Application of Neural Networks To Correlate Core Descriptions of Depositional Environments with Log Responses, and To Extrapolate Over Intervals and Wells Where Cores Do Not Exist

Prepared by
Michael Holmes
Dominic Holmes
Tony Holmes

Digital Formation, Inc.

Denver, Colorado, USA
November 2000

www.DigitalFormation.com

List of Contents

Introduction 1

Overview of Neural Network Application for Distinguishing Rock Facies 1

Hartzog Draw, Powder River Basin, Wyoming 2

Big Stick, Williston Basin, North Dakota 3

List of Figures

Figure 1: Upper Cretaceous oil fields, Powder River Basin, Wyoming. 5

Figure 2: Well locations, Hartzog Draw field and Heldt Draw field, Wyoming. 6

Figure 3: Wide shelf on which Hartzog Draw and other Shannon shelf-ridge sandstones were deposited... 7

Figure 4: Model of facies distributions, Shannon shelf-ridge sandstone complex. 8

Figure 5: Shannon facies summary. 9

Figure 6: Production characteristics of individual facies recognized in slabbed core – Cities Service Federal AE-1. 10

Figure 7: Production characteristics of individual facies recognized in slabbed core – Bud Christensen No. 2. 10

Figure 8: Production characteristics of individual facies recognized in slabbed core –Cities Service Federal AS-1. 11

Figure 9: Cities Service Federal AE-1 Sandstone (Hartzog) Deposition from Neural Networks. 12

Figure 10: Southland Royalty Bud Christensen No. 2 Sandstone (Hartzog) Deposition from Neural Networks. 13

Figure 11: Cities Service Federal AS-1 Sandstone (Hartzog) Deposition from Neural Networks. 14

Figure 12: Heldt Draw Sandstone (Hartzog) Deposition from Neural Networks. 15

Figure 13: Casada Federal 13-28 Sandstone (Hartzog) Deposition from Neural Networks. 16

Figure 14: Cities Service Federal AE-1 Porosity vs. Water Saturation cross plot. 17

Figure 15: Core Description, Federal AE-1 18

Figure 16: Core Description, Federal AS-1 19

Figure 17: Core Description, Bud Christensen No. 2 20

Figure 18: Facies Cross Section, Hartzog Draw 21

Figure 19: Area map of the Big Stick Field 22

Figure 20: Billings Nose well base indicating locations of various fields. 23

Figure 21: Stratigraphic column of the Central Williston Basin. 24

Figure 22: Diagram showing a geological model for the Mission Canyon. 24

Figure 23: Tenneco 1-35 David 25

Figure 24: Stuart USA No. 1-19 Carbonate Deposition 26

Figure 25*:* Kordon 10-6 Carbonate Deposition 27

Figure 26: Anna Osudchuck Carbonate Deposition 28

Figure 27: Stuart USA No. 1-19 Density vs. Comp. Neutron 29
Figure 28: Stuart USA No. 1-19 Porosity vs. Water Saturation Cross Plot.. 30
Figure 29: Facies Cross Section, Big Stick and Tree Top Fields. 31

Introduction

Neural networks approaches can be used to correlate log responses with core descriptions of lithology and/or depositional environments. A series of training sessions are run over intervals where both core data and a complete log suite exists. Any bad-hole intervals should be excluded in the training process. The training can be over a single or multiple wells, and the separate wells do not necessarily need to have the same suites of rock types. However, they do need to have identical log suites.

Once the training has been established, applications can be run over intervals or wells where no core data exists. If rock types have changed from the intervals of training, the results will be unreliable, and the neural network output will indicate these levels of change.

Two examples of Rocky Mountain reservoirs are presented using Digital Formation's Esteem program:

- Hartzog Draw Cretaceous shallow marine Shannon sandstones, Powder River Basin, Wyoming
- Big Stick Mississippian carbonate reservoirs, Williston Basin, North Dakota

The techniques allow for a number of important reservoir interpretations:

- Field-wide recognition of changing depositional and/or rock type sequences
- Correlation of specific rock types with reservoir quality and recognition of flow units
- Recognition of transgressive/regressive sequences through the gross intervals, well-by-well
- Detailed field-wide mapping of each different rock type

Overview of Neural Network Application for Distinguishing Rock Facies

The neural network application used in this study involves the definition of quantified correlation between wireline log response and different rock facies as described by cores. It is not necessarily the case that the two sets of data can be correlated uniquely, although the cases presented have suggested that in excess of about 75% of the data analyzed there is sufficient correlation to allow reliable distinction.

The initial preparation of the data set involves:

For well(s) where core data exists, depth match cores to logs.

- Choose a suite of logs common to the cored wells, and all other wells to be examined, that should be some measure of lithologic variation. If the wells involve both hydrocarbon-bearing and wet intervals, it might be advantageous not to use resistivity logs.
- On all wells identity intervals of potentially unreliable data – for example, bad hole data.

The next stage is to perform training sessions on wells where both logs and cores exist. The training should only be applied where core descriptions and all logs (quality data only) exists. Training can involve a single well only or a combination of wells. Various cases can be run, involving different log combinations, to determine which log curves are needed to distinguish the different rock types.

Verification of how well the neural network has "learned" facies types can be made by comparing the neural network blocking of rock types with the original core descriptions. A poor result is indicated when the neural network blocking involves more than one rock type over any depth interval.

When training is complete, application can be made on any wells that have no core data. Intervals of bad hole or other reliable log data should be excluded from the application. Validity of the application can be verified as follows:

- Blocking that involves essentially only one rock type
- Summation of all rock types at any one level should be approximately one

Hartzog Draw, Powder River Basin, Wyoming

Source of the geologic data and well traces for three of the wells is:

> Tillman and Martinsen "Sedimentologic Model and Production Characteristics of Hartzog Draw Field, Wyoming, A Shannon Shelf-Ridge Sandstone" in Reservoir Sedimentology SEPM Special Publication No. 40, 1987.

Figure 1 is a location map of the Hartzog Draw Field in the Powder River Basin. **Figure 2** shows well locations of the three training wells and the two application wells. **Figure 3** shows the general interpreted geologic setting of the shelf sand Shannon reservoirs, and **Figure 4** is a diagram of relations among five of the reservoir facies described in the cores. **Figure 5** gives details of lithology, sedimentary structures, burrowing, reservoir potential, and relative abundance of all nine reservoir facies recognized. **Figure 6, 7 and 8** gives details of core porosity, permeability and recognized facies for the Federal AE, Christiansen No. 2 and Federal AS-1 wells.

Training and application was performed using the following logs:

- Deep resistivity ILD
- Shallow resistivity SFL
- Density RhoB
- Neutron NPhi
- Gamma ray GR

The following figures apply to the appropriate well:

Figure Number	Well	Type
9	Federal AE	Training
10	Christiansen No. 2	Training
11	Federal AS-1	Training
12	Heldt Draw	Application
13	Casada Federal 13-28	Application

Each of **Figures 9, 10, 11, 12, and 13** show mostly good distinction for each of the facies recognized:

- Shelf (Shale)
- Shelf (Silt/Sandstone)
- Inter Ridge
- Lo Energy Ridge
- High Energy Ridge
- Central Ridge

On each well, the following data are presented:

Track 1	Porosity, shale, matrix
Track 2	Interpreted bulk volumes; water, oil, gas, and core porosity (if applicable)
Track 3	Stacked environments (sum should be between zero and one if data are reliable)
Track 4-9	Individual environments, as marked, ranging from Shelf to Central Ridge
Track 10	The stacked facies assuming the largest quantity is the sole winner at each depth

Figure 14 is a cross plot of water saturation vs. porosity for well Federal AE. The plot indicates that the reservoir facies (Inter Ridge through Central Ridge) have very similar rock types, and can be expressed by

$$Phi^{1.7} \times Swi = 0.01$$

Figures 15, **16 and 17** show core descriptions for the Federal AE-1, Federal AS-1, and Christensen No. 2 wells. **Figure 18** is a cross section of the Christensen No. 2, Federal AE-1, Casada Federal 13-28 and Federal AS-1 wells.

Big Stick, Williston Basin, North Dakota

All geologic data was taken from:

> John J. Brieg "Mississippian Mission Canyon Reservoirs of the Billings Nose, Billings County, North Dakota" in Occurrence and Petrophysical Properties of Carbonate Reservoirs in the Rocky Mountain Region RMAG, 1988.

Figure 19 is a location map of the Big Stick Field. Three wells were examined, one as the raining well, and two as application wells, shown in **Figure 20**. Producing reservoirs belong to the Mission Canyon Formation in **Figure 21** and were deposited in environments ranging from open marine to supratidal in **Figure 22**.

A description of a cored interval from a well in the Big Stick Field is shown in **Figure 23**.

Log response is very consistent, and the cored interval of the **Figure 23** well was correlated readily with the Stuart USA No. 1-19 well, used as a training well. For this well, additional training intervals were recognized for supratidal rocks (anhydrite) and salt (not seen in the cored intervals). Logs used for the training were:

- Gamma Ray GR
- Sonic DT
- Deep resistivity LLD
- Neutron NPhi
- Density RhoB

Neural net training and application results are shown on the following figures:

Figure Number	Well	Type
24	Stuart No. 1-19	Training
25	Kordon	Training
26	Anna Osadchuck	Application

Each of **Figures 24, 25 and 26** show mostly good distinction for each of the facies recognized:

- Open marine
- Restricted marine
- Intertidal
- Supratidal flat
- Supratidal
- Salt

On each well, the following data are presented:

Track 1	Porosity, shale, matrix
Track 2	Interpreted bulk volumes; water, oil, gas, and core porosity (if applicable)
Track 3	Stacked environments (sum should be between zero and one if data are reliable)
Track 4-9	Individual environments, as marked, ranging from Open Marine to Salt
Track 10	The stacked facies assuming the largest quantity is the sole winner at each depth

Also, each well shows a series of regressive/transgressive cycles that are readily correlated from one well to the next. Porosity development is restricted to mostly two of the six facies recognized – marine and restricted marine. Some porosity development is also seen in the intertidal and supratidal flat categories, but is mostly quite minor.

Figure 27 shows a density/neutron cross plot with the various facies. Some of the rock types are uniquely recognized – e.g. Salt and supratidal anhydrites – but others show lithologic overlap among limestones, dolomitic limestones, and dolomite.

Figure 28 is a porosity/water saturation comparison for the Stuart No. 1-19 well with the cored interval facies types.

Most of the porosity belongs to a single rock type with the relationship:

$$Phi^{1.2} \times Swi = 0.02$$

Figure 29 is a facies cross section of the Kordon, Stuart No. 1-19 and Anna Osadchuck wells.

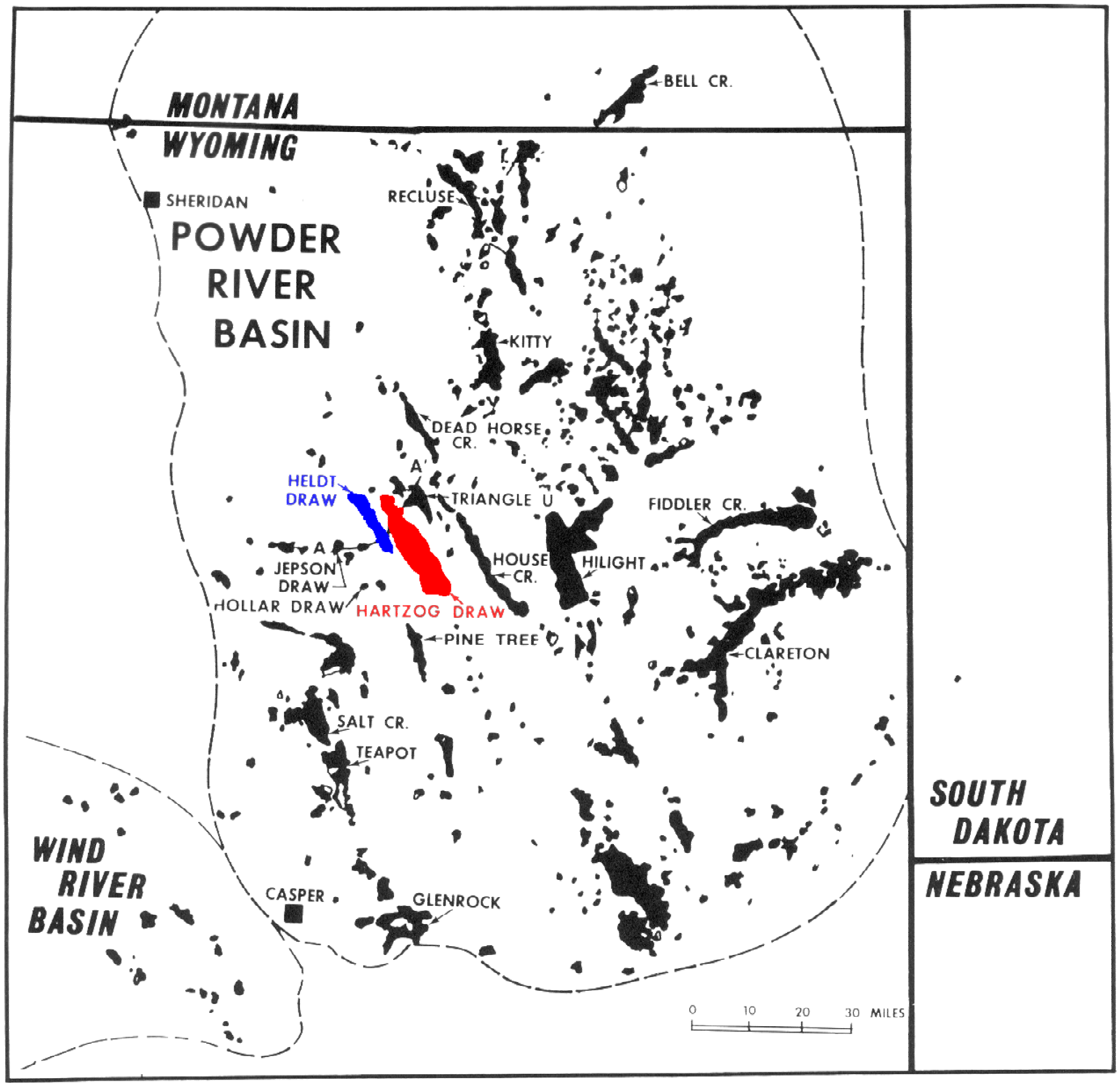


Figure 1: Upper Cretaceous oil fields, Powder River Basin, Wyoming.

