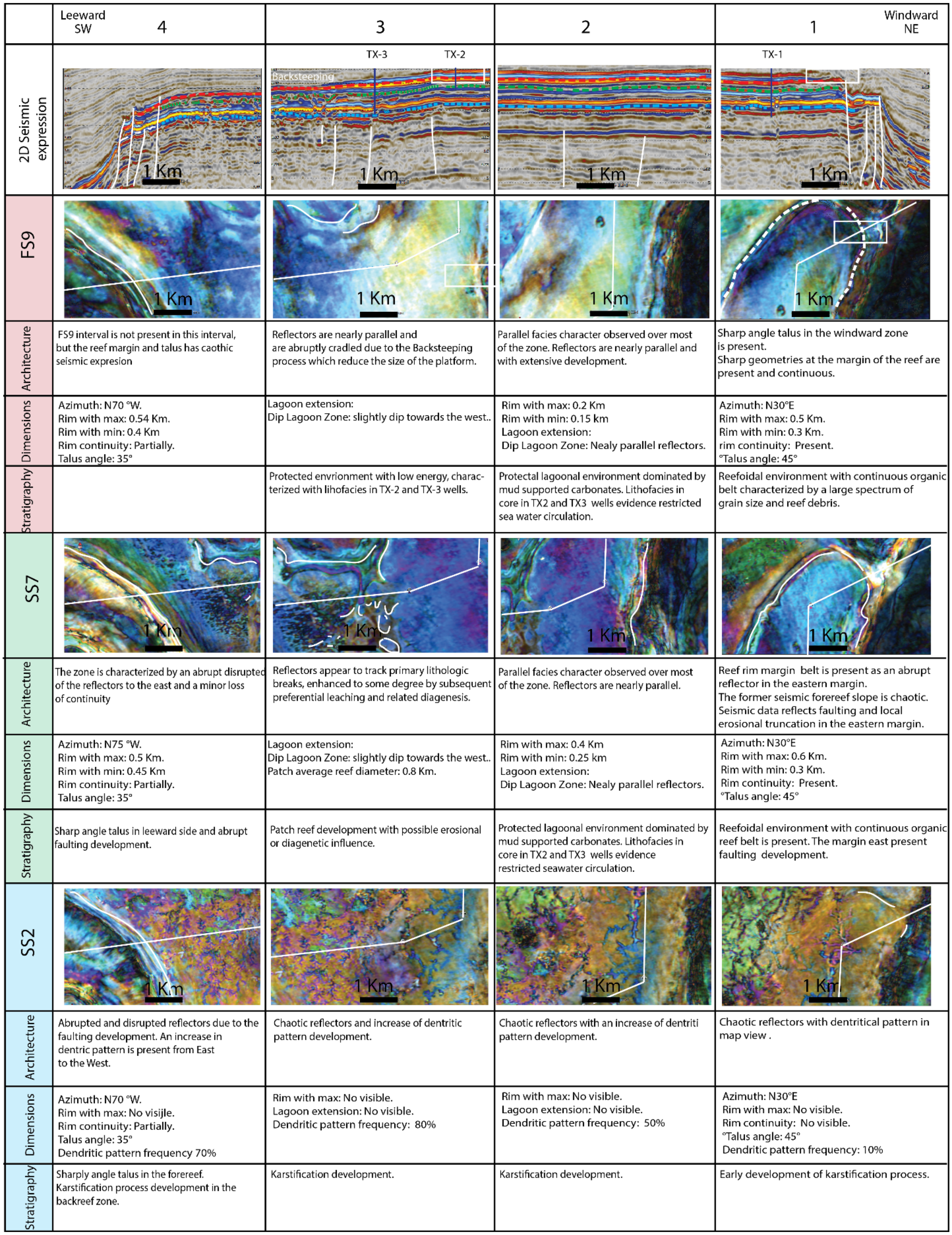

Figure 4. Seismic expression and different morphological features of the Jintan platform. For modelling purposes, three main intervals were selected to describe architecture, dimensions, and stratigraphy of internal seismic facies distribution. FS9 interval (Tight layer), SS7, and SS2 Karst interval

The first characteristic reflector of reverse polarity synthetic is originated near the top of Zone 4 which is interpreted as the Top of Carbonate with an abruptly lower gamma-ray response. Bellow the top of the carbonate, horizon FS9 with a higher density (2.5 g/cm^3) and lower porosity (less than 5%) response was calibrated with core information of argillaceous and mud dominated facies indicating a transgressive event which was correlated and matched among the three available wells. In the northern part of the platform, a sharp talus is observed with a slope of ~45° and azimuth of N30°E, in the middle part of FS9 parallel reflectors are observed and near the western part and abrupt change in slope due to the back steeping event which reduces the platform in 80%. (Figure 5)

