BULLETIN

Corpus Christi
Geological Society

and

Coastal Bend
Geophysical Society

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2017-2018
www.ccgeo.org

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P.O. BOX 2741*C.C. TX. 78403
2017-2018

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Visit the geological web site at www.ccgeo.org

CCGS/CBGS JOINT MEETING SCHEDULE 2017-2018

September 2017							October 2017							November 2017						
S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S
					1	2	1	2	3	4	5	6	7				1	2	3	4
3	4	5	6	7	8	9	8	9	10	11	12	13	14	5	6	7	8	9	10	11
10	11	12	13	14	15	16	15	16	17	18	19	20	21	12	13	14	15	16	17	18
17	18	19	20	21	22	23	22	23	24	25	26	27	28	19	20	21	22	23	24	25
24	25	26	27	28	29	30	29	30	31					26	27	28	29	30		

Monday, Oct. 2, 2017 6:00 pm BBQ Kickoff at Hoegemeyers & Presentation by Carl Tape, Ph.D., Associate Professor of Geophysics, Geophysical Institute, University of Alaska Fairbanks "*Seismology in Alaska: Earthquakes, Bears, & High-Performance Computing.*"

Oct., 18, 2017 11:30am-1:00pm Speaker: David Mittlefehldt, PhD., Planetary scientists, Astromaterials Research & Exploration Science (ARES), Johnson Space Center, National Aeronautics & Space Administration (NASA) "Mars Exploration Rover Opportunity: Exploring the Rim of Endeavour Crater on Mars, Day-4,841+of a 90-Day Mission."

11:30 am – 1:00 pm
Speaker: Eugene L. Ames, Jr. "The History of Discovery: The Largest Oil Field in the World & Other Musing by a Geologist & Wildcatter."

December 2017							January 2018							February 2018						
S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S
					1	2		1	2	3	4	5	6					1	2	3
3	4	5	6	7	8	9	7	8	9	10	11	12	13	4	5	6	7	8	9	10
10	11	12	13	14	15	16	14	15	16	17	18	19	20	11	12	13	14	15	16	17
17	18	19	20	21	22	23	21	22	23	24	25	26	27	18	19	20	21	22	23	24
24	25	26	27	28	29	30	28	29	30	31				25	26	27	28			
31																				

Combined November/December for the Holidays.

11:30 am – 1:00 pm
Speaker: Lindsay Roe, Core Laboratories "South Texas Reservoir Geology Presentation," to be Determined

11:30 am – 1:00 pm
Speaker: Peter Wang, Geophysical Technical Advisor, Paradigm "A New Technique of Lithology and Fluid Content Prediction from Prestack Data: An Application to a Carbonate Reservoir"

CCGS/CBGS Joint Meeting Schedule 2017-2018

March 2018							April 2018							May 2018						
S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S
				1	2	3	1	2	3	4	5	6	7			1	2	3	4	5
4	5	6	7	8	9	10	8	9	10	11	12	13	14	6	7	8	9	10	11	12
11	12	13	14	15	16	17	15	16	17	18	19	20	21	13	14	15	16	17	18	19
18	19	20	21	22	23	24	22	23	24	25	26	27	28	20	21	22	23	24	25	26
25	26	27	28	29	30	31	29	30						27	28	29	30	31		

11:30 am – 1:00 pm
Speaker: Collegiate Month! Presentations from students & faculty from our local colleges regarding their Geological and Geophysical Research & Educational Programs

11:30 am – 1:00 pm
Speaker: Phillipe Tissot, Ph.D., Department of Physical & Environmental Sciences, TAMUCC "Coastal Processes Presentation," to be determined

11:30 am-1:00 pm
Speaker: To be determined

Calendar of Meetings and Events

Calendar of Area Monthly Meetings

Corpus Christi Geological/Geophysical Society.......... Third Wed.—11:30a.m.
SIPES Corpus Christi Luncheons.......... Last Tues.—11:30a.m.
South Texas Geological Society Luncheons.......... Second Wed—noon San Antonio
San Antonio Geophysical Society Meetings.......... Fourth Tuesday
Austin Geological Society.......... First Monday
Austin Chapter of SIPES.......... First Thursday
Houston Geological Society Luncheons.......... Last Wednesday
Central Texas Section of Society of Mining, Metalllurgy & Exp.......... 2nd Tues every other month in San Antonio

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CCGS Monthly Letter - April 2018

Some time ago I was inspired by a colleague who took to liberally writing her thoughts in an artful way after major events or travels in her life. Vicki taught me that articulation can "seal" a recollection or thought – and the process may serve a practical documentation, expression of gratification, and as entertainment. Hopefully this message does all three.

In 2018, I am personally amazed by our Geological Society members and leadership. We, like our sister societies across the Gulf Coast, are experiencing the great shift change in the petroleum industry. Yes, membership is declining and our budgets are getting tighter. However, there continues in the Society a substantial remnant of optimistic and good-hearted friends who find fulfilment in participation and inclusion. Likewise, there are many inspiring young professionals and students in our community who are eager to improve and grow as geoscientists.

Young people are looking to us for professional guidance and insights to navigate their career path. We still have a lot to do.

About our Leaders - Our Society benefits from great leadership today. Foremost is President Austin Nye. Austin's no nonsense approach to helping lay a practical path for the CCGS has been helpful finding our way in the post-GCAGS Convention period. Our Vice-President, BJ Thompson, brings energy and vitality to our luncheon and special events. Casey Mibb, Treasurer, is accessible and responsive on financial issues, and like Austin, she is pragmatic in her solutions. Barbara Beynon has served the Board well as our past President. Rounding out the board are our fine Counselors, Rick Paige and Brent Hopkins - the sages of Suemaur. Looking at next year, our President-Elect, Frank Cornish, will be a great leader for our Society. *And me?* Well, I just take notes and mutter absurdities (and sometimes obscenities).

There are other leaders that I have to mention. Those who make the Society run each month – the big events and the little things, continually helping. Marian & Sebastian Wiedmann, Dorothy Jordan, Wes Gisler, Leighton Devine, Dawn Bissell, Will Graham, Robbie Sterett, Juan Cabasos, Fermin Munoz, Lonnie Blake, Tom Mcgehee, Erin Matthys, and Dennis Moore. Yes, there are many more of you, too, who I might have missed in this listing…and I want to include you who attend luncheons, participate in committees, and do the fun stuff.

Each year it seems like we have to decide to keep on going on as a Society. It feels this way because of the reluctance of many members to step forward into leadership positions. I get it. Why, at this point in my life, would I want to take on a responsibility (like a Board or Committee Position) when I should be relaxing and taking it easy? Haven't I done enough?

My answer is simply, no, you haven't done enough. Because there is not enough to be done!

I was recently asked by a friend if *I* was bored. His question originated after I shared that I was doing some research into the nature of geology and wine, and preparing a presentation on the relationship between minerology and minerality. He was seeking my reasoning for taking on yet another responsibility in addition to work, teaching, parenting, clubs, etc. He actually said, "Are you bored?"

No, silly – I am alive. And I intend to be alive until I am not - Because a good life is defined by what you give, not what you acquire.

So, I don't know why my fellow ripe-aged members think they are excused from serving on our Board or on committees. The good news today is that we have solved most every pressing issue of our Society and are well-positioned to enter 2018-19 with a good program, a better venue, and a balanced budget.

The only thing we need is you! Please help by expressing your willingness to be on the Board, serve in a position, or be on our Scholarship Committee!!!

There is so much great about the CCGS! The new venue at Water Street makes our meetings more accessible and convenient. We have speakers wanting to come to Corpus Christi to present to our Society. We have wonderfully fun events planned for this season and next, like the Golf Tournament on April 13 and the Pub Crawl on April 14.

Please think about your role in the Society – today and tomorrow.

We are counting on you.

Randy Bissell, CCGS Secretary & Membership Czar

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CBGS President's Letter

CBGS Scholarships

The board awarded two scholarships of $2,000 each to undergraduate geophysics majors from Texas A&M University-College Station, and University of Houston. Another scholarship of similar value will be given to geophysics major from Texas A&M University-Kingsville in Spring 2018.

The following criteria is followed in awarding the scholarships.

1. Must be a citizen of the USA
2. Must have declared Major Geophysics at the main campus of the receiving university
3. Must have GPA 3.0
4. Must be in good standing with the school
5. Must make effort to attend a Coastal Bend Geophysical Society Meeting in Corpus Christi Texas after being awarded a scholarship to be recognized by the society.

Dr. Subbarao Yelisetti- President
Lonnie Blake- Vice President
Matt Hammer- Secretary/ Treasurer
Dr. Robert Schneider- Continuing Education
Lonnie Blake- Golf Chair
Ed Egger- Scholarship Chair

News

- Oil climbed to the highest level in six weeks after crude inventories dropped for the first time in a month as reported by Jessica Summers on rigzone.com.
- At the time of writing this report, U.S. crude futures have averaged over $50.85 a barrel in 2017, as opposed to an average of $43.47 a barrel in 2016. This is expected to rise to $57 and $54 a barrel in 2018 and 2019, respectively as reported by Scott DiSavino on reuters.com.
- According to the U.S. Energy Information Administration projections in February, U.S. production would rise to a record high annual average of 10.6 million barrels per day (bpd) in 2018 and 11.2 million bpd in 2019, up from 9.3 million bpd in 2017.

- There were 975 oil and natural gas rigs active on Feb. 9. On average, there were 876 rigs available for service in 2017, 509 in 2016 and 978 in 2015 as reported by Scott DiSavino on reuters.com.

CBGS Business

CBGS currently has 56 members.

CBGS workshop

CBGS will be offering a Geophysics workshop on April 20th in EOG conference center.

When: 11:00 am – 4:00 pm, April 20th

Where: EOG 3RD Floor Conference Room, 539 N. Caranchua, Corpus Christi, Texas

Cost: Free for CBGS Members/students, $25 to join CBGS membership for non CBGS members.

Lunch provided by HIS

Talks:

1. **IHS – What's new/coming in the Kingdom Software Suite**
2. **Tad Smith – SEG Distinguished Lecturer: Seismic Petrophysics**
3. **CGG/Hampson Russell: Reservoir Property Prediction with Seismic**

Contact Lonnie Blake Lonnie_Blake@eogresources.com for additional information.

CBGS is looking forward to offer many such workshops in the future. Topic/speaker suggestions are welcome. Email your suggestions to Subbarao.Yelisetti@tamuk.edu or Lonnie_Blake@eogresources.com

Golf Tournament

CBGS organized its annual **Golf Tournament** to fund its scholarship program on October 6, 2017 at Northshore Country Club.
20 Players, 10 sponsors, 7 contributing cash, 3 contributing golf balls, coolers, etc…..

Raised $1951 for the scholarship fund.

2018 Golf tournament will be in the first week of October. If you are interested in the Golf Tournament, please contact Lonnie Blake at 361-887-2665 or Lonnie_Blake@eogresources.com

New Degree Tracks at TAMUK

- TAMUK is currently accepting applications for **MS Petrophysics** program for Fall 2018.
- **BS degree in Geophysics, Minor in Geophysics and Certification in Geophysics** offered at Texas A&M University-Kingsville from Fall 2017.

Please contact Dr. Subbarao Yelisetti (Subbarao.Yelisetti@tamuk.edu) or Dr. Robert Schneider (Robert.Schneider@tamuk.edu) for additional information.

SEG Distinguished Lecture
CBGS and TAMUK SEG student chapter organized 2018 SEG Distinguished Lecture in January, 2018. We wish to organize many more lectures in the future.

Education/Events

-SEG

SEG annual meeting will be held in Anaheim, CA from Oct 14th-19th, 2018. Abstract due date is April 1st, 5 pm CDT. See https://seg.org/Annual-Meeting-2018 for additional details.

See https://seg.org/Education/Lectures/Distinguished-Lectures for information about upcoming SEG distinguished lecture in Houston and other locations.

