GCS Solutions, Inc.

geopressure consulting services & solutions

RhoVe™ Method

(U.S. patent pending - copyright © 2016)

A New Empirical Pore Pressure Transform

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Research paper

RhoVe method: A new empirical pore pressure transform

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A R T I C L E I N F O

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Pore pressure

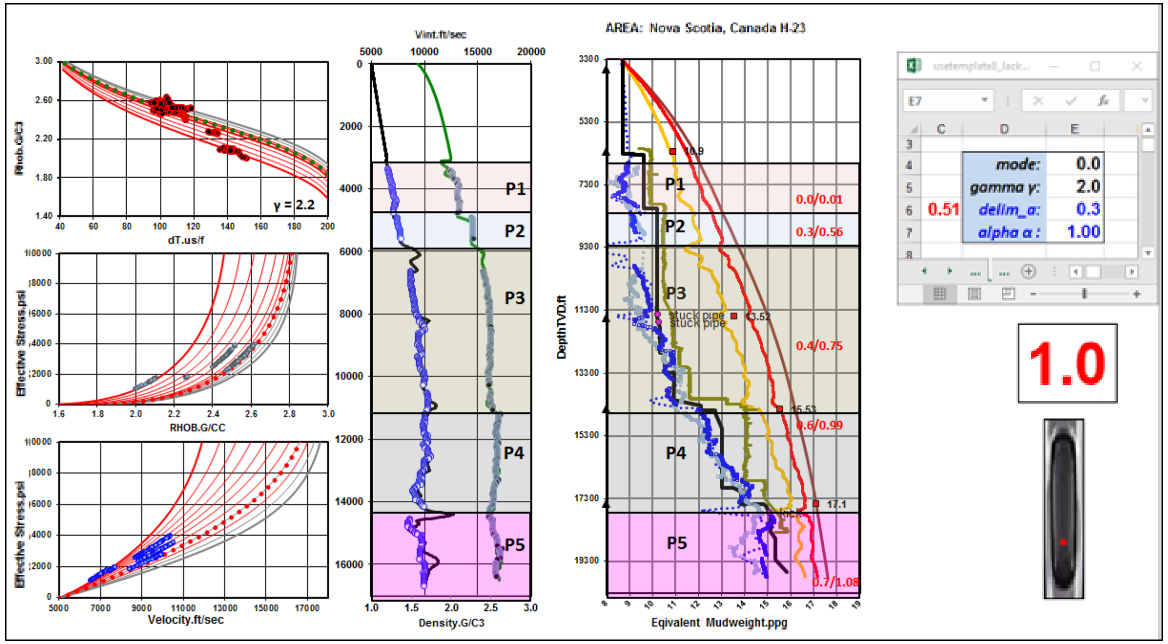
A B S T R A C T

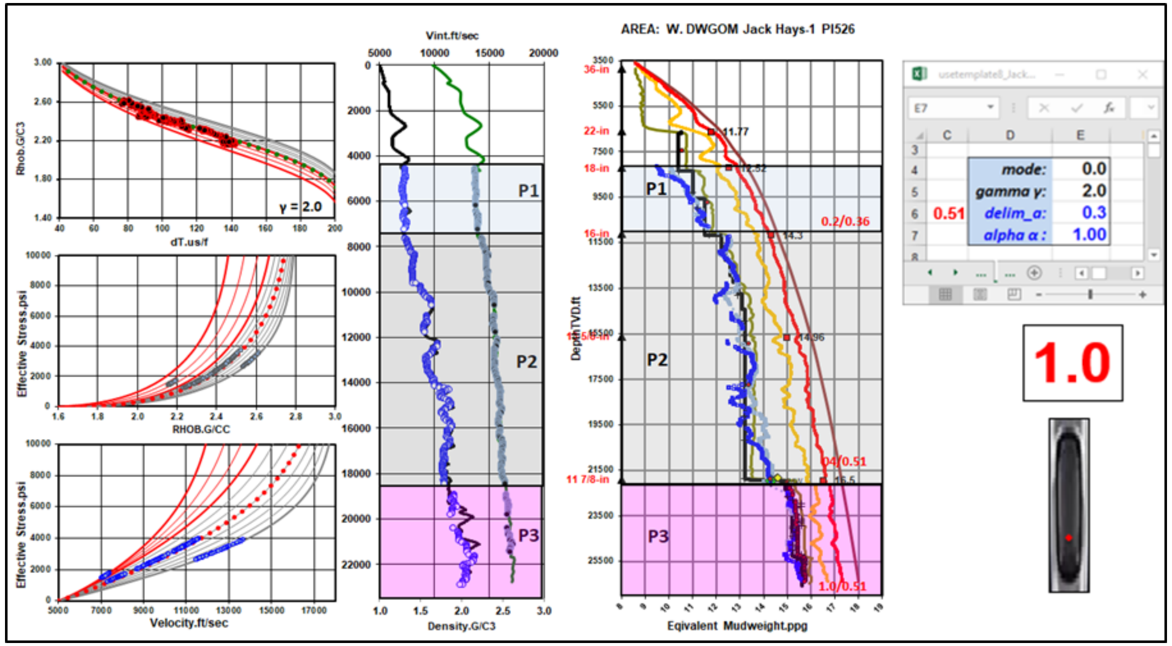
A new empirical pore pressure transform has been developed that includes many of the advanced, state-of-the-art concepts that are useful in today's pore pressure estimation and theory. The rhob-velocity-effective stress (Rho-V-e) method produces a model-driven, stand-alone set of "virtual" rock property relationships, which at intermediate positions are consistent with Bowers method default values for the Gulf of Mexico. The RhoVe method uses a single transform to convert both compressional sonic and bulk density to common estimates of effective stress and pore pressure where convergence of the two transformed properties offers a robust solution.

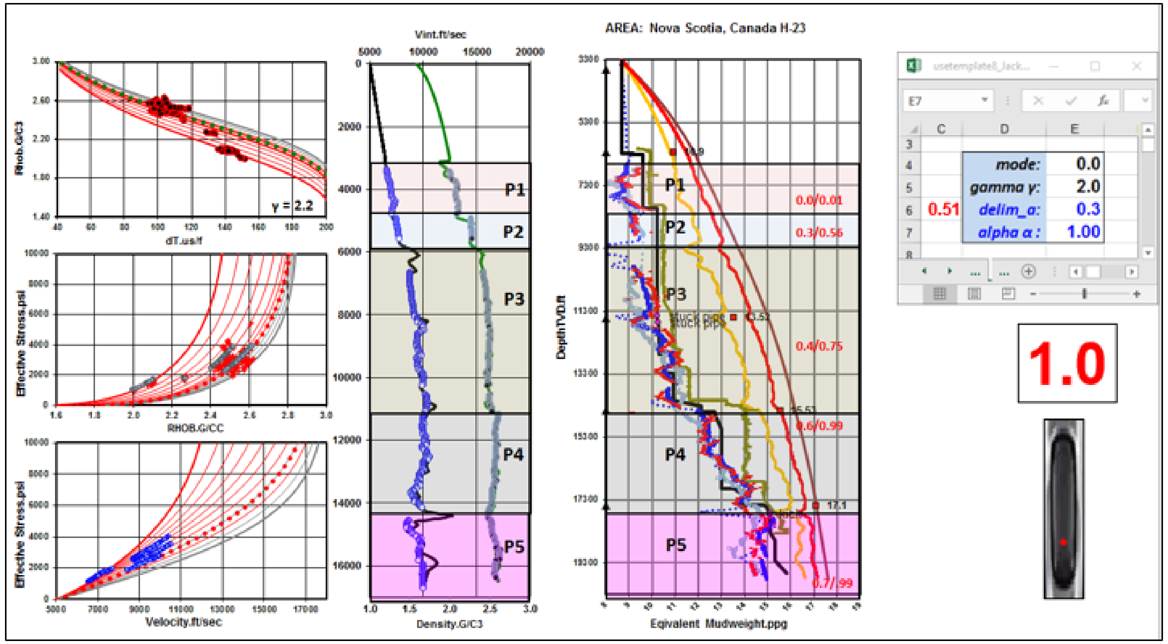
Velocity-density conversion functions are mathematically linked to a continuous series of velocity-depth normal compaction trend functions. The calculations are limited by bounding end-member curves that provide a basis for intermediate (fractional) solutions of velocity-effective stress and density-effective stress relationships that are applied to a well of interest.

Paired "virtual" velocity-depth compaction trends were iteratively solved by using published theoretical smectite and illite porosity trends and velocity-depth normal compaction trends. By using the

RhoVe™ Method







RhoVe™ Auto

Compositional Changes

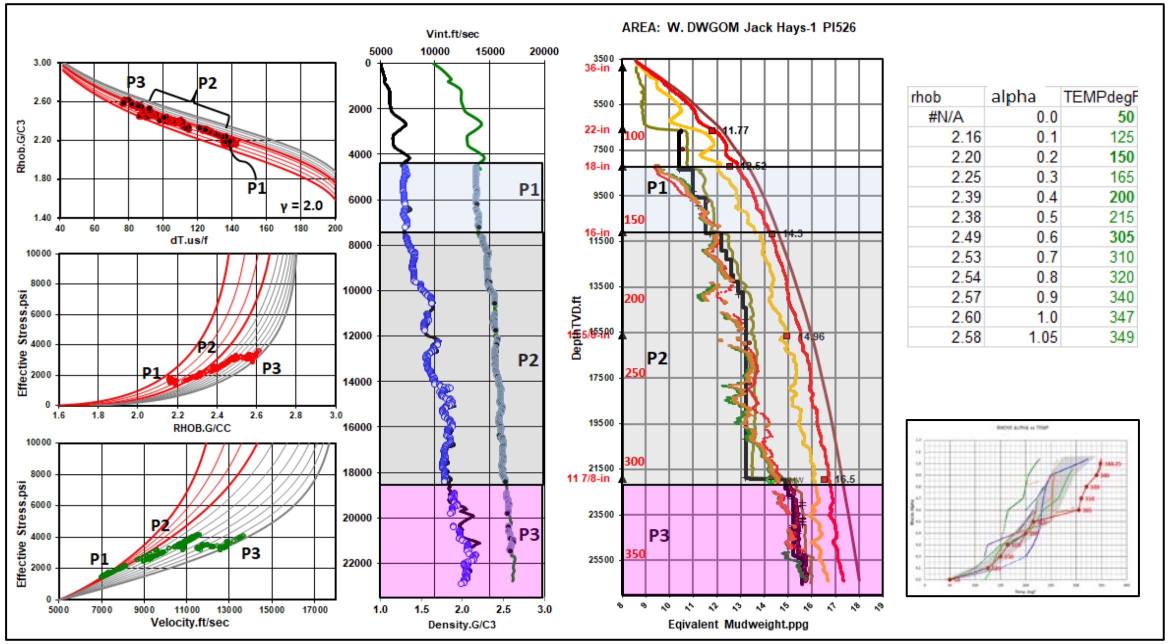
(executable)

RhoVe™ T

Thermodynamic Solutions

(executable)

Acoustic Impedance, Density, Sonic



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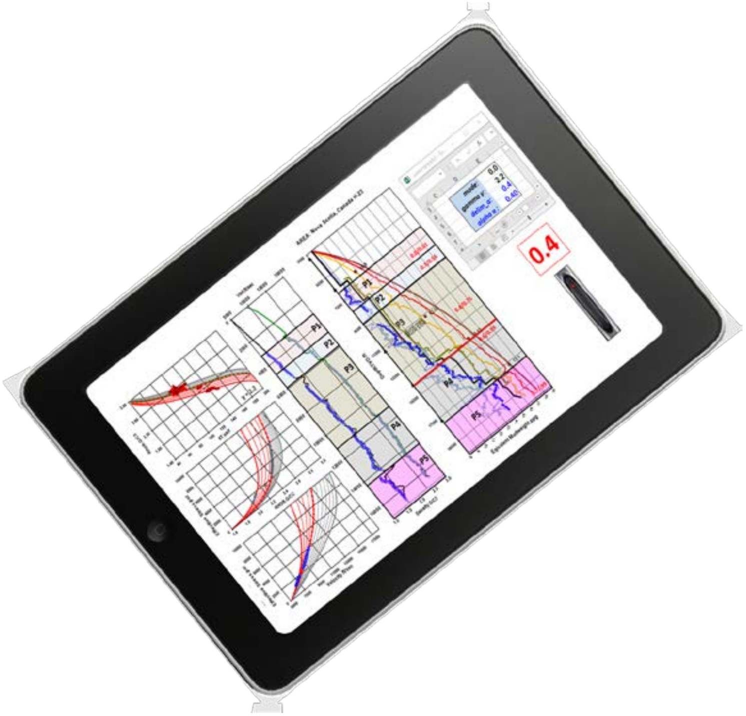


RhoVe™ Method

(U.S. patent pending - copyright © 2016)

JIP – seeking $55,000 investment for:

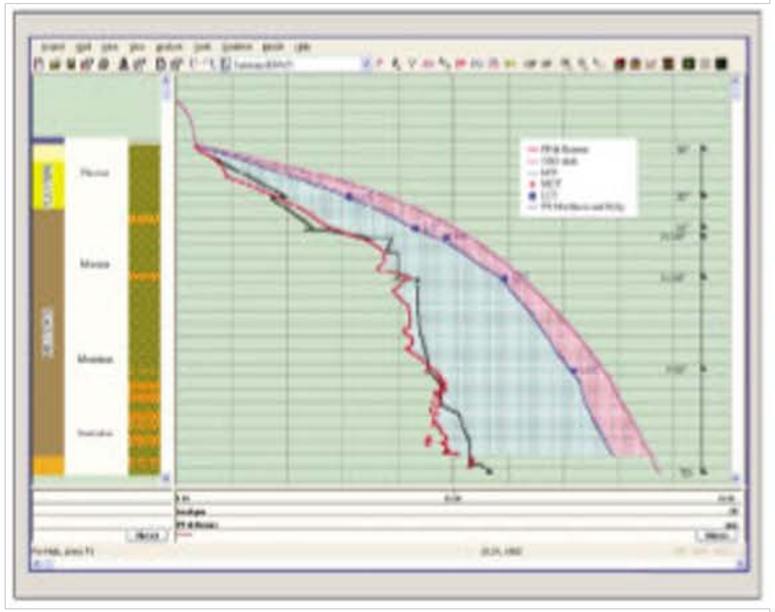
- Commercial implementation of RhoVe method as a plug-in or web-based application to include:
  - Real-Time WITSML connectivity,
  - notebook (iPad) capability,
  - 1D temperature modeling,
- Explore automation capabilities,

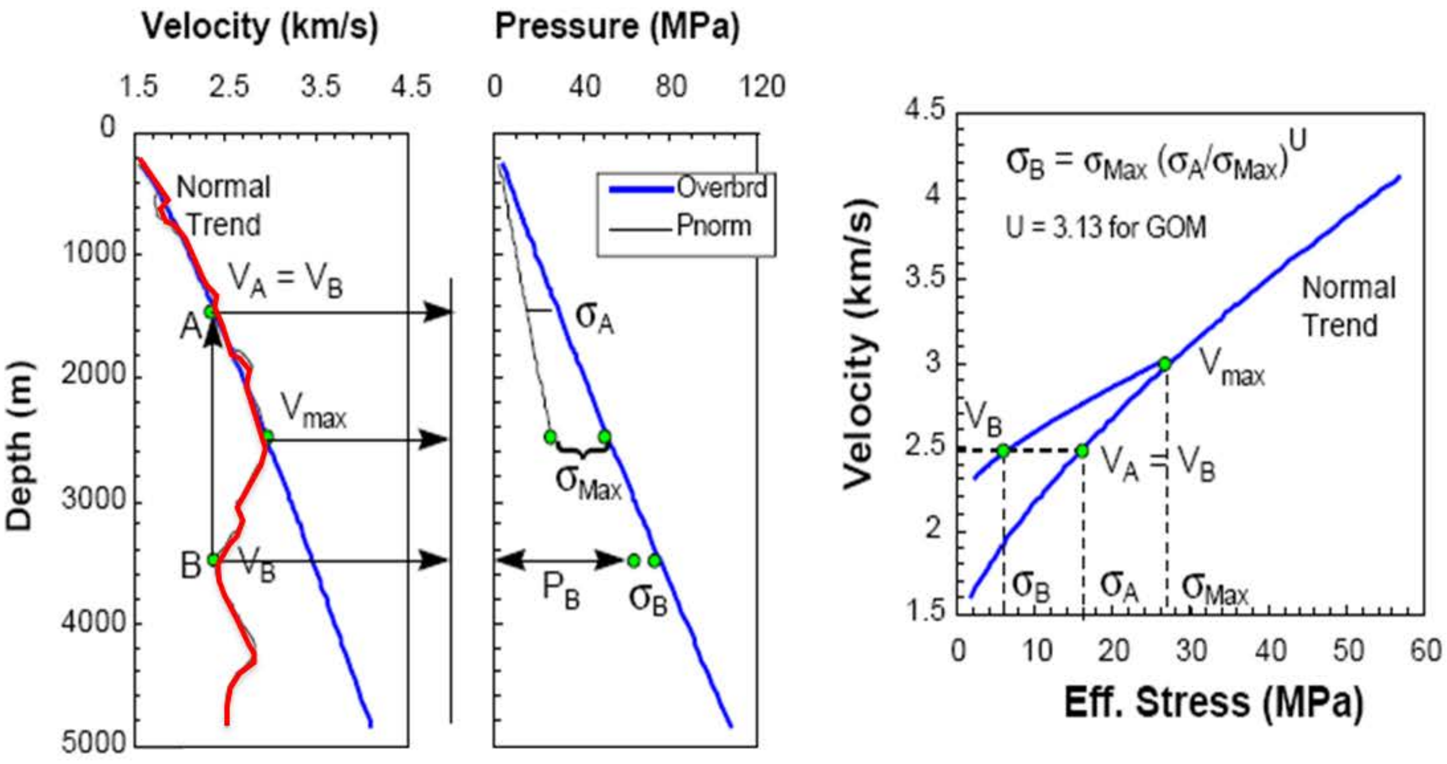
Joint Industry Project - DEA 119

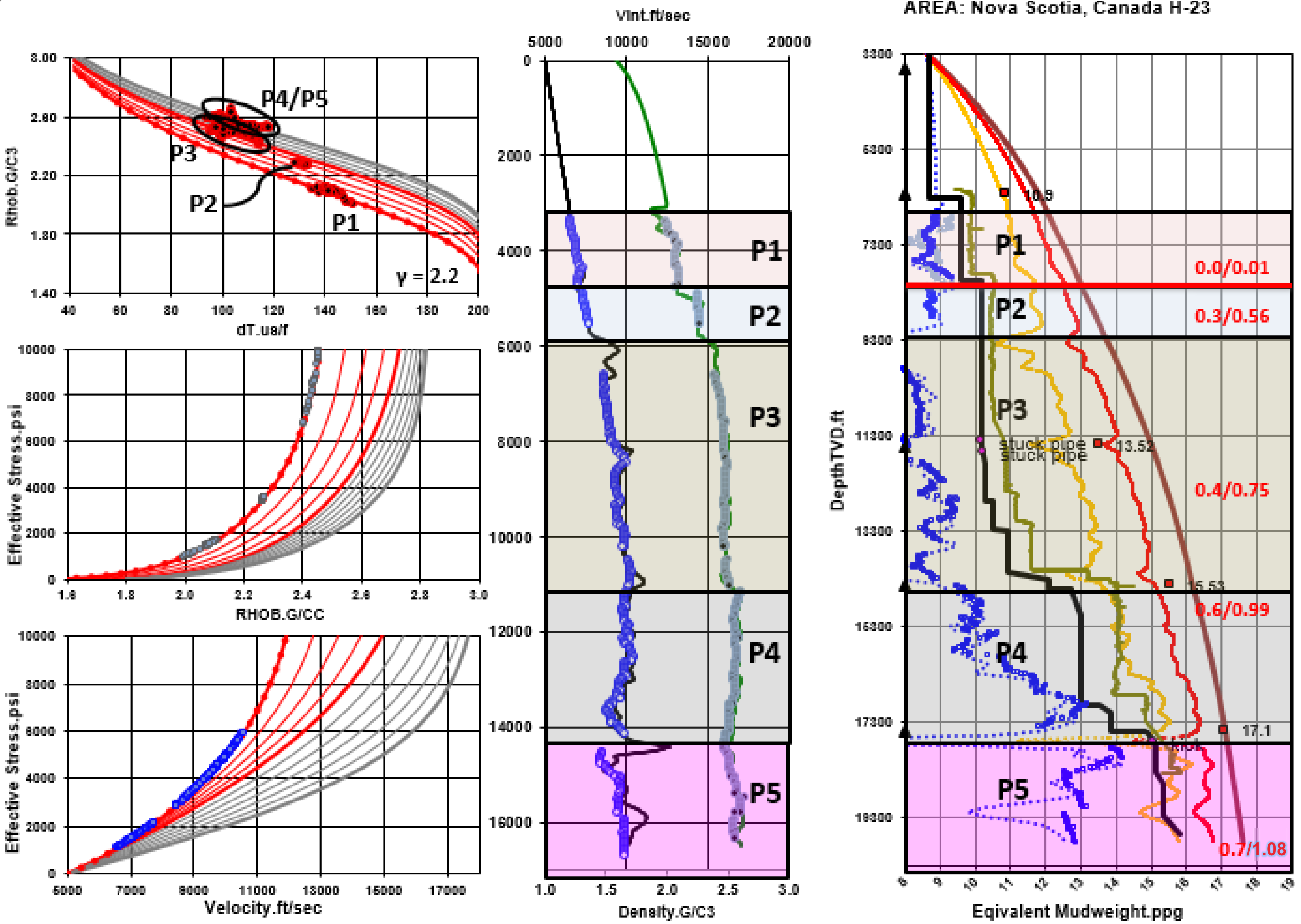
An Improved Methodology to Predict Predrill Pore Pressure in Deepwater Gulf of Mexico - KSI