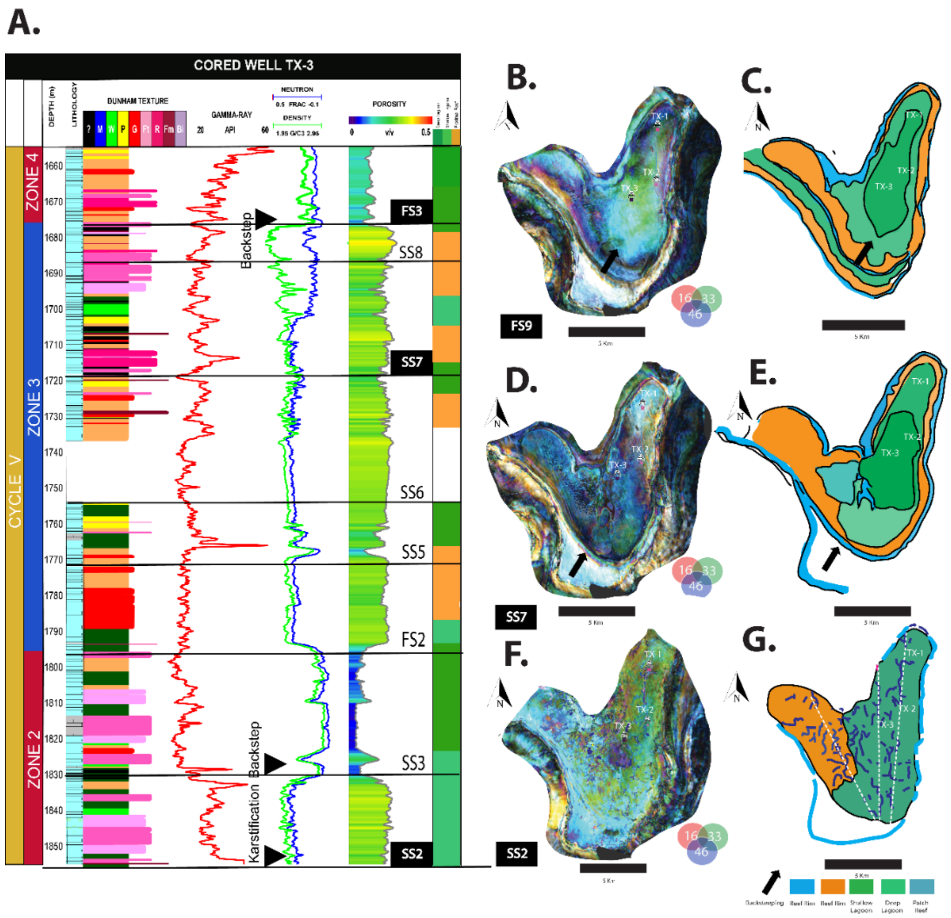

Figure 5. A. Well –Core-Seismic correlation of TX-3 well. The three selected intervals were used to define the trend maps for modelling. B, C correspond to FS9 is the Flooding interval with backstepping evidence in SD maps. D, E, corresponds to SS7 interpreted as an aggradational interval. F, G. corresponds to SS2 with a karst interval with dendritically pattern features

Zone 3 is made by horizons SS8 and SS7, which were fully cored in both wells. In TX-2 and TX-3 with lower density and higher porosity response is present. The lithology is characterized by mud dominated packstone interpreted as lagoon depositional setting. In the western part of the build-up, reflectors appear to break to track primary lithological break with a patch reef and a broader internal late-growth build-up.

Zone 2 ties very well to the horizon FS2 which calibrated with the core is interpreted as a flooding interval and which roughly correlates among the wells, similar to horizon FS9 argillaceous and mud dominated facies indicates flooding interval. Higher density and lower porosity log response at this interval are present. Below FS2, at horizon SS2 the reflectors appear to track primary lithological breaks and enhanced preferential diagenesis with dendritic pattern development due to the karstification events.

4.1.2. Core-spectral decomposition seismic-facies calibration

Spectral decomposition (SD) is a common geophysical method for mapping by its spectral content. This technique was applied to highlight the stratigraphic features and extracting the reef architectural elements such as reef rim belt and dendritically karst patterns. The dominant frequency of the seismic data is measured approximately at 30 Hz. The processing Discrete Fourier Transform (DFT) and the Red-Green-Blue (RGB) colour blended maps are used in a horizon stack of more than 100 horizons. The three frequency ranges are 16Hz, 33Hz, and 46Hz.

Based on the seismic horizon stack and amplitude four different seismic facies were defined in the study. Some of these facies which covered the well location area are correlated with core and wireline logs (Figure 6).

The proposed facies are:

- **Seismic Facies 1 (SF1):** The facies are discontinuous, strong high amplitude strength reflections, and based on comparative sedimentology with the modern analog is interpreted as a reef rim belt. No wells correlation is possible as no wells have drilled the area.
- **Seismic Facies 2 (SF2):** The facies are continuous parallel with moderate amplitude values. The well and core data were used to interpret these facies with good lateral connectivity of a low to moderate energy of the lagoon environment.
- **Seismic Facies 3 (SF3):** The facies consists of abrupt reflectors in the southern region of the platform in interval SS7 and SS6. No wells correlation is possible as no wells have drilled the area, but using the modern analog similar patch reef geometries are present in the lagoon setting.
- **Seismic Facies 4 (SF4):** The facies consists of discontinuous, moderate high amplitude reflections. Well and core data correlates with relatively higher energy in a proximal reef setting.
- **Seismic Facies 5 (SF5):** The facies consists of abrupt and higher amplitudes values with dendritic patterns interpreted as karst features.

4.1.3. 3D seismic – stratigraphy core correlation

Carbonates build-ups margin can show progradational, aggradational, and retrogradational stacking patterns, depending on the balance among the carbonate production and accumulation rates [14]. These processes are encrypted in the external build-up morphology and internal seismic geometries and can provide when calibrated with core and well-exposed build-ups, templates for digital modelling [1].

The Spectral seismic attributes applied in horizon stack cube allowed to correlate with core data for stratigraphic events identification:

Flooding tight layer interval (FS9)

The tight intervals are present with lower amplitudes values on seismic. Log reading interpretation with low Gamma Ray (20-40 API), high density (~2.3 g/cm^3), and lower porosity (~18%) (Figure X). FS9 is available core and thin sections description is mainly composed of argillaceous limestones, well-preserved foraminifera, and red algae.

The main pore types observed are micropores observed in red algae and rarely observed mouldic porosity. External morphology evidences a size reduction of 20% of the platform area. The flooding interval is interpreted as a drowning event which implies backstepping. In the northern part of the platform, sharp angle talus with a continuous reef rim (SF1) is present and in the southern part, two parallel reef rim is observed evidence of reduction on the size of the platform. (Figure 7).