See https://seg.org/Education/Lectures/Honorary-Lectures for SEG honorary lecture locations in Texas.

-GSH

SEG and GSH jointly organizing a live webinar on "**Introduction to Applied Depth Imaging**" by **Dr. Ruben Martinez**. It is scheduled from **10 am-2 pm, March 26-29th, 2018** (four half-days). It covers the basic concepts and practical aspects used in depth velocity model building and depth imaging. See below link for additional information.

https://www.gshtx.org/SharedContent/Events/Event_Display.aspx?EventKey=011cd5de-1f54-4c39-826d-876185a5ea4a&WebsiteKey=955f17e6-46ad-4401-acbd-2af6c393752b

Webinar Pricing	Per Person
Individual Registration	$390
Company/Group 2-10	$325
Company/Group 11+	$295
Individual Student	$100
Student Group	$60

-AGU

2018 Fall AGU annual meeting will be held in Washington, DC from December 10th-14th, 2018.
https://fallmeeting.agu.org/2018/

Monthly Saying

"You have to continually press yourself to convert information into action" **-** John Masters

Monthly Summary

Texas Oil and Gas Info	Current Month	Last Month	Difference	
Texas Production	**MMBO/BCF**	**MMBO/BCF**	**MMBO/BCF**	
Oil	93.6	98.1	-4.5	November
Condensate	9.6	10.5	-0.9	November
Gas	613.7	644.2	-30.5	November
	Current Month	**Yr to date - 2018**	**Yr to date - 2017**	
Texas Drilling Permits	1097	2263	1947	February
Oil wells	284	527	517	February
Gas wells	87	165	104	February
Oil and Gas wells	647	1431	1247	February
Other	11	15	16	February
Total Completions	882	1845	1213	February
Oil Completions	672	1411	951	February
Gas Completions	149	328	179	February
New Field Discoveries	2	3	6	February
Other	5	6	3	February

Subbarao Yelisetti—CBGS President
President, CBGS

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CORPUS CHRISTI GEOLOGICAL SOCIETY
COASTAL BEND GEOPHYSICAL SOCIETY

LUNCHEON MEETING ANNOUNCEMENT

APRIL 18, 2018

Location: Water Street Events (Previously the Seafood Company Restaurant), 300 Block N. Water Street, CC, TX 78401

Student Sponsor: Imagine Resources, Nye Exploration, Viper Exploration, Ltd.

Bar Sponsor: ***SPONSORSHIP OPPORTUNITIES AVAILABLE!!!***

Time: 11:30 am Bar, Lunch follows at 11:45 am, Speaker at 12:00 pm

Cost: $25.00 (additional $10.00 surcharge without reservation; No-shows may be billed and non-RSVP attendees cannot be guaranteed a lunch); ***FREE*** for students with reservation (discounted by our generous sponsors)!

Reservations: Please **RSVP** by **4PM** on the **FRIDAY** before the meeting!
E-Mail: *arrangements@ccgeo.org*

Please note that luncheon RSVPs are a commitment to the Ortiz Center and must be paid even if you can't attend the luncheon.

SPONSORSHIPS OPPORTUNITIES ARE AVAILABLE!
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arrangements@ccgeo.org

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VIPER EXPLORATION, LTD.

Real Impacts of Sea Level and Subsidence along the Texas Coast

A discussion regarding general sea level rise, followed up with the importance, the spatial variability, and likely causes of subsidence along shorelines of the Coastal Bend and the resulting impact on future nuisance floods.

Presented by:

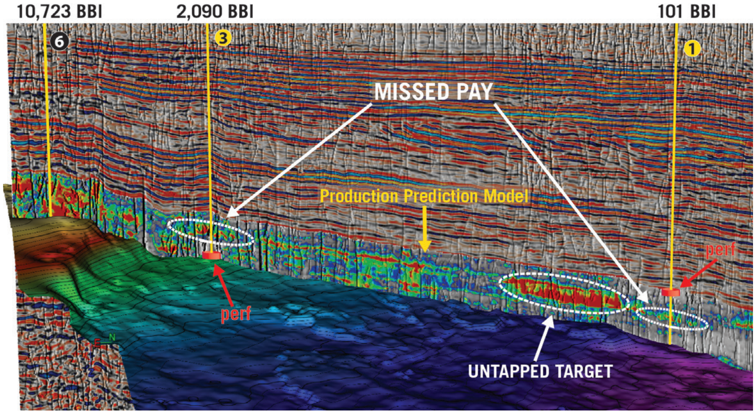
Phillipe Tissot, Ph.D.

About our Presenter:

Dr. Phillipe Tissot is the former Associate Professor of Physics at Texas A&M University, Corpus Christi, He studied at Texas A&M receiving his Ph.D. in Nuclear Engineering, as well as École Polytechnique Fédérale de Lausanne (EPFL), in Lausanne, Switzerland, receiving a Diploma in Physics Engineering.

Dr. Tissot is the Associate Director of the Conrad Blucher Institute, and an Associate Research Professor at Texas A&M University, Corpus Christi, studying and developing coastal physics models often based on artificial intelligence and hydrologic models. He is the Chair of the American Meteorological Society Committee on Artificial Intelligence Applications to Environmental Sciences.

SEISMIC-BASED ANALYTICS



An arbitrary line through 3 vertical wells in the West Texas Permian Basin shows the lateral variations of the Production Prediction Model and reveals refrac potential for Wells 1 and 3 where the red disks indicate the actual completion intervals and the white circles highlight the missed pay. Note the untapped target near Well 1.

FIND WHAT YOU'VE BEEN MISSING

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Contact ANALYTICS@globalgeophysical.com

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- High-grade prospective drilling areas and zones
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- Boost EUR of individual wells
- Identify candidates for refrac

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GEOPHYSICS WORKSHOP – SEISMIC HAPPY HOUR

When: 11:00 – 4:00 April 20, 2018

Where: EOG 3rd Floor Conference Room, 539 N. Caranchua, C.C., TX.

Cost: Free for CBGS Members/students, $20 to join CBGS
Membership Dues for non CBGS members

Lunch provided by IHS

IHS – What's new/coming in the Kingdom Software Suite

Tad Smith – SEG Distinguished Lecturer: Seismic Petrophysics

CGG/Hampson Russell: Brian Russell: Reservoir Property Prediction with Seismic Happy Hour???

Please contact Lonnie Blake or Robert Schneider to register

CORPUS CHRISTI GEOLOGICAL SOCIETY

1ST Annual Spring Golf Tournament

NorthShore Country Club

April 13, 2018

12:30 p.m. Shotgun Start

Four-Person Scramble

100 Player Limit * Sign up Early

Contact: Fermin Munoz, fmunoz04@hotmail.com, 361-960-1126

Name ________________________________

Email ________________________________

Company Name ______________________

Address ______________________________

City, State, Zip ________________________

Phone _______________________________

_____ Yes, Please Place on a Team

_____ I want to be on a Team with: (list below)

Player 2: ____________________________

Player 3: ____________________________

Player 4: ____________________________

____________ $100 per Golfer

____________ $400 per Team (4 players)

____________ Sponsorship Total

____________ **TOTAL AMOUNT DUE**

PAYMENT INFORMATION

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Make Checks payable to:

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CCGS Golf Tournament

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#____ Hole Sponsor $200 ea. _______

#____ Longest Drive $100 ea. _______

____ Closest to Pin $100 ea. _______

Door Prize Sponsor $ _________

General Sponsor $ _________

Total Sponsorship $ ___________

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Portland, TX 78374

Entry Fee Includes:

- Green Fees
- Range Balls
- Carts
- Beverages on the Golf Course (limited)
- Door Prizes
- Dinner

CORPUS CHRISTI GEOLOGICAL SOCIETY

BREWERY CRAWL

SATURDAY – APRIL 14, 2018

SCHEDULE

1:30 PM TO 2:00 PM – Meet at Railroad Seafood Station & Brewing Company, 1214 N. Chaparral, CC, TX 78401

2:00 pm – Depart for Lorelei Brewing Co.

2:15 pm to 3:15 pm – at Lorelei Brewing Co.

3:15 pm– Depart for Lazy Beach Brewing

3:30 to 4:30 pm – at Lazy Beach Brewing

4:30 pm – Depart for B&J's Pizza & Brewpub

4:45 to 5:45 pm – at B&J's Pizza & Brewpub

5:45 pm – Depart for Rebel Toad Brewing Co.

6:00 to 7:00 pm – at Rebel Toad Brewing Co.

7:15 pm – Return to Railroad Seafood Station & Brewing Co.

$60.00 per person to include transportation and at least one (1) pint at each venue

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NAMES: ______________________________

____

____

TELEPHONE: ______________________________

$______________TOTAL ______________ **CHECK # (Payable to CCGS)**

Please send completed form and payment by APRIL 7, 2018!!!
(check payable to CCGS) to:
CCGS BREWERY CRAWL 2018 – P.O. BOX 1068 – CORPUS CHRISTI, TX 78403

Seismic Facies Prediction and Modeling

A Paradigm Geoscience Data Service

Rock facies define the internal architecture of the reservoir. The ability to accurately predict and model the distribution of facies in the reservoir results in a better understanding of reservoir quality and behavior. An accurate facies model will be a good predictor of in-place volumes and fluid flow. Facies determination is substantially improved with the use of both seismic and well bore predictive methods. The calibration of the two can be used to construct 3D proportional facies volumes to guide the stochastic simulation of facies models.

Paradigm facies prediction and modeling services make use of both electrofacies and seismic facies classification procedures to determine the distribution of facies. Both procedures are designed to eliminate or mitigate user bias, allowing the data to drive the facies description. For electrofacies classification, multi-resolution graph-based clustering offers a solution which determines the optimal number of clusters at different resolutions and allows the geoscientist to control the final level of detail to more accurately represent the facies.

Seismic facies classification methods seek to establish a relationship between the rock facies and natural cluster structures in the seismic data. The natural clusters can be determined from an analysis of the waveform shape. Paradigm seismic facies classification solutions include a wealth of schemes adaptable to different depositional and stratigraphic settings. These solutions include supervised and unsupervised classifications of waveform shape, attribute intervals, and attribute maps using artificial neural networks (Self-Organizing Maps). Multi-attribute schemes are also available using partitional or hierarchical schemes.

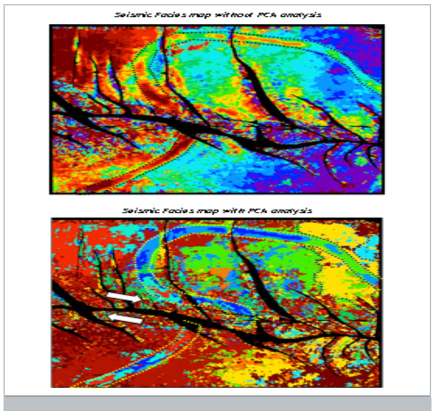
Paradigm facies modeling solutions incorporate the electrofacies and seismic facies predictions into a modeling (chronostratigraphic) framework with optimized grid support for facies modeling. Multiple facies modeling methods (e.g. deterministic modeling, sequential indicator simulation, truncated Gaussian simulation, multi-point simulation, object modeling) combined with trend analysis (1D, 2D, 3D), honor geological and seismic constraints and ensure that the conceptual model is honored.