All new pore pressure methods published since the late 60's have been effective stress approaches. They differ only in the way that they determine effective stresses. These techniques can be subdivided into three categories

1) Vertical Methods
2) Horizontal Methods
3) Other

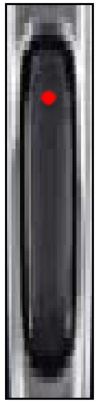


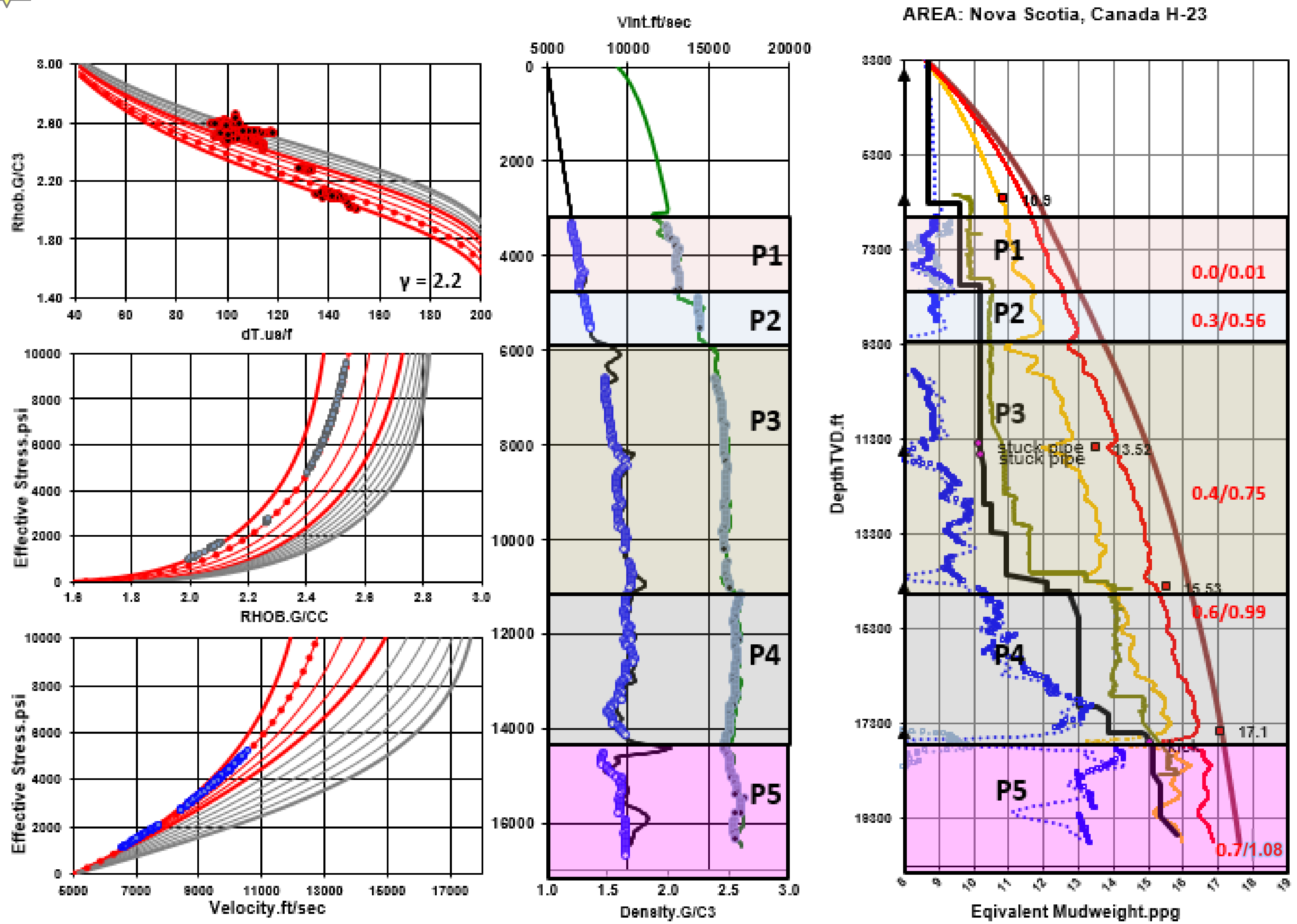




AREA: Nova Scotia, Canada H-23
P4/P5
P3
P2
P1
γ = 2.2
Rhob.G/C3
dT.us/f
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
DepthTVD.ft
Eqivalent Mudweight.ppg
P1
P2
P3
P4
P5
10.9
stuck pipe
13.52
15.53
17.1
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08

0.0

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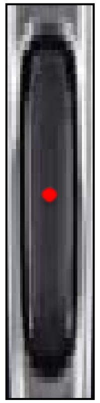
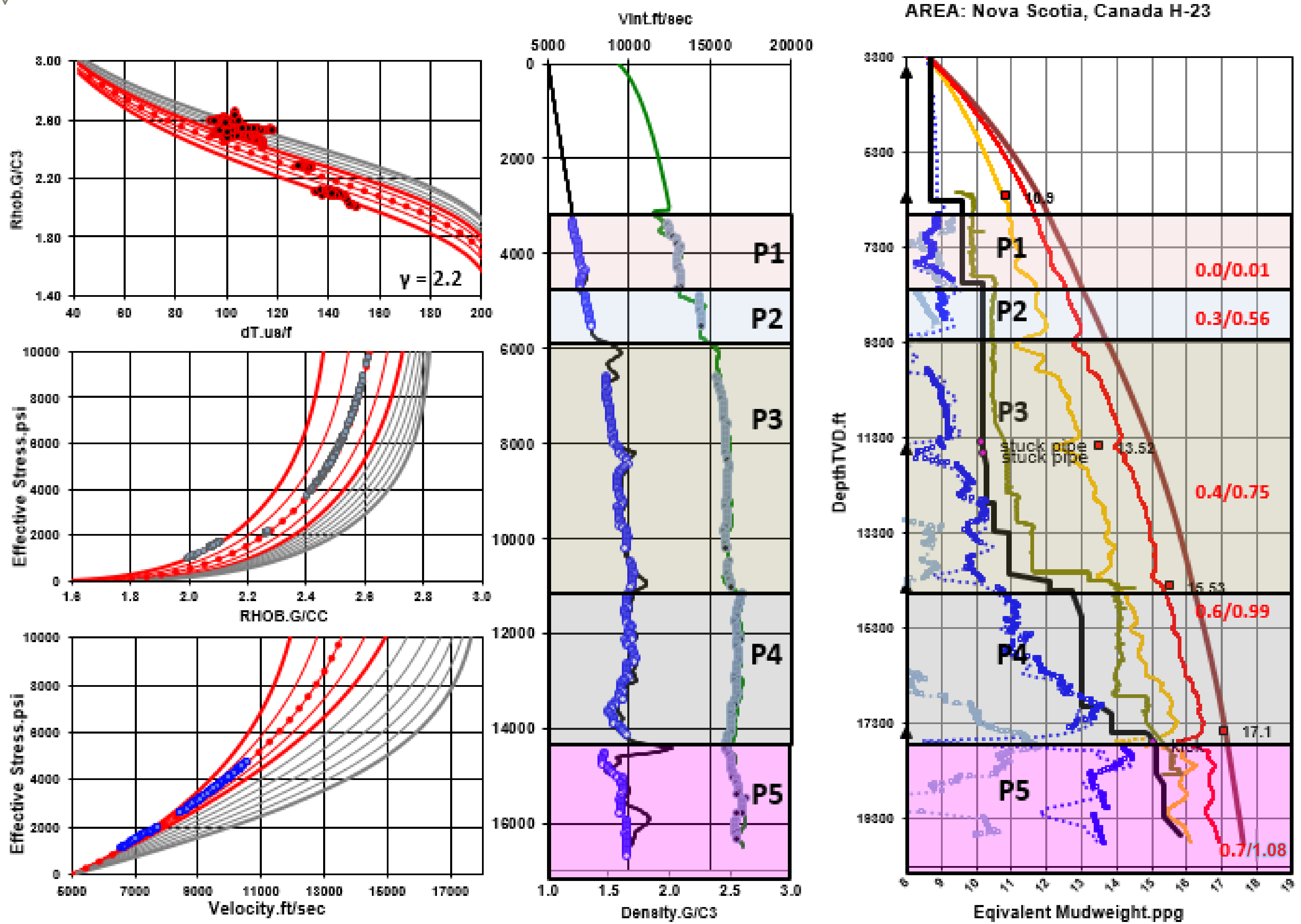
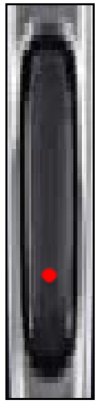
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Effective Stress.psi
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
10.9
stuck pipe
13.52
15.53
17.1
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08

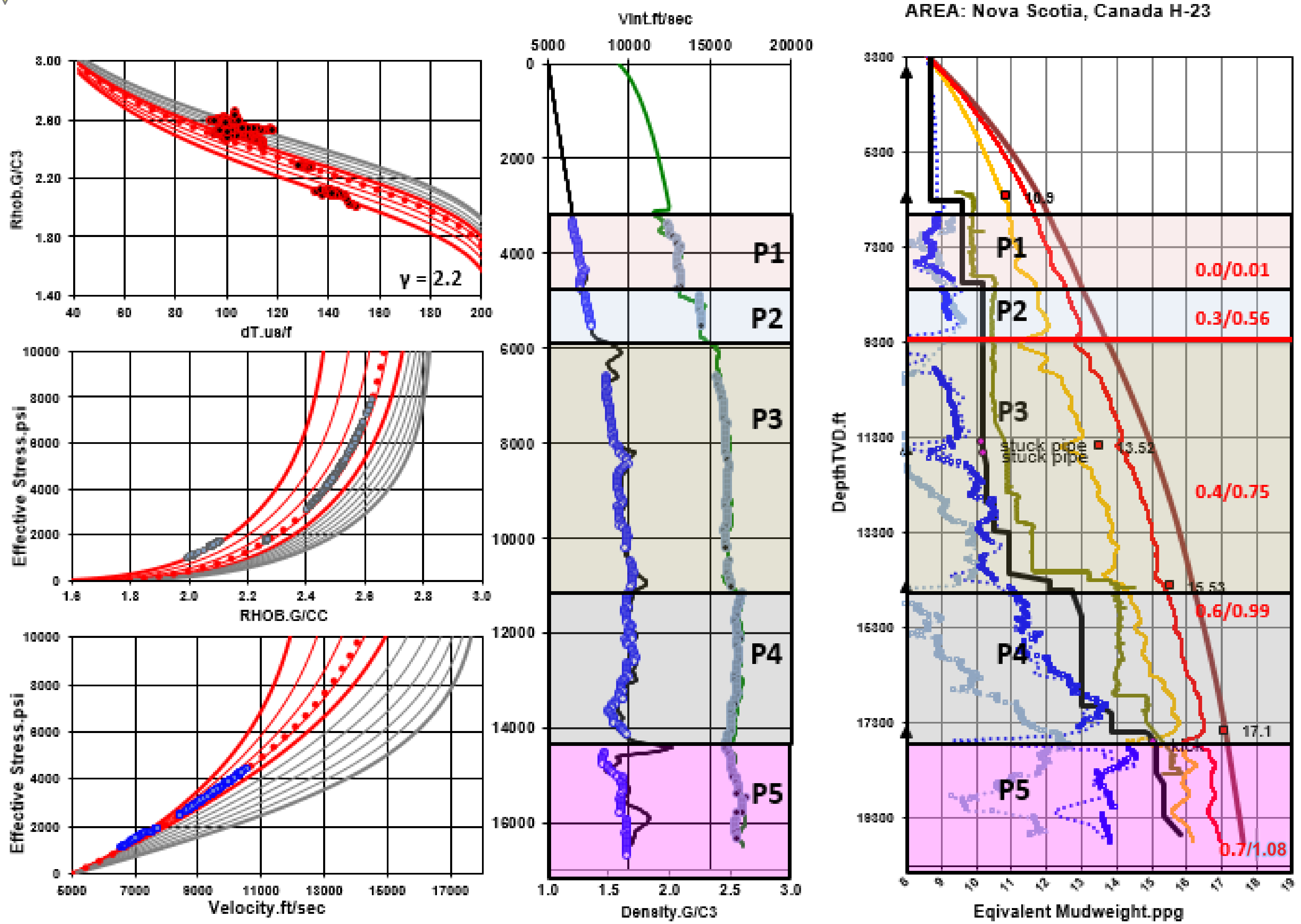
0.1




AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
stuck pipe
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08
10.9
13.52
15.53
17.1

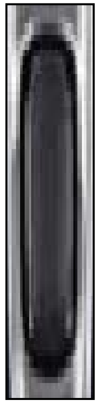
0.2

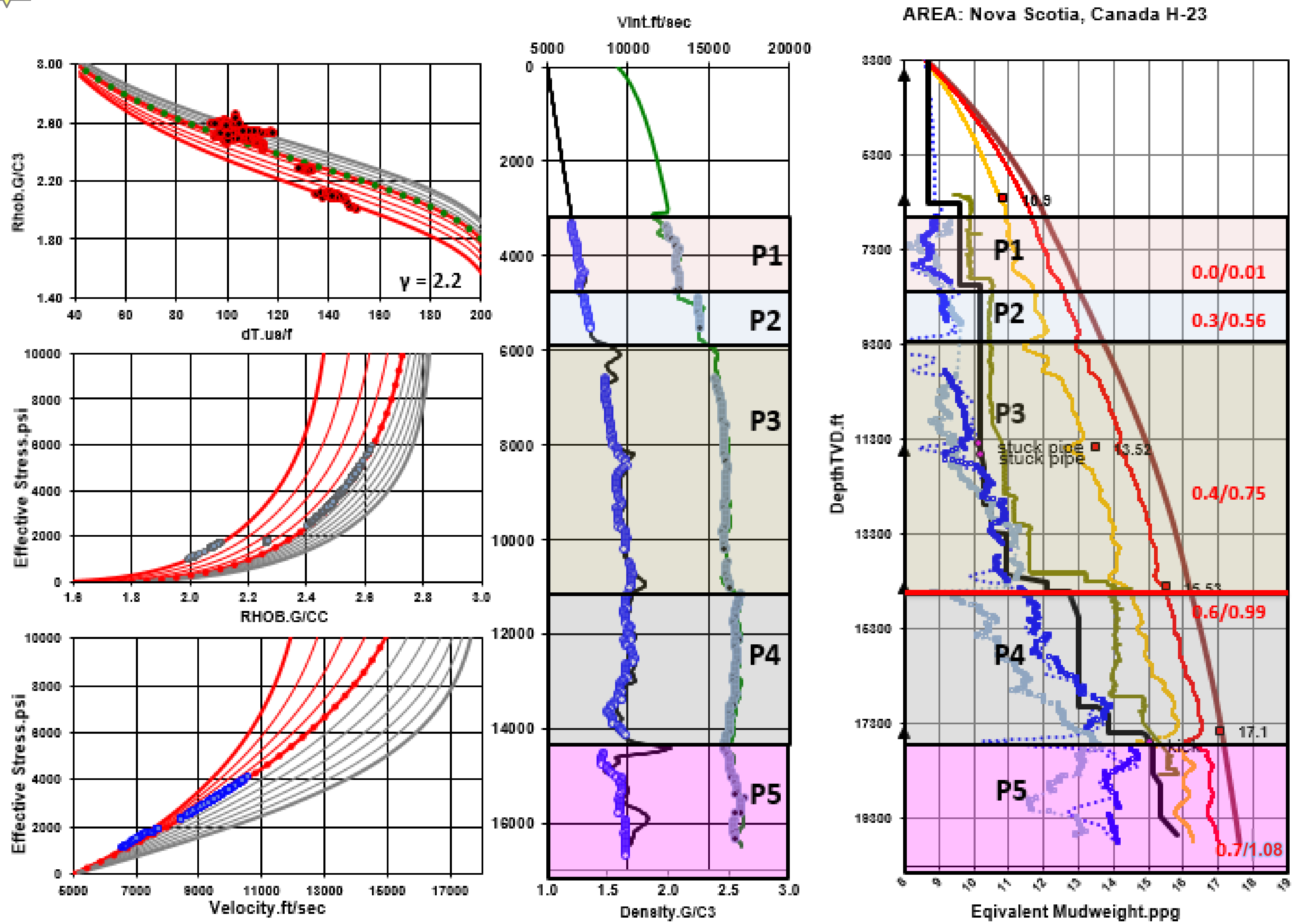




AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
10.9
stuck pipe
13.52
15.53
17.1
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08

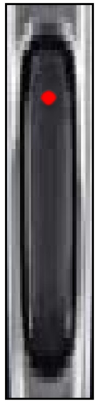
0.3





AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Effective Stress.psi
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
10.9
stuck pipe
13.52
15.53
17.1
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08

0.4



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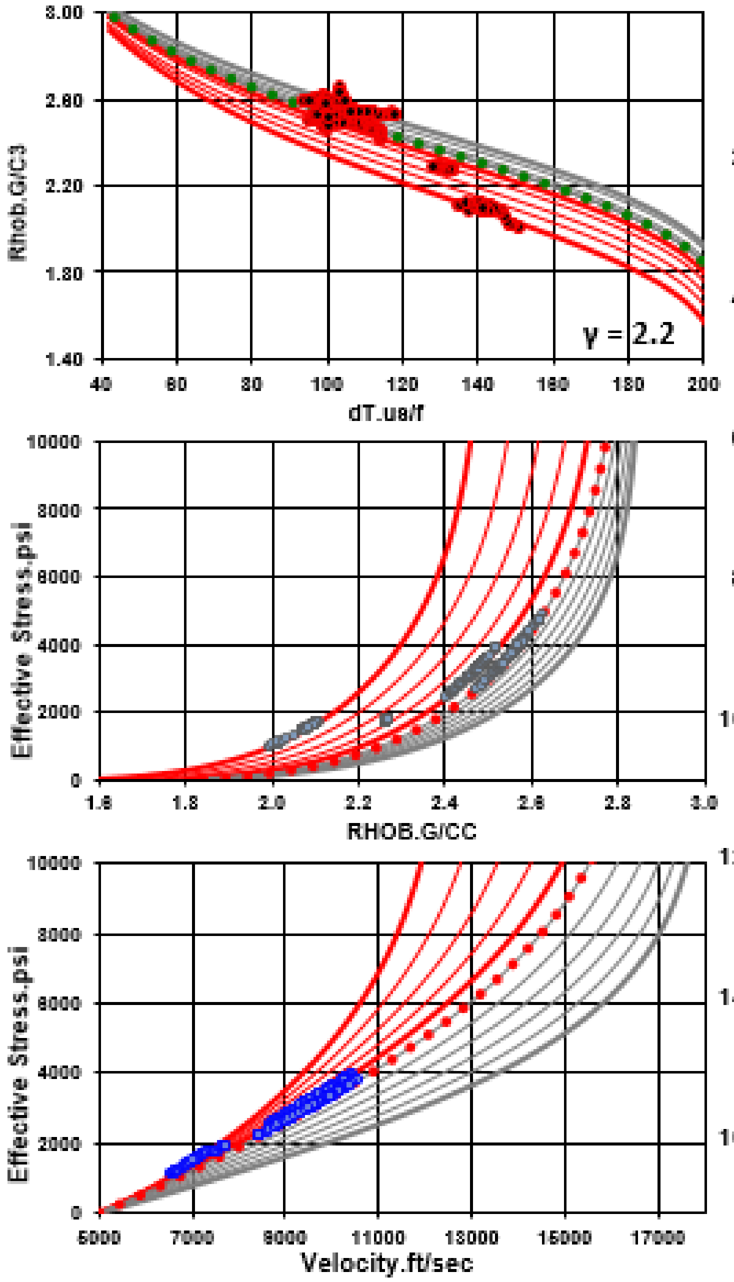