Note the parallelism and elongation of the fields. Among the larger fields are House Creek Dead Horse Creek fields that produce from the Sussex sandstones.

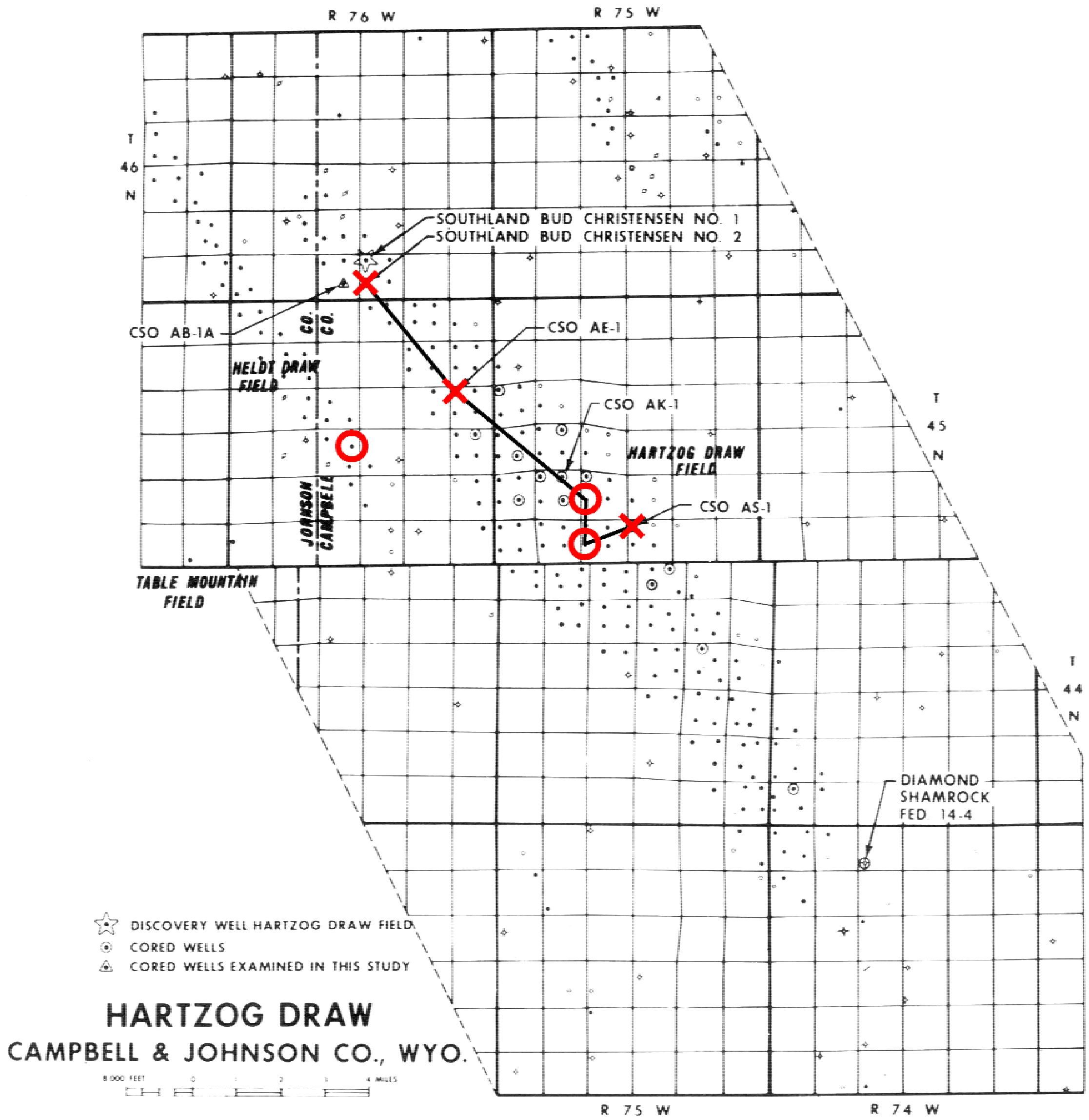


Figure 2: Well locations, Hartzog Draw field and Heldt Draw field, Wyoming.

Hartzog Draw field discovery well is marked by a star. Wells cored during primary producing phase are indicated by circles. Locations of the cored wells discussed in the text are shown. Wells marked with X are wells with core and logs used for training. Wells marked with O are wells with log only and are application wells.

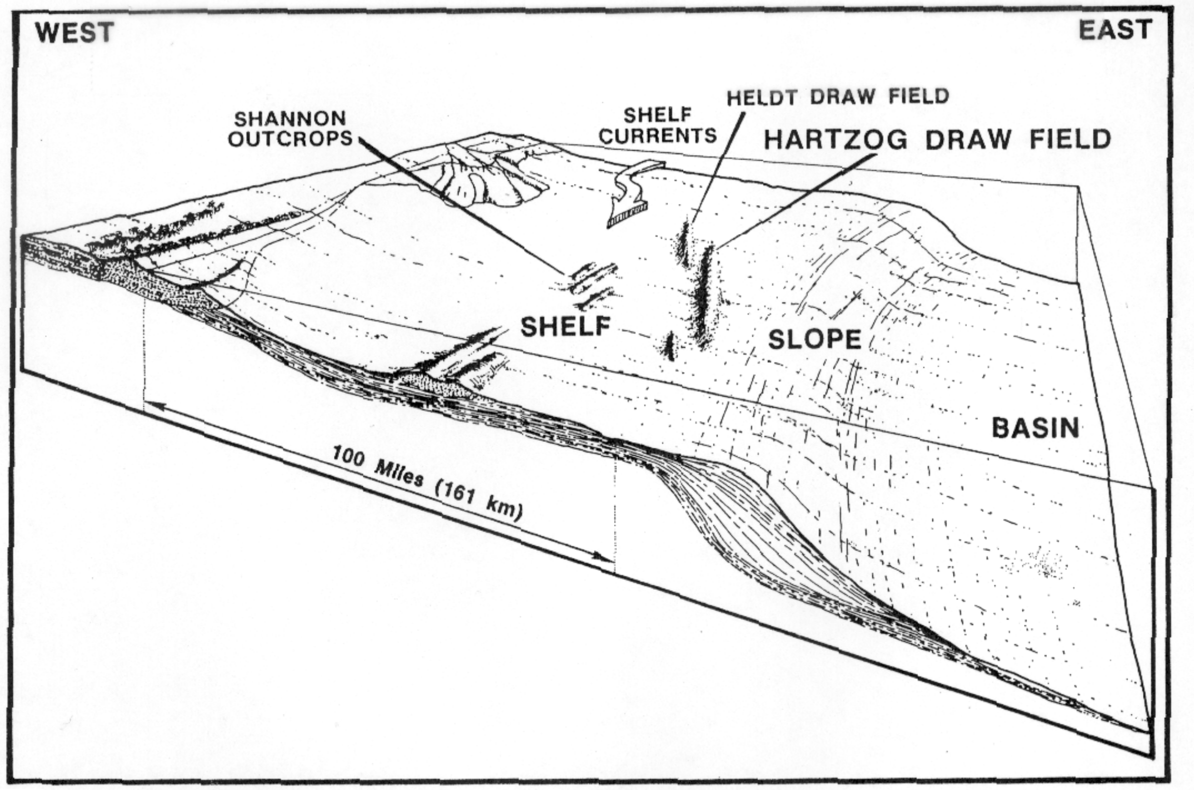


Figure 3: Wide shelf on which Hartzog Draw and other Shannon shelf-ridge sandstones were deposited.

NNW-SSE-trending subsurface shelf-ridge sandstones are superimposed on a model developed by Asquith (1970). Note that Hartzog Draw field is the largest Shannon shelf-ridge sandstone discovered to date.

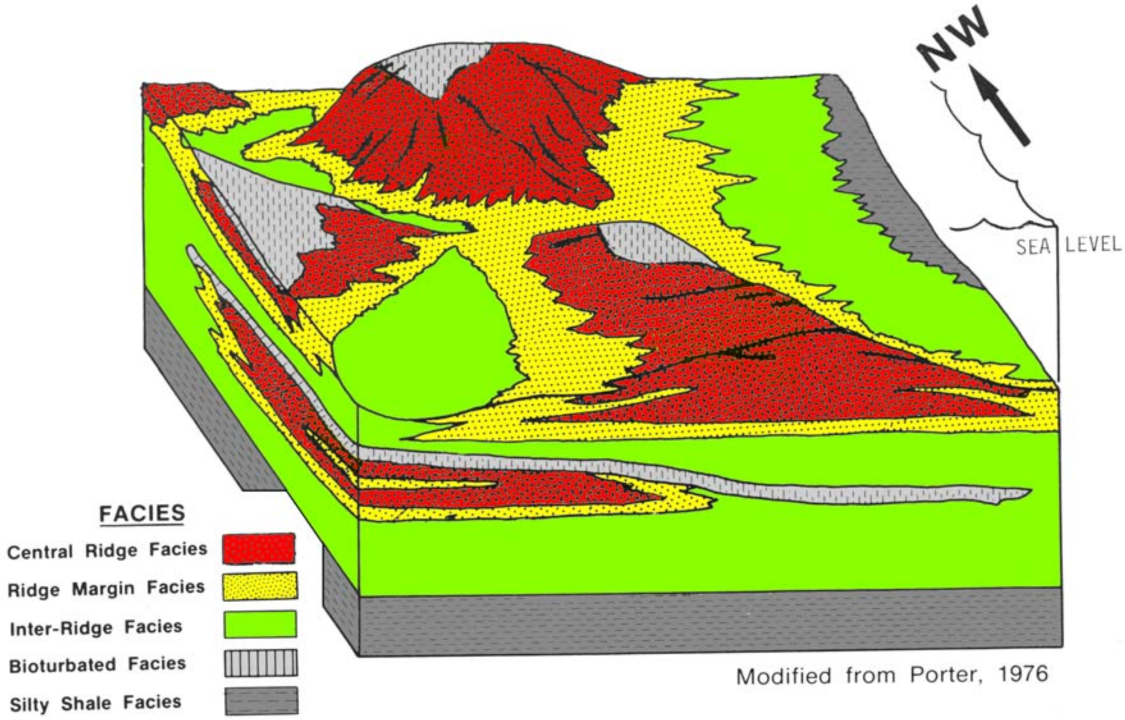


Figure 4: Model of facies distributions, Shannon shelf-ridge sandstone complex.

This diagram has extreme vertical exaggeration, but the abrupt lateral changes indicated here are substantiated by detailed outcrop study (Tillman and Martinsen, 1984, Figs. 35-37).

SHANNON FACIES SUMMARY

	CENTRAL-RIDGE FACIES	CENTRAL-RIDGE (PLANAR LAMINATED) FACIES	HIGH-ENERGY RIDGE-MARGIN FACIES	LOW-ENERGY RIDGE-MARGIN FACIES
LITHOLOGY	Fine to medium grained quartzose sandstone, moderately glauconitic; rare siderite clasts and shale rip-up clasts.	Fine to medium grained quartzose sandstone.	Predominately medium grained sandstone, abundant shale and limonite rip-up clasts and lenses, commonly very glauconitic.	Fine-grained sandstone with only rare shale interbeds. Fewer clasts and lenses and less glauconitic than High-Energy Ridge-Margin Facies.
SEDIMENTARY STRUCTURES	Predominantly moderate angle trough and planar-tangential cross bedding. Trough sets commonly horizontally truncated.	Mostly sub-horizontal plane-parallel laminated sandstone, 0.5'-thick laminasets. Minor shale and sandstone ripples.	Mostly moderate angle troughs, some current ripples, shale clasts rarely show preferred orientations.	Sequences of several beds of troughs interbedded with sequences of several rippled beds.
BURROWING	Sparse	Sparse	Sparse	Sparse
RESERVOIR POTENTIAL	Excellent	Limited?	Good	Moderate to Good
SUBSURFACE OCCURENCES HARTZOG DRAW FIELD	Common	Very uncommon	Common	Common

	INTER-RIDGE FACIES (SHALEY)	INTER-RIDGE SANDSTONE FACIES	BIOTURBATED SHELF-SANDSTONE FACIES	BIOTURBATED SHELF-SILTSTONE FACIES	SHELF SILTY-SHALE FACIES
LITHOLOGY	Thinly interbedded fine to very fine-grained silty sandstone and silty shale, slightly glauconitic.	Fine-grained sandstone. Virtual absence of silty shale. Slightly glauconitic	Silty, fine-grained sandstone. Up to 15% shale, primarily associated with burrows. Slightly glauconitic.	Shaly, slightly sandy dark gray siltstone, traces to moderate amounts of glauconite.	Silty dark gray shale; rare thin (1/8" thick) silty sandstone lenses.
SEDIMENTARY STRUCTURES	Predominantly horizontal ripple-form bedding surfaces marked by interbedded shales. Trace of wave ripples; current ripples predominate	Predominantly horizontal ripple-form bedding surfaces. Bedding commonly indistinct. Trace of wave ripples; current ripples predominate.	Few physical structures preserved. Mottled appearance. Some ripple-form horizontal beds up to 8 inches thick. Trace of distinct ripples and small troughs.	Few physical structures preserved. Scattered thin rippled sand and horizontal laminasets. Bedding commonly destroyed.	Common sub-horizontal laminae. Bedding surfaces indistinct, horizontal. Rare current ripples.
BURROWING	Moderate to locally high	Low to Moderate	Mottled to distinctly burrowed. More than 75% burrowed.	More than 75% Burrowed	Low to moderate
RESERVOIR POTENTIAL	Limited	Limited	Limited	None	None
SUBSURFACE OCCURENCES HARTZOG DRAW FIELD	Common	Uncommon	Common	Moderately Common	Common

Figure 5: Shannon facies summary.