Paradigm Facies Prediction and Modeling Solutions

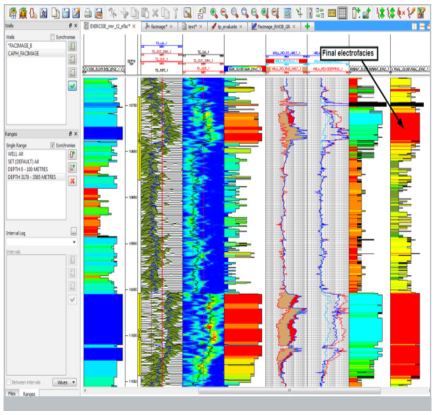
- A multi-resolution graph-based electrofacies clustering method that determines the optimal number of clusters at different resolutions and allows the geologist to control the final level of detail in the classification
- Supervised and unsupervised seismic facies classifications based on the Self-Organizing Map Neural Network method, for a more geologically sound classification
- Waveform shape classifications, map and interval attribute classifications, and multi-attribute classifications adaptable to many different depositional and stratigraphic environments
- Chronostratigraphic facies modeling solution with optimal geologic grid support for facies models (preservation of distances and volumes)
- Facies data analysis solutions, including data preparation (e.g. data blocking, smoothing of distributions), trend analysis, seismic-to-well facies classifications, and the creation/ combination of multiple facies proportion volumes
- Broad set of facies modeling solutions, including multipoint simulations, truncated Gaussian simulations, etc. with trends

Paradigm Facies Prediction and Modeling Advantages

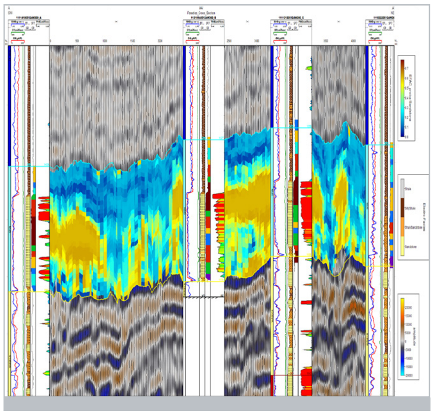
The Paradigm Geoscience Data Services team combines wellbore and seismic facies prediction methods with the most advanced facies modeling solution, enabling oil and gas operators to better understand the reservoir architecture, quality, and behavior.



▲ Seismic facies classifications (with and without Principal Component Analysis)



▲ Electrofacies classification for field wide delineation of facies



▲ Facies probability volume

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A new technique for lithology and fluid content prediction from prestack data: An application to a carbonate reservoir

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Abstract

One of the leading challenges in hydrocarbon recovery is predicting rock types/fluid content distribution throughout the reservoir away from the boreholes because rock property determination is a major source of uncertainty in reservoir modeling studies. Spatial determination of the lateral and vertical heterogeneities has a direct impact on a reservoir model because it will affect the property distributions. An inappropriate determination of the facies distribution will lead to unrealistic reservoir behavior. Because these data can take different forms (lithologs, cuttings, and for seismic, poststack, and prestack attributes) and have different resolutions, the manual integration of all the information can be tedious and is sometimes impractical. We developed a new neural network-based methodology called *democratic neural network association* (DNNA). The DNNA method was trained using lithology logs from wells simultaneously with prestack seismic data. This technique, using a probabilistic approach, aims to find patterns in seismic that will predict lithology distribution and uncertainty.

Introduction

The economic viability of a field is dependent on the quality and accuracy of lithology distribution prediction, as well as by the heterogeneity of a potential reservoir. These components are the keys to successful hydrocarbon exploration and production. The rise in unconventional resource prospecting and the increasing complexity of conventional plays have made accurate lithology prediction even more critical. All relevant data must be used optimally to determine lithology at the prospect scale with the highest degree of resolution, resulting in the most geologically meaningful lithology distribution. Risk increases with complexity, however, and the probability of success and the integration of uncertainty into the nature and distribution of lithology must be taken into account in any approach that tries to predict lithology.

Conventional approaches are mainly based on 2D or 3D analyses of inverted data to describe the elastic properties of the reservoir. However, precise lithology description in such attribute spaces often overlaps. This makes it difficult to clearly differentiate, for example, intermediate-type facies such as thin interbedded layers. The result is nonunique and highly sensitive to facies interpretation. It, therefore, becomes critical to estimate reservoir connectivity, as some lower quality or intermediate-type facies could improve understanding of the reservoir's development.

Democratic neural network association (DNNA) is a new methodology to be considered alongside acoustic, elastic, and stochastic inversion methods. It allows for the generation of lithology probabilities from a combination of quantitative rock typing analysis at wells and seismic data at the well location (Hami-Eddine et al., 2009). The validity of the method has been demonstrated through the direct use of angle gathers (representing the seismic data) combined with well facies analysis, to predict the lithology and fluid content.

This methodology will be applied to a carbonate reef data set, in which conventional attributes and inversion have shown limitations when describing reservoir heterogeneities.

Methodology for predicting lithology from well data and seismic

Well data analysis and facies definition

Well log information is the main source of information for lithology and fluid content. Therefore, a key step in lithology and fluid prediction is precise and careful analysis of the well data. DNNA is designed to use lithology logs or facies determined using petrophysical properties calibrated to cores.

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Combining rock typing and multiresolution graph-based clustering (MRGC) (Ye and Rabiller, 2000) brings two different aspects to lithology prediction using log data. The first approach is mainly based on crossplot analysis, in a multi-2D manner. The simplicity of the tools used for rock typing makes facies estimation quality control understandable and easily reproducible. However, plot analysis is limited, in that it cannot catch subtle variations that MRGC electrofacies will identify in a multilog analysis study. DNNA input facies logs are determined through the calibration of rock-typing lithology and fluid estimation with electrofacies (Figure 1).

Seismic data as a propagation guide for lithology prediction

Well analysis is considered to be reliable information when describing the reservoir; however, well data are generally too sparse of a data set to adequately describe a prospect. Attributes derived from prestack seismic data analysis (e.g., amplitude variation with offset [AVO] inversion or inversion results) are typically used to predict the lithology of reservoirs and their fluid content, but separation of facies is hard to define clearly on 2D log crossplotting (Figure 2). Alternatively, raw data such as gathers bring a huge quantity of highly valuable, but often subtle, information, which is difficult to handle without making approximations.

A neural network application through the use of DNNA offers the possibility of inferring facies defined at wells using prestack seismic data. The probabilistic approach of DNNA combines all seismic-related information to build facies probability cubes.

Neural network predictive aptitudes and evaluation of probabilities

The prediction of lithology at the prospect scale is strongly limited because the inversion workflow is a seismic data-driven process that provides few attributes derived from impedance contrasts, and spatial lithology separation becomes a challenge if performed with a limited number of attributes. The goal of using a methodology based on neural network techniques is to enable the addition of more inputs and eventually use the complete information contained in a full set of seismic gath-

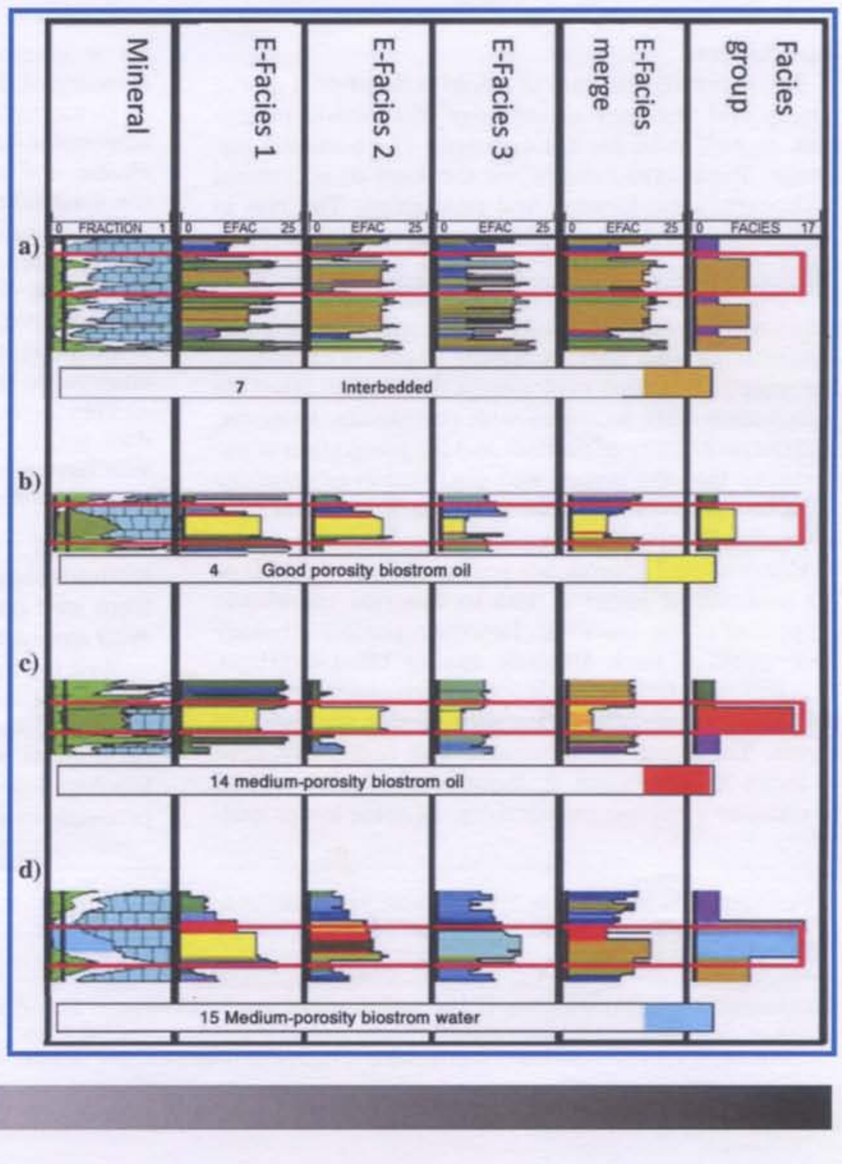

Figure 1. Carboniferous interval facies description at the well bore are defined through the combination of rock typing and electrofacies analyses. (a) Interbedded facies, (b) good-porosity biostrom (oil), (c) medium-porosity biostrom (oil), and (d) medium-porosity biostrom (water). Each facies group shows a different type of log response.

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ers. The DNNA method allows a better separation of lithology and facies because the input set of data provides more detailed information. Moreover, this probabilistic approach will quantify the uncertainty in the prediction.

The training data set for the DNNA is constructed by selecting seismic data and facies interpreted at wells. The $\mathbf{x}_w$ is defined by a d-dimensional vector $\mathbf{x}$ and a weight w being high for hard data and low for soft data. Hard data are considered to be highly reliable information and contribute with a large weight to neural network trainings. In the DNNA case, hard data are a combination of prestack amplitudes and facies information extracted at wells. Soft data provide information on the seismic prestack amplitude values but provide no information about the nature of the facies. They are, therefore, used with lower weights during DNNA training phases.

This weight qualifies the degree of reliability of training data. Each dimension corresponds to seismic data (such as angle gathers) characterizing the sample. Initially, training samples are built from seismic attribute values extracted along well trajectories, and a lithological facies index is used as a class indicator. A training sample is a pair of $(\mathbf{x}_w, c)$, where $\mathbf{x}_w$ is the vector of attributes, and c is the index of the lithological facies at a given well position. A training set is an ensemble of training samples.

Associative neural networks

Many limitations are clearly identified for discrete prediction using seismic data. Lithological information, interpreted and gathered at wells, is not linearly correlated with seismic data. Facies are not ordered, and there is no notion of mathematical separation between them. Each neural network is designed to learn in a specific way. Using only one supervised neural network tends to bias the results of the training (Tetko, 2002a). A network is built to reach one objective, which is usually to approximate data or class densities (Kohonen, 2001). The problem of "well-to-seismic" data classification renders this one-goal approach unsatisfying because classes often overlap with one another. The use of several networks running simultaneously as an associative combination is preferred (Tetko, 2002b).

With regard to the data, different approaches can be considered to simultaneously train several neural networks. Usually, multiple-view learning methods are used (Gao et al., 2010). By definition, this approach requires multiple independent sets of attributes. The application of this kind of approach to facies prediction is not optimal in a reservoir characterization sense because seismic data are interdependent, as in the case of near- and far-angle partial stacks, for example.