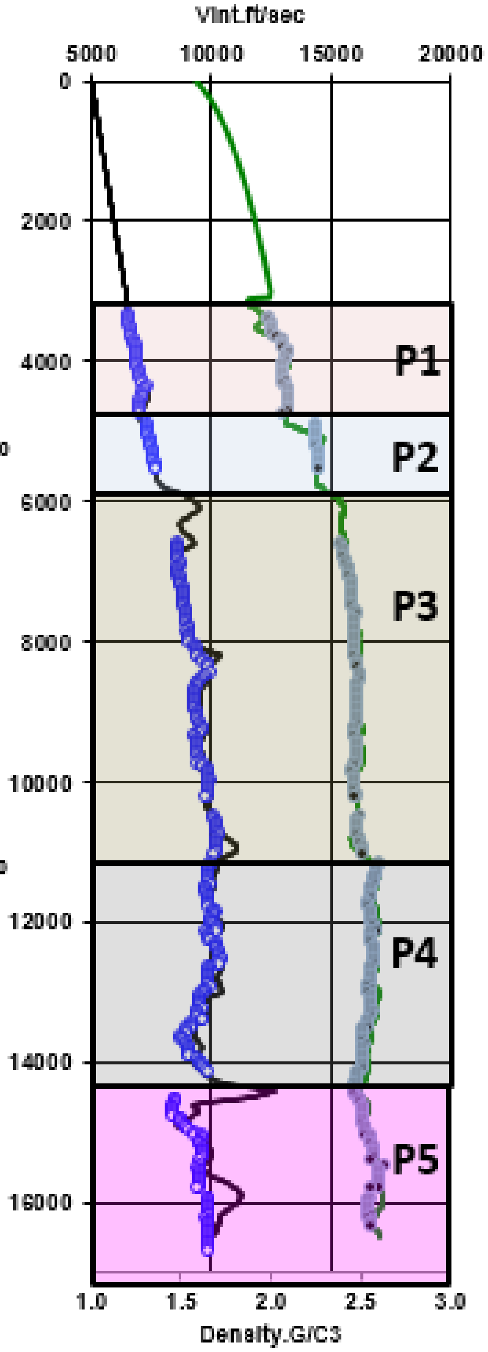

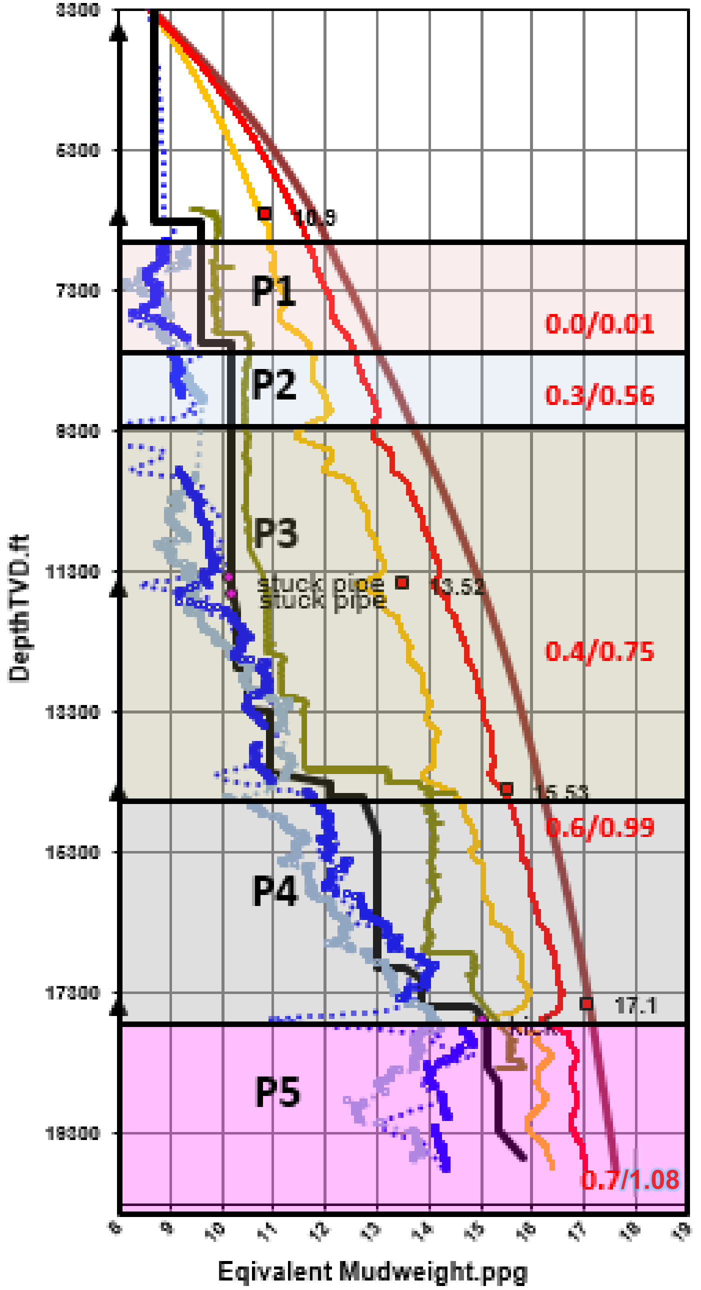

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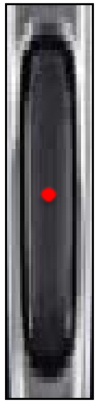

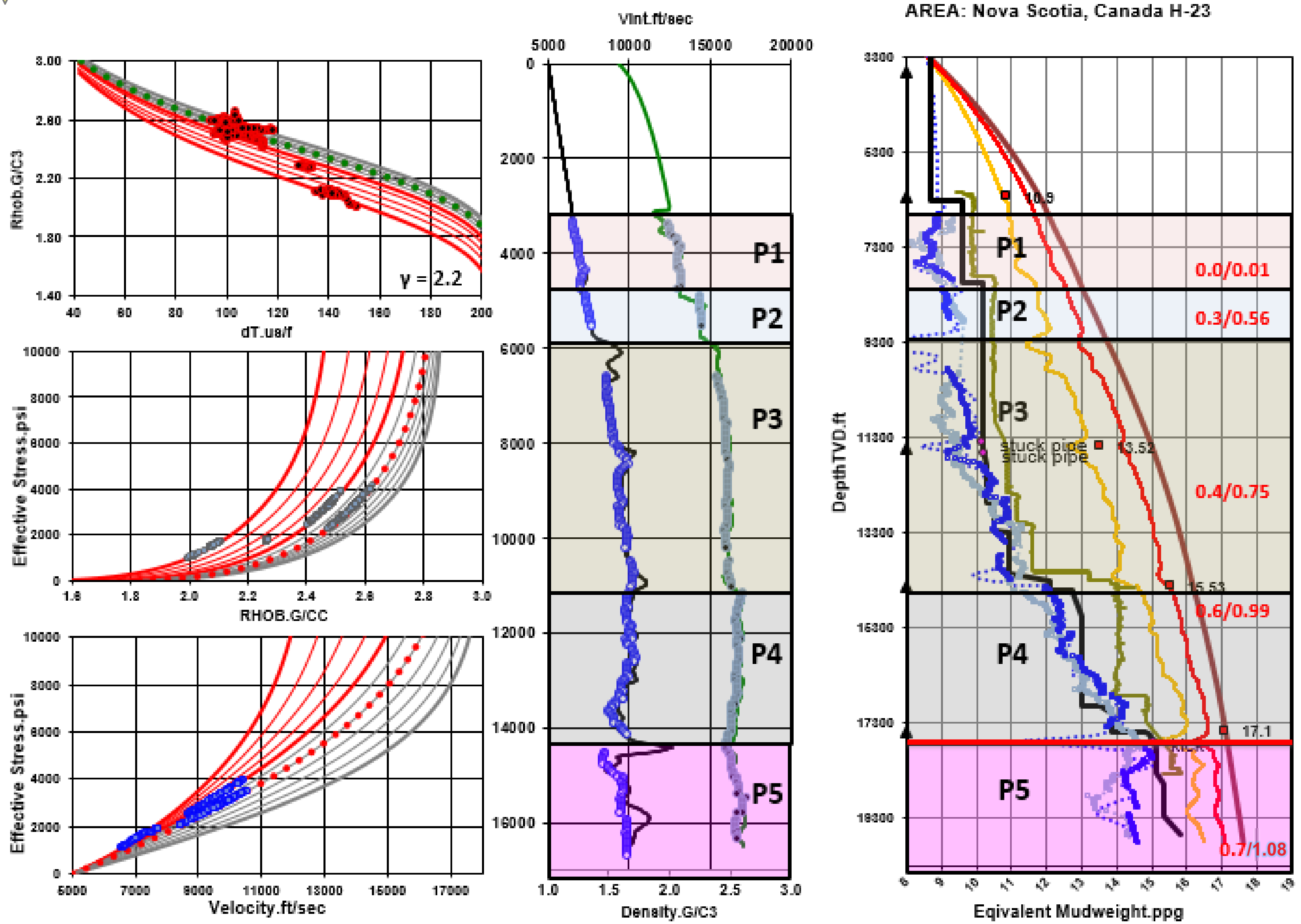

AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
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P3
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DepthTVD.ft
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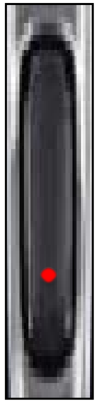
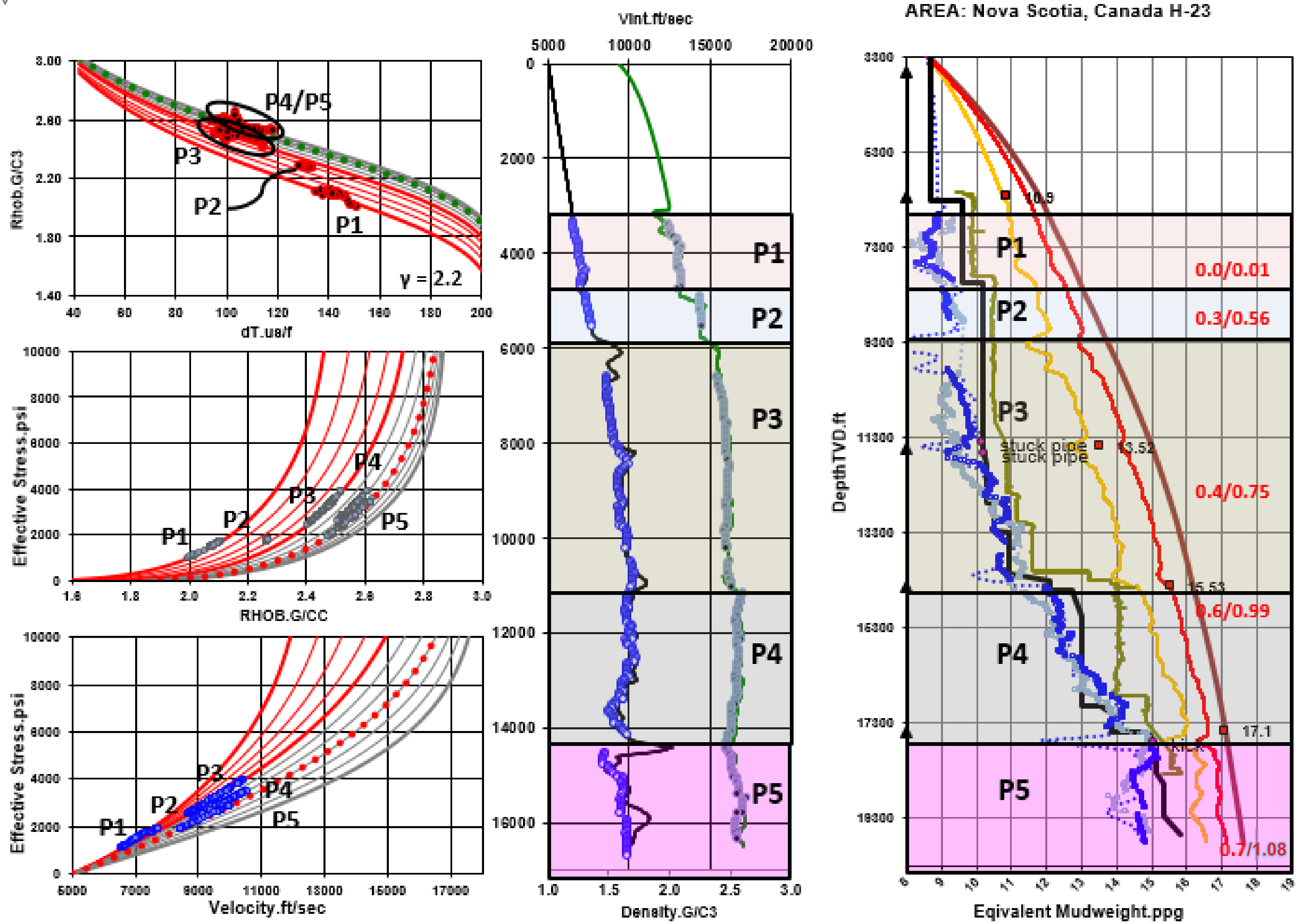
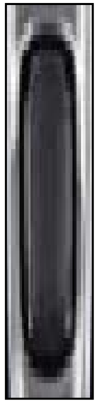
15.53
17.1
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08

0.6




AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
P4/P5
P3
P2
P1
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
DepthTVD.ft
Eqivalent Mudweight.ppg
stuck pipe
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08
P4
P5



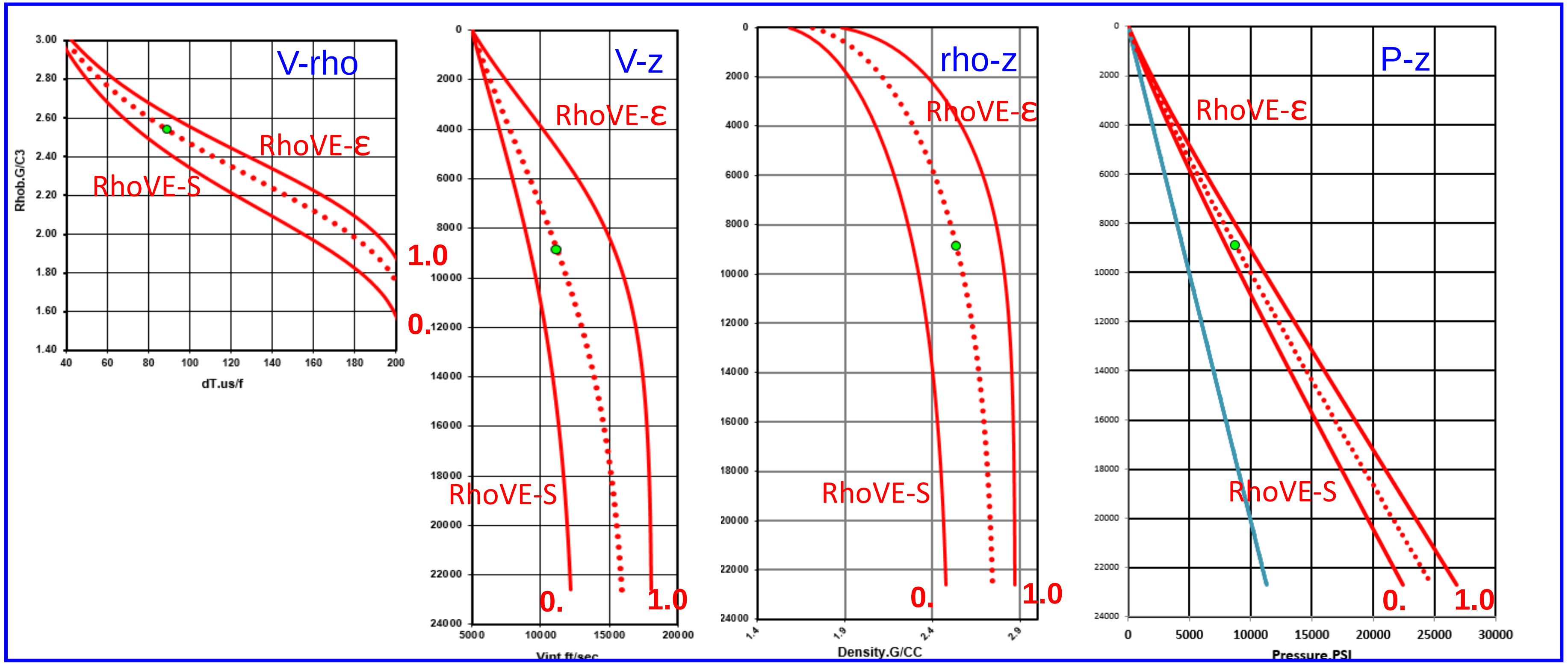
0.7

RhoVe™ Method

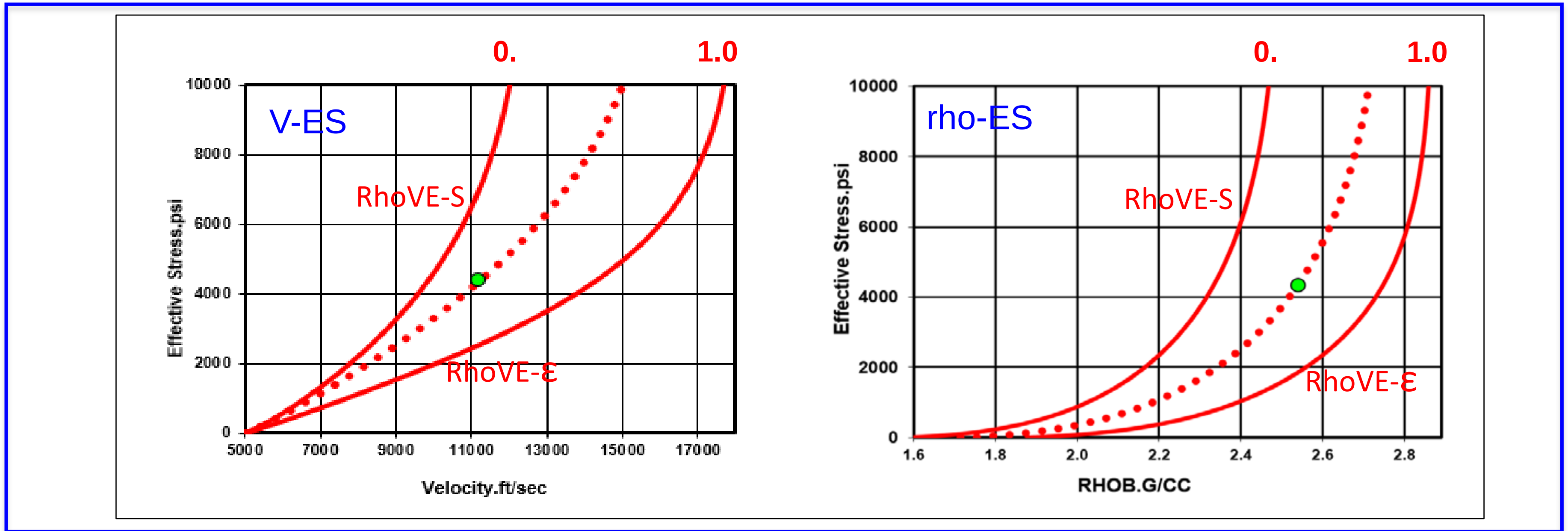
(U.S. patent pending - copyright © 2016)