Agradational Porous layer (SS7)

The porous layers SS5, SS6, SS7, and SS8 are considered with good reservoir potential. From core information, they are mainly composed of coral-dominated grainstone and coral-dominated floatstone indicating a porosity ~23%. The poretypes are mouldic and vuggy porosity. Seismic geomorphology allowed to recognize clearly the presence of a continuous reef rim belt (SF1), lagoon (SF2), and patch reefs (SF3) features on the western side of the platform which is recognized by their chaotic seismic signature in assumed sedimentary conditions of higher accommodation space. (Figure 8)

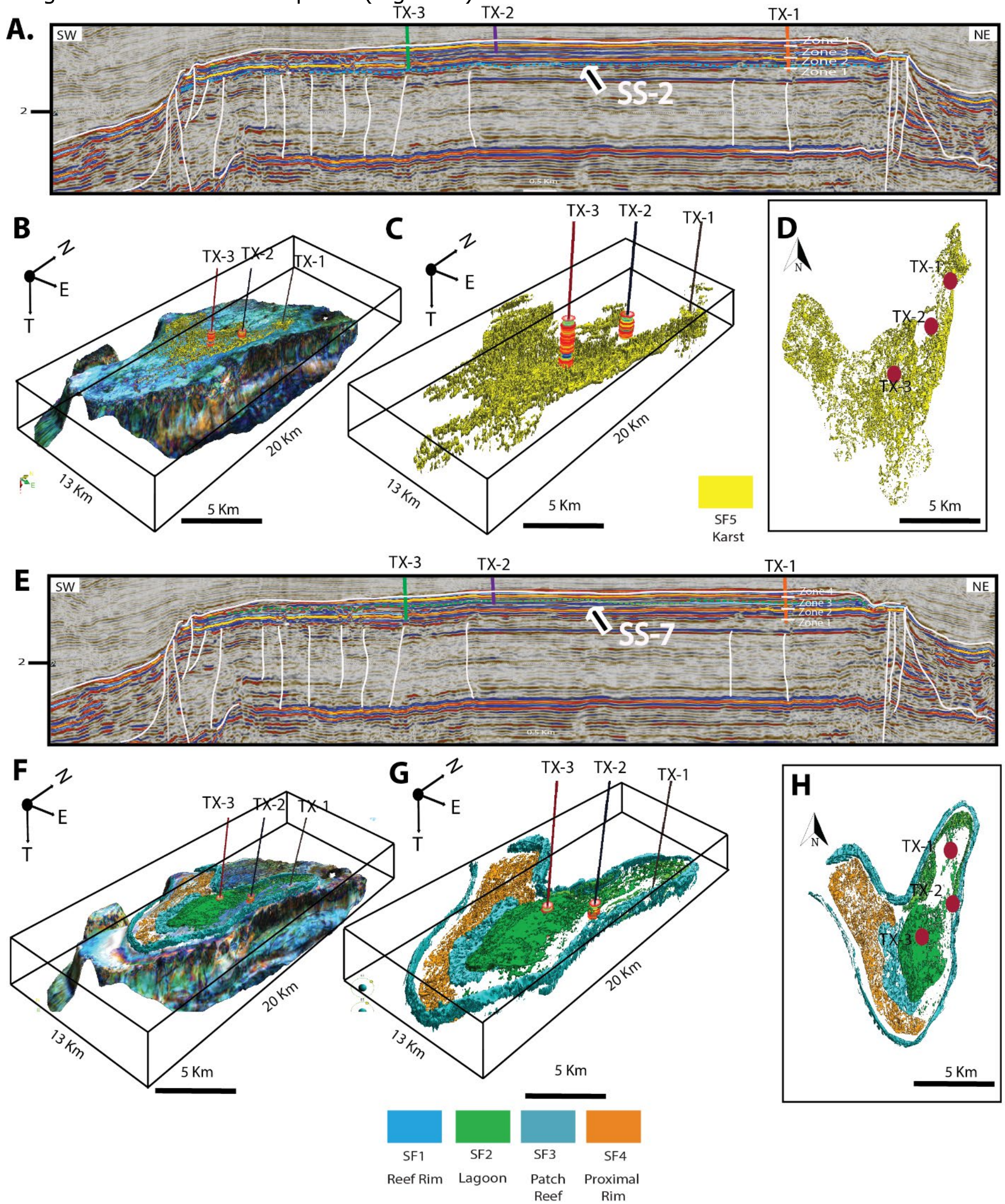

Figure 6. A) Well –Arbitrary line-oriented northeast to southwest showing the location of the SS2 interval used as a reference for geobodies extraction. B) Three-dimensional karst geobodies extraction at SF2 horizon and bellow Zone 1. C) Map view of SF2 karst distribution. E) Well –Arbitrary line-oriented northeast to southwest showing the location of SS7 interval used for geobodies extraction F) Three-dimensional reef geobodies extraction at SS7 horizon and bellow Zone 2. G) Three-dimensional reef geobodies extraction at SS7 horizon and bellow Zone 2. H) Map view of reef seismic facies

Progradational Karst Layer (SS2)

Extensive karstification is present in the upper part of the platform. Karst in seismic is characterized by discontinuous to chaotic seismic facies. This pattern correlates with chalkified limestone with mouldic and abundant vuggy pores in core samples and thin sections [15].

Based on seismic SD attributes at the interval, FS2 has identified dendritic karst (SF5) pattern range in size from 2 km to 15 km and its presence may be influenced by the presence of pre-existing faults of zone 1. This interval was developed during a sub-aerial exposure where dissolution generated various geomorphic features, including large-scale cave systems. (Figure 9). Photomicrograph of FS2 interval, blue areas are epoxy-impregnated porosity. Packstones with large connecting vugs.