The second approach is to simultaneously run different neural networks to be trained with the same hard data set (Zhou and Goldman, 2004). This single-view colearning approach provides the ability to handle the training of associative neural networks (ASNNs) with a unique set of seismic data attributes that are not necessarily independent, paired with the well information. This is the approach we prefer.

Defining an ensemble of networks with different learning strategies helps to compensate for the existing bias when using only one network. The ASNN explicitly corrects the bias of the neural network ensemble and leads to an improved prediction ability (Gao et al., 2010). This has been demonstrated (Hami-Eddine et al., 2011) in the case of lithological facies prediction based on prestack amplitudes.

Democratic learning concepts

The multistrategy learning ASNN performance is limited by the number of hard data samples in the training set. If the volume of data is too small, it is probable that the training set is too limited in terms of diversity as compared to the population to qualify. The risk of overlearning is significant in that case, and the predictive properties of the networks are seriously reduced and unreliable.

The combination of hard and soft data in the learning phase (Figure 3) improves the training data set (Guillaumin et al., 2010). In the case study developed further in this paper, hard data $X.(\mathbf{x}_w, c)$ comprise prestack amplitude values and a facies index c, whereas soft data are limited to $(\mathbf{x}_w, ?)$. Soft data provide information

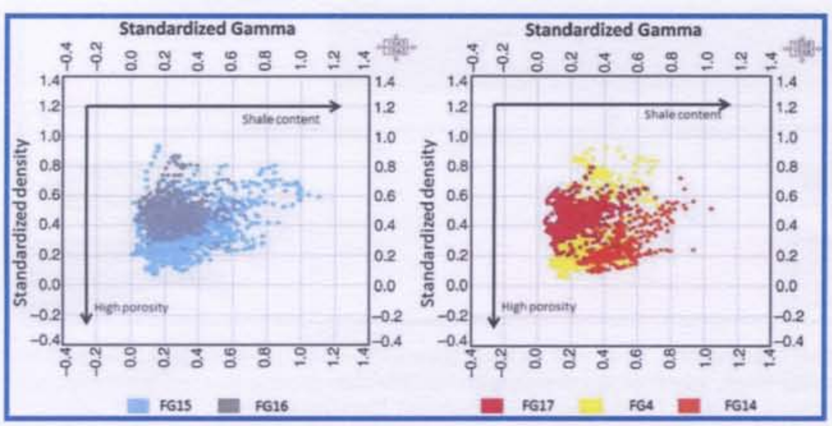

Figure 2. Multiwell crossplots of standardized gamma and density logs with facies group color coding (Table 1). Two-dimensional facies analysis shows interesting grouping; however, clear limits between identified facies groups are hard to identify.

on seismic prestack amplitude values, but they give no information about the nature of the facies.

We can summarize the training steps of the democratic ASNN as follows:

- Define a number p of neural networks.
- Apply learning over the p neural networks with each training set and examine the training quality by analyzing misclassification rates at well locations.
- Enrich training set: Apply a democratic vote system over a user-defined set of soft data and add the ones that pass the majority vote test as training data, with a lower weight than hard data.
- Apply learning over p neural networks using the expanded training set now containing hard and soft data.

Validation of network prediction by bootstrapping

Cross validation is a well-known technique that measures prediction quality (Hastie et al., 2009). This method was used in the project, but experiments resulted in the use of the bootstrapping method. This method is more robust and less time-consuming for large data sets (Efron and Gong, 1983). The learning process can be halted, for example, by setting a maximum bootstrap error or a few iterations. The performance of democratic ASNNs has to be measured to avoid erroneous prediction capabilities as well as the overlearning phenomenon.

The bootstrap error is computed by taking the ".632+" estimator (Hastie et al., 2009):

$$\widehat{\mathrm{Err}}^{(.632+)} = (1-\hat{\omega})\overline{\mathrm{err}} + \hat{\omega}\widehat{\mathrm{Err}}^{(1)} \quad (1)$$

where

- $\overline{\mathrm{err}}$ is the misclassification rate
- $\hat{\omega}$ is a weighting factor: $\hat{\omega} = .632/(1-0.368\hat{R})$
- $\hat{R}$ is the relative overfitting error: $\hat{R} = (\widehat{\mathrm{Err}}^{(1)} - \overline{\mathrm{err}})/(\hat{\gamma} - \overline{\mathrm{err}})$
- $\hat{\gamma}$ is the no-information rate:

$$\hat{\gamma} = \sum_{i=1}^{C} \hat{p}_i(1-\hat{q}_i), \quad (2)$$

with $\hat{p}_i$ being the observed proportion of responses, $\mathbf{y}_j$ equaling i, $\hat{q}_i$ is the observed propor-

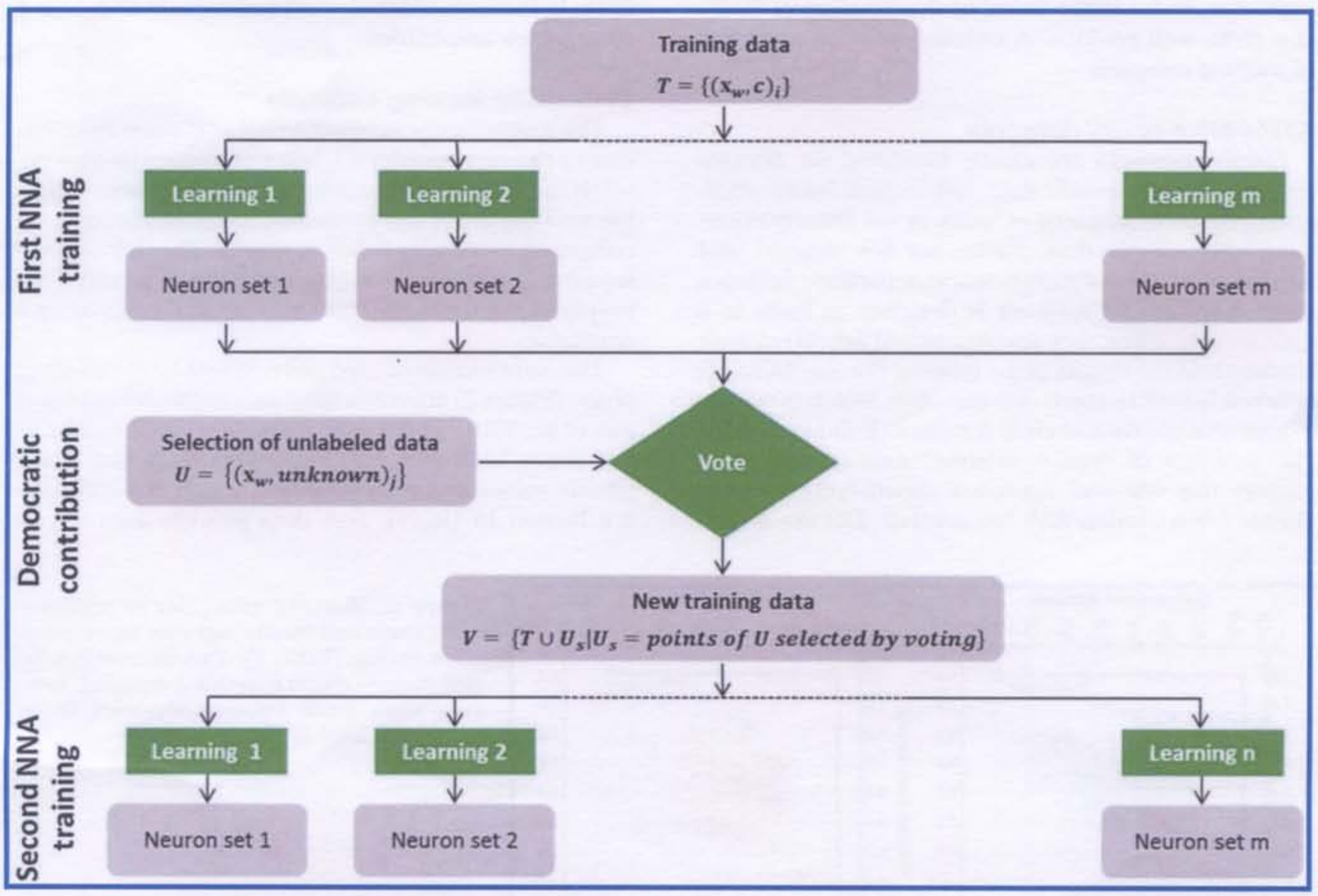

Figure 3. Description of DNNA training steps: Initial training data, from well facies groups and seismic prestack data, are used as hard training samples for the first supervised learning stage, whereas the democratic contribution (voting system) involves only soft data (seismic prestack) to enrich the final training data set for the second supervised learning stage.

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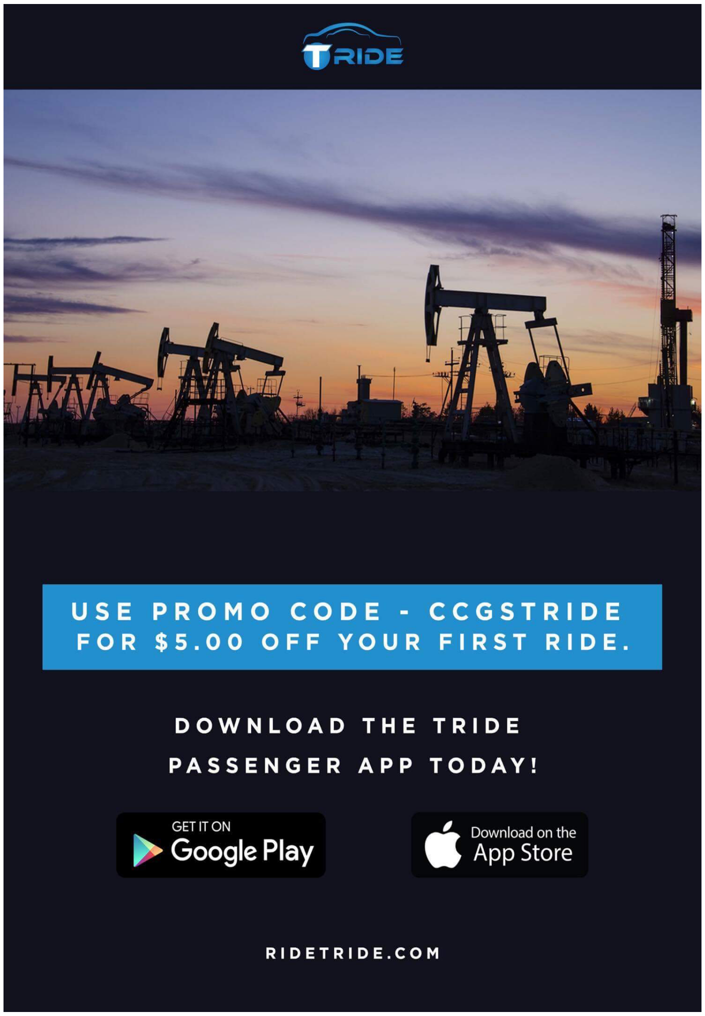
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tion of predictions $\widehat{f^l}(\mathbf{x}_i)$ equaling i, and C is the number of classes.

The value $\widehat{\mathbf{Err}}^{(1)}$ is the bootstrap error in which only predictions from bootstrap samples that do not contain the $\mathbf{x_i}$ observation are kept (Figure 4) as

$$\widehat{\mathbf{Err}}^{(1)} = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{|\mathbf{C_{-i}}|}\sum_{j\in \mathbf{C_{-i}}} 1-\delta_{\mathbf{y_i}\widehat{\mathbf{f^l}}(\mathbf{x_i})} \quad (1)$$

Here, $\mathbf{C_{-i}}$ is the set of indices of bootstrap samples that do not contain observation $\mathbf{i}$ and $|\mathbf{C_{-i}}|$ is the number of such samples. Terms for which $|\mathbf{C_{-i}}| = \mathbf{0}$ are left out; $\mathbf{f^l}(\mathbf{x_i})$ is the class prediction made by the network trained with the lth bootstrap set; and $\mathbf{y}_i$ is the expected answer. The bootstrap error $\widehat{\mathbf{Err}}^{(.632+)}$ gives a robust estimation of the prediction error committed using DNNA. Our experiments have led us to adopt heuristics: A value of less than 0.3 means that the prediction quality is satisfying.