Summary

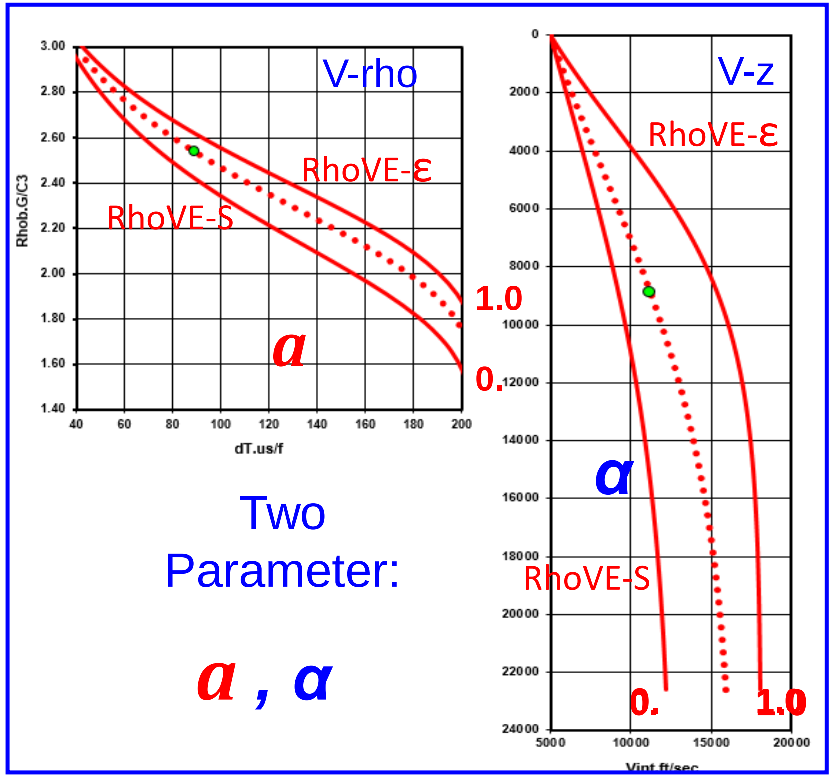
- Interactive (and fast).
- Premised on a continuum of “virtual”, normally pressured synthetic rock property relationships.
- Pore pressure is calculated by directly applying RhoVe-derived Velocity & Density-Effective Stress trends.
- Subsalt Applications –
- Two-parameter approach: a-term & alpha (α); includes the effects of compositional changes (clay diagenesis)
- Rationale for subdivision of major flow units, which can be utilized in layer-based basin modeling simulations.



V-rho
RhoVE-Ɛ
RhoVE-S
1.0
0.
Rhob.G/C3
dT.us/f
V-z
RhoVE-Ɛ
RhoVE-S
0.
1.0
Vint.ft/sec
rho-z
RhoVE-Ɛ
RhoVE-S
0.
1.0
Density.G/CC
P-z
RhoVE-Ɛ
RhoVE-S
0.
1.0
Pressure.PSI



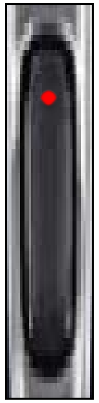
V-ES
0.
1.0
RhoVE-S
RhoVE-Ɛ
Effective Stress.psi
Velocity.ft/sec
rho-ES
0.
1.0
RhoVE-S
RhoVE-Ɛ
Effective Stress.psi
RHOB.G/CC

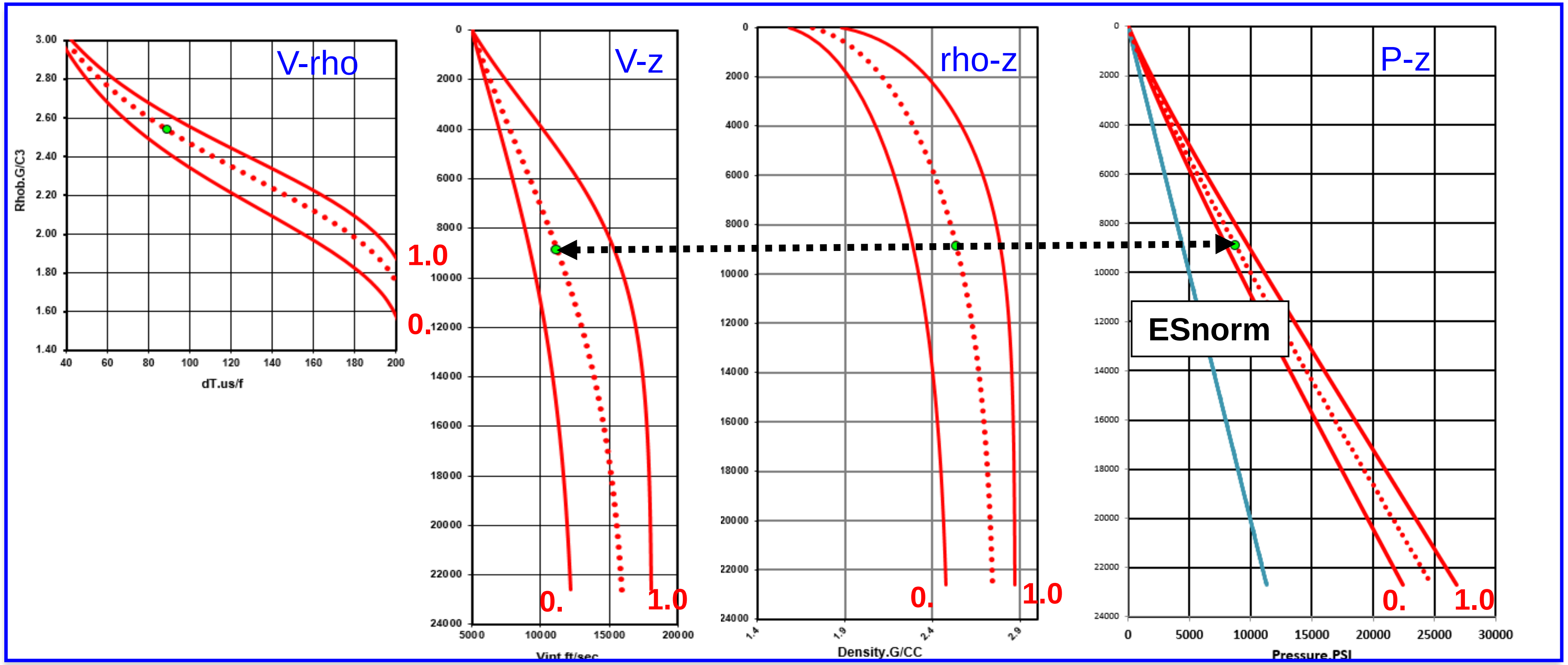


a : fractional distance

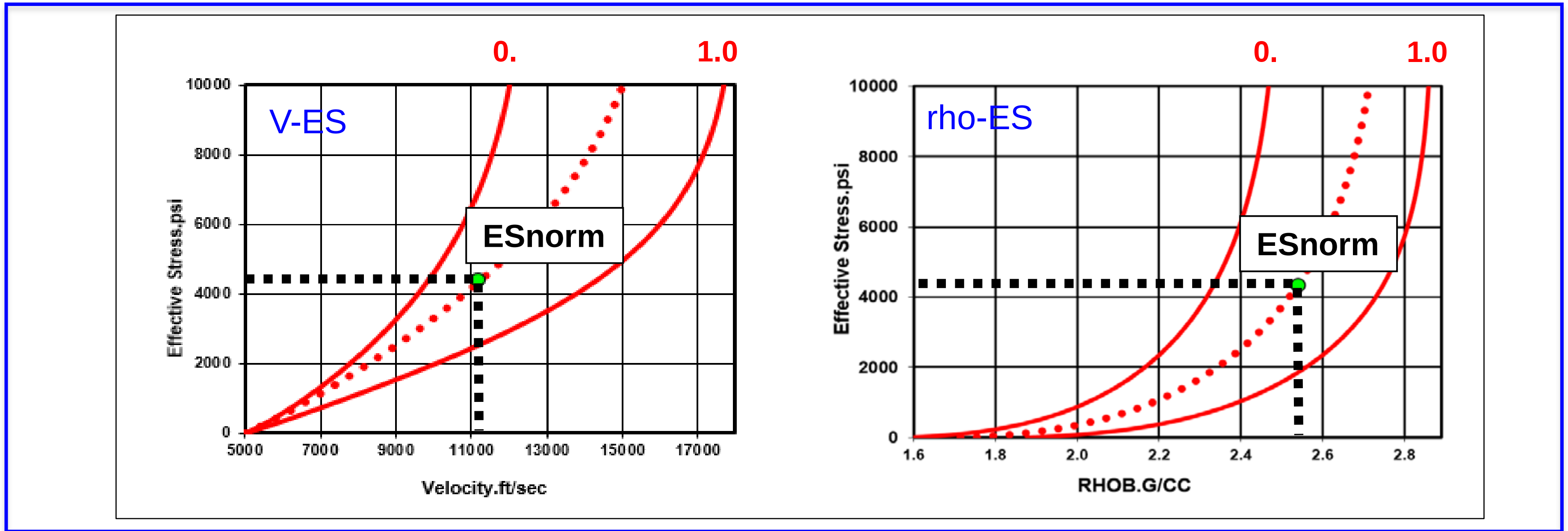
α : calculated property

0.37

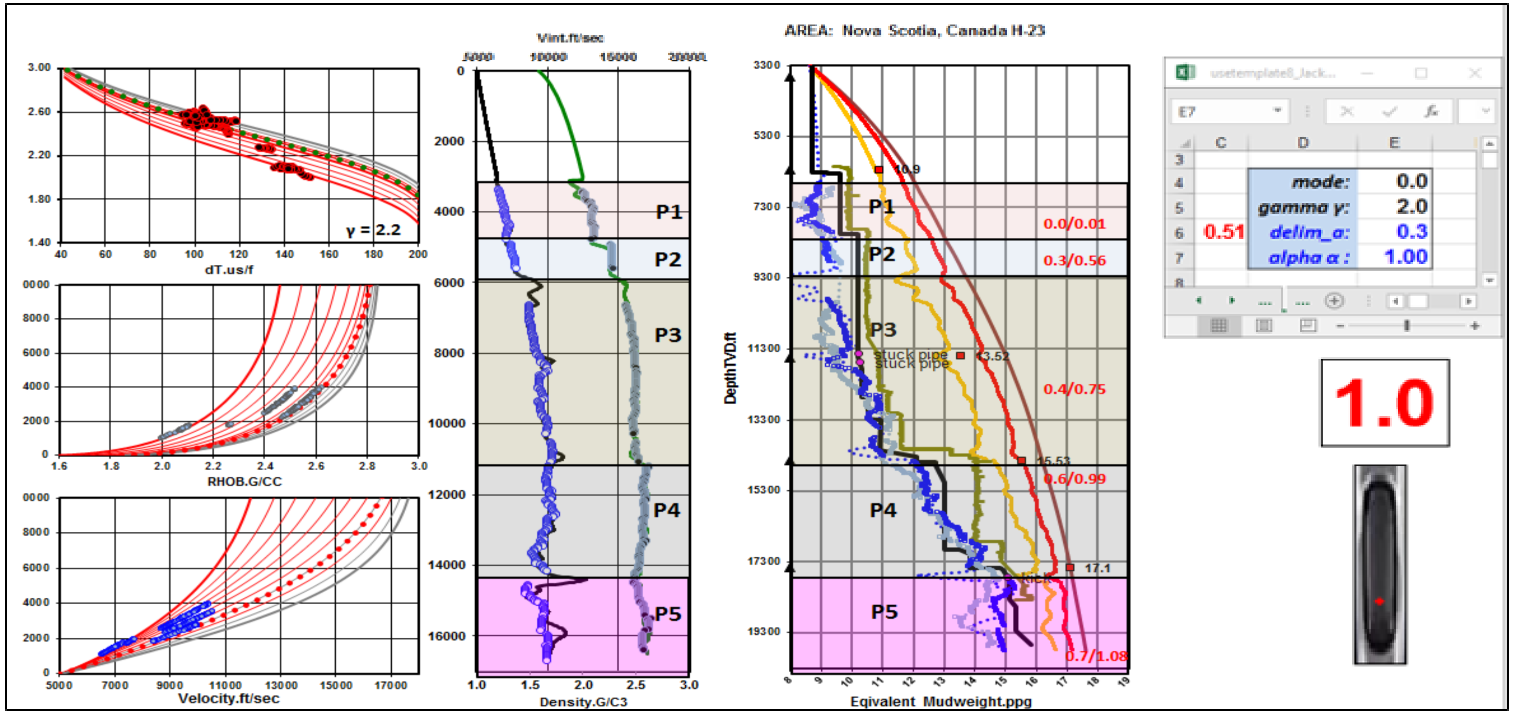




V-rho
Rhob.G/C3
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
40
60
80
100
120
140
160
180
200
dT.us/f
1.0
0.
V-z
Vint ft/sec
5000
10000
15000
20000
rho-z
Density.G/CC
1.4
1.9
2.4
2.9
P-z
Pressure.PSI
0
5000
10000
15000
20000
25000
30000
ESnorm
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
0.
1.0

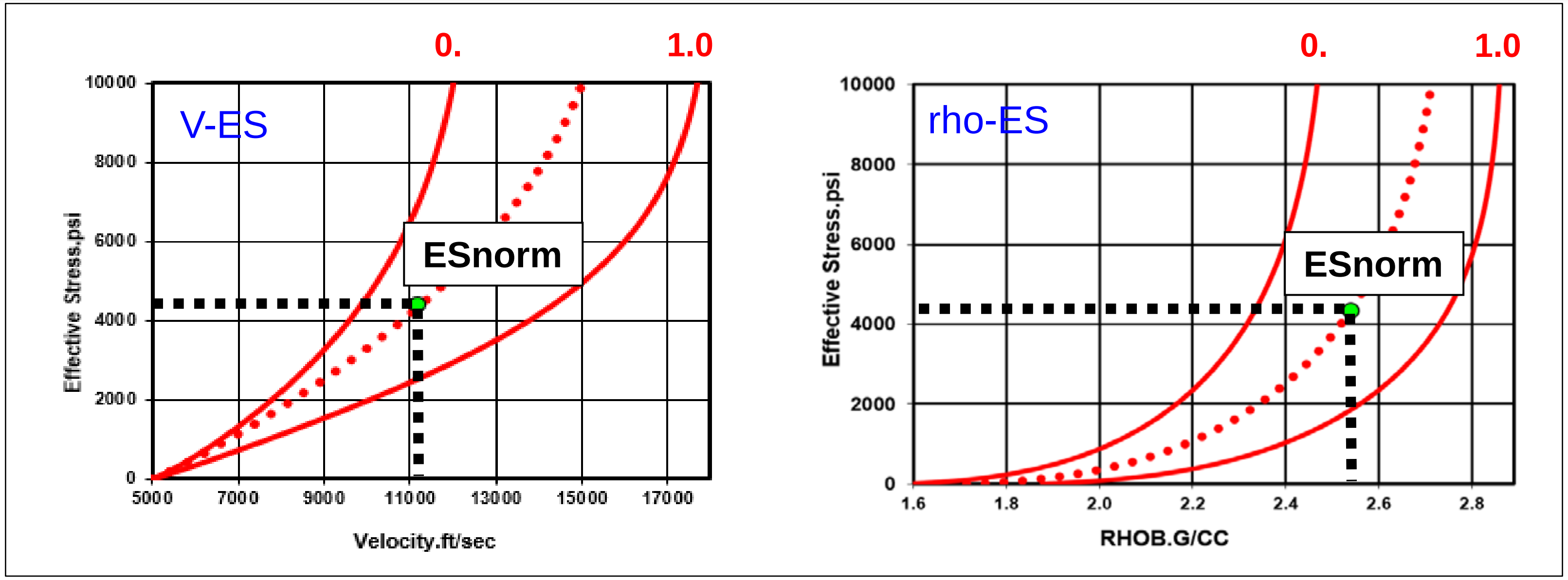


V-ES
Effective Stress.psi
10000
8000
6000
4000
2000
0
Velocity.ft/sec
5000
7000
9000
11000
13000
15000
17000
0.
1.0
ESnorm
rho-ES
RHOB.G/CC
1.6
1.8
2.0
2.2
2.4
2.6
2.8