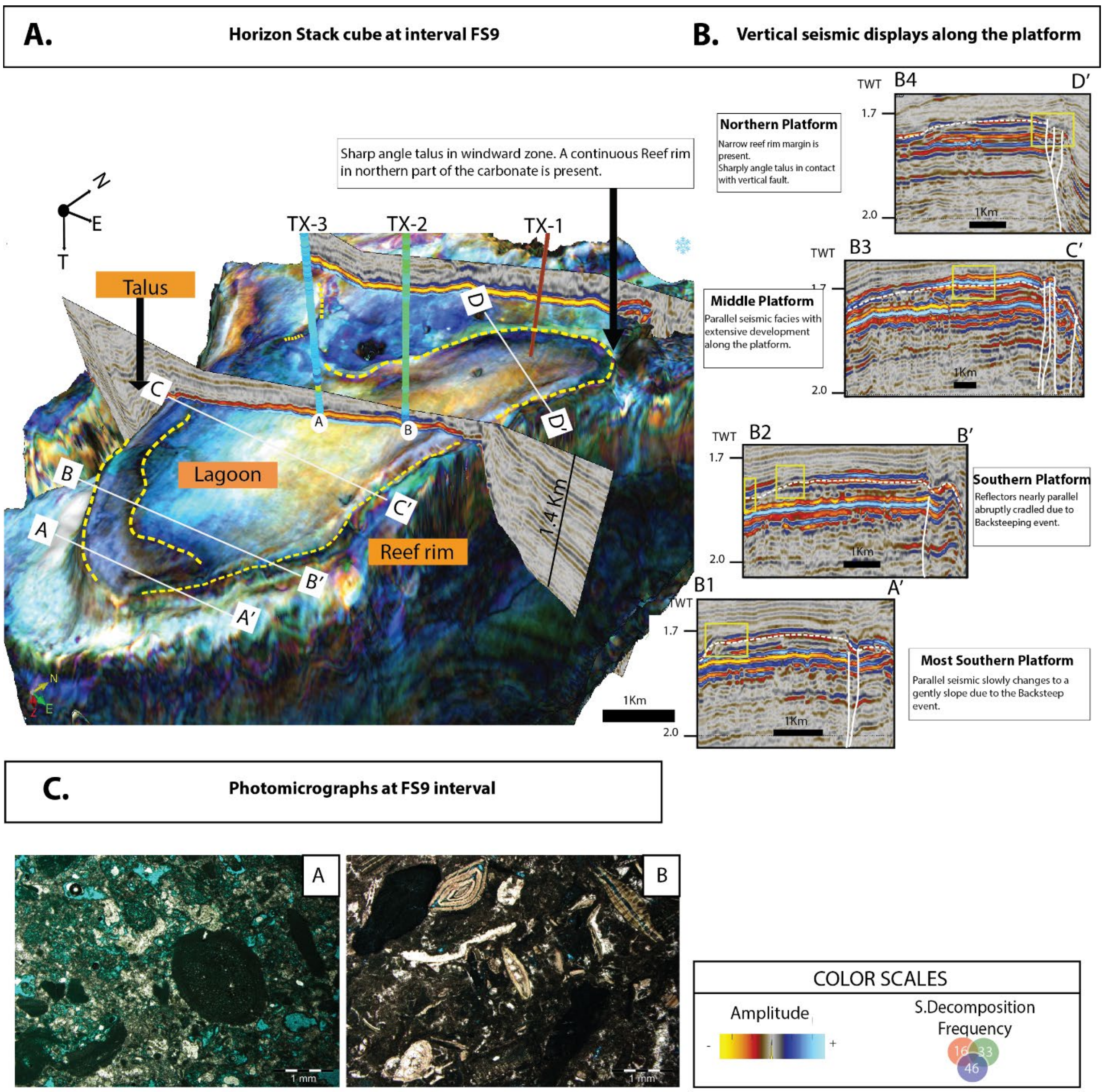

Figure 7. A. Cube display of SD attribute in horizon stack at FS9 interval B1, B2, B3 Vertical seismic displays along with the platform where the less negative amplitude highlights the flooding interval. C1,

C2 Photomicrographs at FS9 interval with foraminifera packstones to wackestones dominated facies with microporosity and less than 10% of porosity and permeability of 0.4 mD