Propagation of network properties using a weighted k-nearest neighbor algorithm

When the DNNA learning has reached a satisfying bootstrap error value, we then predict facies values for the full amount of unlabeled data. The extrapolation of the network properties is based on a Bayesian approach using the a priori defined by the DNNA. The inference of classes performed by the DNNA is used to compute an a posteriori probability based on an a priori defined by the network.

The weighted k-nearest neighbors (WKNN) algorithm is a local version of the probabilistic neural network (PNN) (Specht, 1990), which computes a posteriori probabilities of class labels.

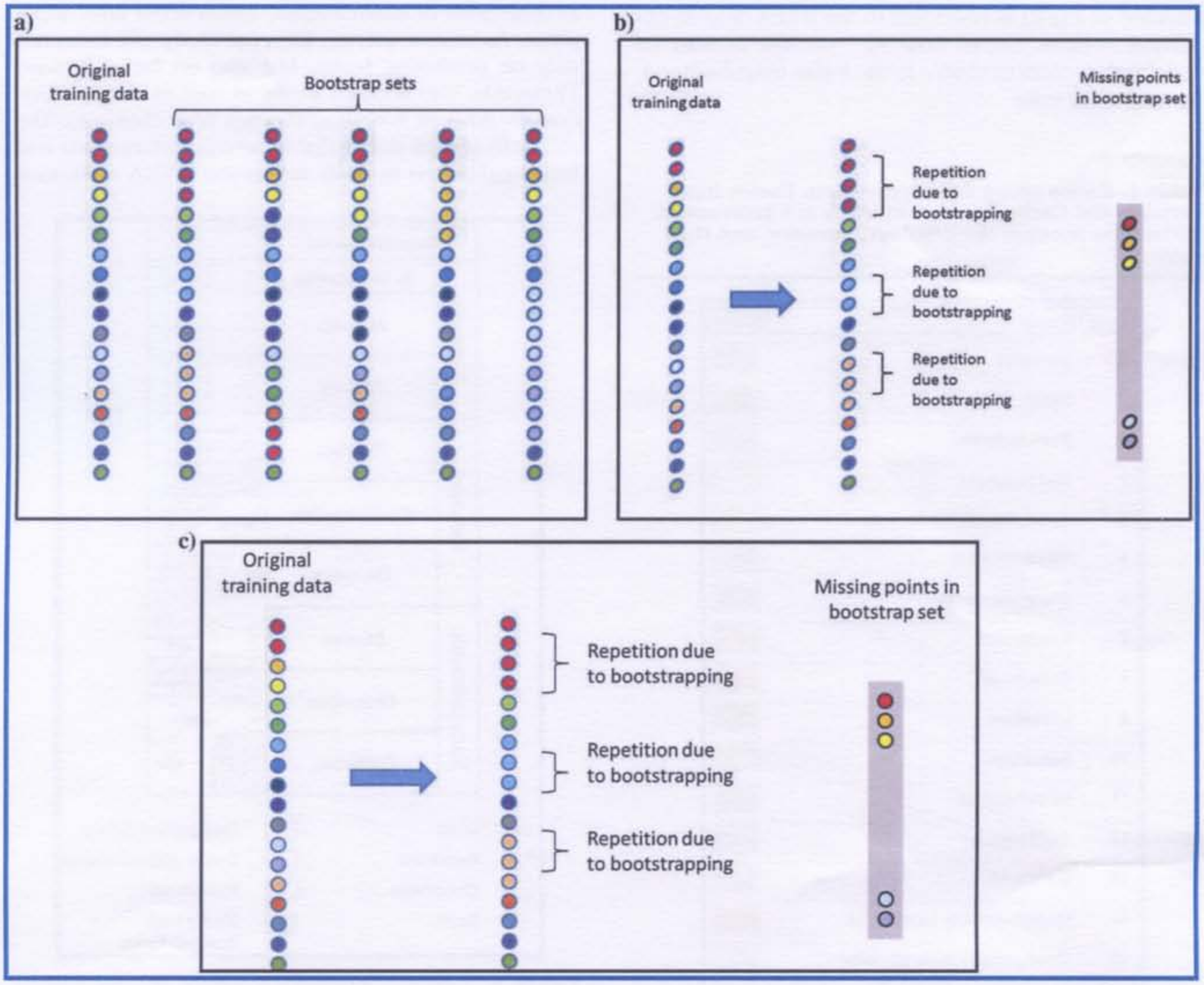

Figure 4. (a) Bootstrap set contains the same number of data as the original set. Consequently, some repetitions are observed as well as some missing data. (b) Each bootstrap set is used to train one DNNA entity. (c) Points missing in a bootstrap set because of repetition of other points. Missing points are used to validate predictive DNNA aptitudes.

According to the Bayes formula, we can define the a posteriori probability that y belongs to class c by

$$P(c|\mathbf{y}) = \frac{P(\mathbf{y}|c)P(c)}{\sum_{c=1}^{C} P((\mathbf{y}|c)P(c)} \quad (4)$$

The PNN makes the assumption that the probability $P(\mathbf{y}|c)$ is modeled by a multivariate Gaussian distribution kernel:

$$P(\mathbf{y}|c) = \frac{1}{n_c}\sum_{k=1}^{n_c} \exp\left(-\frac{\|\mathbf{y}-\mathbf{x}_k^c\|^2}{2\sigma^2}\right) \quad (5)$$

where n_c is the number of elements of class c, σ is a smoothing parameter, and $\mathbf{x}_k^c$ is the kth neuron of class c. The nonlabeled vector $\mathbf{y}$ is assigned to class c for which $P(c|\mathbf{y})$ is maximal. In the case of WKNN, the computation of $P(\mathbf{y}|c)$ is restricted to the k first nearest codebook vectors. Let us note n_{k_c} the number of codebook vectors of class c in the k-size neighborhood; we can then write

$$P(c|\mathbf{y}) = \frac{\frac{1}{n_{k_c}}\sum_{i=1}^{n_{k_c}} \exp\left(-\frac{\|\mathbf{y}-\mathbf{x}_{(i)}^c\|^2}{2\sigma^2}\right)}{\sum_{j=1}^{C}\frac{1}{n_{k_j}}\sum_{i=1}^{n_{k_j}} \exp\left(-\frac{\|\mathbf{y}-\mathbf{x}_{(i)}^j\|^2}{2\sigma^2}\right)} \quad (6)$$

where $\mathbf{x}_{(i)}^c$ is the ith nearest training sample of class c to $\mathbf{y}$.

The use of WKNN allows the determination of probabilities associated with each facies. Each location in the prospect area will be evaluated by the DNNA and probabilistically estimated from facies and seismic data learning process.

Reservoir prediction in a carbonate reef

The challenge in evaluating the quality of a carbonate prospect is not limited to understanding facies distribution. Carbonate reservoir properties are directly impacted by the depositional environment, but they are also highly dependent on chemical processes, such as diagenesis or karstification, which occur after deposition. As a consequence, this case study will focus not only on predicting facies, but also on facies groups. These take into account facies as well as rock properties due to rock evolution through time (Table 1). The ability to use all the available seismic information and facies calibrated to wells makes the DNNA methodol-

Table 1. Facies group final repartition. Facies from Permian and Carboniferous intervals are determined, taking into account the lithology, porosity, and fluid content.

Code	Name	Color
0	Nonvalue	
1	Shale	
2	Tight biostrom	
3	Wet bioherm 1	
4	Good porosity biostrom oil	
5	Wet boiherm 2	
6	Shaly limestones	
7	Interbedded	
8	Bioherm oil	
9	Limestone	
10	Silicoclastic	
11	Silicoclastic oil	
12	Tight bioherm	
13	Facies_13	
14	Medium-porosity biostrom oil	
15	Good-porosity biostrom water	
16	Low-porosity biostrom water	
17	Low-porosity biostrom oil	

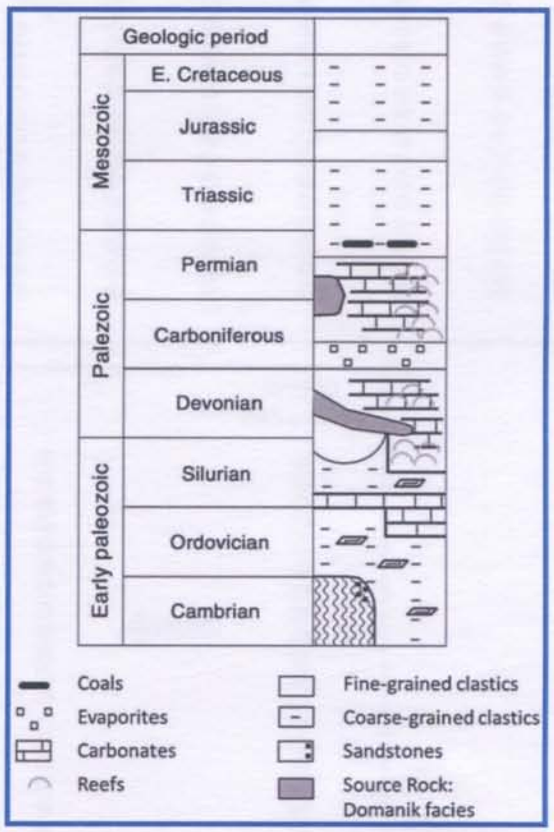

Figure 5. Simplified stratigraphy column showing depositions throughout epochs. The Carboniferous and Permian intervals are our zones of interest and show biostrom and bioherm depositions, respectively.

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The Desk & Derrick Club of Corpus Christi is a proud affiliate of the Association of Desk And Derrick Clubs, www.addc.org ogy an ideal candidate for carbonate reef studies through the multidimensional approach.

Geologic context

We focus on limestone carbonate reservoirs (Figure 5). Subaerial exposure in terrestrial and coastal environments has initiated a series of physical, chemical, and biological processes that have modified the carbonate rocks. The related karstic process is of paramount importance for reservoir enhancement, particularly within Palaeozoic rocks. The setup of potential reservoirs distributed through karstic galleries is not clearly identifiable on seismic data due to seismic resolution limitations.

The major trapping mechanism involved in the region is stratigraphic, with the top and lateral seals provided by overlying shale. Existing wells have shown an oil presence at the Permian and Carboniferous levels. The description of the 16 facies groups is shown in Table 1. They are derived from facies (e.g., limestone, siliciclastic, bioherm, and biostrom rocks) groups based on porosity variation and fluid contents.

Combining prestack data and observation at wells in a heterogeneous environment to predict facies groups, where no wells are drilled, is challenging. We can observe AVO effects on carbonates, but these are generally more subtle (Li et al., 2003) than in a clastic-type reservoir due to the lower sensitivity of the response of carbonate rocks to porosity and fluid. In the selected data, the dominance of class I (Rutherford and Williams, 1989) anomalies can also make the interpretation difficult.