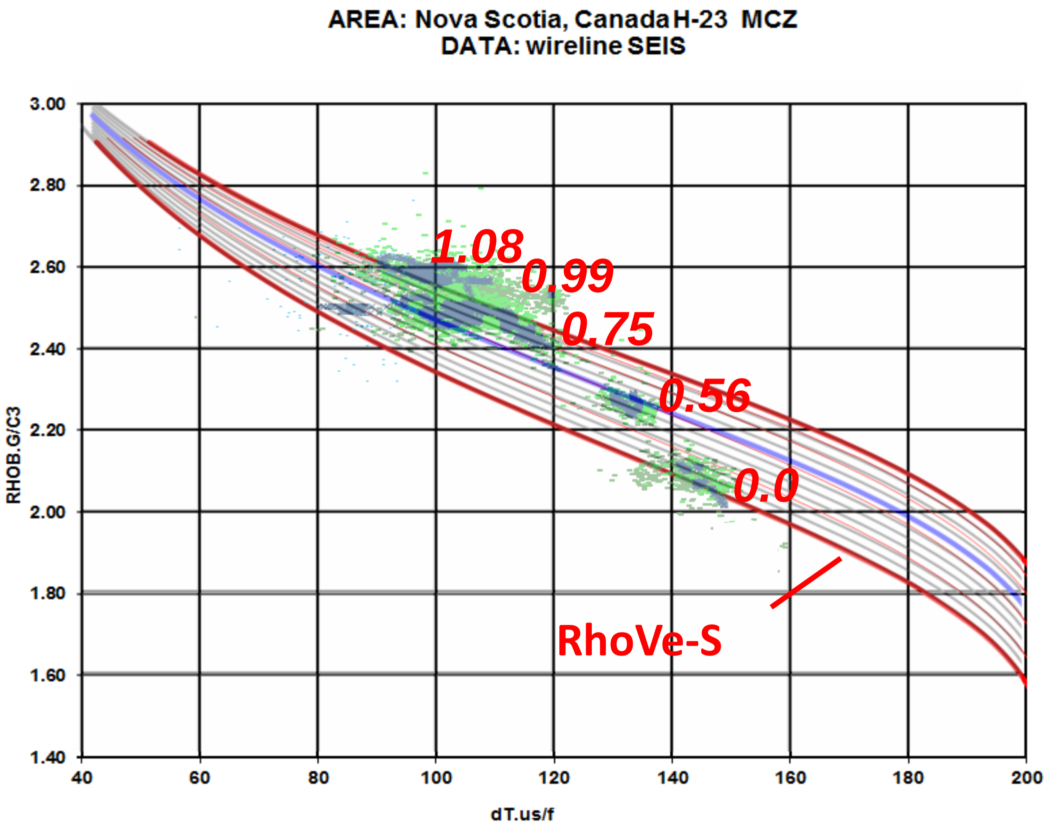


RhoVe™

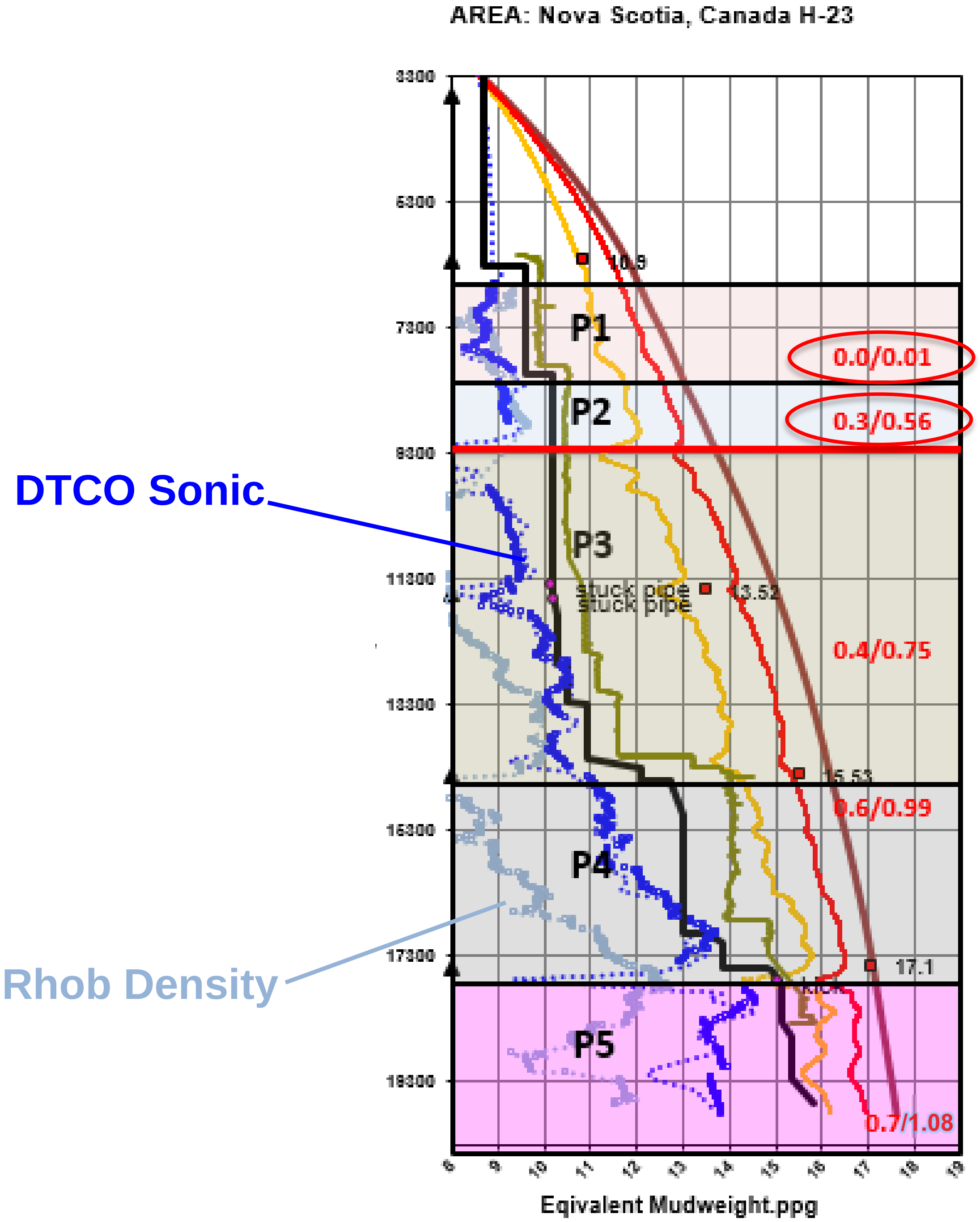
Method



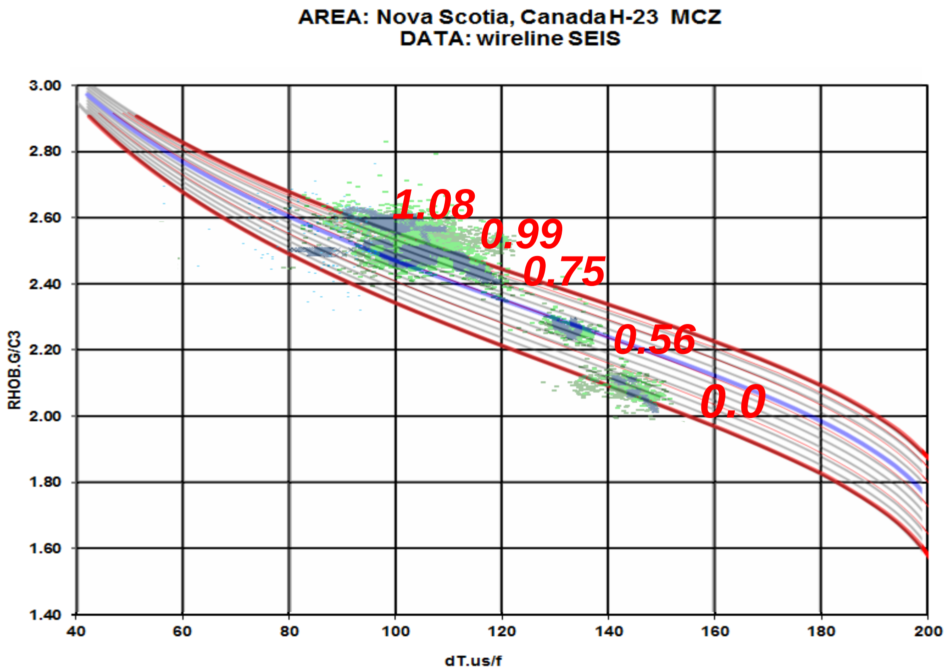
Examples



a : fractional distance

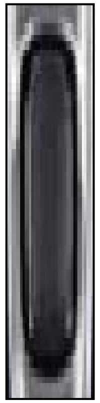


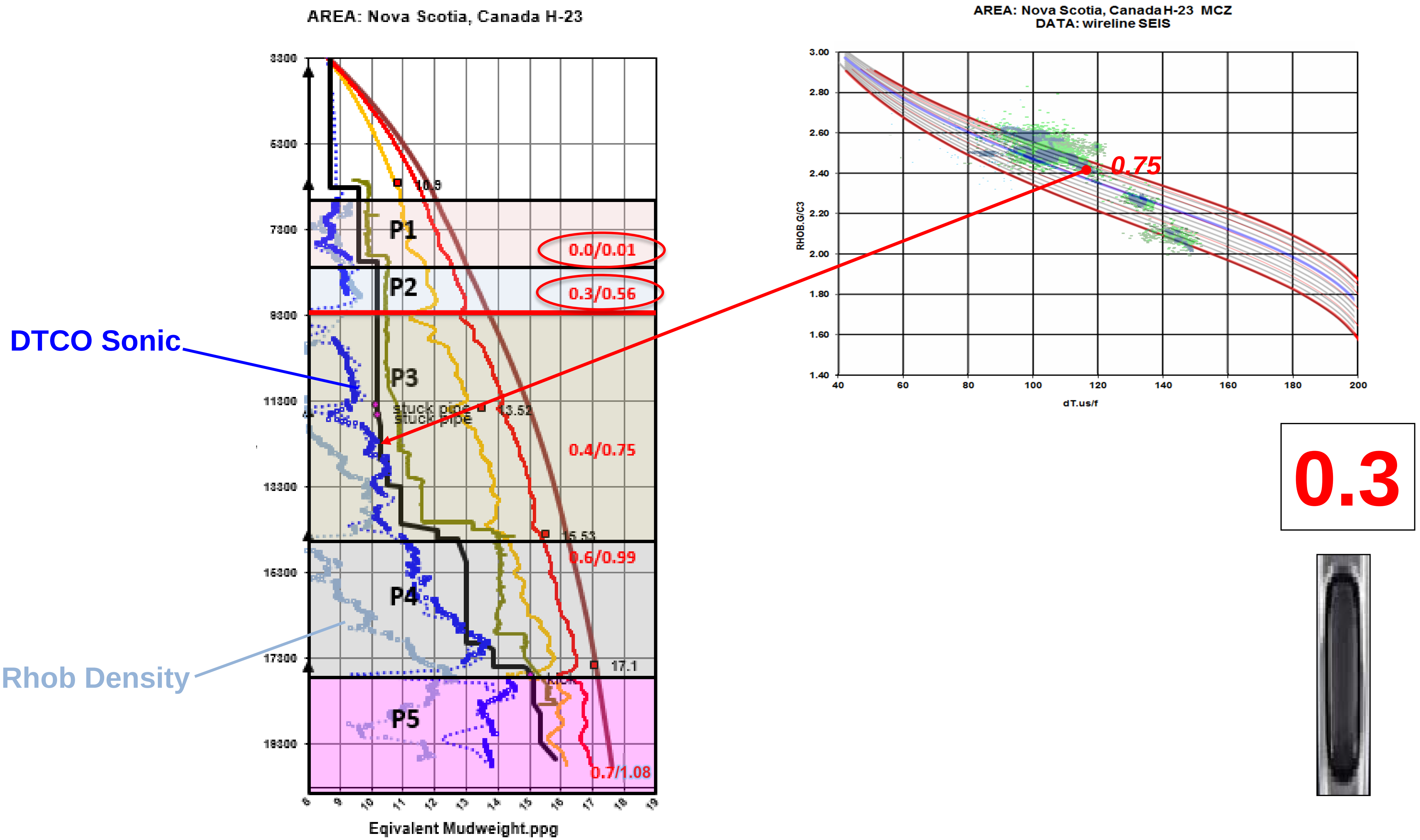
AREA: Nova Scotia, Canada H-23
DTCO Sonic
Rhob Density
P1
P2
P3
P4
P5
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08
10.9
13.52
15.53
17.1
stuck pipe
3300
6300
7300
8300
11300
13300
15300
17300
18300
8
9
10
11
12
13
14
15
16
17
18
19
Eqivalent Mudweight.ppg



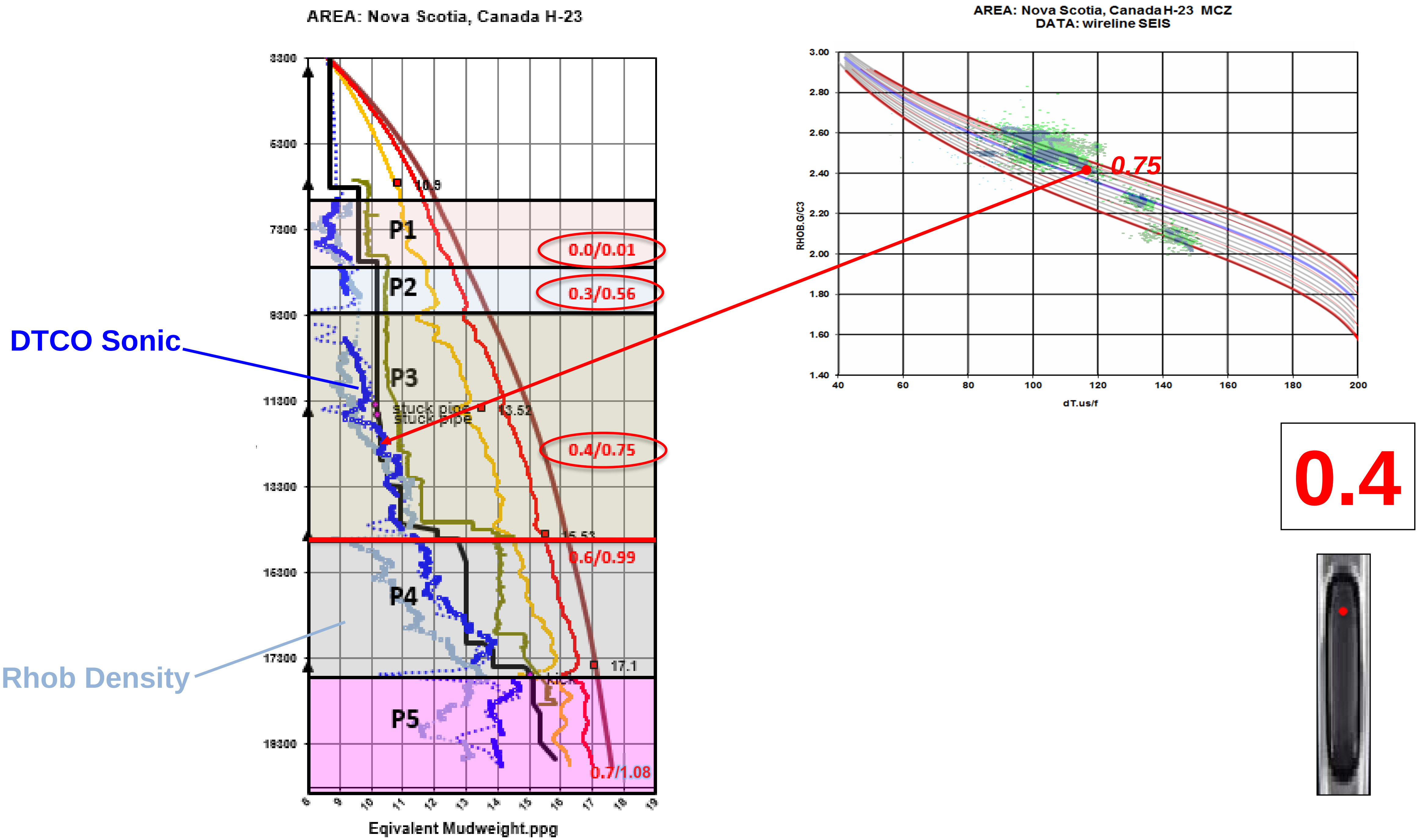
AREA: Nova Scotia, Canada H-23 MCZ
DATA: wireline SEIS
1.08
0.99
0.75
0.56
0.0
RHOB.G/C3
dT.us/f
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
40
60
80
100
120
140
160
180
200

0.3

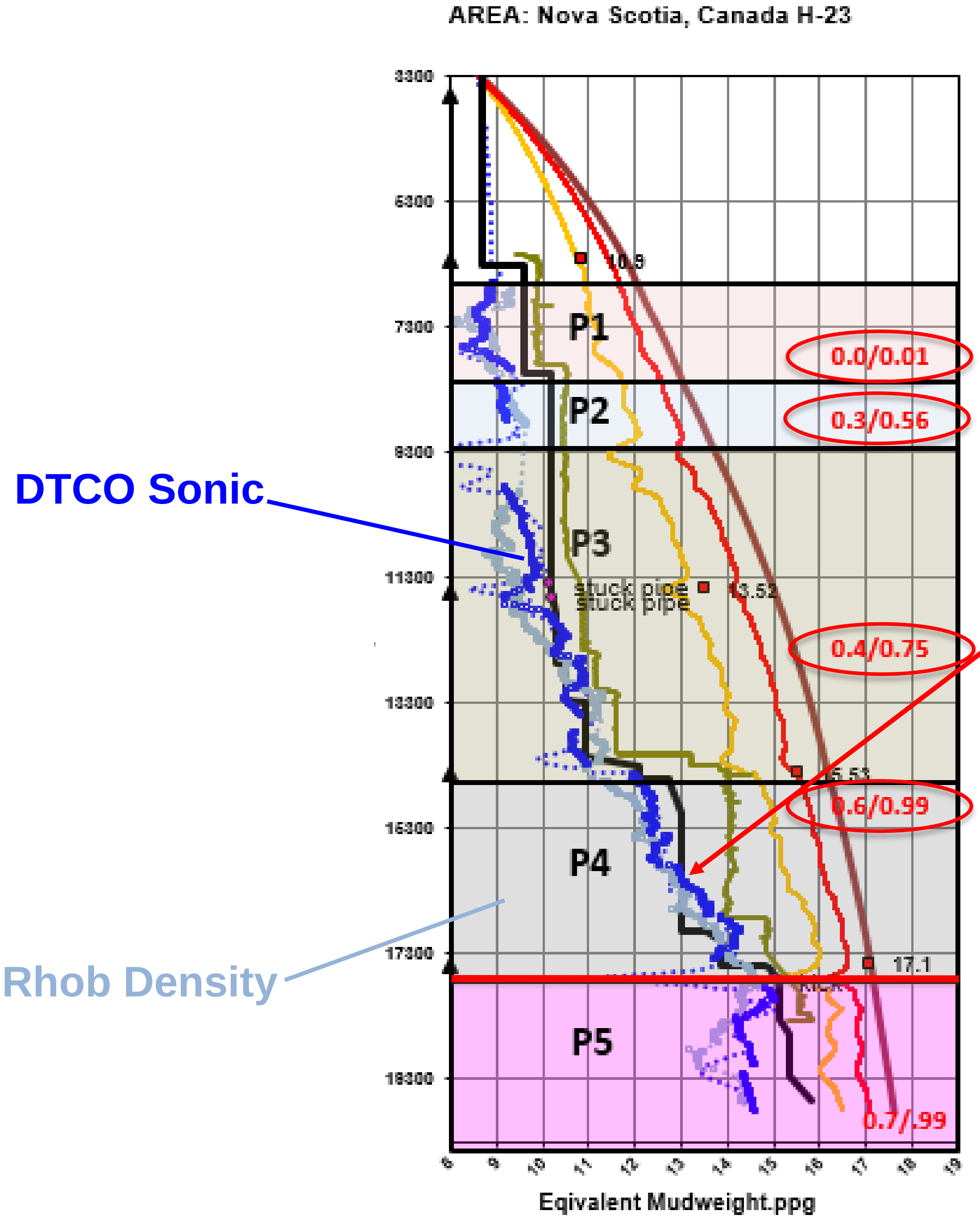


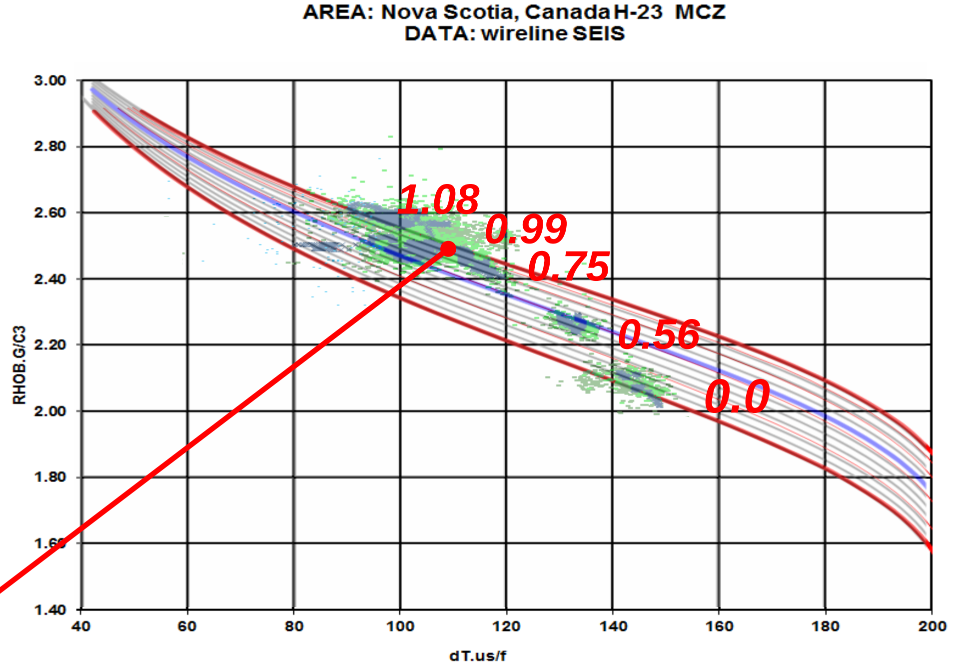


AREA: Nova Scotia, Canada H-23
DTCO Sonic
Rhob Density
P1
P2
P3
P4
P5
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08
10.9
13.52
15.53
17.1
stuck pipe
Eqivalent Mudweight.ppg
AREA: Nova Scotia, Canada H-23 MCZ
DATA: wireline SEIS
RHOB.G/C3
dT.us/f
0.75
0.3