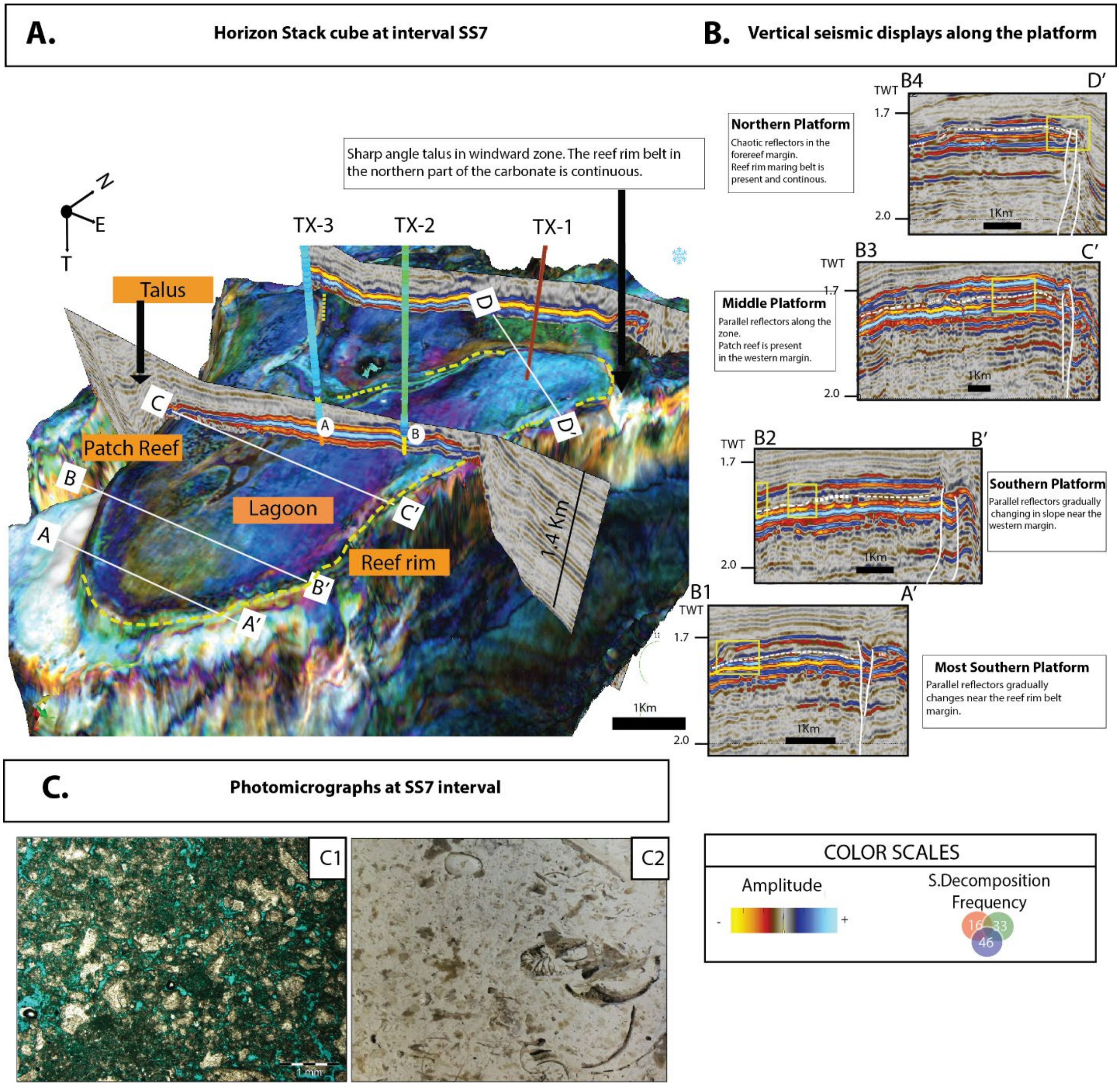

Figure 8. A. Cube display of SD attribute in horizon stack at SS7 interval B1, B2, B3, B4 Vertical seismic displays along with the platform where the less negative amplitude highlights the aggradational interval. C1, C2 Photomicrographs at SS7 interval with coral-dominated grainstone and coral-dominated floatstone with mouldic dominant poretypes and porosity of 28% and permeability of 42 Md

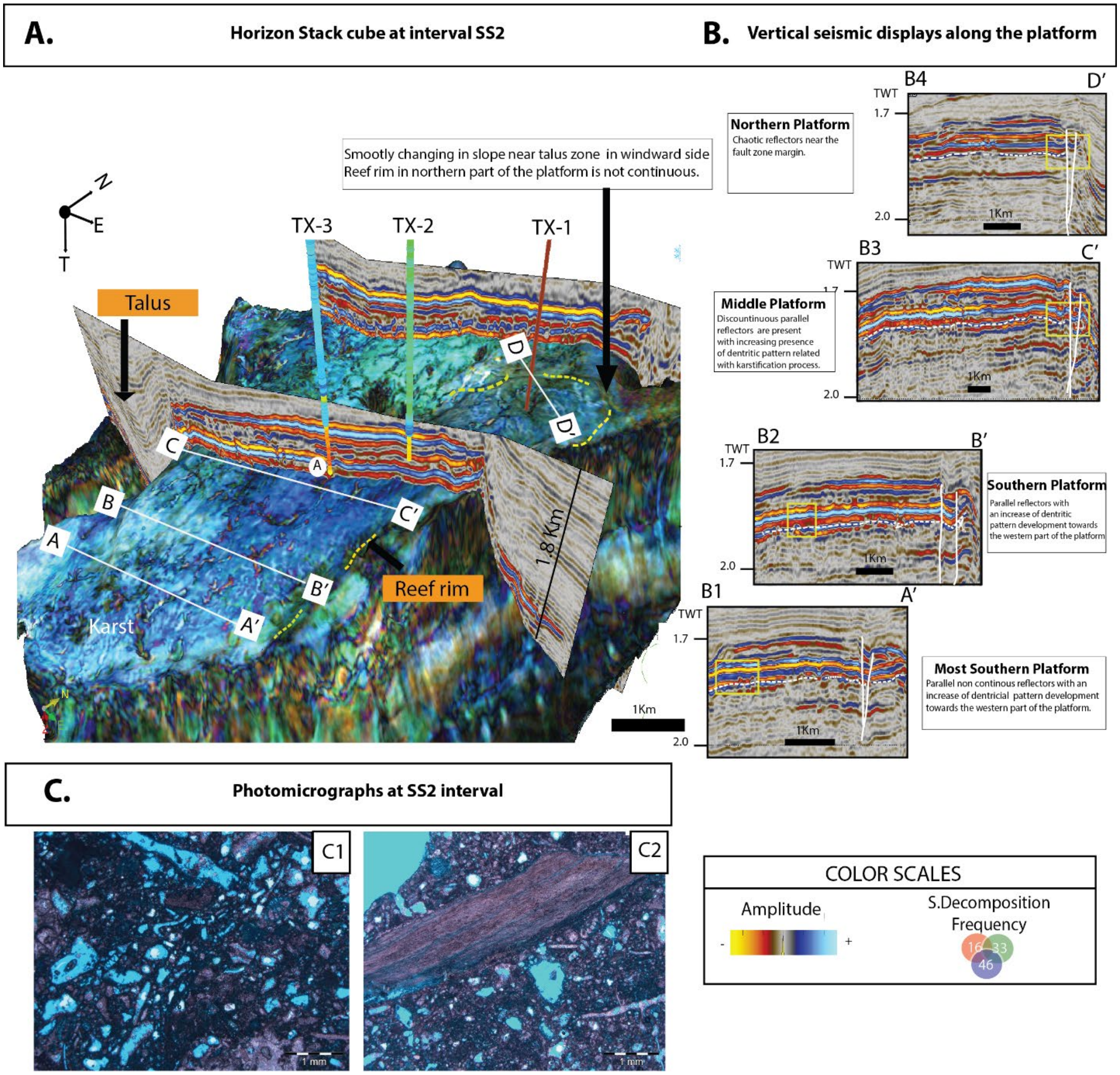

Figure 9. A. 3D Cube display of SD attribute in horizon stack at FS9 interval B1,B2,B3,B4E) Vertical seismic displays along with the platform where the most positive amplitude highlights the karst interval. C1, C2 Photomicrographs at SS2 interval with packstones to wackestones dominated facies with vuggy dominant poretype and porosity of 30% and average kh of 62 mD

4.2. Training image

Open source satellite imagery from Google Earth was used to select a modern carbonate build-up to understand 2D lateral facies architecture. For this work, a modern build-up selected from Tun Sakaran Marine Park in Malaysia. This site includes seven main isolated carbonate platforms: Gaya, Selakan, Kapikan, Mantabuan, Church reef, Maiga, and Sibuan, previously studied and mapped by [16]. The area is situated 7.5 km east of Semporna, and it is surrounded by deep water ranging in depth between 60 m off the western edge of the study area.