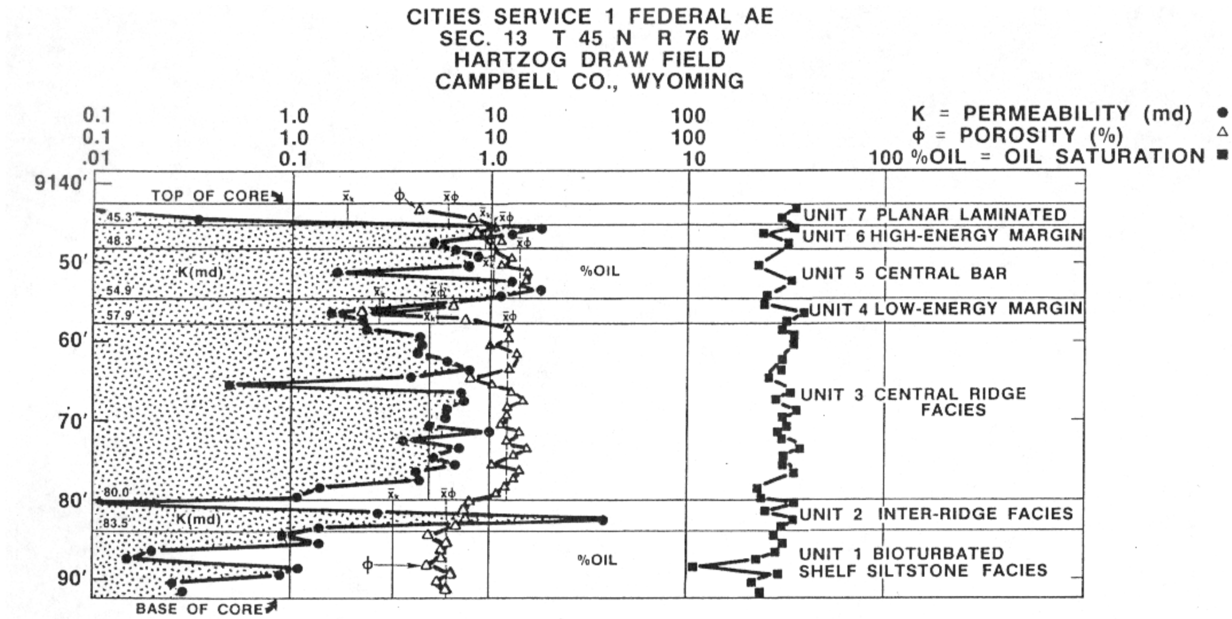


Figure 6: Production characteristics of individual facies recognized in slabbed core – Cities Service Federal AE-1.

Semi-log plot of porosity, permeability and oil saturation for cored interval in Cities Service Federal AE-1. Note that porosities (open triangles) are similar throughout the *Central Ridge* and in most of the *Ridge Margin Facies*; however, both porosity and permeability (circles) are significantly less in the Inter-Ridge Facies (Shaley). Average values of porosity (xΦ) and permeability (xκ) for each unit are also indicated.

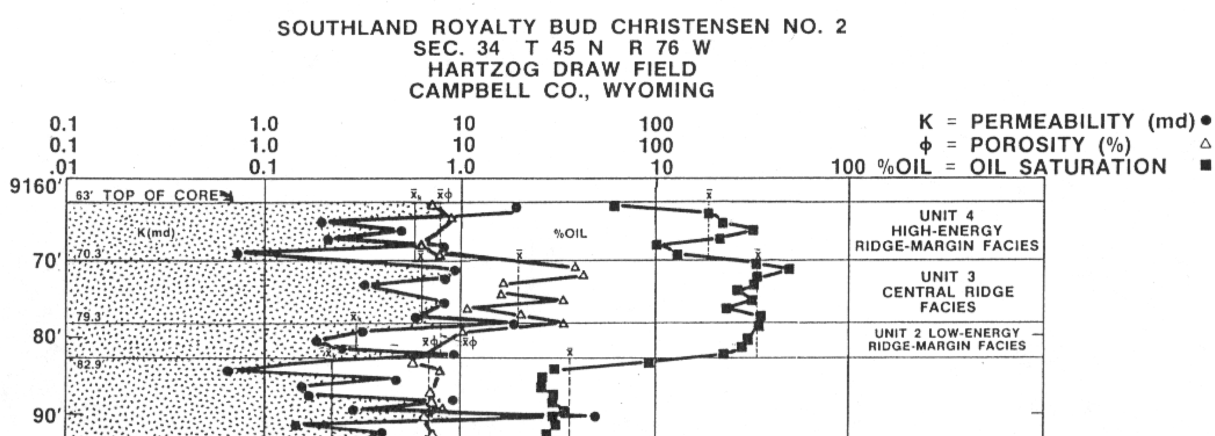


Figure 7: Production characteristics of individual facies recognized in slabbed core – Bud Christensen No. 2.

Semi-log plot of porosity (open triangles), permeability (circles) and oil saturation (squares) in Southland Royalty Bud Christensen No. 2. Note that porosities are significantly higher in the *Central Ridge Facies* than any of the others. Average values of porosity (xΦ), permeability (xκ), and oil saturation (x) are indicated for each unit.

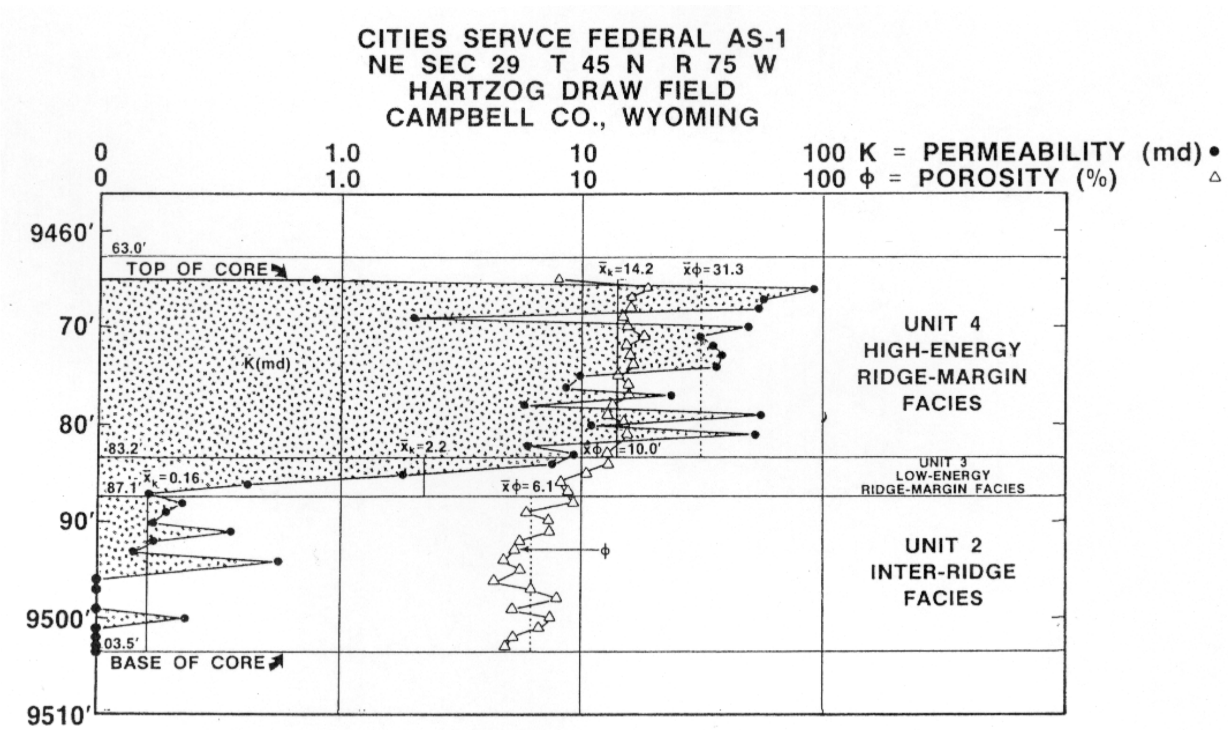


Figure 8: Production characteristics of individual facies recognized in slabbed core –Cities Service Federal AS-1.

Semi-log plot of porosity (open triangles) and permeability (circles). Oil saturation values were not calculated. This is the only cored well studied which has as its main producing interval a High-Energy Ridge-Margin Facies. The absence of a Central Ridge Facies is this well may be responsible for lower primary production values.

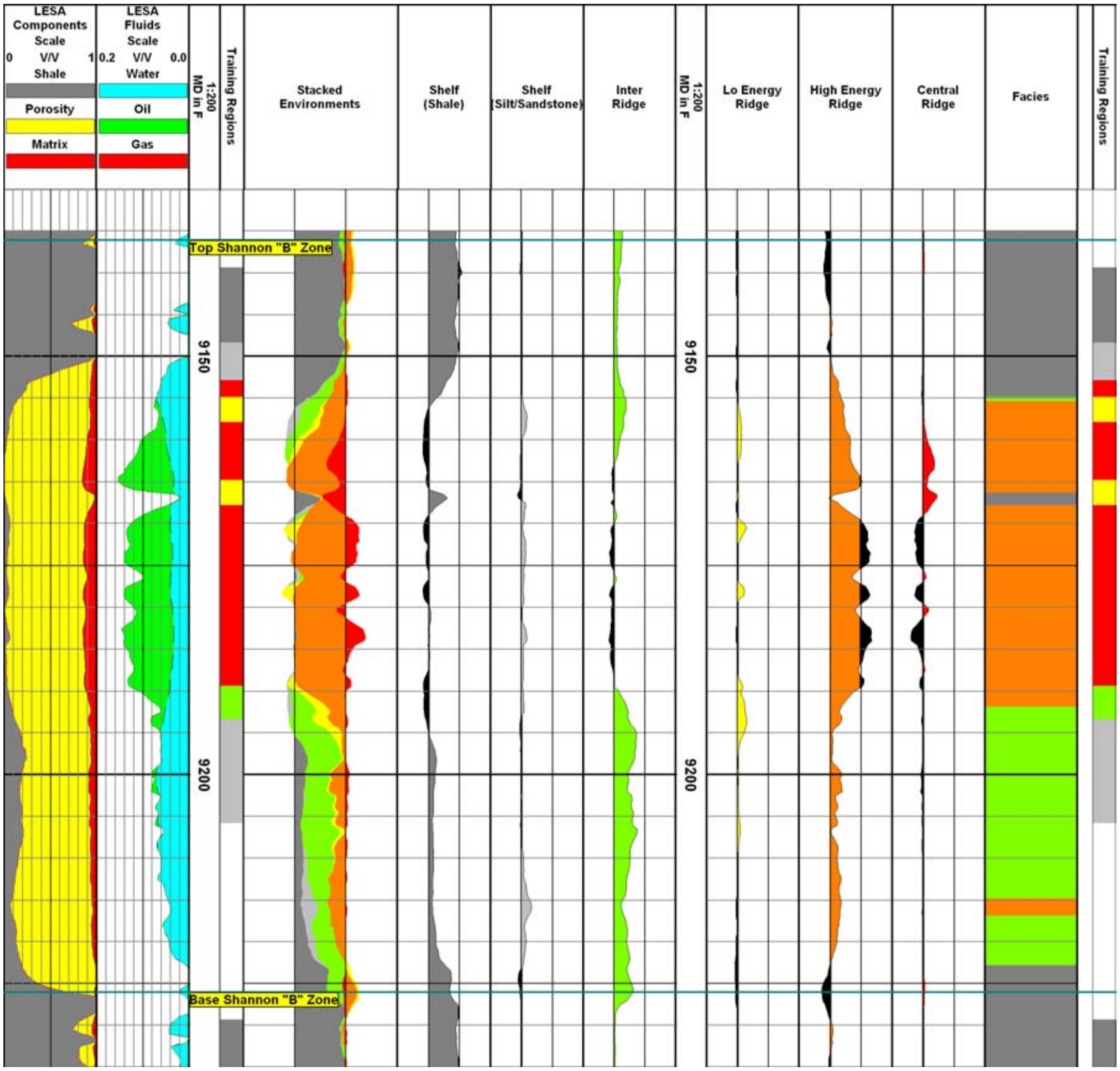


Figure 9: Cities Service Federal AE-1 Sandstone (Hartzog) Deposition from Neural Networks.