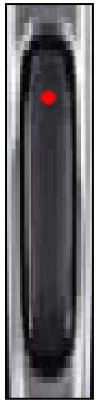


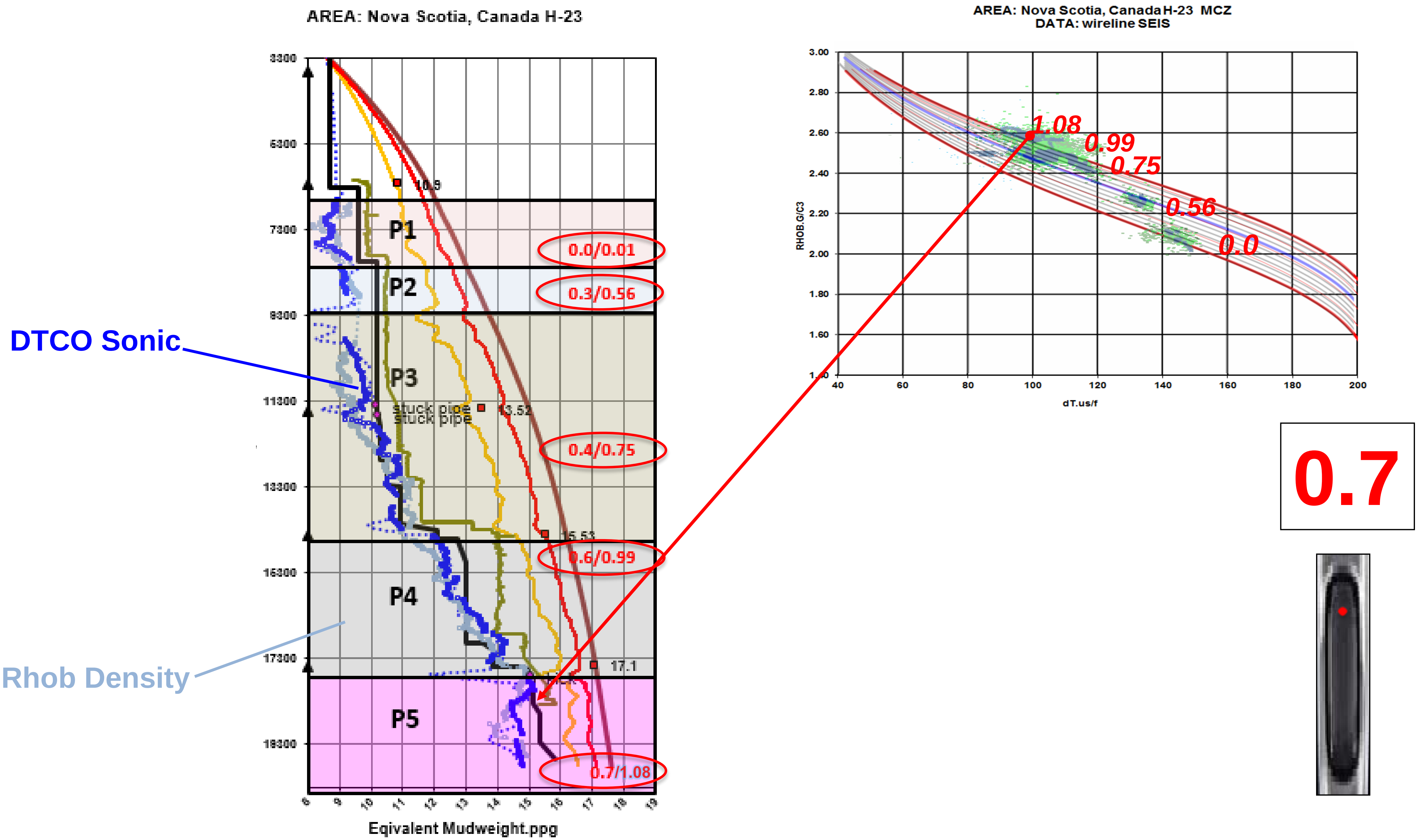
AREA: Nova Scotia, Canada H-23
3300
7300
11300
13300
17300
19300
P1
P2
P3
P4
P5
10.9
stuck pipe
stuck pipe
13.52
15.53
17.1
kick
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08
8
9
10
11
12
13
14
15
16
17
18
19
Eqivalent Mudweight.ppg
DTCO Sonic
Rhob Density
AREA: Nova Scotia, Canada H-23 MCZ
DATA: wireline SEIS
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
RHOB.G/C3
40
60
80
100
120
140
160
180
200
dT.us/f
0.75
0.4

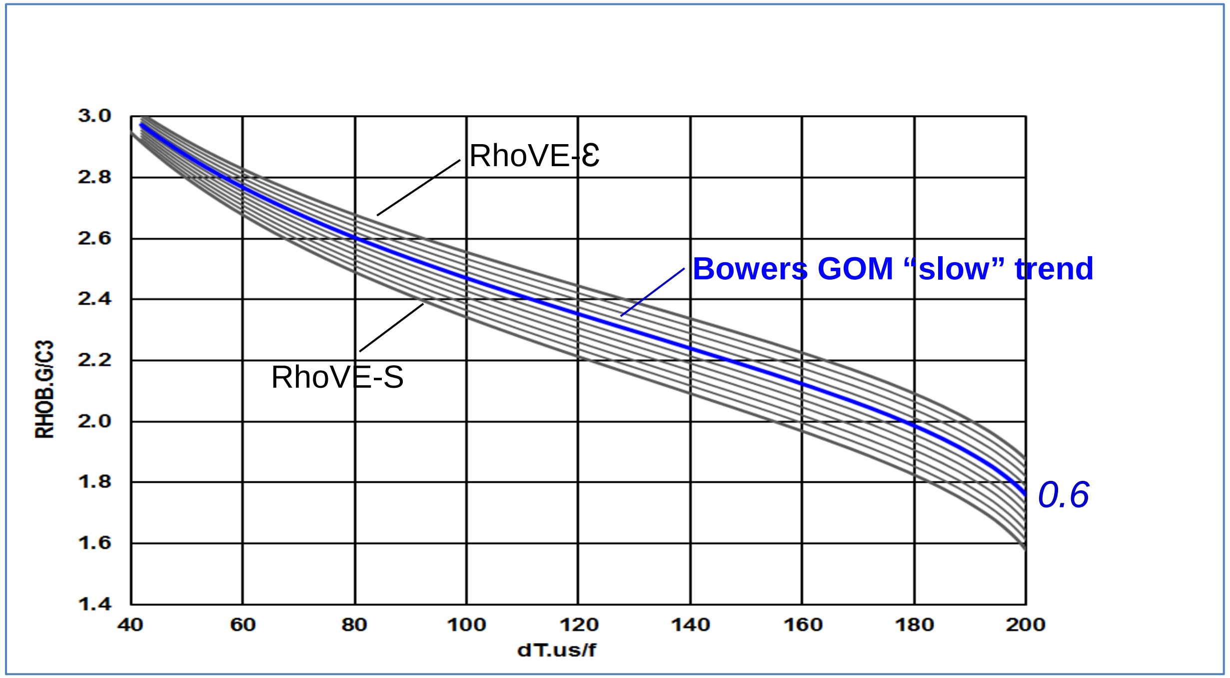

AREA: Nova Scotia, Canada H-23
P1
P2
P3
P4
P5
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/.99
10.9
stuck pipe
13.52
17.1
DTCO Sonic
Rhob Density
Eqivalent Mudweight.ppg

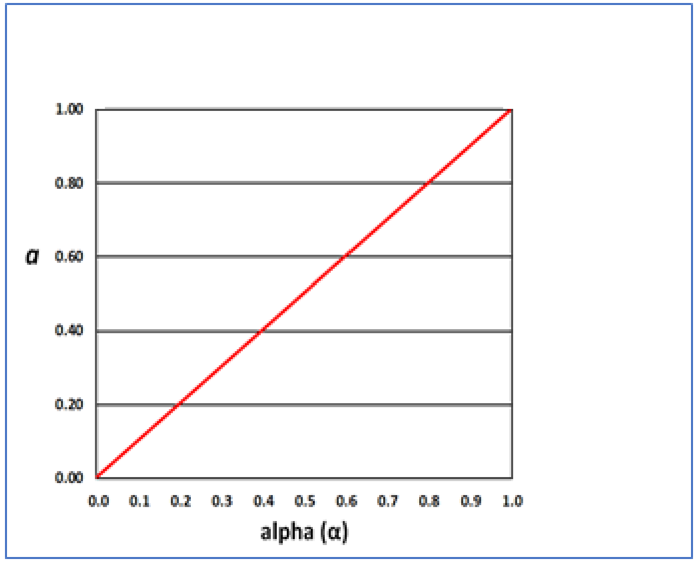

AREA: Nova Scotia, Canada H-23 MCZ
DATA: wireline SEIS
RHOB.G/C3
dT.us/f
1.08
0.99
0.75
0.56
0.0

0.6




AREA: Nova Scotia, Canada H-23
P1
P2
P3
P4
P5
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08
stuck pipe
10.9
13.52
15.53
17.1
DTCO Sonic
Rhob Density
Eqivalent Mudweight.ppg
AREA: Nova Scotia, Canada H-23 MCZ
DATA: wireline SEIS
RHOB.G/C3
dT.us/f
1.08
0.99
0.75
0.56
0.0
0.7





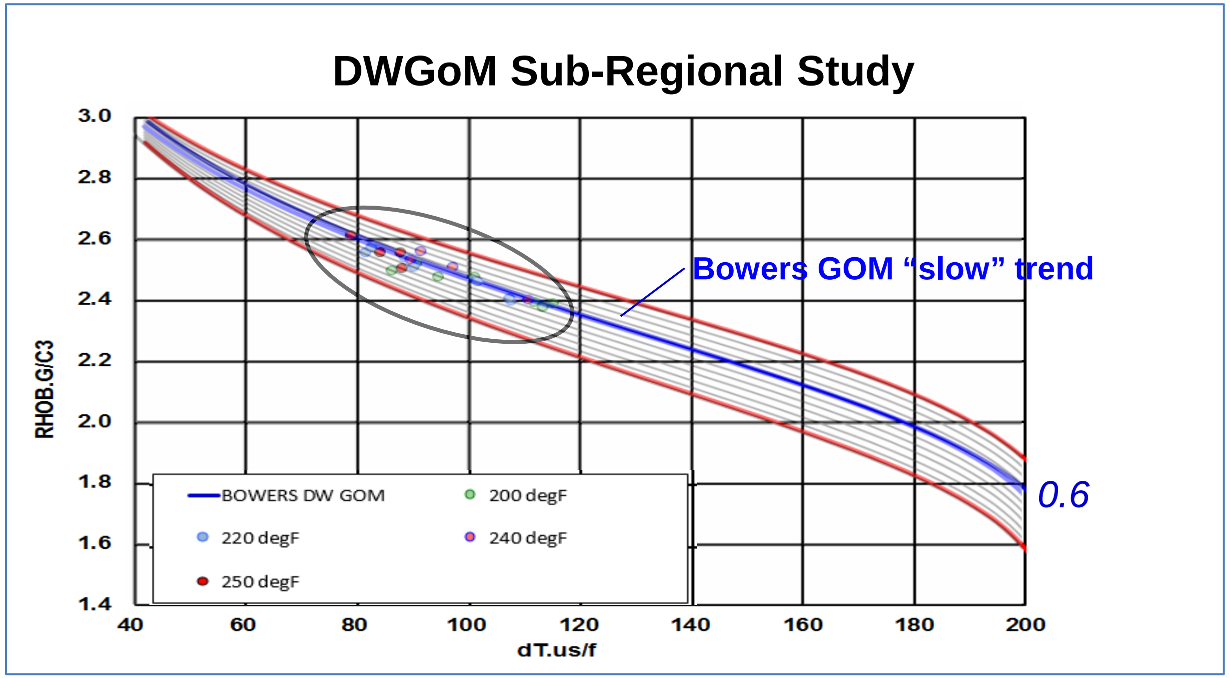
a = α

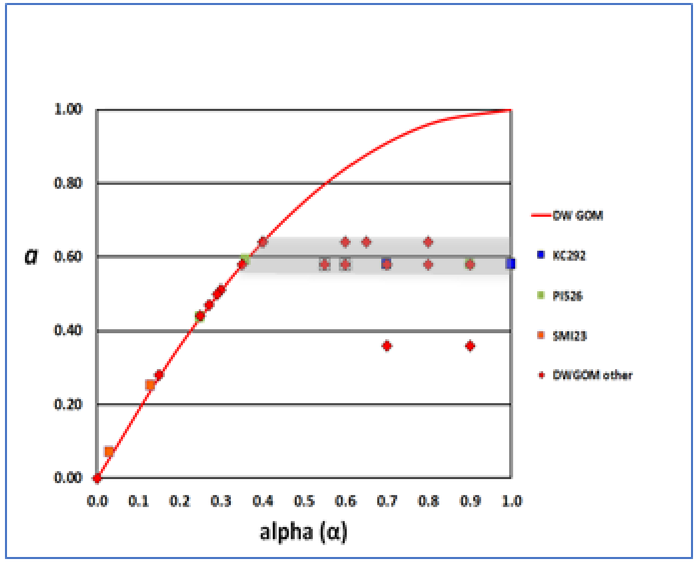
V-Rho equation (Bowers, OTC 2001) :

$$V = V_0 + A\,(\rho - \rho_o)^{B}$$

BOWERS GOM "Slow" Trend		RhoVE-Ɛ	RhoVE-S
Vo:	4790	4800	4900
A:	2953	2000	4500
B:	3.57	4.2	3
ρ_o:	1.3	1.3	1.3

RhoVE interm: *a* * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S





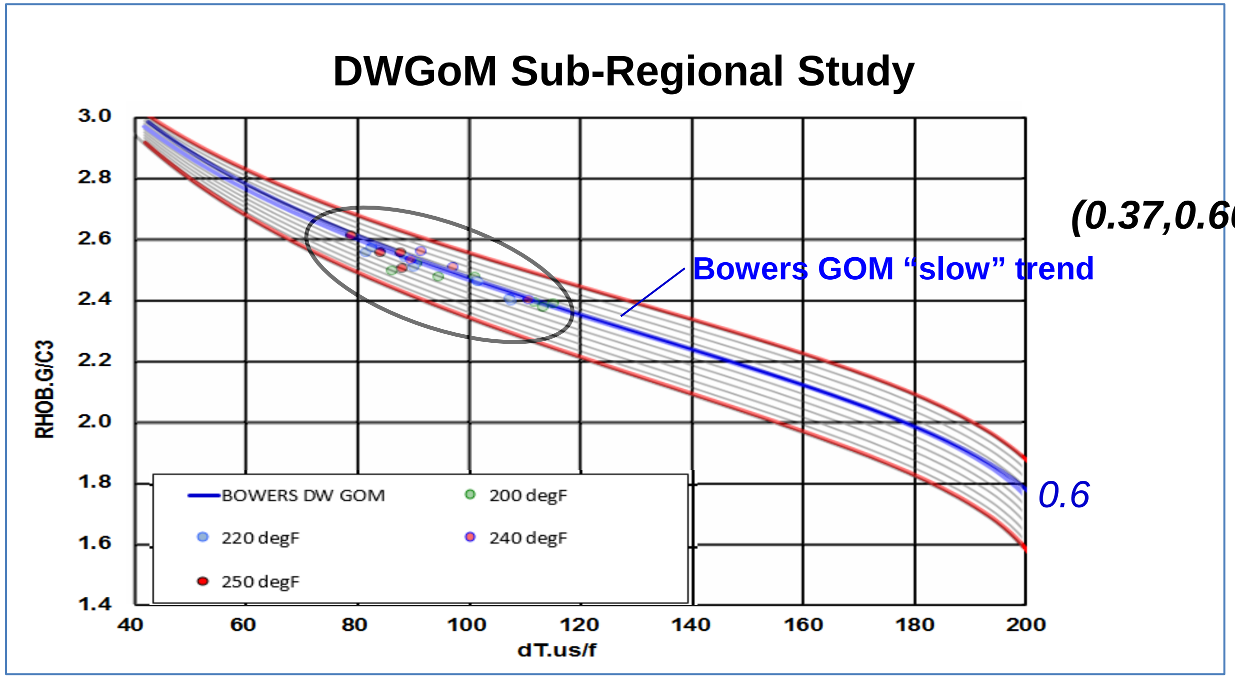
$$a = 2\alpha - \alpha^2$$

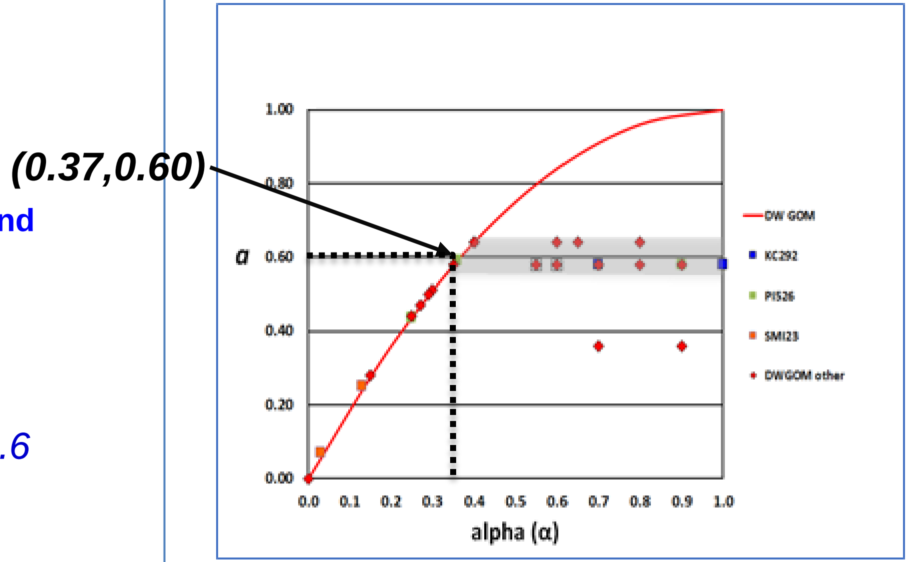
V-Rho equation (Bowers, OTC 2001) :

$$V = V_0 + A\,(\rho - \rho_o)^{B}$$

BOWERS GOM "Slow" Trend		RhoVE-Ɛ	RhoVE-S
Vo:	4790	4800	4900
A:	2953	2000	4500
B:	3.57	4.2	3
ρ_o:	1.3	1.3	1.3

RhoVE interm: a * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S



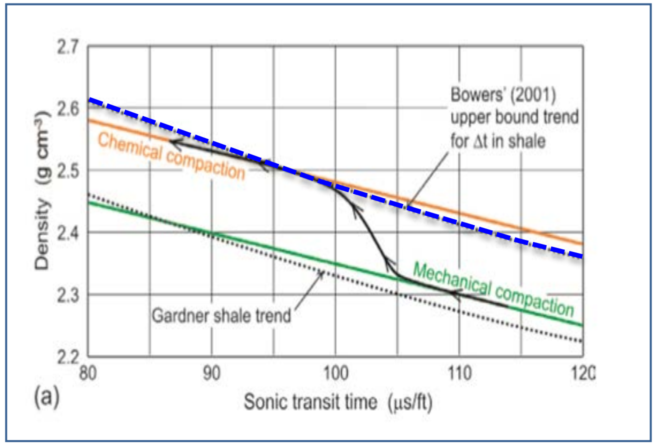


$$a = 2\alpha - \alpha^2$$

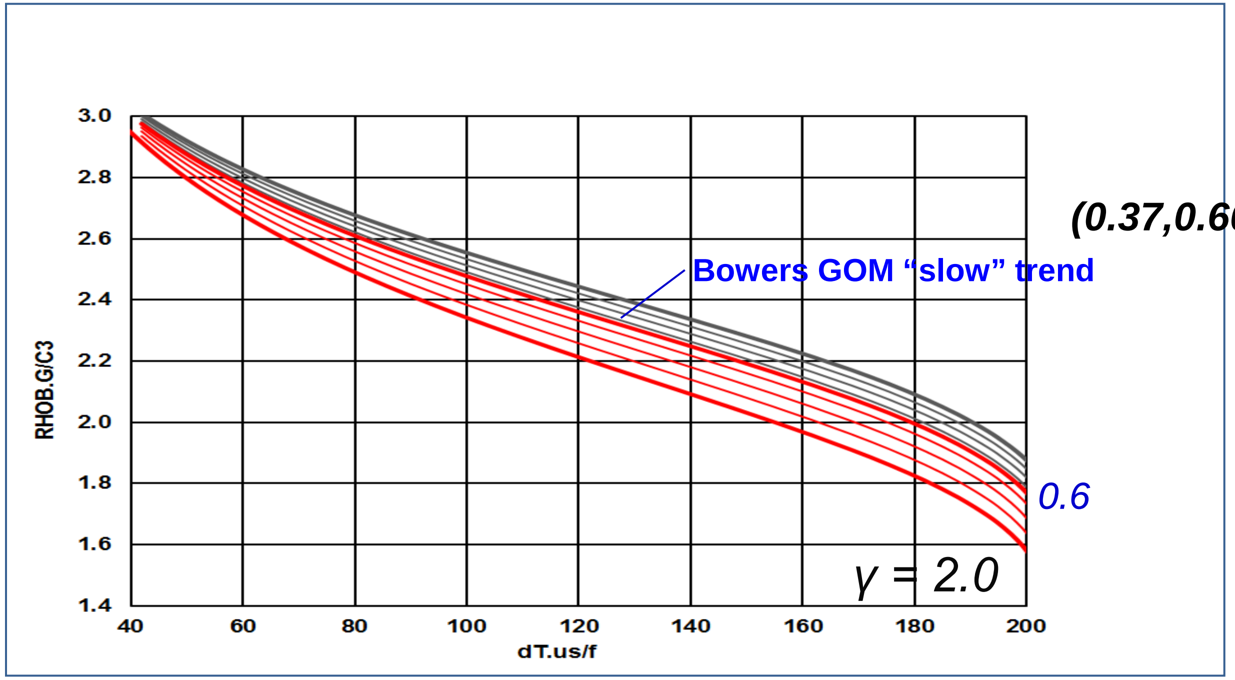
V-Rho equation (Bowers, OTC 2001) :