The Church reef platform is the fifth largest platform in the Tun Sakaran Marine Park with an area of 4 km² and contains a few patch reefs and is surrounded by carbonate sand shoals. (Figure 10). The geospatial image was imported in JewelSuiteTM and was processed and converted into the 3D GSLIB format grid file by defining several cells. A previous facies map by

Chalabi, 2012 [14] allowed to recognize four main zones: reef complex, carbonate sand shoal shallow lagoon, and deep lagoon and to (Figure 10A).

The analogue based on comparative sedimentology allowed to establish the lateral facies relationship TI grid (Figure 10B). Such comparison identified a lateral facies rule for a second Ti construction. In this new TI, the lateral relationship is defined and two new facies described in the core were added: Proximal reef and patch reef features.

In the MPS simulations, the main objective is not to reproduce the identical geological patterns or geometries in the TI, but to generate similar features, then is advisable to create a simple TI which may reflect simple facies relationships.

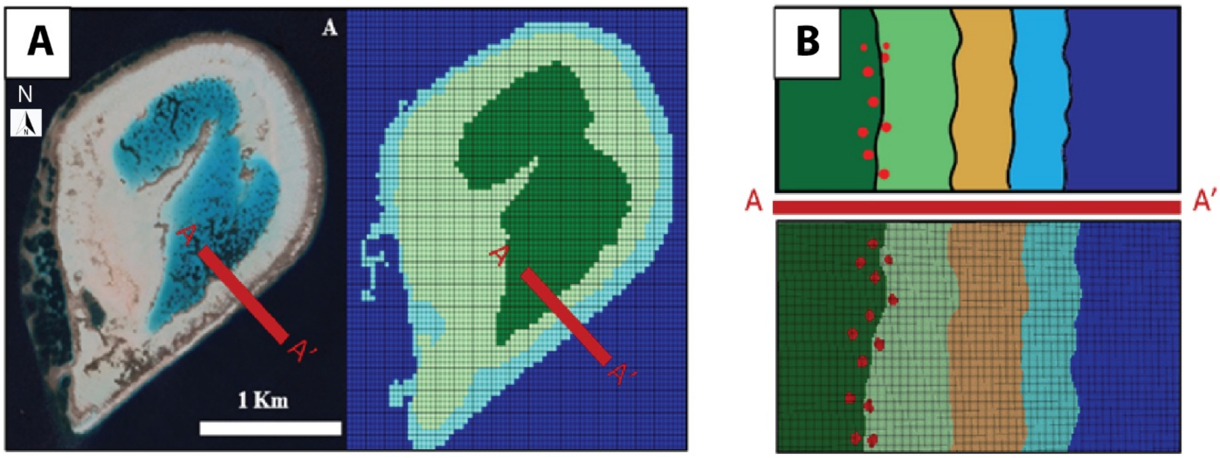

Figure 10. A. Training images in GLSIB format of Church Reef platform (B) Lateral segment of the platform

4.3. Auxiliary variables based on seismic geobodies extraction

An auxiliary variable is a 3D grid property that is defined in both the training image and simulation model and describes the presence of a trend without explicitly referring to any conventional condition [17].

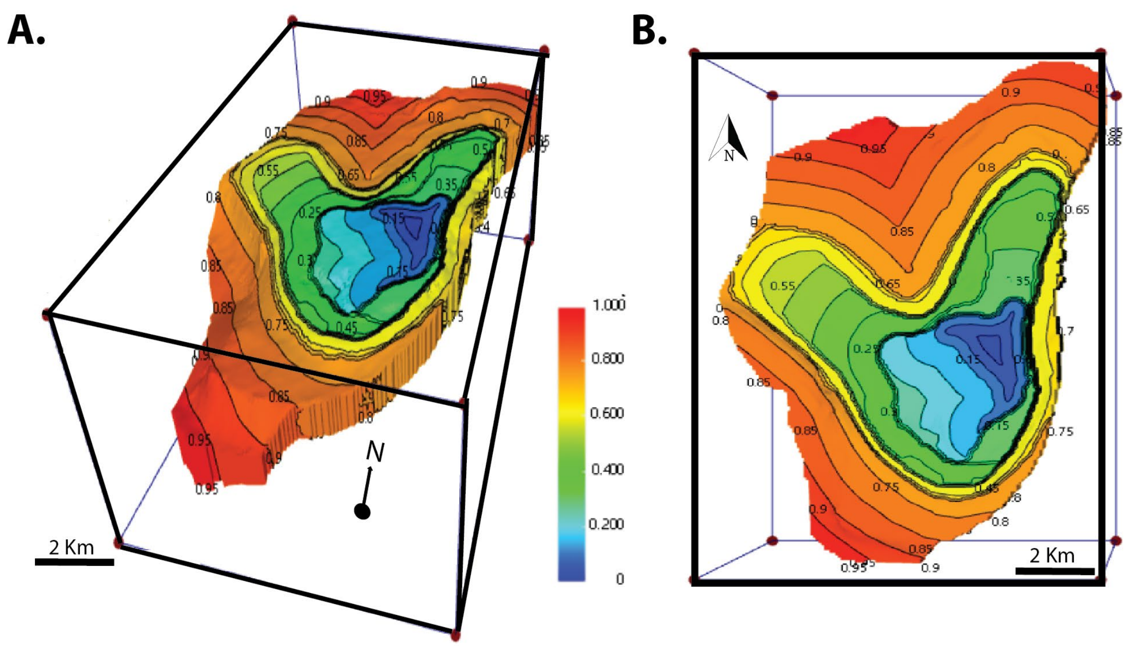

Figure 11. A. 3DAuxiliary variable cube representation B. 2D map of the energy trend map