The DNNA methodology was applied to carbonate reefs in two layered reservoirs. Although the basin of interest is known for containing good-quality, proven oil and gas reservoirs, the geologic setting has a signifi-

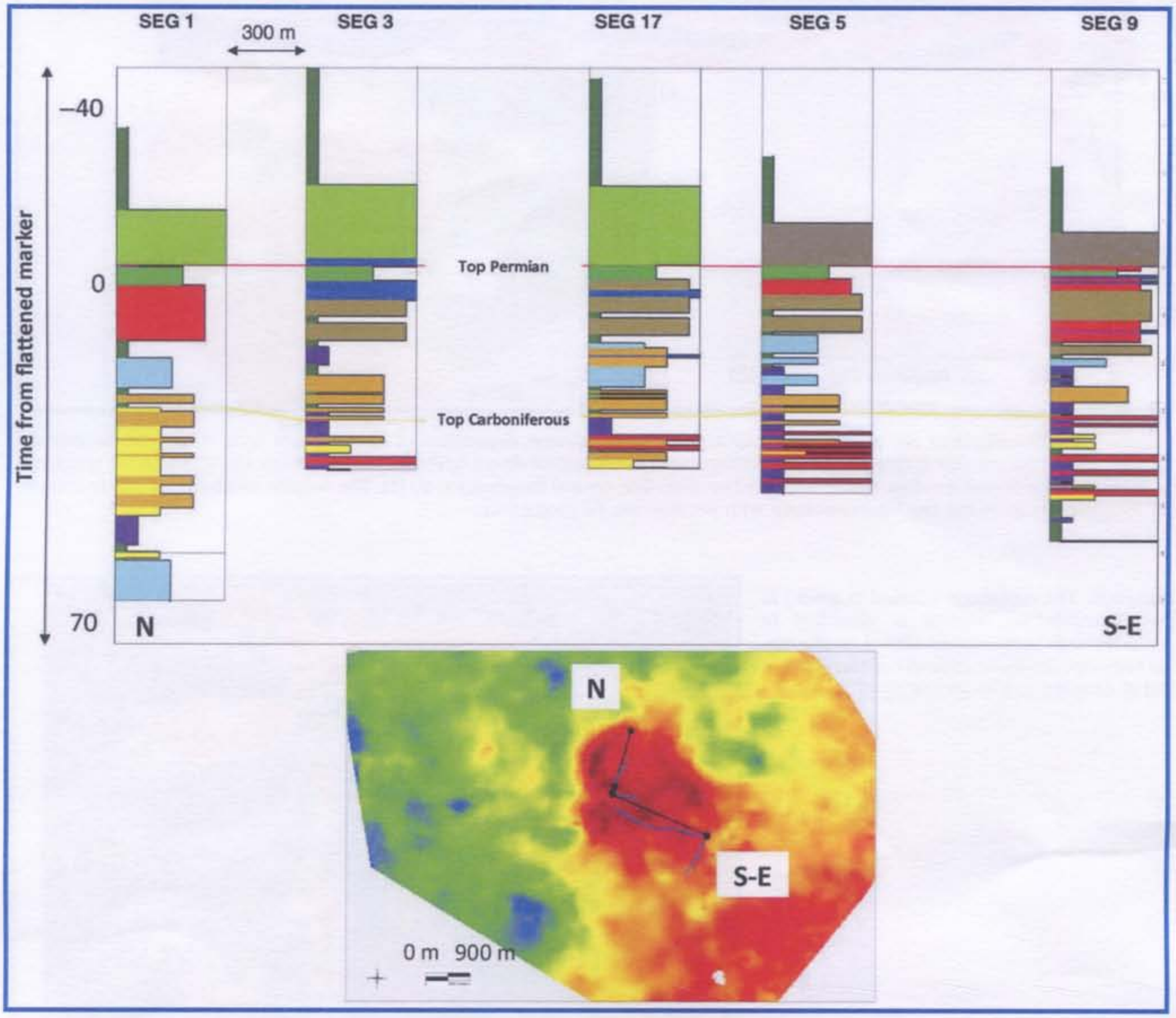


Figure 6. The cross section north–southeast shows poor lateral continuity in Permian and Carboniferous reservoirs.

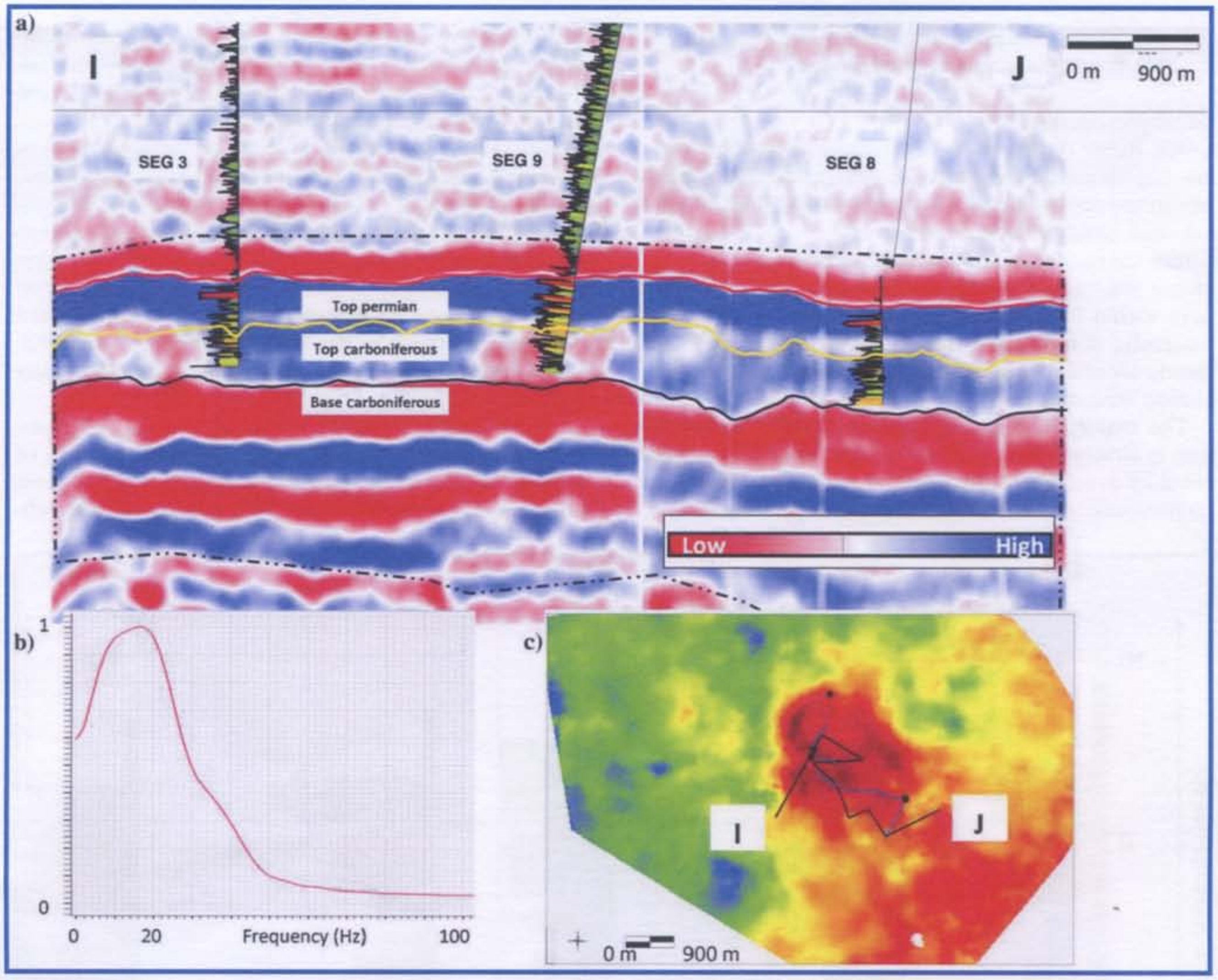
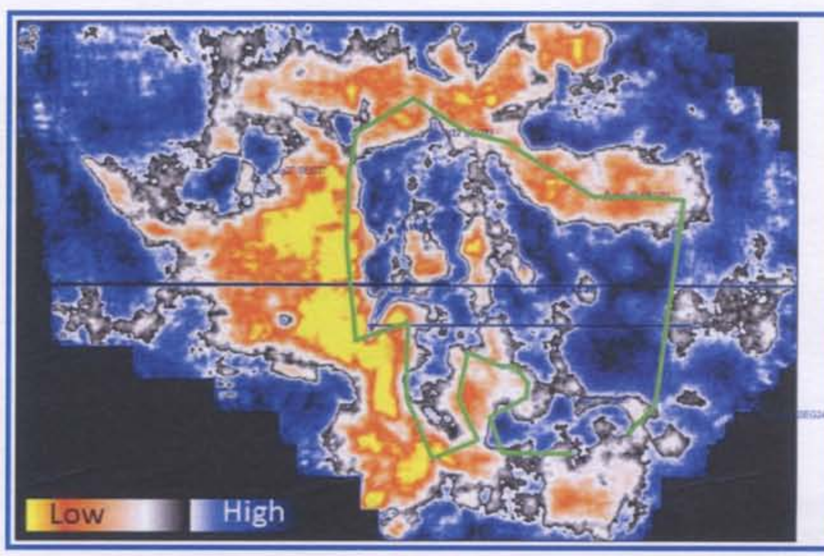


Figure 7 (a) Seismic data are of low frequency in the area of interest. Separation of the reservoir units is unclear. Seismic reflectors show high energy across the whole section, with no apparent direct hydrocarbon indicator. (b) The seismic spectrum calculated in the dotted window visible on the I-J section. The central frequency is 20 Hz. The seismic resolution is highly limited. (c) Structural map of the top Carboniferous with section line I-J projection.

Figure 8. The reef shape (circled in green) in the Carboniferous interval is identified in green through proportional slicing on the signal envelope attribute. Lateral continuities are highly exaggerated, however.



cant impact on risk evaluation and control of the exploration and development of a field.

Results

Facies group determination was performed using only 13 of the available 22 wells because the method requires having a full suite of electric logs available for facies determination purposes. The group of 13 wells was used to analyze lithology distribution as well as fluid content when reservoirs intersect. In the Permian, bioherm-type depositions have occurred, whereas in the Carboniferous, we observe biostrom-type deposition. Combining density and neutron porosity logs, gamma ray and sonic, and as M-N plots, allowed the separation of shale, carbonates of various types, and their discrimination by porosity. A parallel study was performed at multiwell scale using MRGC to generate electrofacies. The same logs used for rock typing were integrated into the MRGC workflow. The result was integrated with crossplot analysis to determine facies based on lithology type and porosity. The MRGC approach constitutes a multivariate approach, whereas rock typing is a multilog pair analysis method. An additional MRGC was completed using SP logs and resistivity ratios to integrate fluid content information (Table 1). This fluid version of electrofacies was compared to pay flags on existing wells.

As shown in Figure 6, the final facies logs consist of low-resolution groups, taking into account lithology type and fluid content. Well sections such as the north–southeast (Figure 5) show relatively poor lateral continuities in reservoir bodies and sharp terminations, as expected in this type of environment. As mentioned,

Table 2. Facies group prediction at the well bore. High reconstruction rates show the good match at the well after DNNA training.