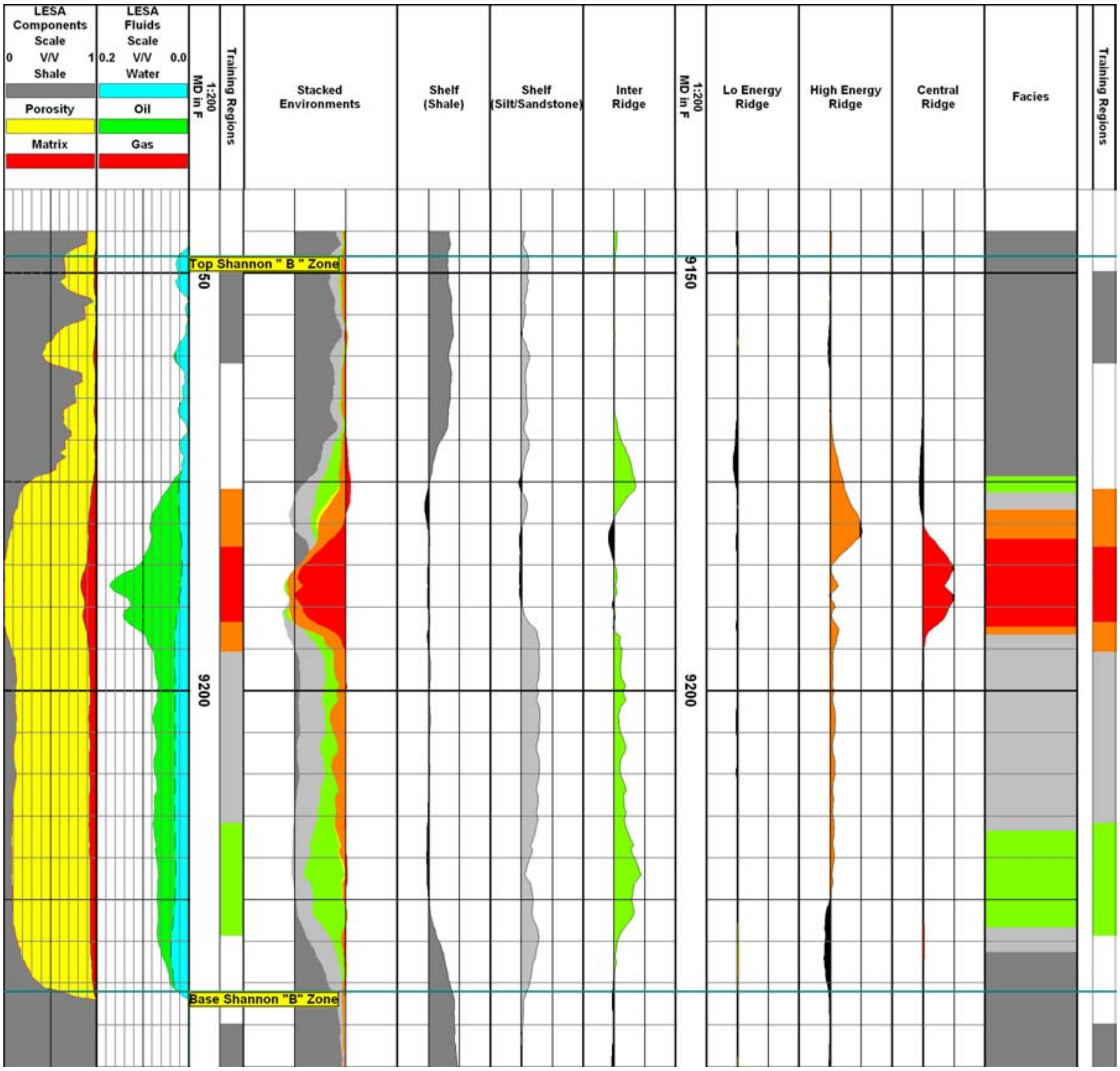


Figure 10: Southland Royalty Bud Christensen No. 2 Sandstone (Hartzog) Deposition from Neural Networks.

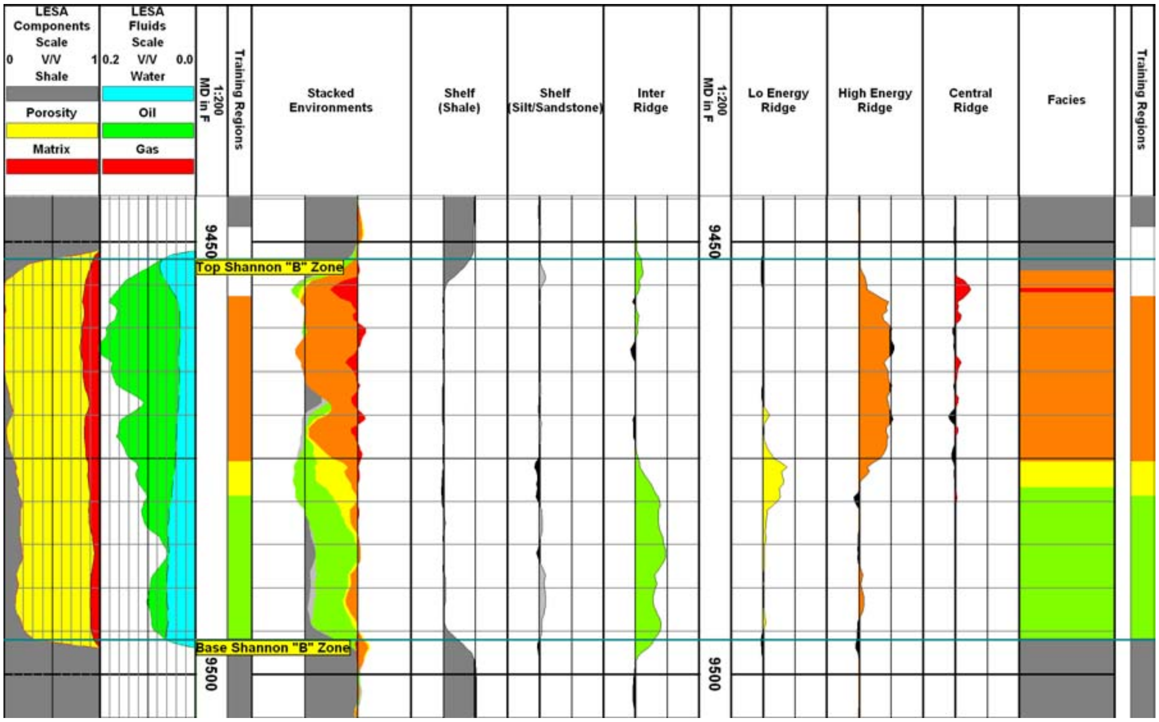


Figure 11: Cities Service Federal AS-1 Sandstone (Hartzog) Deposition from Neural Networks.

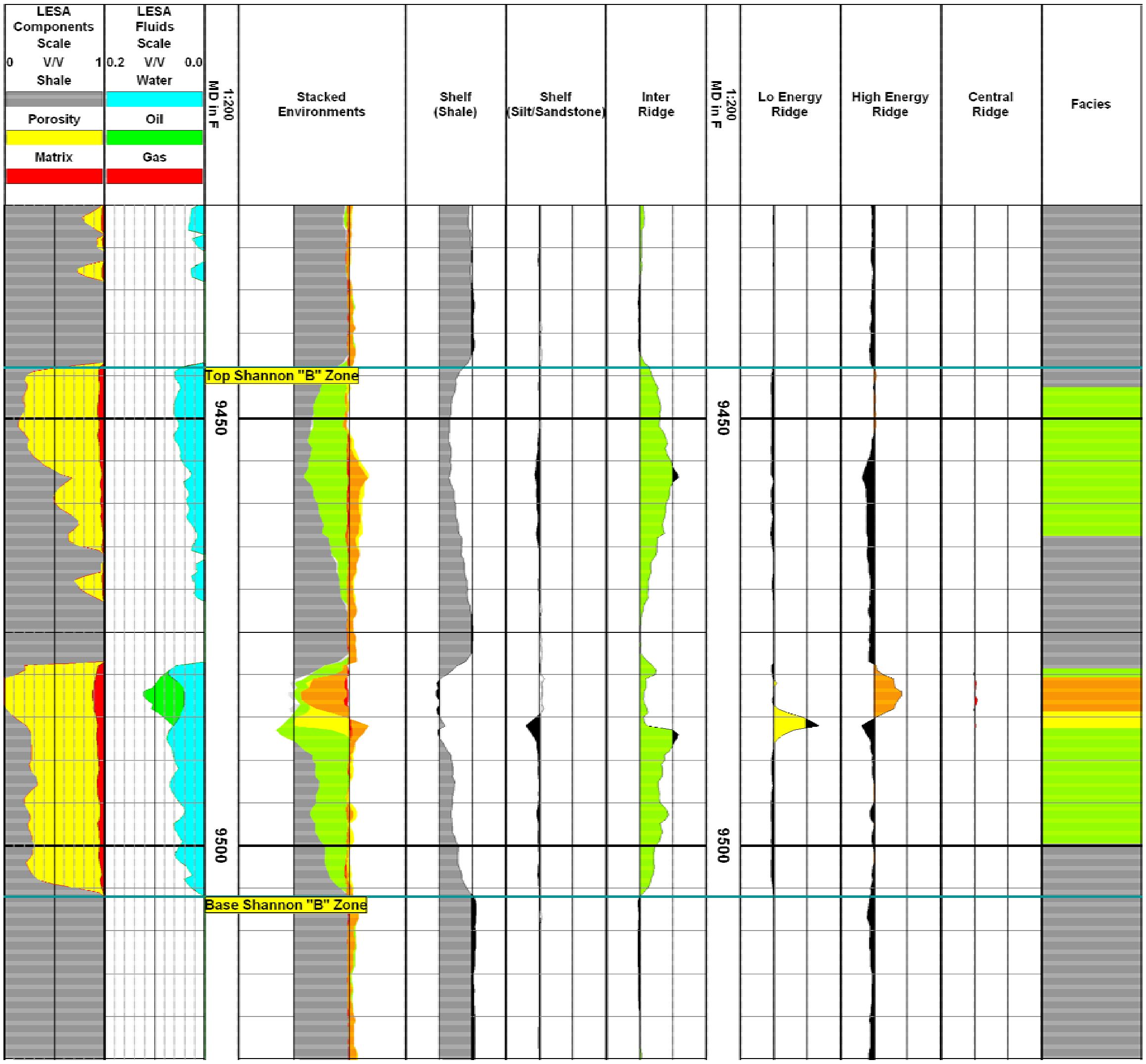


Figure 12: Heldt Draw Sandstone (Hartzog) Deposition from Neural Networks.

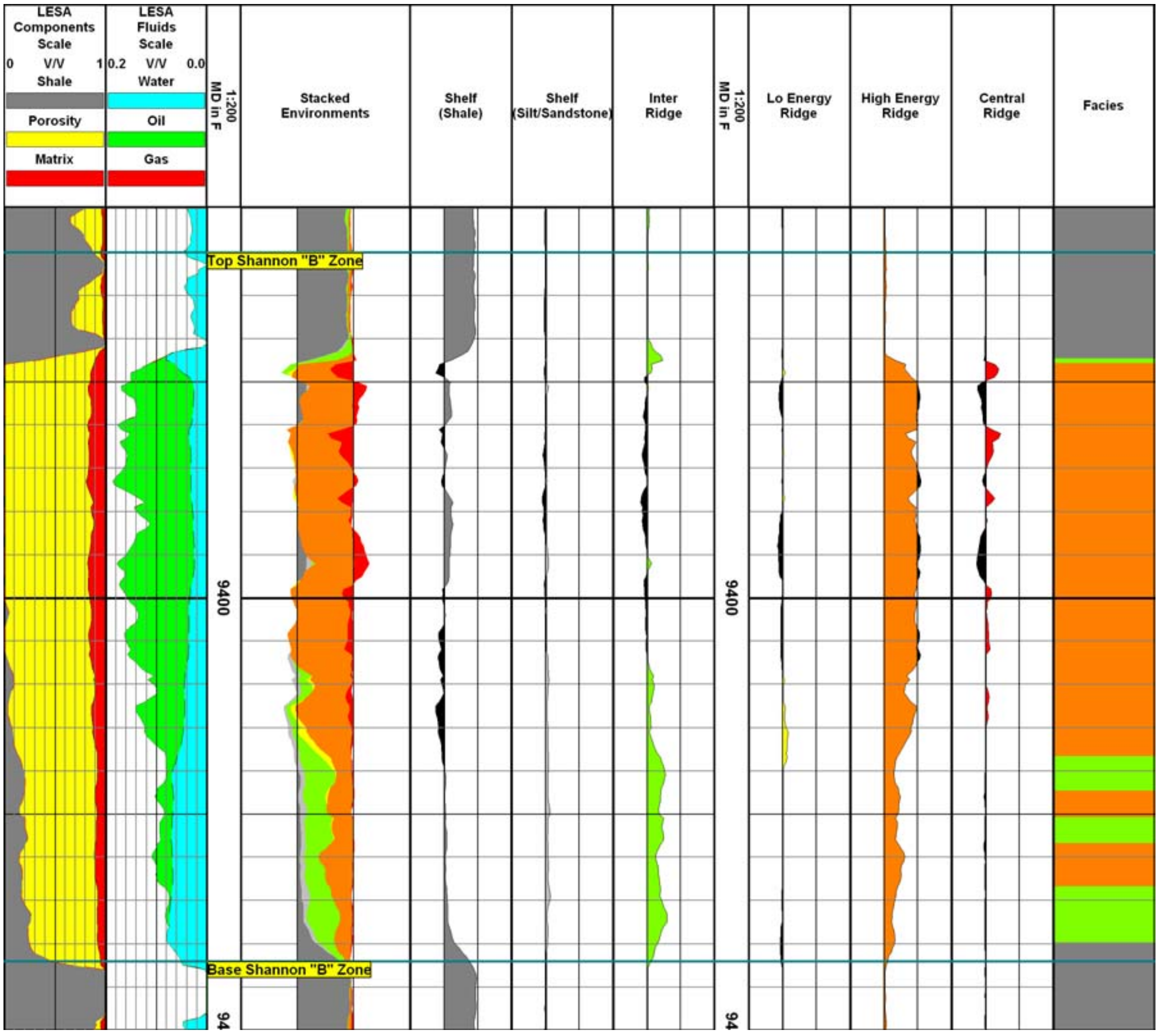
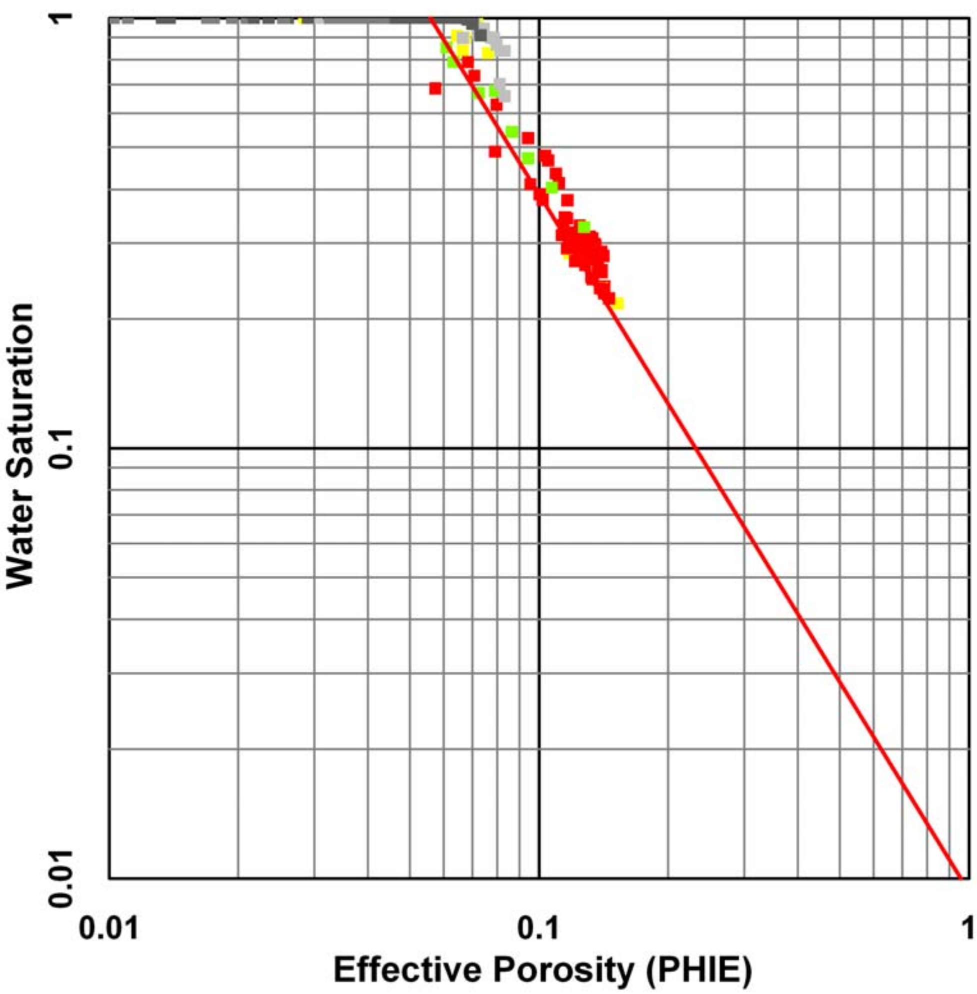