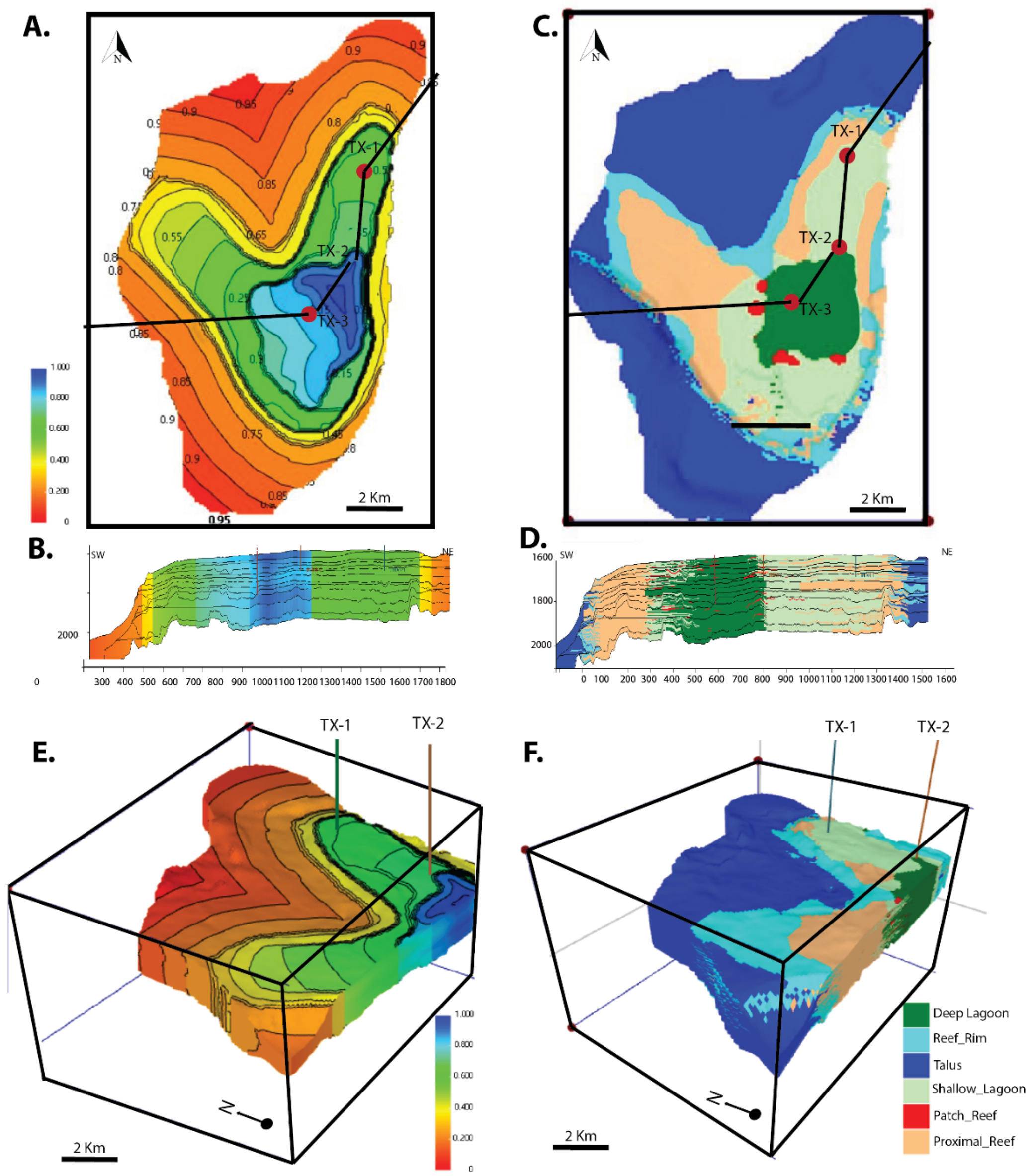

Figure 12. A. 3D energy trend model as an auxiliary variable for MPS simulation B. Northeast to the south-western cross-section of the energy trend map C. MPS 3D facies model of "TX" platform D. Northeast to a south-western cross-section of the facies model. E. Western to Eastern cross-section of the 3D energy trend F. Western to Eastern cross-section of the 3D facies model

Depositional and sequence-stratigraphic models suggest that modern and ancient carbonate platforms should have a well-stratified internal character, representing the development of distinct depositional elements generated by the interaction of various relative sea level, climatic, and diagenetic controls. Some depositional models suggest that carbonate platforms consist of high-energy deposits (reefs or sand shoals) at margins and protected interior lower-energy lagoonal deposits, possibly containing small patch-reef bodies [14].

For the modelling purposes and honor the facies distribution a 3D trend was created to simulate the sedimentary energy expected in Jintan platform. Values from 0 to 0.5 are expected to develop sedimentary depositional corresponding to the deep, shallow lagoon (SF2) and proximal reef (SF4). Values from 0.5 to 0.8 are expected to develop the reef rim belt (sf1) which may represent the high energy of deposit and finally, values from 0.8 to 1 are expected to be the talus and open marine facies.

4.4. MPS simulation

The final simulation grid using the workflow (Figure 8) is capable to create a simple 3D consistent carbonate pattern from very simple training images and one auxiliary variable. The 3D trend has been conditioned to SD results and geobodies extraction (soft data) and core and well data (hard data) to create a representative 3D facies distribution grid. The following facies distribution matched with depositional setting interpreted in TX-1 and TX-2 wells. (Figure 12)

- Deep Lagoon and Proximal reef are modeled in the most interior part of the platform and they matched with TX-1 and TX-2 sedimentary core description.
- Reef Rim: The reef rim belt is modeled in a continuous way based on SD seismic geometries extraction, however, no wells have been drilled the reef rim. The windward northern side shows clearly a continuous rim while in the leeward a non-continuous reef belt is present.
- Patch Reef is modeled on the western side of the Jintan platform. No available wells have been drilled on this side of the platform.