Well name	Reconstruction rate (%)
SEG1	90.63
SEG17	73.45
SEG18	61.95
SEG2	74.05
SEG20	91.89
SEG22	74.78
SEG23	71.05
SEG25	73.68
SEG27	80.99
SEG3	90.11
SEG4	81.48
SEG5	80.43
SEG6	75.34
SEG8	98.31
SEG9	75.81

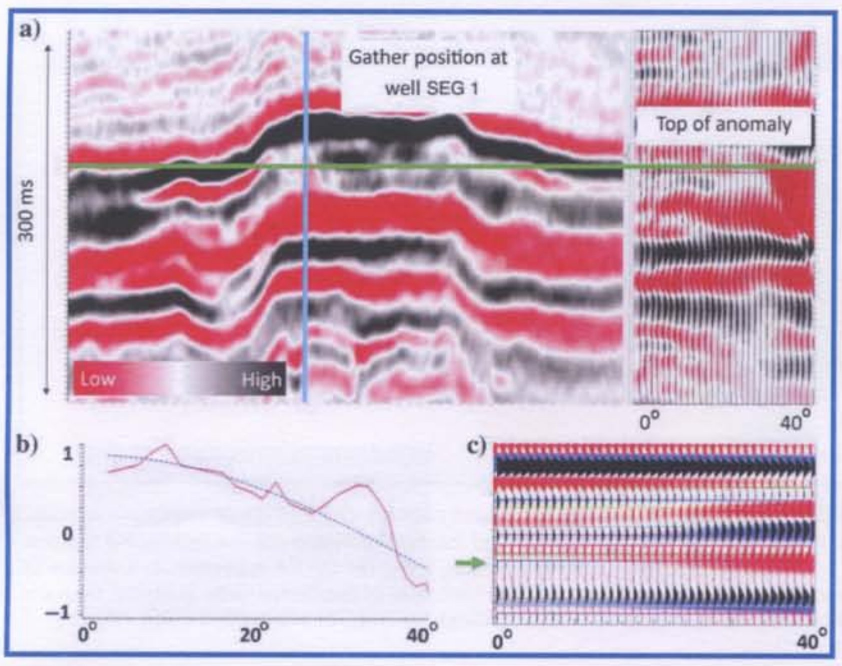
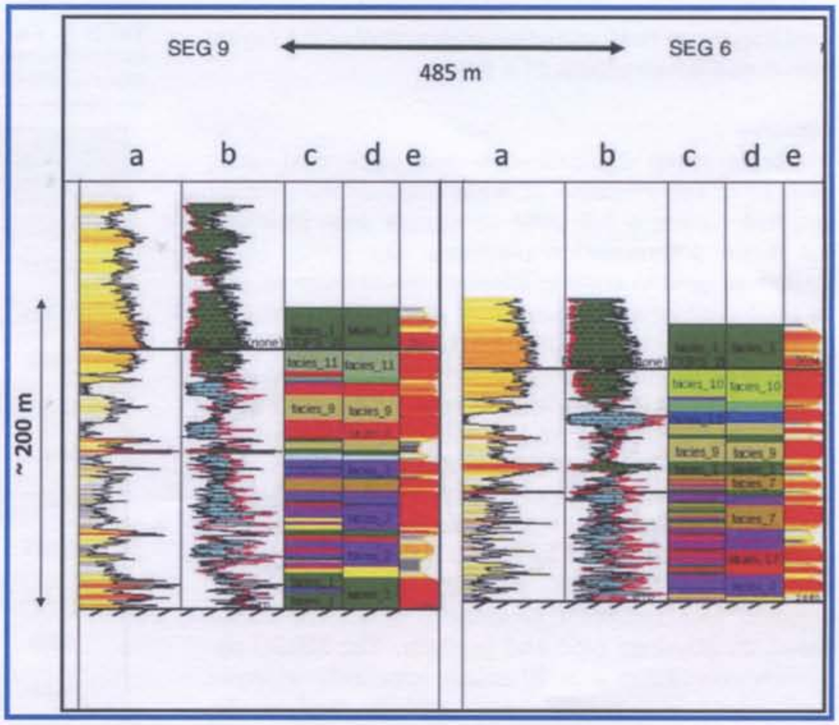


Figure 9. (a) The seismic section on the left shows a projected gather position in blue. Corresponding gathers on the right show a large variation in frequency with angle. The green line corresponds to the top of the Carboniferous reservoir. (b) Amplitude versus angle response at the green line location shows the unclean class I effect. (c) 1D elastic modeled response based on well information. The expected response is materialized at the green arrow position. The class I effect is visible but subtle. This behavior explains the dimming of amplitude and phase reversal observed on stacked inline. AVO effects are consistent with modelization, despite the fact that they are subtle.

Figure 10. Reconstruction rates are high, as shown in Table 2. (a) Gamma ray track, (b) neutron-density crossing track, (c) interpreted facies group log, (d) predicted facies group log, and (e) probability log. Associated maximum probability values are displayed in last track, showing how confident the prediction is.



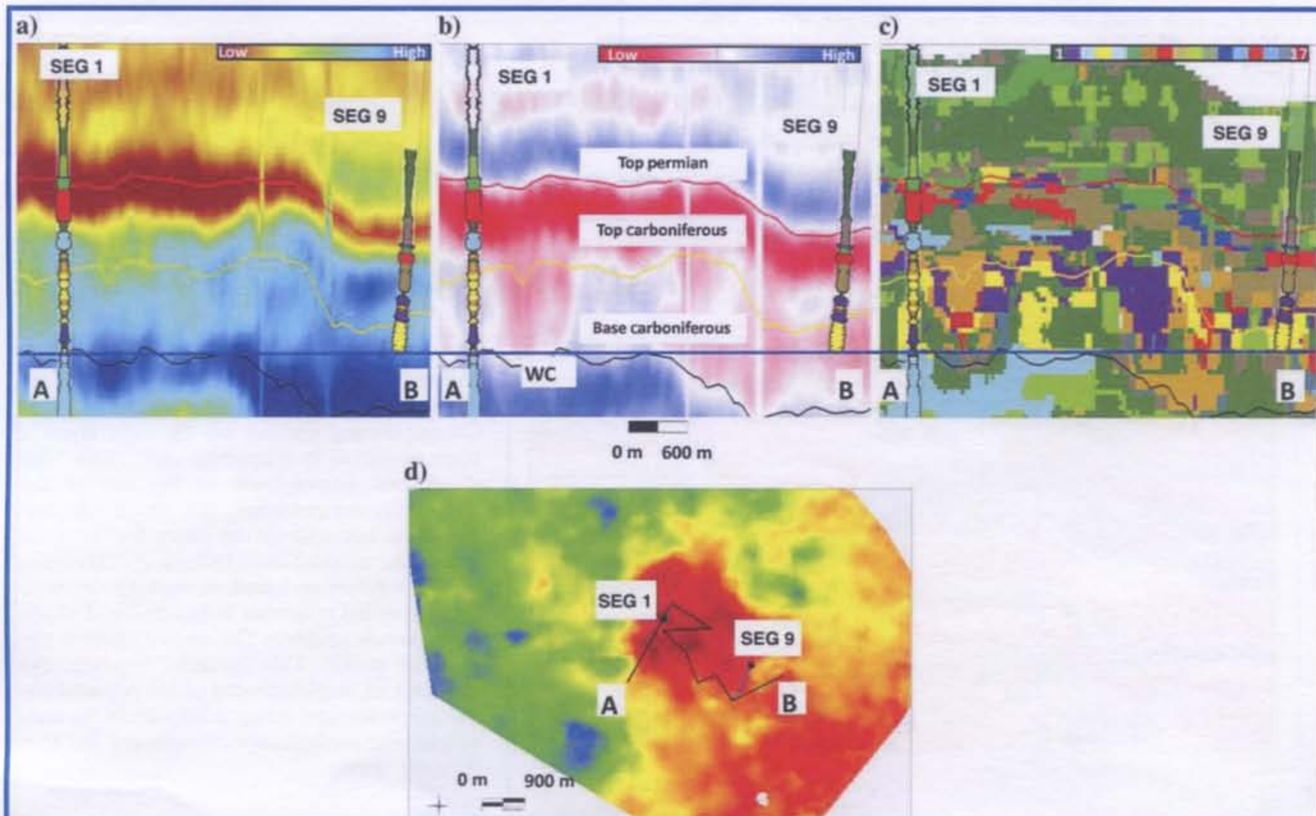


Figure 11. (a) P-impedance section: As expected, acoustic inversion does not detect contact. (b) Full-stack amplitude section: Seismic section shows dimming responses at the reservoir. The seismic vertical and lateral resolution makes estimating the reservoir extension difficult. (c) DNNA facies group prediction: The result of the prediction, using the DNNA approach, is a volume of the most probable facies. It clearly shows the water contact proven at well 1. The resolution of the facies cube is higher than for poststack seismic data. The subtle extra information contained in prestack angle gathers has been extracted by DNNA. (d) Map of top Carboniferous showing cross section A-B projection.

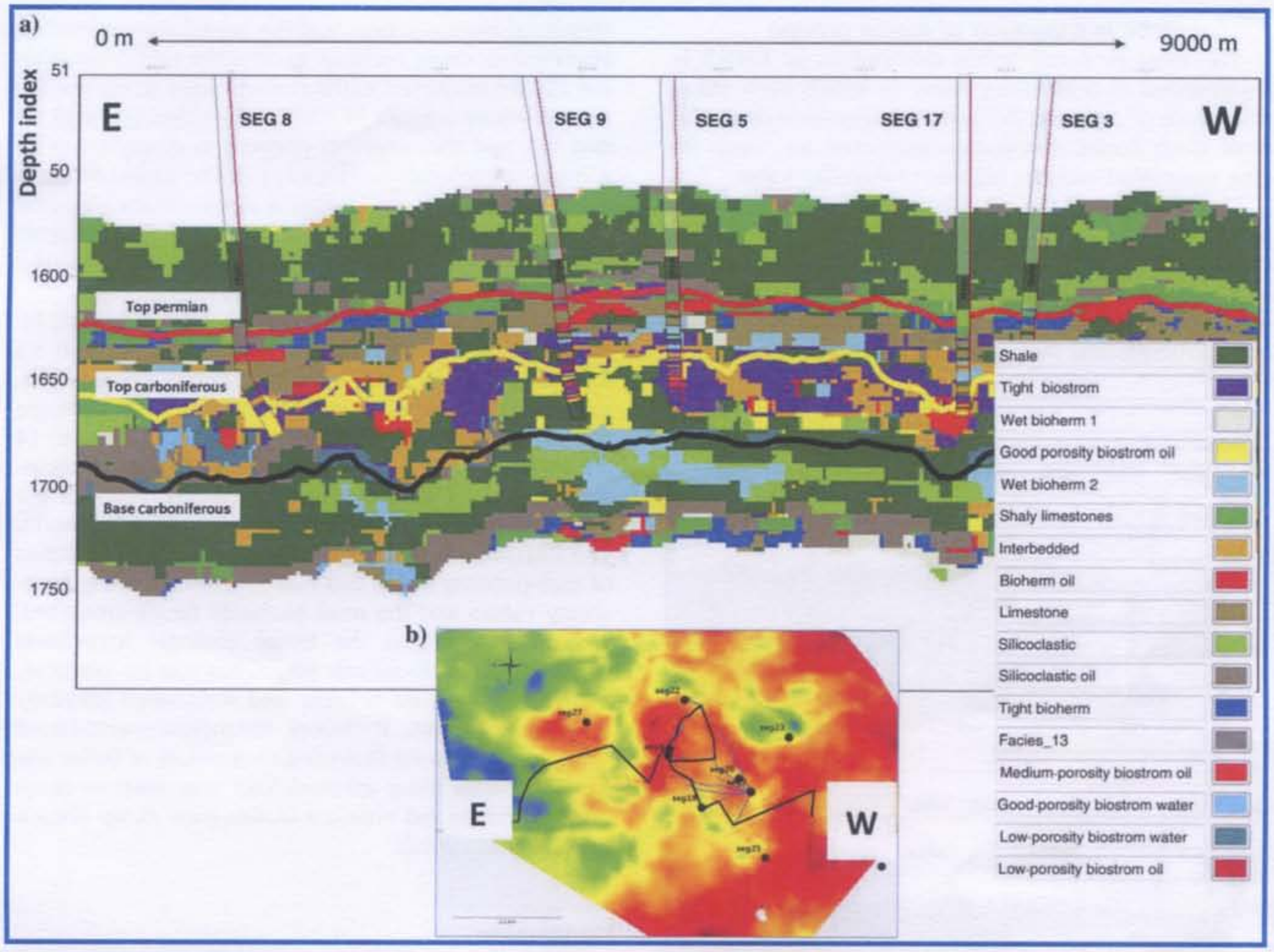


Figure 12. (a) The most probable facies distribution gives a detailed description of Permian and Carboniferous targets. Based on facies group definition at wells, DNNA has been able to clearly redistribute facies consistently with the stratigraphic unit. The geologically consistent oil/water contact increases confidence in the result. We can observe how the shape of the Carboniferous reservoir (bottom) correlates with the karstic galleries hypothesis. (b) Base Carboniferous map, showing cross-section projection east–west in black.

seismic data have low frequencies; therefore, the vertical resolution does not allow for the separation of different deposition units (Figure 7).