Figure 13: Casada Federal 13-28 Sandstone (Hartzog) Deposition from Neural Networks.

Porosity / Water Saturation



$$Phi^{1.70} x Swi = 0.01$$

Figure 14: Cities Service Federal AE-1 Porosity vs. Water Saturation cross plot.

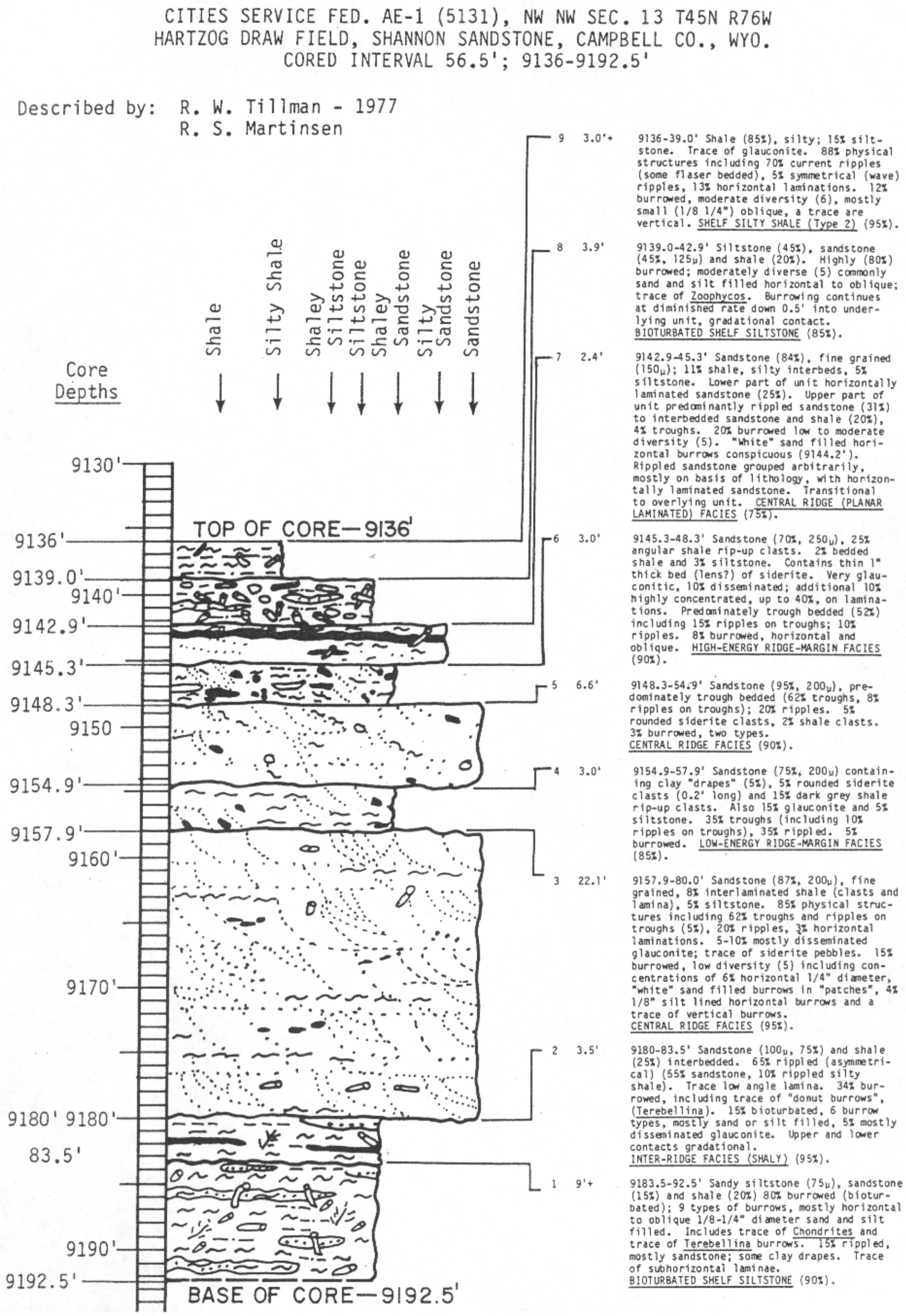


Figure 15: Core Description, Federal AE-1

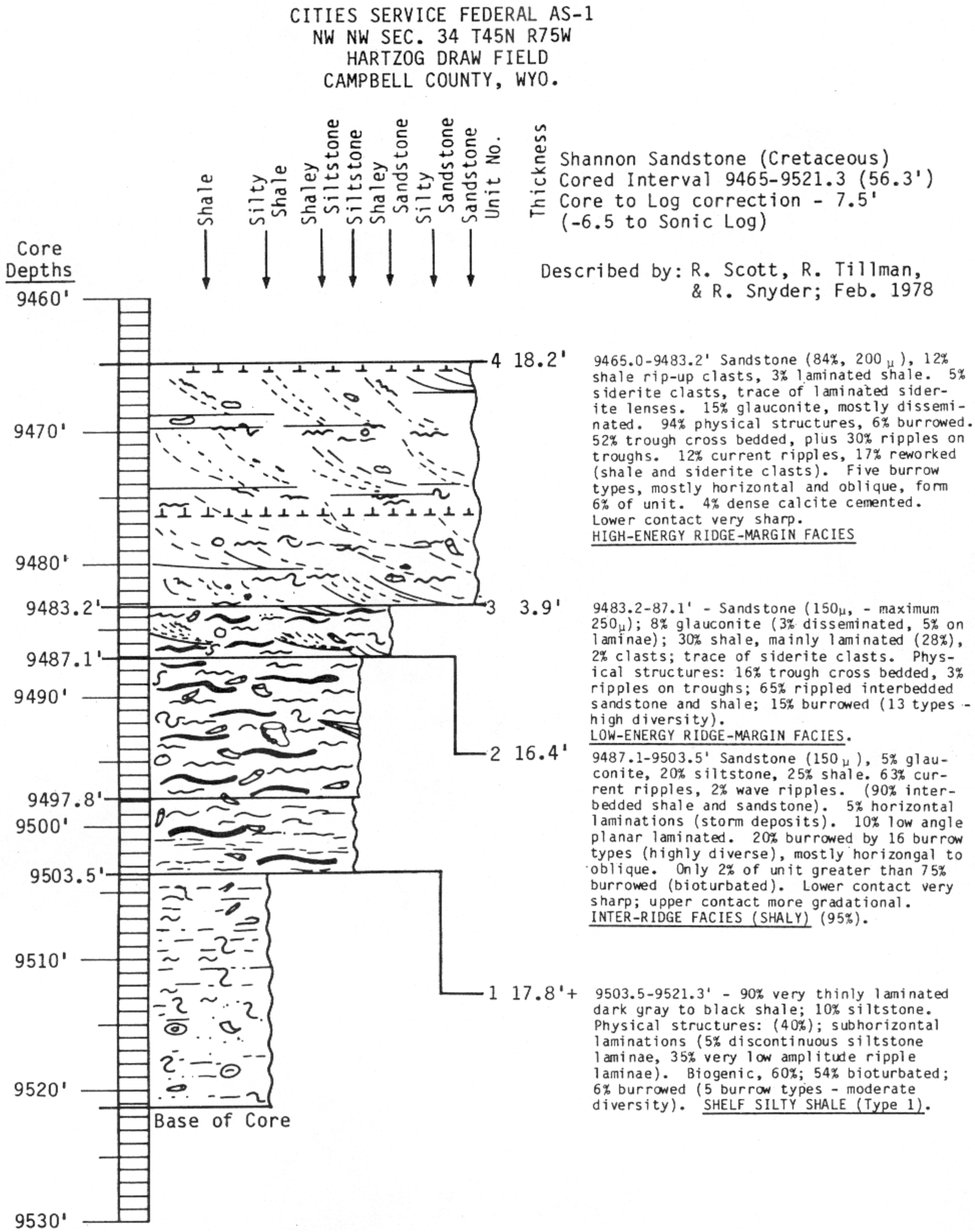


Figure 16: Core Description, Federal AS-1

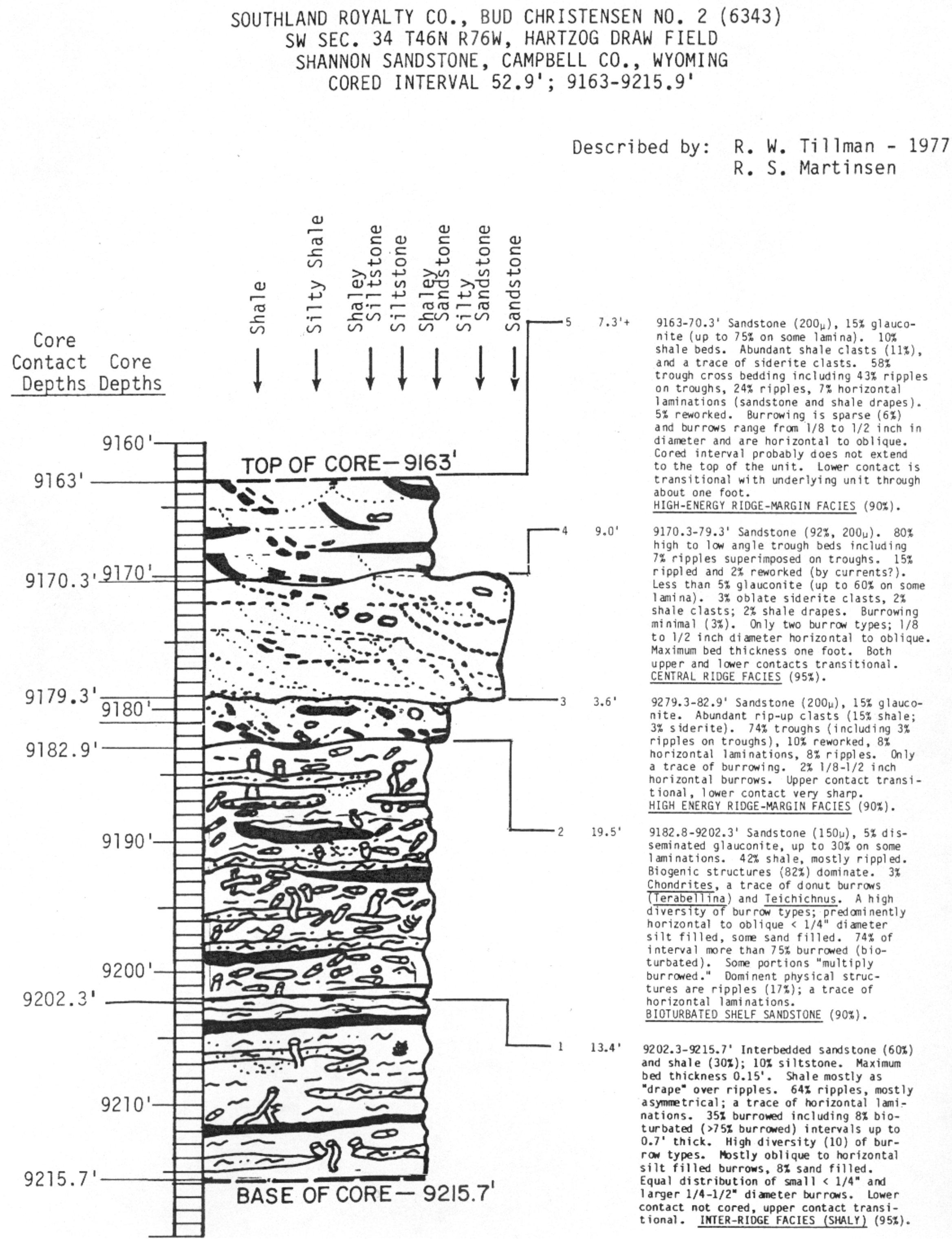


Figure 17: Core Description, Bud Christensen No. 2

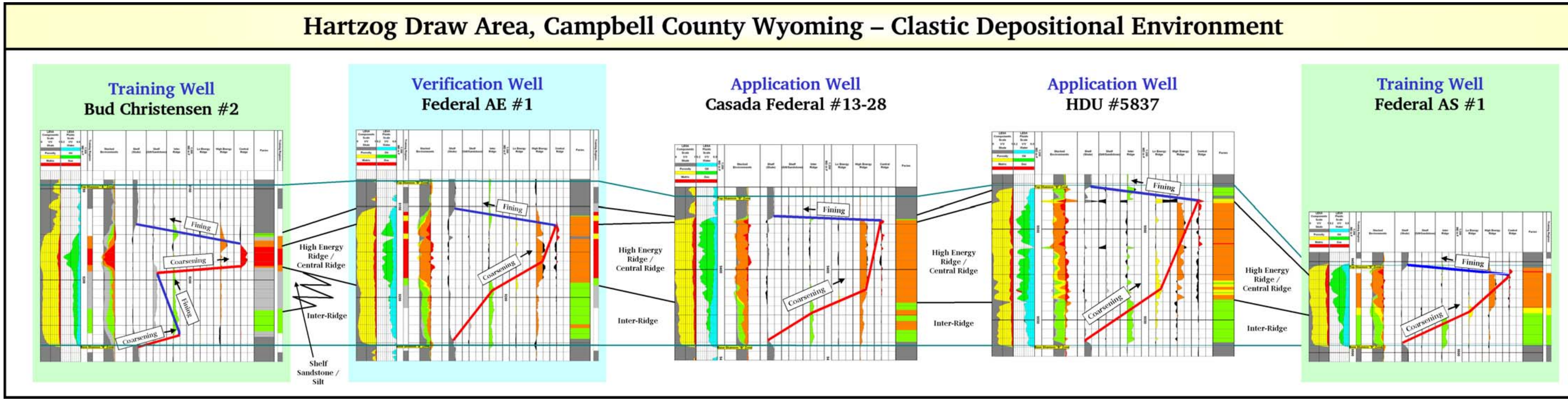


Figure 18: Facies Cross Section, Hartzog Draw

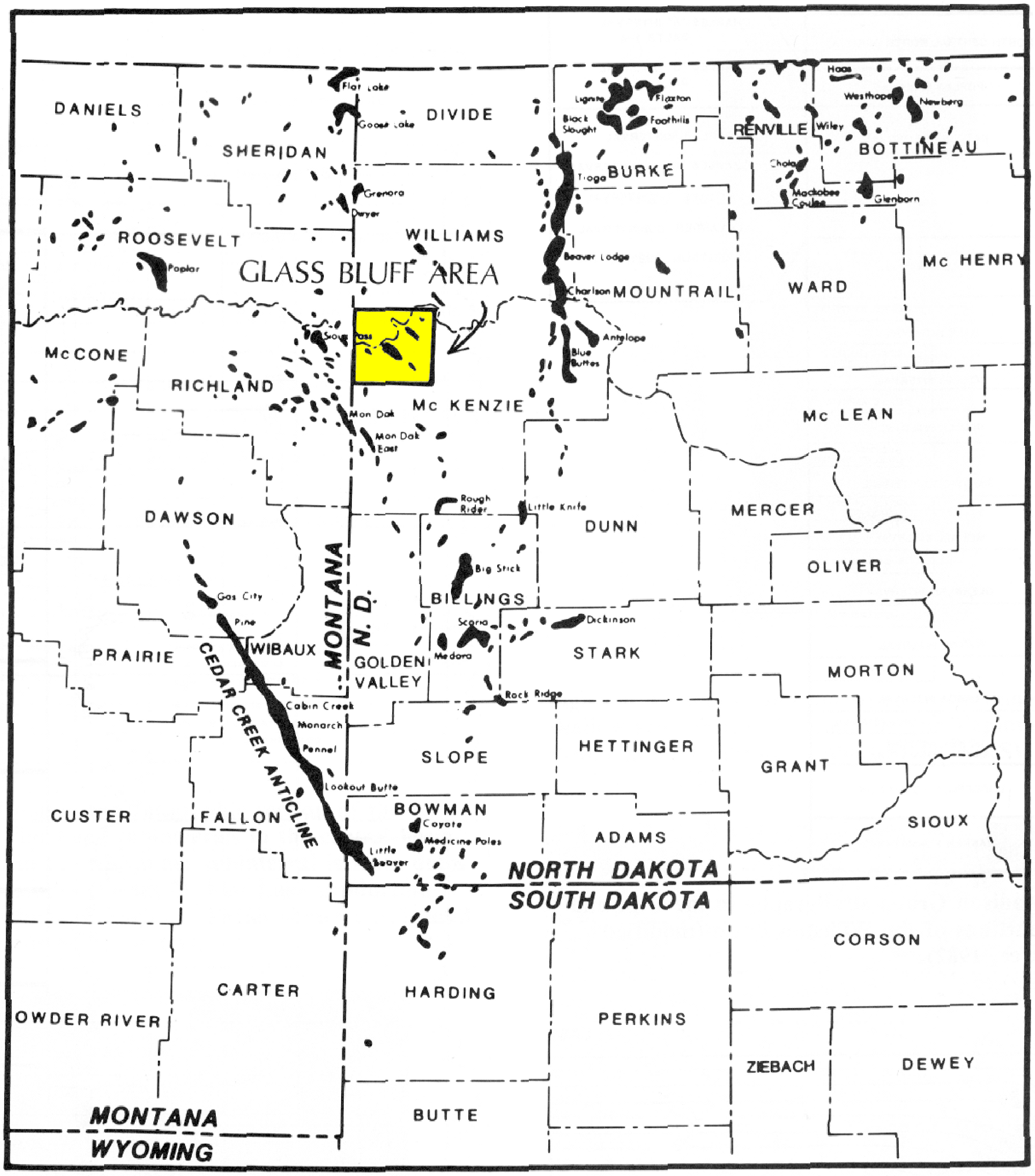


Figure 19: Area map of the Big Stick Field

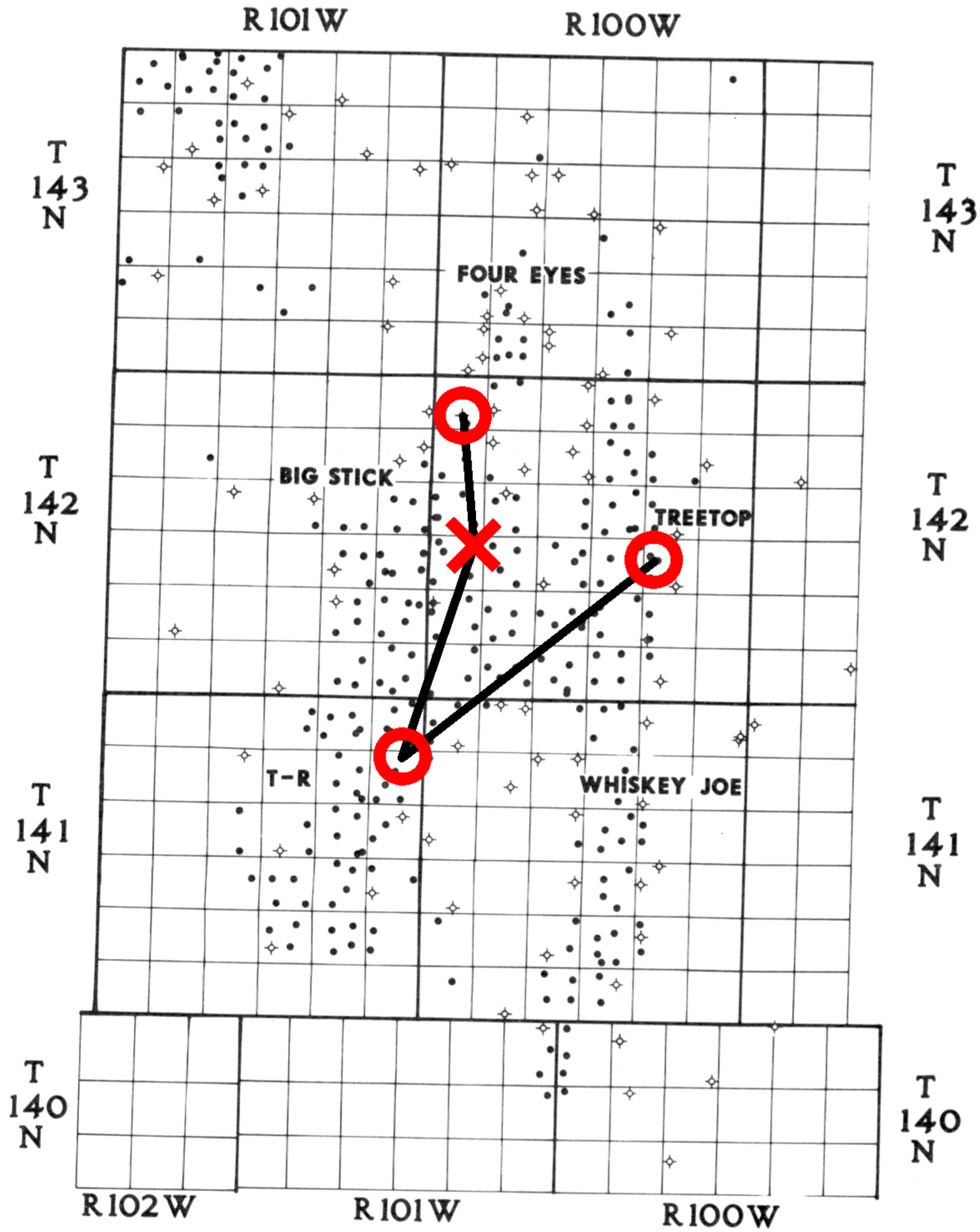


Figure 20: Billings Nose well base indicating locations of various fields.

Wells marked with X are wells with core and logs used for training. Wells marked with O are wells with log only and are application wells.

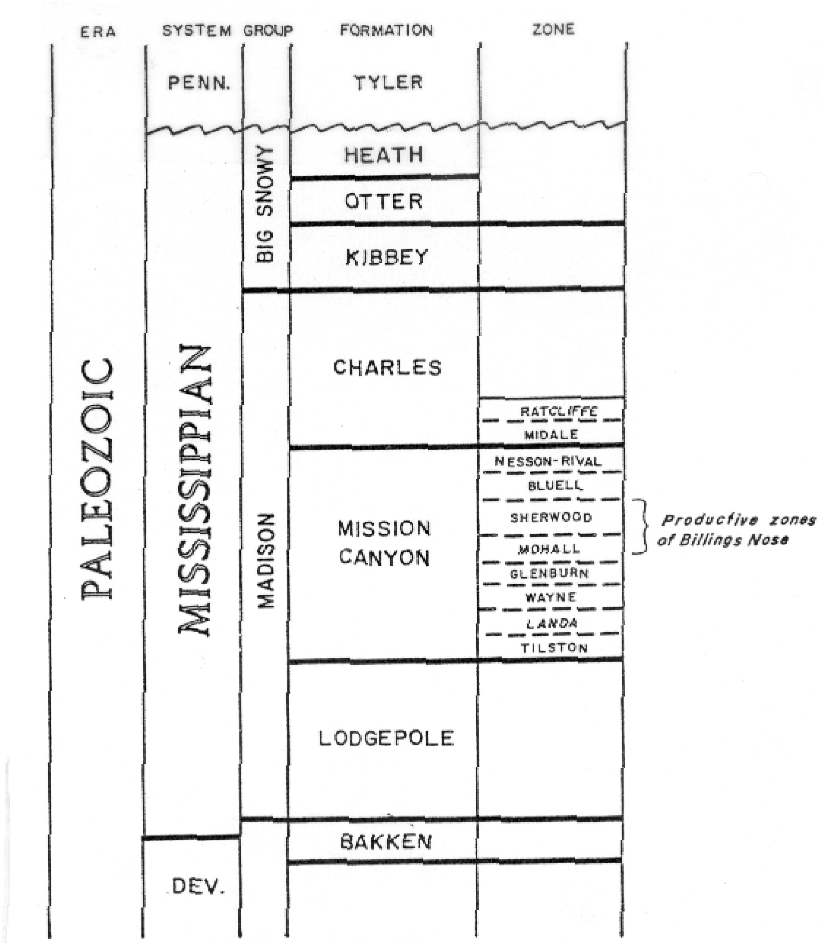


Figure 21: Stratigraphic column of the Central Williston Basin.

Main pay zones of the Billings Nose are form the Sherwood and Mohall beds of the mission Canyon (Harris, et al, 1966).