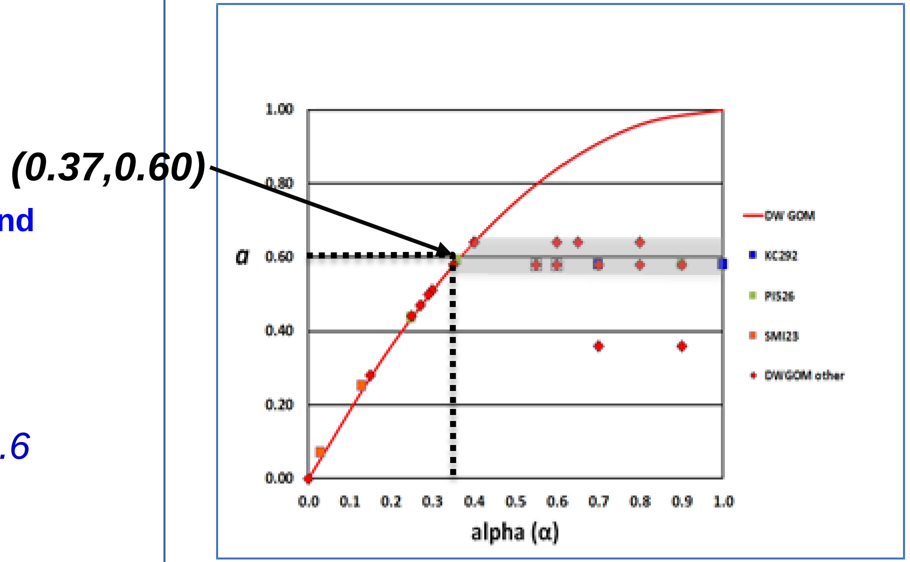
$$V = V_0 + A\,(\rho - \rho_o)^{B}$$

BOWERS GOM "Slow" Trend		RhoVE-Ɛ	RhoVE-S
Vo:	4790	4800	4900
A:	2953	2000	4500
B:	3.57	4.2	3
ρ_o:	1.3	1.3	1.3



RhoVE interm: a * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S





$$a = \gamma\alpha - \alpha^{\gamma}$$

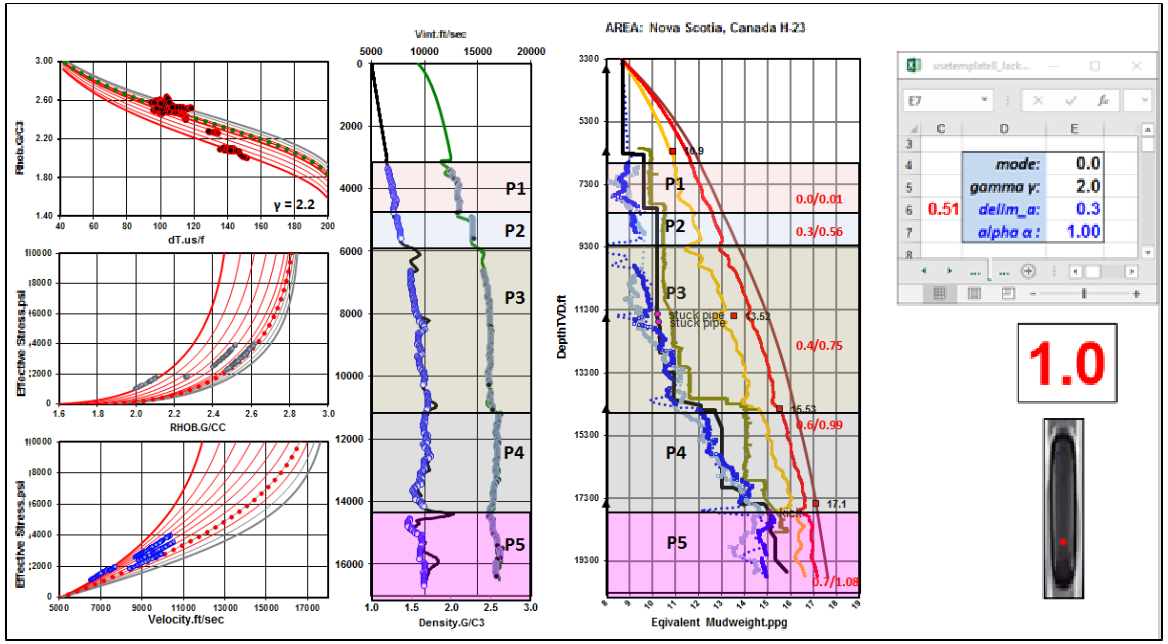
V-Rho equation (Bowers, OTC 2001) :

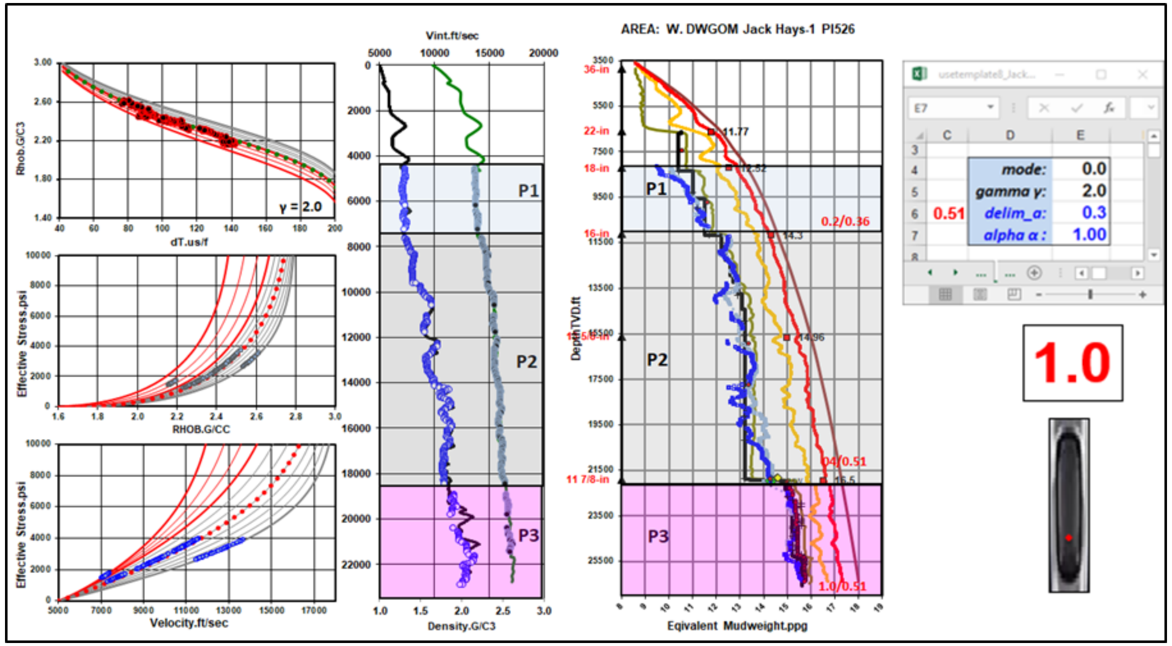
$$V = V_0 + A\,(\rho - \rho_o)^{B}$$

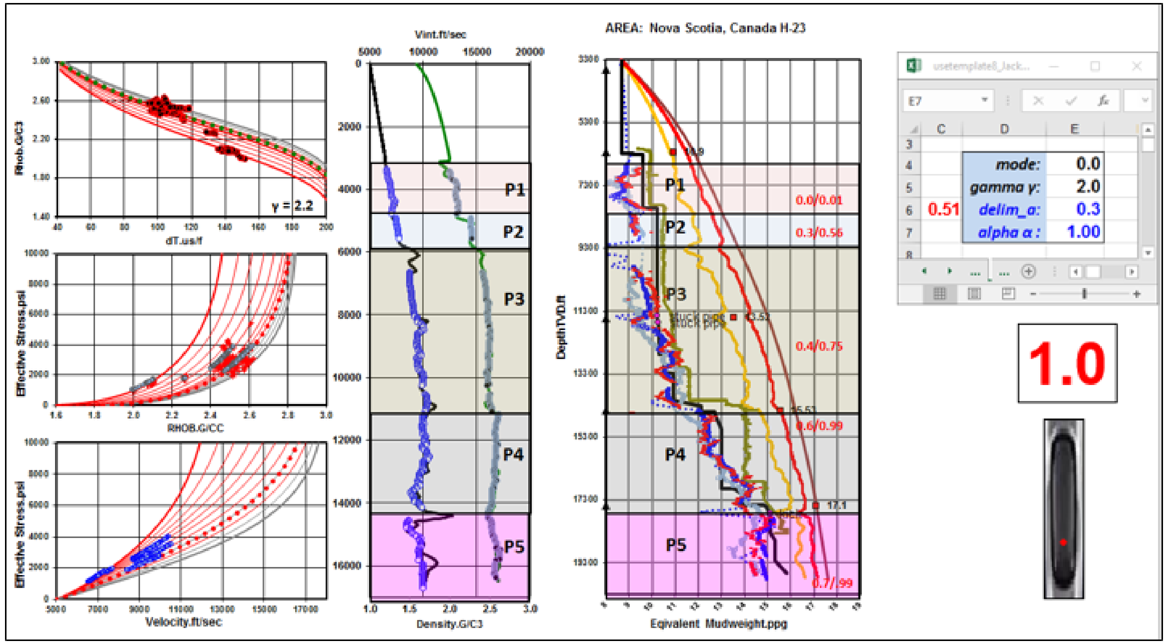
BOWERS GOM “Slow” Trend		RhoVE-Ɛ	RhoVE-S
Vo:	4790	4800	4900
A:	2953	2000	4500
B:	3.57	4.2	3
ρ_o:	1.3	1.3	1.3

RhoVE interm: $f(\alpha)$ * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S

RhoVe™ Method







RhoVe™ Auto

Compositional Changes

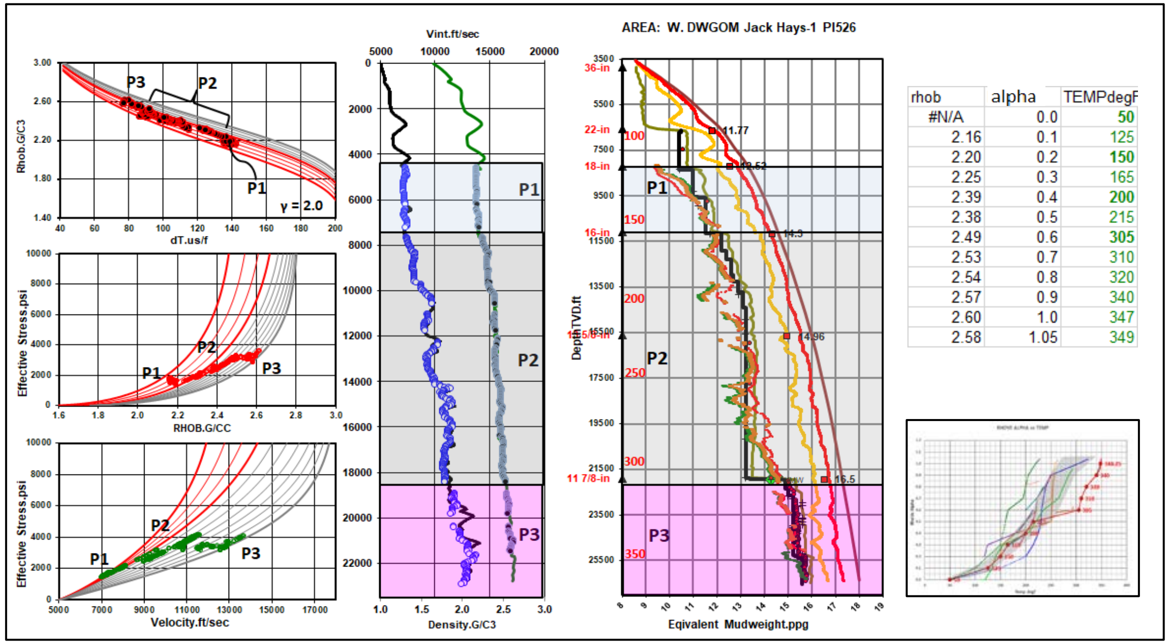
(executable)

RhoVe™ T

Thermodynamic Solutions

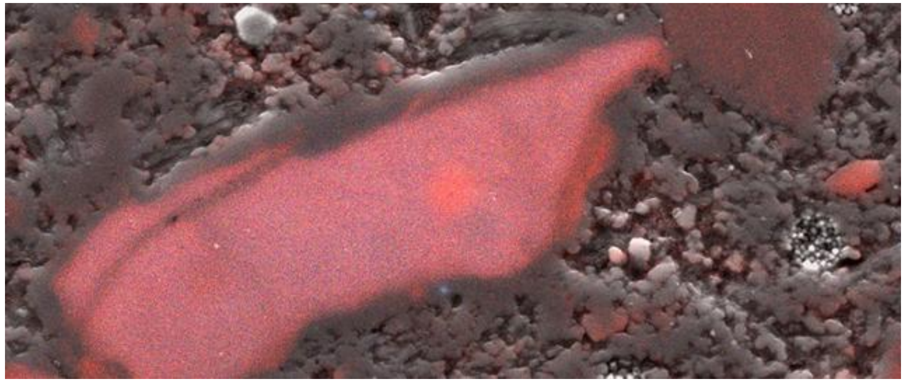
(executable)

Acoustic Impedance, Density, Sonic



Chemical Compaction

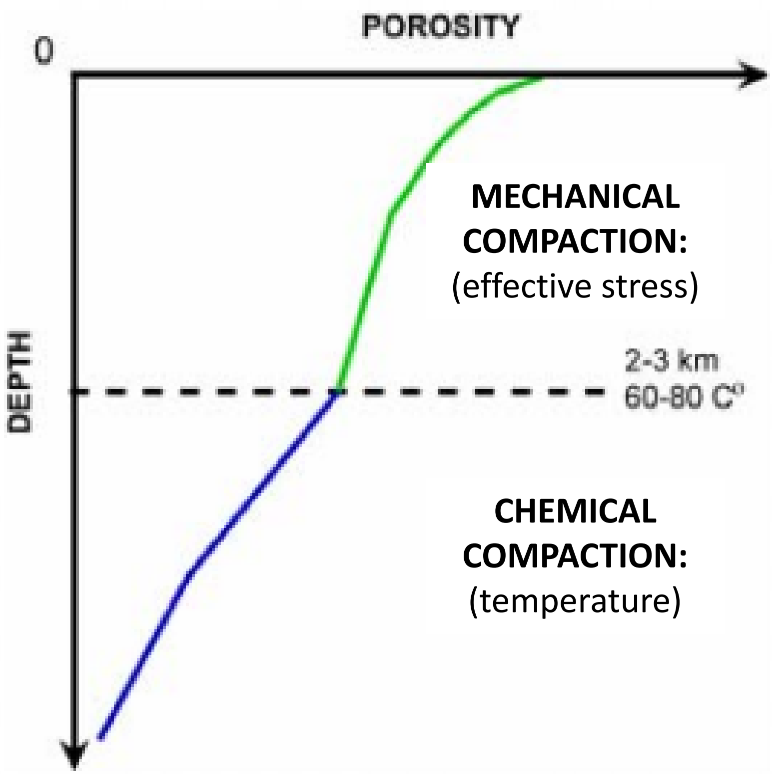
From recent advances in EMI (electron microbeam instrumentation) and sample preparation… "it is now clear that the principal diagenetic processes of sandstones and limestones, compaction and cementation, also operate in mudrocks" (Milliken, K., 2017).



**Mudrocks at the Scale of Grains and Pores: Current Understanding, Kitty Milliken, 2017, Bureau of Economic Geology, The University of Texas, Austin.

UNIVERSITY OF OSLO

Controlling factors on porosity reduction in both sandstones and shales



Mechanical compaction is a function of increased stress.

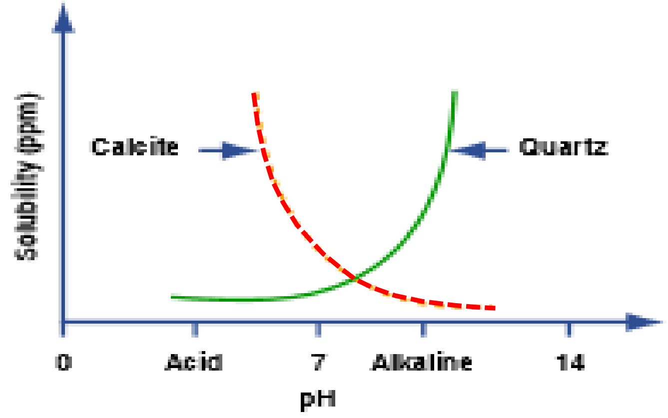
Chemical compaction is a function of thermodynamics and kinetics and is independent of the confining stress (e.g., Bjørlykke, 1998).

Department of Geosciences

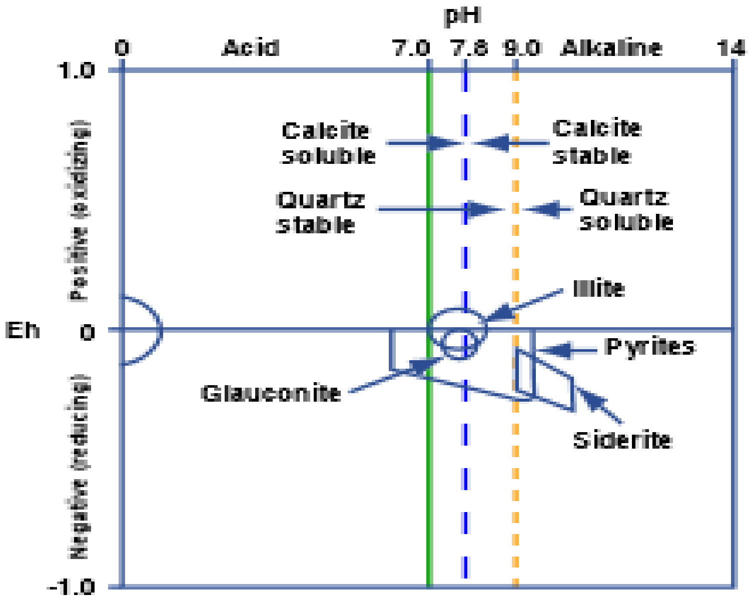
Chemical Compaction

Diagenesis (late)

The solubility of calcite and silica are unaffected by Eh but are strongly affected—and in opposing ways—by pH. Silica solubility increases with pH, whereas calcite solubility decreases with pH. Thus in acidic pore fluids, like meteoric waters, calcite tends to dissolve and quartz overgrowths are precipitated, whereas in alkaline waters calcite cements precipitate and may even replace quartz. For mildly alkaline fluids (pH 7–10) both quartz and calcite cements may form.