An initial study would consist of performing a seismic attribute analysis from seismic volumes. Computations of signal envelope, instantaneous frequency, and frequency-weighted amplitudes have helped map the lateral extension of the reef. However, the inner composition of the reef is not detailed and it would not allow the derisking of any well plan. The lack of reservoir continuity observed at wells is not honored by seismic attributes, which show either exaggerated continuities (Figure 8) or dimming responses due to class I reservoir type (Figure 9). Seismic attributes and inversion have proved to be of limited use in describing the bodies of interest, because amplitude and frequency do not significantly vary laterally in the area of interest. Detailed facies differentiation was not possible; therefore, uncertainty about reservoir extension and connections, thickness, and gross volume remains high. In the rest of the article, we demonstrate the use of DNNA that will add the ability to correlate the full collection of gathers with facies groups and extrapolate them at the prospect level, with an estimated probability of success.

Training of democratic neural network association and quality control of predictive aptitudes

Facies logs from 13 wells and time-migrated angle gathers are used for DNNA training. The quality control of DNNA predictive capabilities is showing promising results because it combines low bootstrap error values (0.3 ± 0.05) with good reconstruction rates at wells (Table 2). Thin beds are not reconstructed with exact thickness and become the main source of prediction errors along well bores. Reservoir facies groups are well reconstructed, as shown by associated probability values (Figure 10).

Probabilistic propagation of facies groups

The most probable facies distribution by DNNA is summarized in a lithology cube, in which each value at a given (x-, y-, and z-) position corresponds to the most likely facies distribution predicted, i.e., each facies associated with its highest probability value.

Figure 11 shows the poststack seismic response and acoustic impedance compared to facies group prediction. Analysis of the results shows higher lateral and vertical detail than that provided by conventional attributes and seismic inversion. The distribution of Permian and Carboniferous facies groups is consistent with the structural interpretation, and the lateral discontinuities observed on cross sections such as the east–west (Figure 12) are respected in the DNNA facies group prediction. A water contact is clearly identified (Figures 11 and 12), and the reservoir position is consistent with AVO anomaly locations (Figure 11). The lateral continuity of reservoir bodies respects discontinuity observations. At the same time, the shape of the reservoir conforms to the karstic gallery hypotheses in the area.

As described in the methodology, DNNA outputs facies group probability values for each (x-, y-, and z-) location (Figure 13). These probability values, calibrated to wells, can be used directly in a 3D geologic model to generate multiple realizations. Figure 14 shows the distribution of facies group four (good-porosity biostrom oil in the Carboniferous reservoir) for the most pessimistic scenario and the most likely scenario. The distribution of a good oil reservoir shows patches of high-porosity zones that can be detected using probability values and the most probable facies group volume. This confirms the initial geologic hypothesis about the zone. Reservoir properties can be modeled, taking into account seismic and well-based lithology and fluid definition. Therefore, the multiscenario-based approach is used for assessing uncertainty of facies distribution. This latter methodology was used to accurately estimate net volumes in this case study (Hami-Eddine et al., 2013).

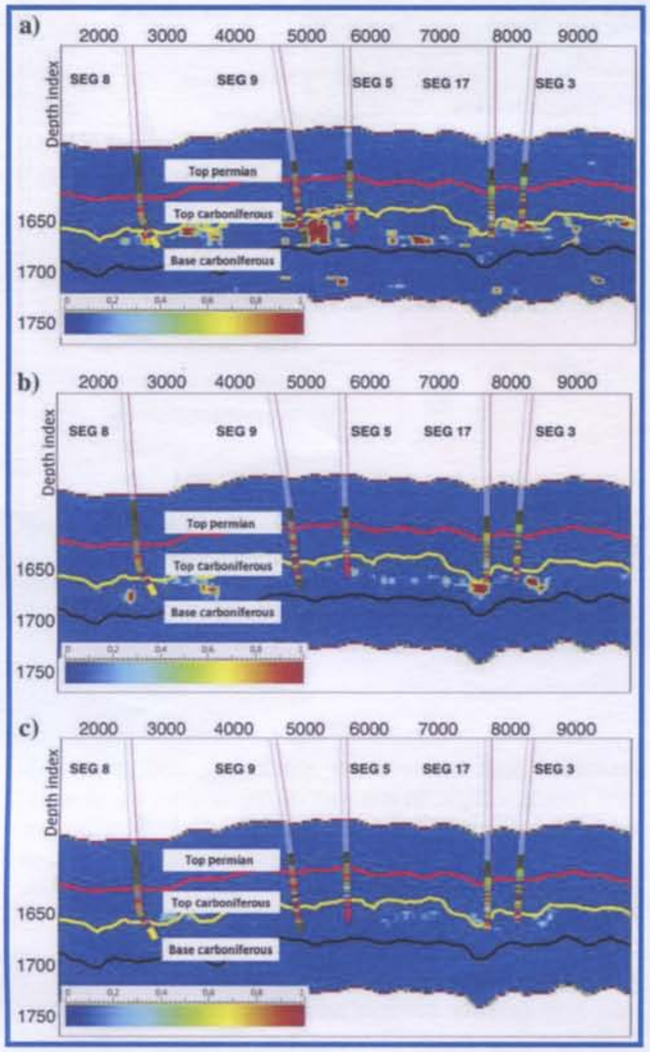


Figure 13. Cross section east–west from Figure 12 is used to display probability values of the biostrom reservoir facies groups. The probability values bring a strong quality control tool to assess prediction certainty. Facies group probabilities are compared to facies reconstruction rates and probabilities along the well bore. Signatures in the facies probability distribution give a good, consistent quality indicator. (a) Probability of biostrom high-porosity oil reservoir, (b) probability of biostrom medium-porosity oil reservoir, and (c) Probability of biostrom low-porosity oil reservoir.

Conclusion

The determination of reservoir extension and internal description is highly challenging in a carbonate environment. It is crucial to use all available data to extract maximum information. It is equally crucial to capture the geoscientist's input and understanding of the geology. The DNNA approach combines the ability to perform a multidimensional analysis of seismic data with the analysis of well-based facies interpretation. We show that the introduction of soft data during the training process provides the ability to stabilize the result and reduce bootstrap error rates. The results obtained on this carbonate reef are consistent with geologic hypotheses and with wells that were used for blind testing. The most probable facies volume shows geologically reasonable facies group lateral distribution and thickness. The analysis of the probability distribution gives good insight into prospect uncertainty and seismic data reliability for prediction. The probability volumes can be used to evaluate risk on volumes and contribute to target rating.

In other words, DNNA performs facies inversion based on lithologs and seismic data, and is a robust alternative to conventional approaches. The addition of lithology probabilities directly based on well observations will help to reduce uncertainty in reservoir prospecting and qualification.

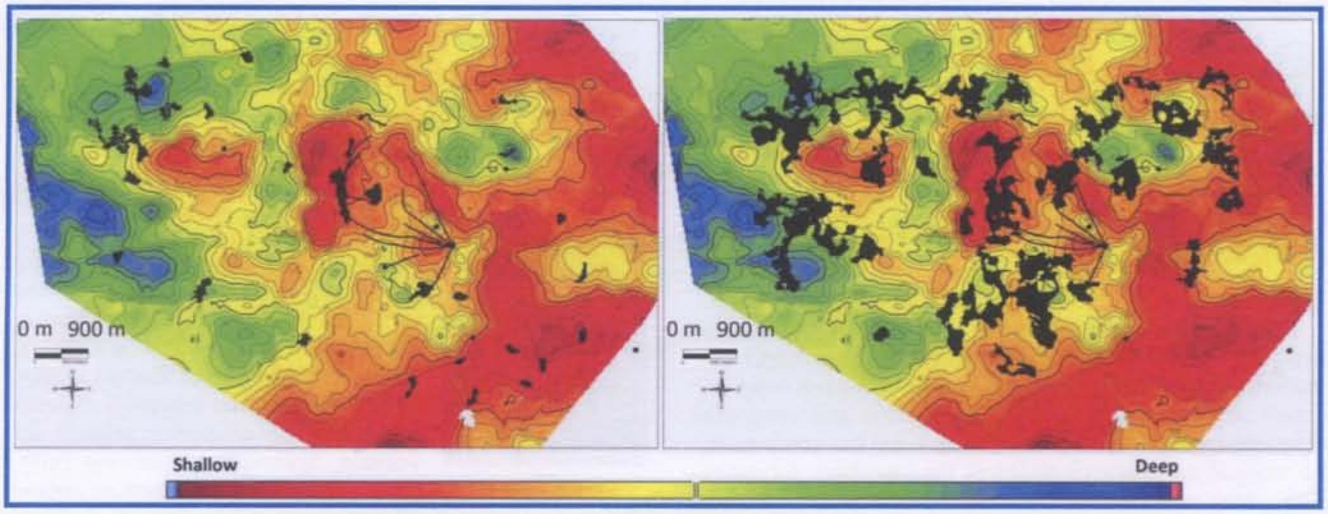


Figure 14. Multiscenario realization of reservoir hypothesis based on probability distributions. The most probable scenario fitted at best the four blind well testing performed in this study. (a) The most pessimistic case in which only good-porosity oil reservoirs were kept if the probability value was greater than 0.9. (b) The most probable geobody detection for good-porosity oil reservoirs.

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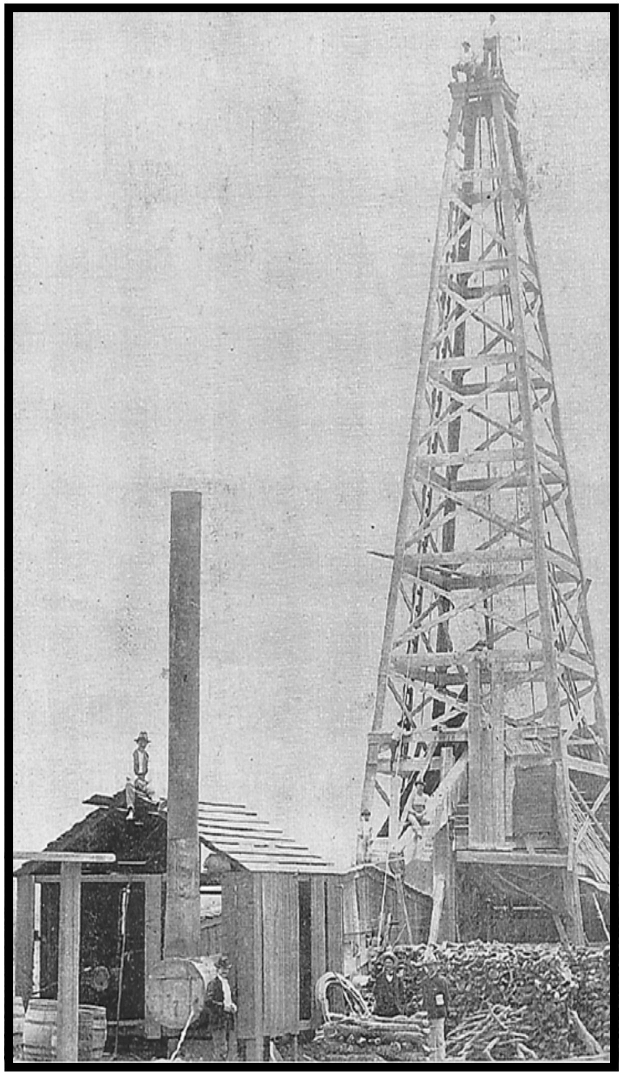

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