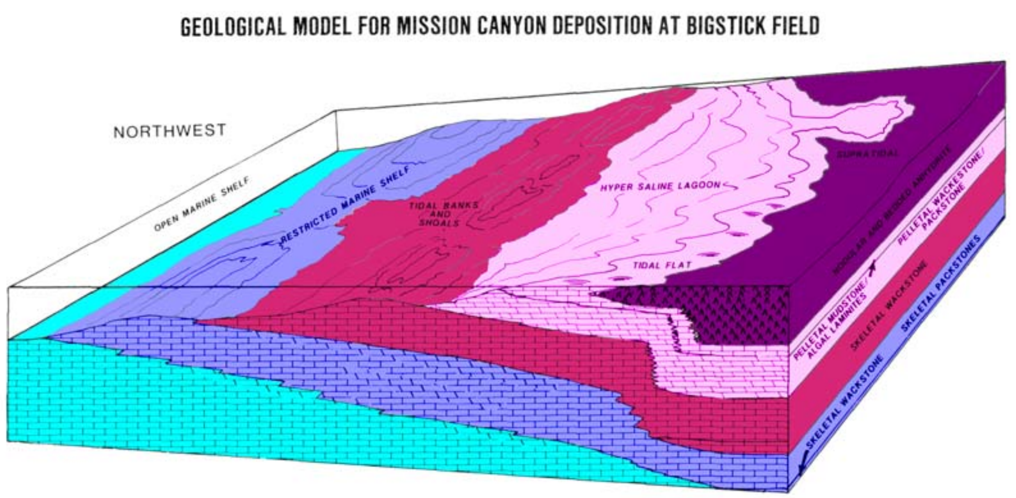


Figure 22: Diagram showing a geological model for the Mission Canyon.

Open marine skeletal packstones grade laterally to transitional and restricted marine wackestones and mudstones, peritidal algal laminated wackestones, and supratidal evaporites. Dolomitization of the restricted marine facies forms the reservoir rock. Nonporous limestones of the open marine and peritidal environments form stratigraphic traps.