This model can be used as an input for the porosity model and later for flow modelling simulation purposes.

5. Concluding remarks

The MPS method proved to create a simple model combining object-based concepts from the comparative sedimentology of a modern carbonate and ancient platform. This comparison assisted to provide a training image which provides simple facies lateral relationship and seismic geobodies to create an auxiliary variable or trend maps to handle non-stationarity in both TI and simulation model. The proposed workflow includes the following steps:

Step 1: Integrated Stratigraphic core – logs calibration with seismic attributes and geomorphology

Step 2: Create a training image or set of training images with sufficient geological information to provide facies neighbourhood patterns.

Step 3: Create an Auxiliary Variable or Trend Map to handle one or more trends.

Step 4: Simulate depositional facies with 2D training images and 3D auxiliary variables.

The workflow proposed in this work is general and can potentially be used as an input for different sedimentary settings and used for reservoir simulation stages. The simple model can also help to improve the general understanding of reef rim growth patterns and diageneses karst behavior.

Acknowledgements

The authors acknowledge the full support of the South East Asia Carbonate Research Laboratory (SEACARL) at Geoscience Department, Universiti Teknologi PETRONAS (UTP) to complete this study. We acknowledge PETRONAS's Malaysian Petroleum Management for providing the data and allowing the publication of this work. We also are grateful to the following software companies for providing academic licenses: Eliis for providing PaleoScan™ and Baker Hughes for JewelSuite™.

References

[1] Elvebakk G, Hunt DW, Stemmerik L. From isolated build-ups to build up mosaics: 3D seismic sheds new light on upper Carboniferous–Permian fault controlled carbonate buildups, Norwegian Barents Sea. Sedimentary Geology, 2002; 152(1–2): 7-17.

[2] Warrlich G, Adams E, Ryba A, Tam T, Ting K, Tang H. What matters for flow and recovery in carbonate gas reservoirs: Insights from the mature Central Luconia Province, offshore Sarawak, Malaysia. AAPG Bulletin, 2019; 103(3): 691-721.

[3] Koša E. Sea-level changes, shoreline journeys, and the seismic stratigraphy of Central Luconia, Miocene-present, offshore Sarawak, NW Borneo. Marine and Petroleum Geology,2015; 59: 35-55.

[4] Epting M. The Miocene carbonate build-ups of central Luconia, offshore Sarawak. In A. W. Bally (Ed.), Atlas of seismic stratigraphy (pp. 168–173). AAPG 1989 (Tulsa). Studies in Geology.
[5] Ho KF. Stratigraphic framework for oil exploration in Sarawak. Geol. Soc. Malays. Bull., 1978; 10: 1e13.
[6] Epting M. Sedimentology of Miocene carbonate buildups, central Luconia, offshore Sarawak. Buletin Persatuan Geologi Malaysia, Bulletin Geological Society of Malaysia, 1980; 12: 17–30.
[7] Epting M. The Miocene carbonate buildups of central Luconia, offshore Sarawak. In A. W. Bally (Ed.), Atlas of seismic stratigraphy (pp. 168–173). AAPG 1989(Tulsa). Studies in Geology
[8] Doust, H. Geology and exploration history of offshore central Sarawak. In M. T. Halbouty (Ed.), Energy resources of the Pacific region (pp. 117–132). AAPG 1981, (Tulsa), Studies in Geology.
[9] Vahrenkamp VC, David F, Duijndam P, Newall M, and Cravello P. Growth architecture, faulting, and karstifcation of a Middle Miocene carbonate platform, Luconia Platform, offshore Sarawak, Malaysia, Chapter 15 in Eberli, G.P., Masafero, J.L., and Sarg, J.F.R., (eds.), Seismic imaging of carbonate reservoirs and systems, AAPG Memoir, 2004; 81: 329-350.
[10] Pauget F, Lacaze S, Valding T. A global approach in seismic interpretation based on cost function minimization. SEG Technical Program Expanded Abstracts 28(1):2592-2596, https://doi.org/10.1190/1.3255384.
[11] Pyrcz M, and Deutsch CV. Geostatistical Reservoir Modelling. Oxford University Press 2014, ISBN 13: 978-0199731442.
[12] Jimenez G, Pöppelreiter M, Rahmatsyah K. Non stationarity training images from modern carbonate analogues for MPS modelling in Central Luconia Province. National Geoscience Conference 2019. Kota Kinabalu.
[13] Jimenez G, Arshad B, Pöppelreiter M, Rahmatsyah K. Features extraction from carbonate modern platforms satellite imagery using Computer Vision. Petroleum and Coal, 2020; 62(3): 899-906.
[14] Burgess PM, Winefield P, Minzoni M, Elders C Methods for identification of isolated carbonate buildups from seismic reflection data. AAPG Bulletin, 2013; 97(7): 1071-1098.
[15] Yusliandi A, Sautter B, Poppelreiter M. The Various Controls on the Platform Architecture of Carbonate Build-ups in The Central Luconia Province, Offshore Sarawak. Petroleum and Coal, 2019; 61(6): 1425-1437.
[16] Chalabi A, Pierson B, Talib J. Remote Sensing Analysis of Recent Carbonate Platforms, East of Sabah: Potential Analogues for Miocene Carbonate Platforms of the South China Sea. Indonesian Journal of Geology, 2012; 7(3): 123-135.
[17] Riou J, Hocker C. Practical recommendations for Successful Application of the MPS Facies Modelling Method. Abu Dhabi International Petroleum Exhibition and Conference 2015. SPE-177675-MS.

To whom correspondence should be addressed: Dr. Grisel Jiménez Soto, South East Asia Carbonate Research Laboratory, Department of Geosciences, Universiti Teknologi PETRONAS, Malaysia,
E-mail: jimenezsotogrisel@gmail.com