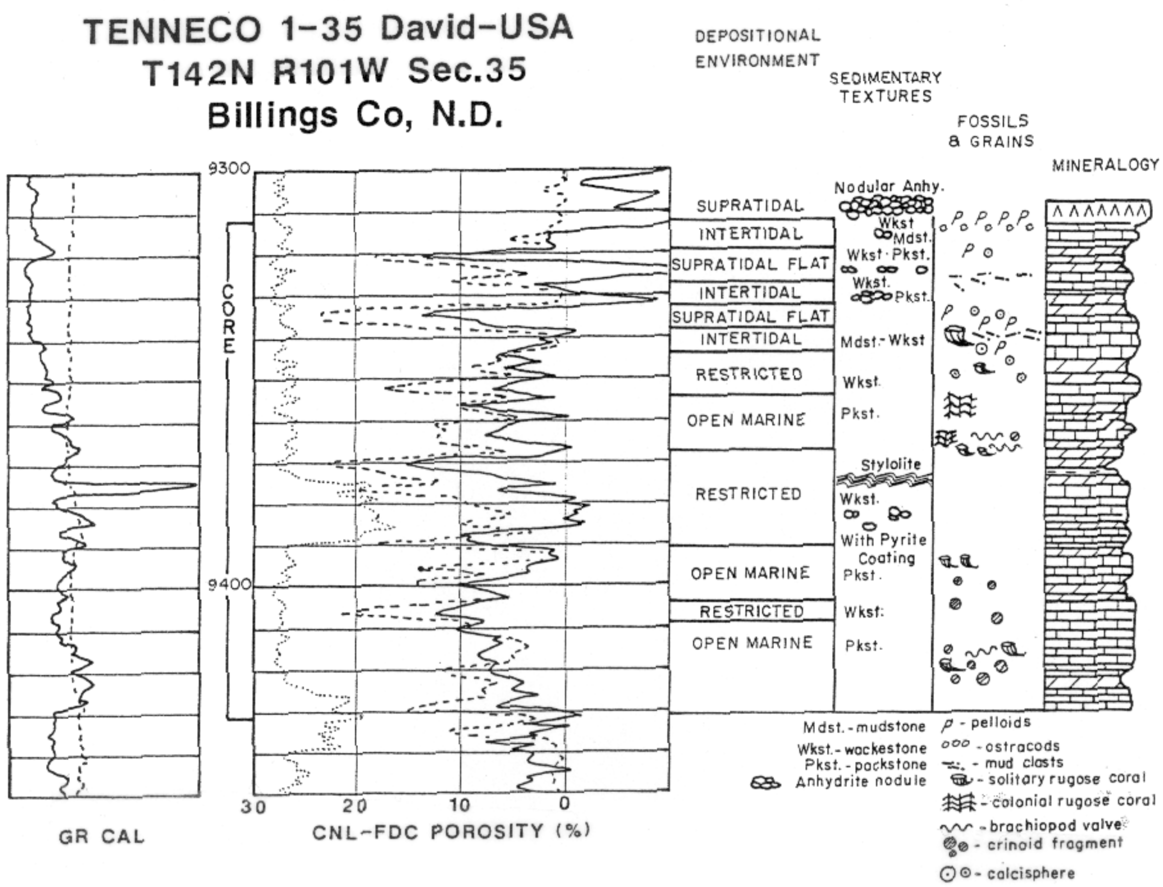


Figure 23: Tenneco 1-35 David

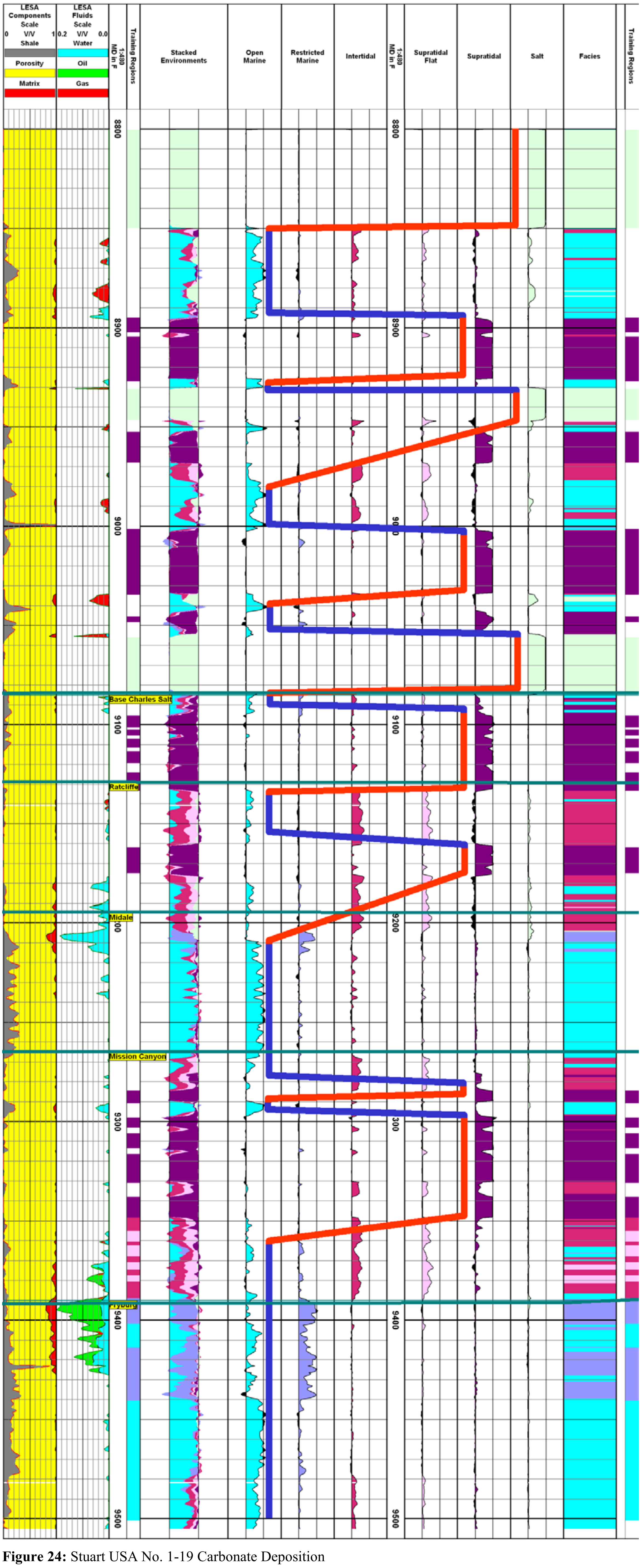


Figure 24: Stuart USA No. 1-19 Carbonate Deposition

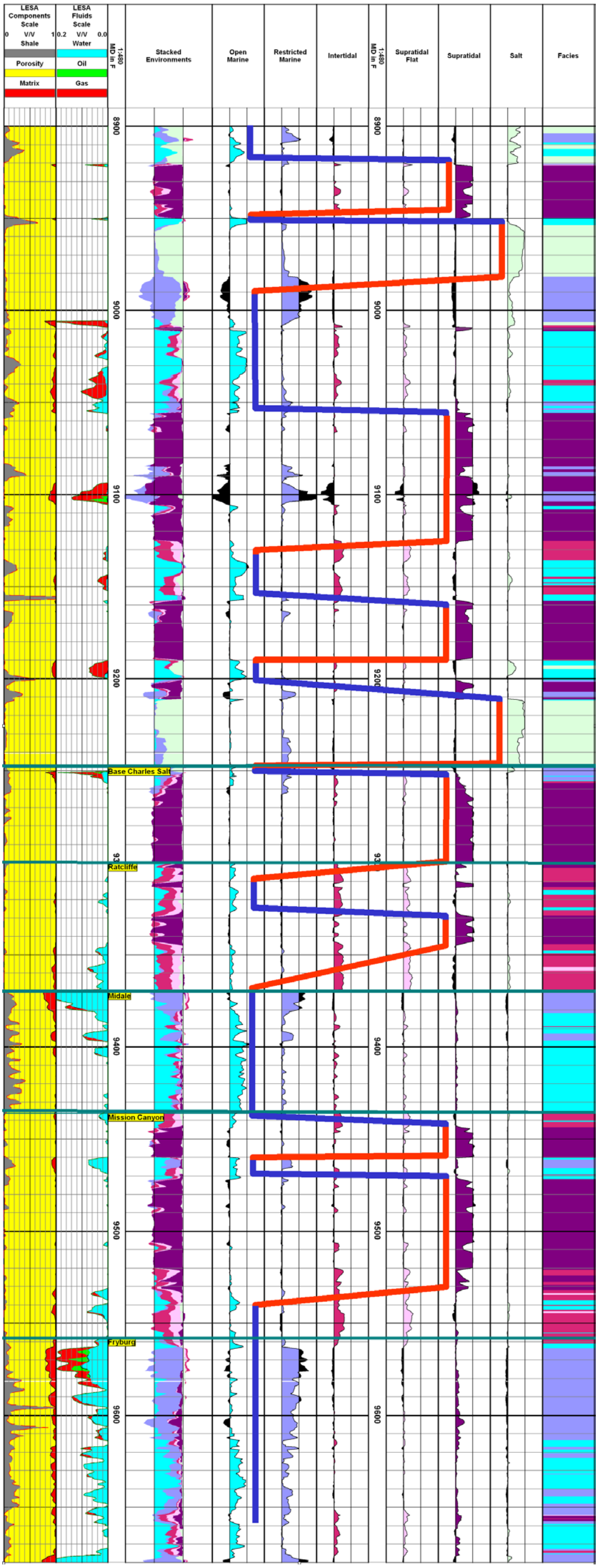


Figure 25*:* Kordon 10-6 Carbonate Deposition

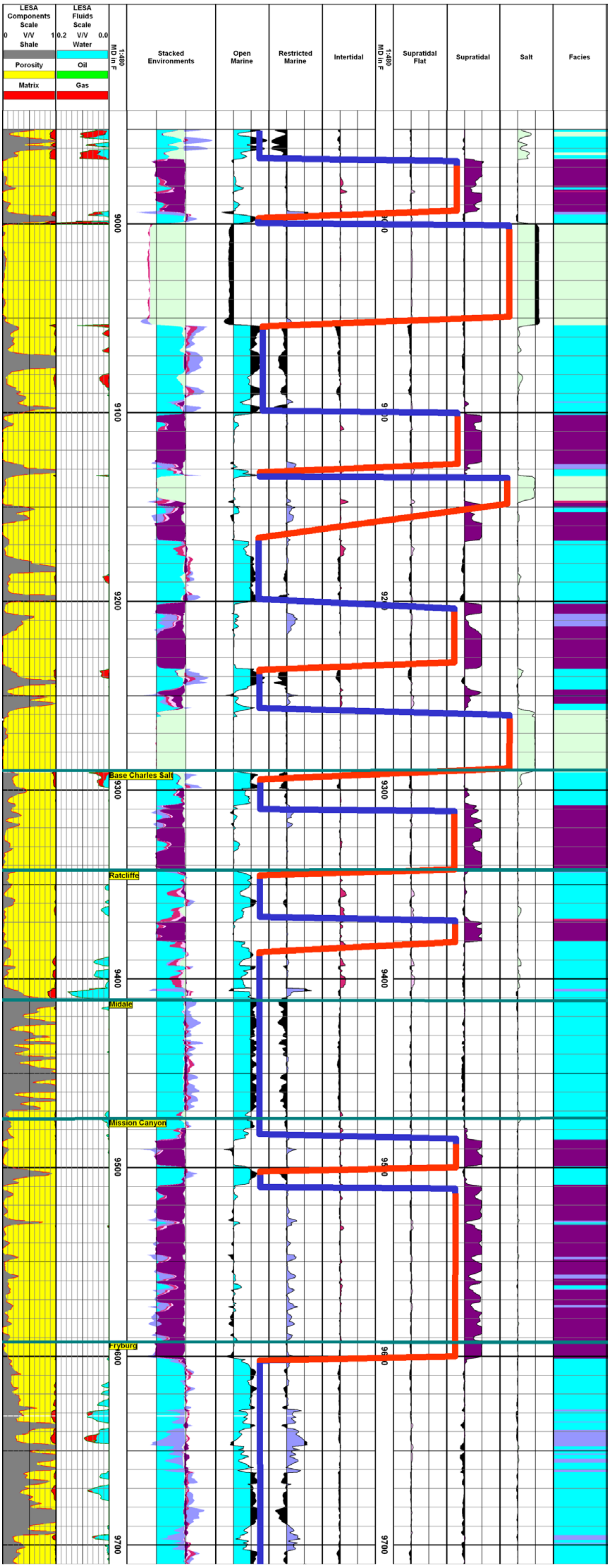


Figure 26: Anna Osadchuck Carbonate Deposition

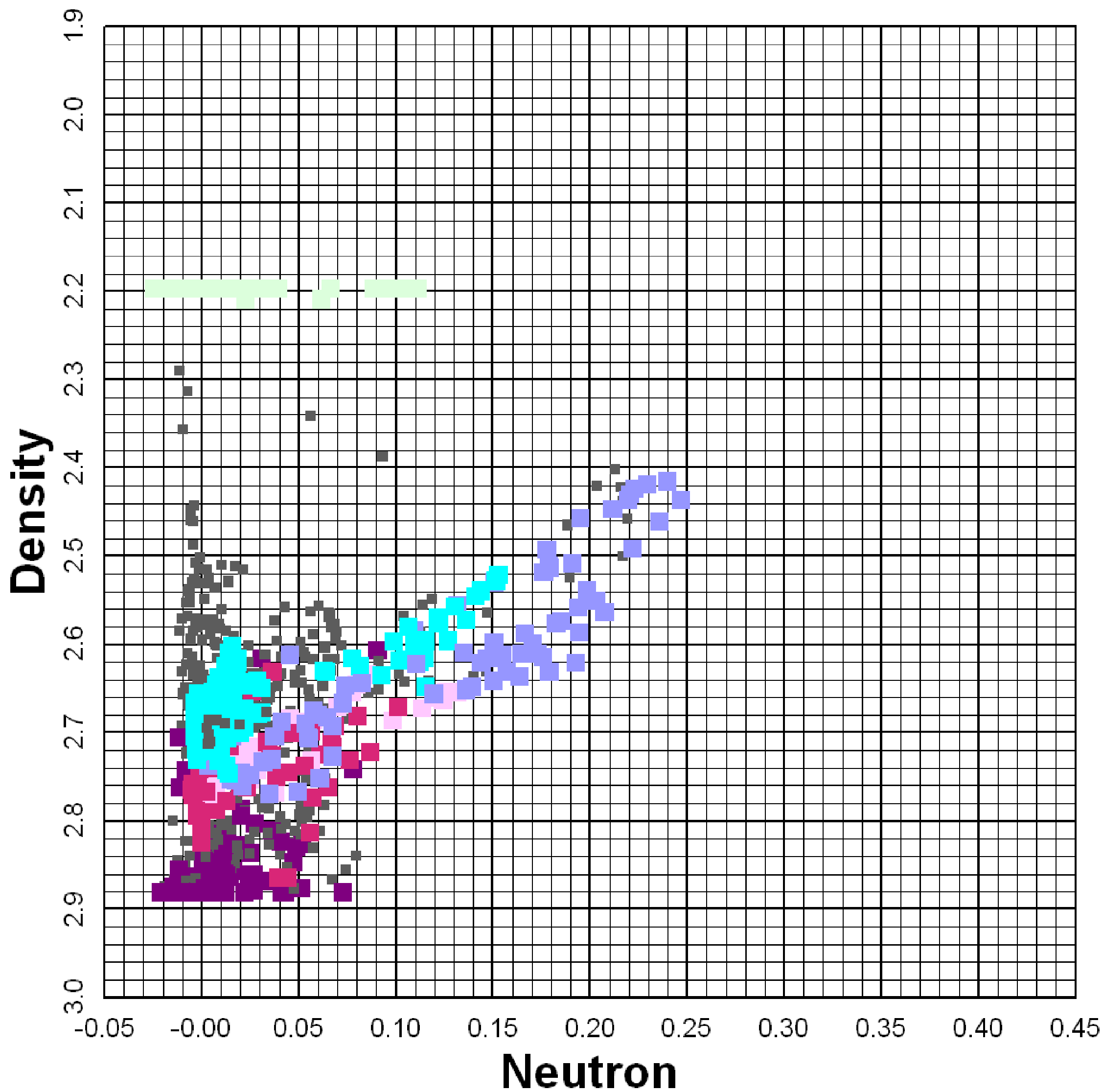


Figure 27: Stuart USA No. 1-19 Density vs. Comp. Neutron

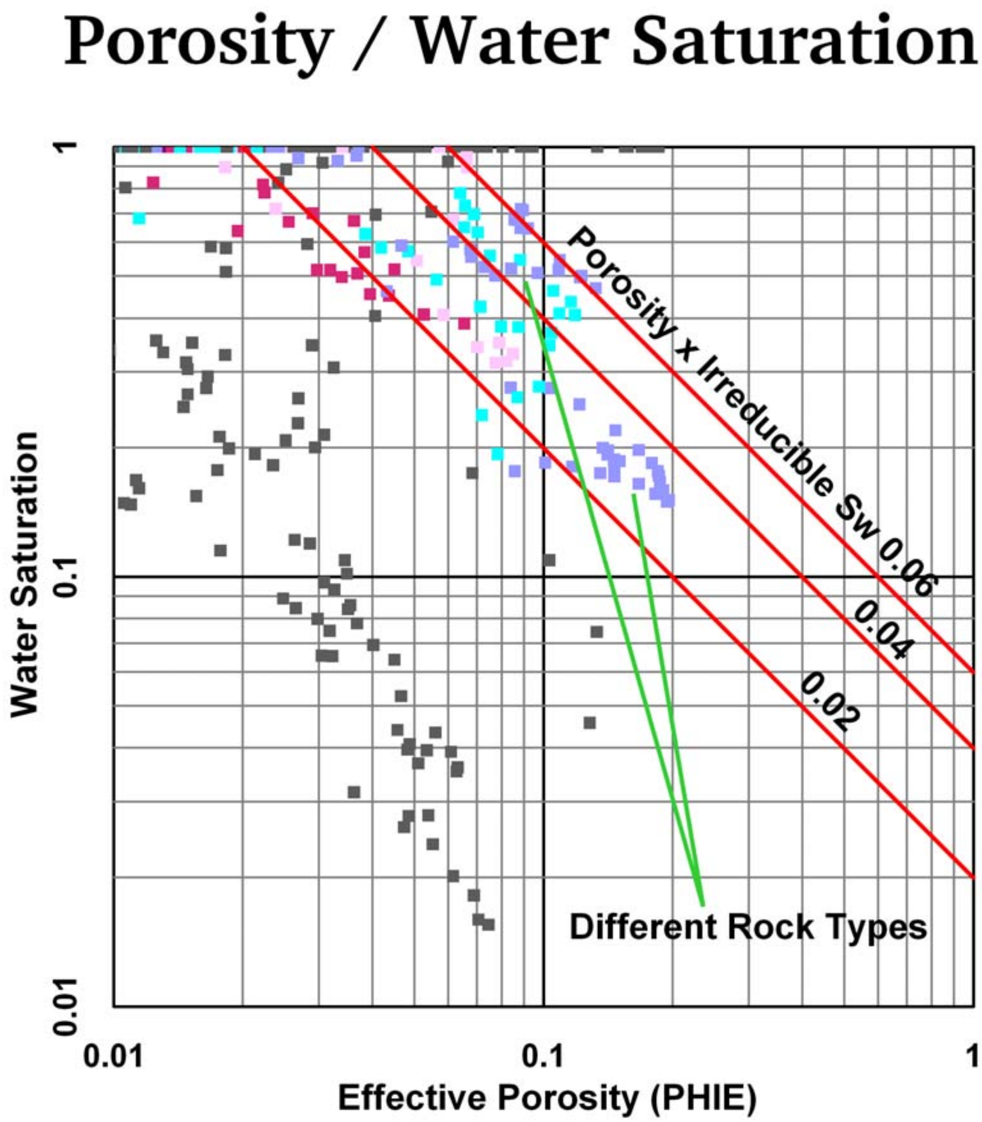


Figure 28: Stuart USA No. 1-19 Porosity vs. Water Saturation Cross Plot.

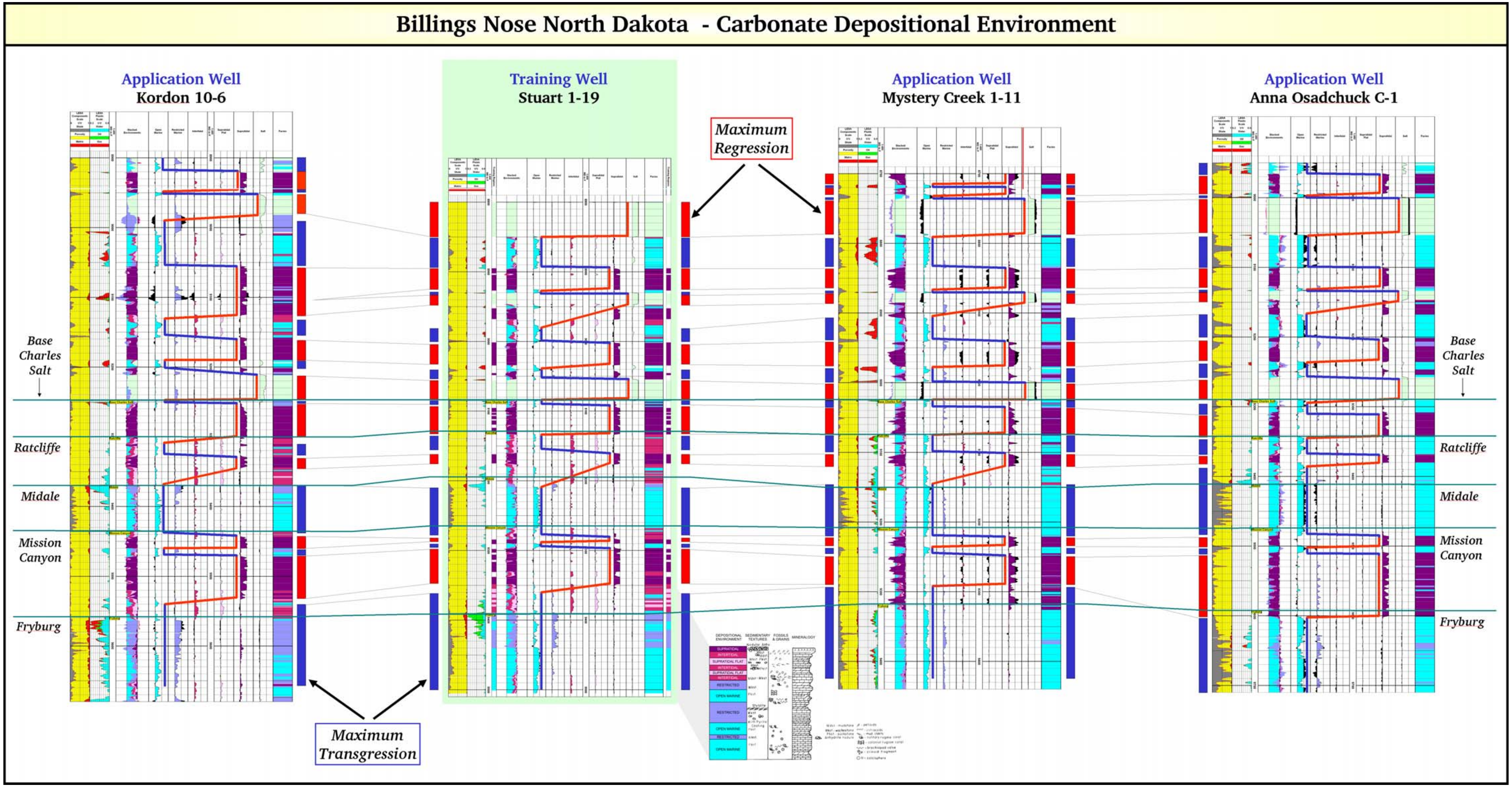


Figure 29: Facies Cross Section, Big Stick and Tree Top Fields.

DIGITAL FORMATION

About the Company

With over 70 years of combined experience in the oil and gas industry, **Digital Formation** has established itself as one of the premier sources of well data presentation systems and professional services.

Digital Formation provides quality consulting and technical services for geological and petrophysical activities of the exploration and production industry, as well as analysis and presentation software (for Microsoft® Windows™). Our software was originally designed by our consulting staff, to help solve industry specific problems, and is continually upgraded with suggestions from our consultants and from the industry. **Digital Formation** has revolutionized the area of data graphical presentation on a PC platform, setting the standard for flexible, readable log presentation.

Used by clients worldwide, **Digital Formation** software provides a range of presentation and analysis solutions that can be customized by you to meet your specific needs. This gives you the power to present concise graphically appealing data both accurately and efficiently.

Whether you are a large multinational organization, a small independent, or a single-site user, **Digital Formation** stands ready to help provide solutions to your oil and gas industry needs. Solutions that will help you reach your true exploration and production potential.

If you would be interested in improving your business' capabilities in the oil and gas industry, please allow us to answer your questions or download a free 45-day examination of our software via the Internet. Contact us at any of the following:

Telephone:	(888) 747-5372 US & Canada only (303) 770-4235	
Facsimile:	(303) 770-0432	
Postal address:	6000 East Evans Avenue Suite 1-400 Denver, Colorado 80222-5415 USA	
Web address:	http://www.DigitalFormation.com ftp://www.DigitalFormation.com/pub	
Electronic mail:	General Information:	Info@DigitalFormation.com
	Sales:	Sales@DigitalFormation.com
	Customer Support:	Support@DigitalFormation.com
	Webmaster:	Webmaster@DigitalFormation.com