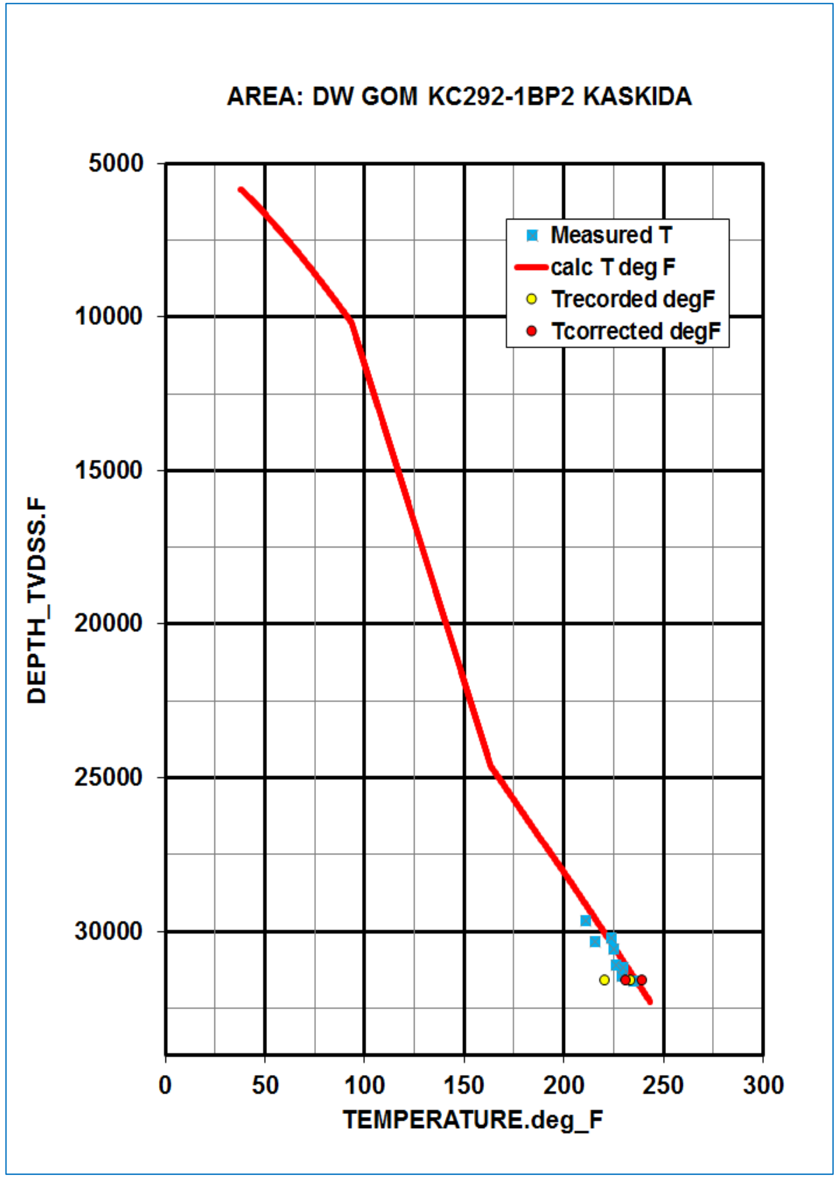


A

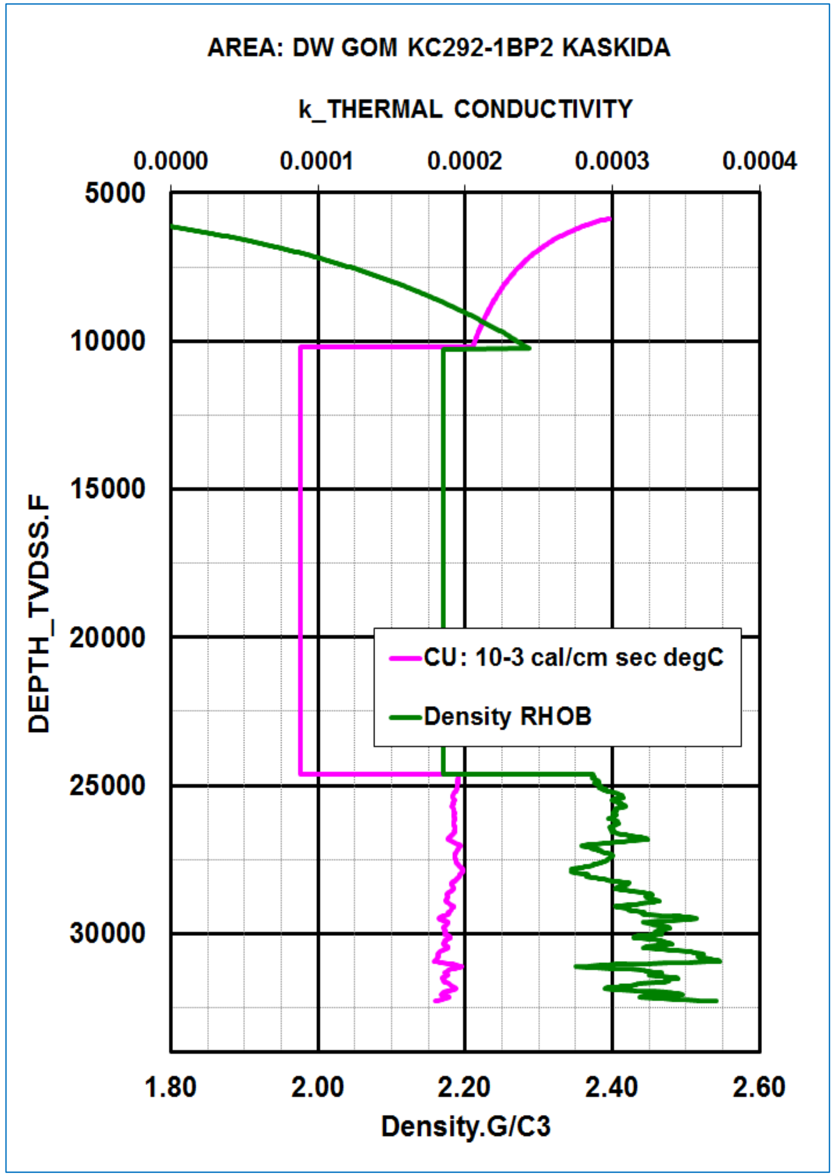


B

** MIT course notes on sedimentary processes



Temperature versus depth profile
BP Kaskida KC292-1BP2

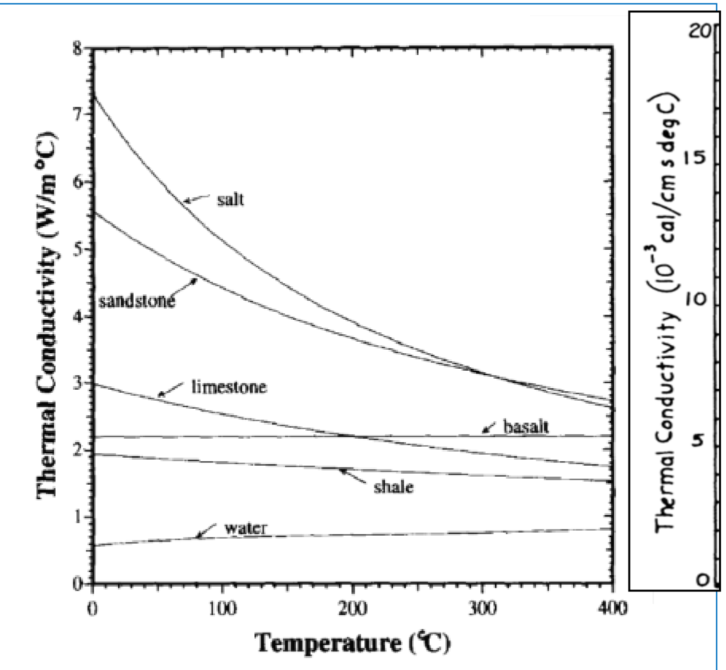


$$T\,z_{o(bml)}\,(^{o}F) = 65^{o}F > (266.4*WD)^{-0.2333} < 36^{o}F$$

$$k_{(z)} = ø_{(z)} * k_w + (1 - ø_{(z)}) * k_{mx}$$

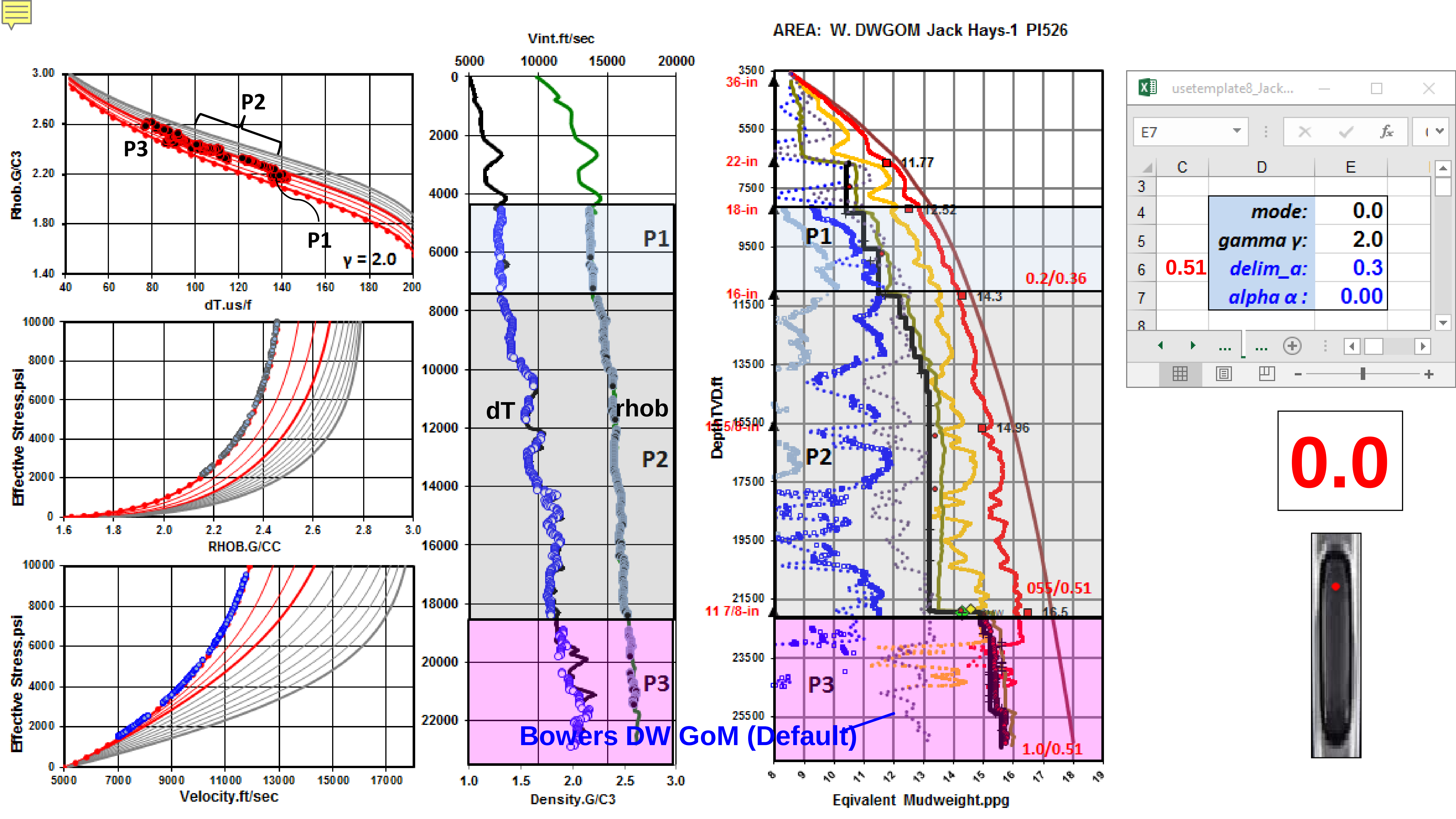
$$dT/dz_{(z)} = Q * 3.048E\text{-}05 / k_{(z)}$$

$$T_{(z)}\,(^{0}C) = T_{(z-1)}\,(^{0}C) + \{dT/dz_{(z)} * ((z_{(bml)} - z_{(bml-1)}) * 30.48(cm/ft)\}$$

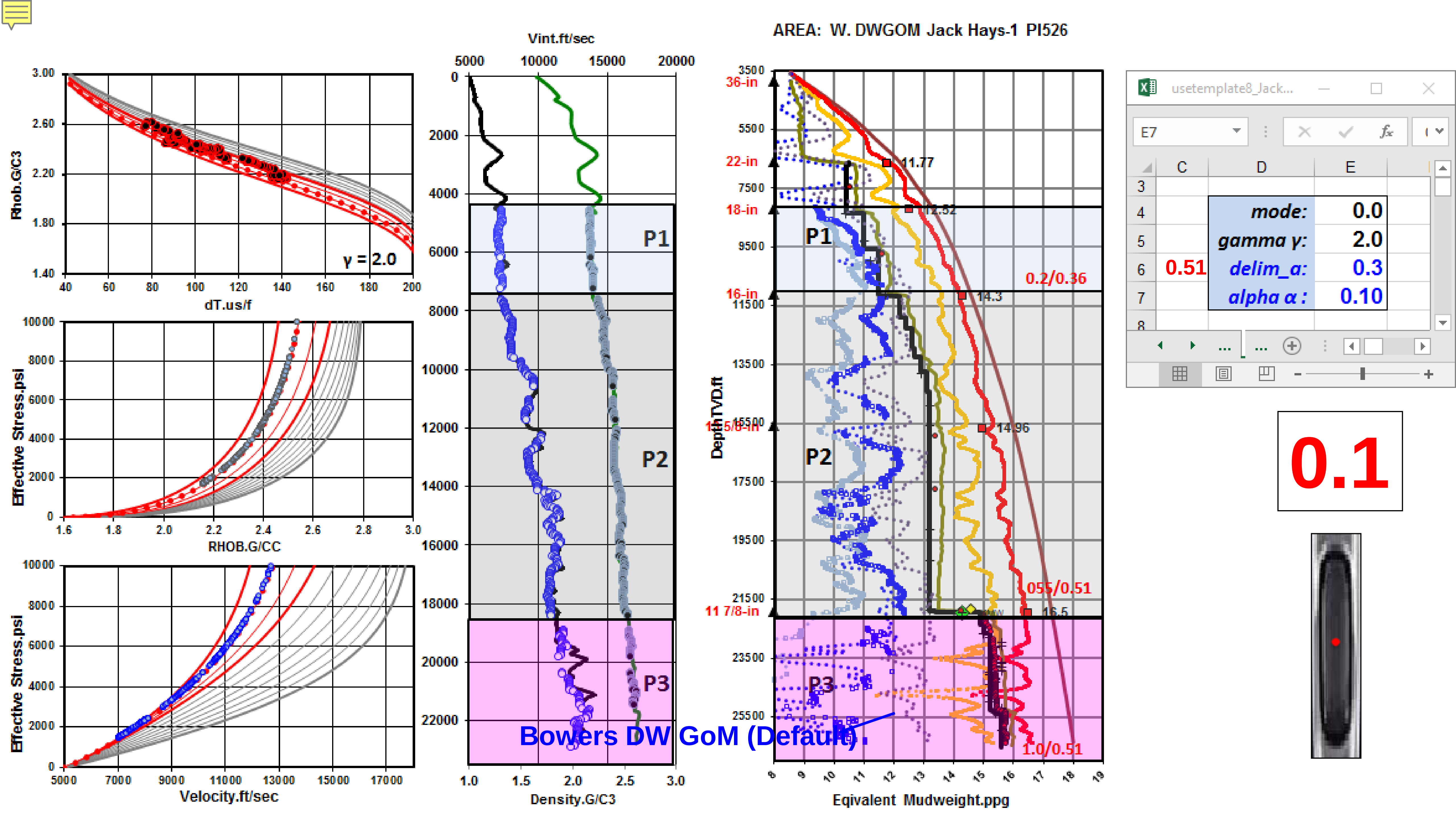


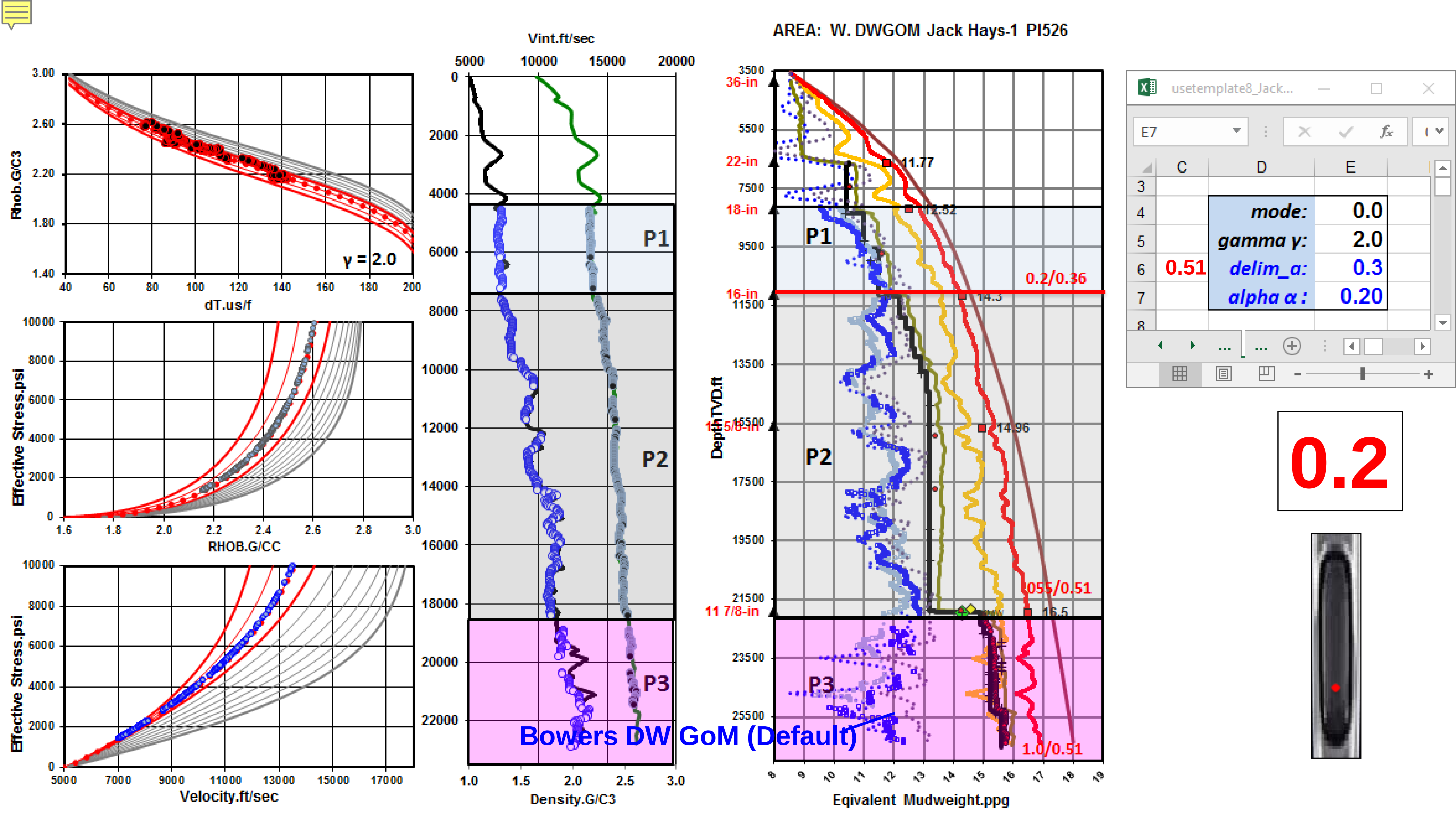
As temperature increases, the thermal conductivity of sandstone, limestone, shale, and salt decrease (Robertson, 1988).

PI526-1 Jack Hays DW Gulf of Mexico, U.S.A.

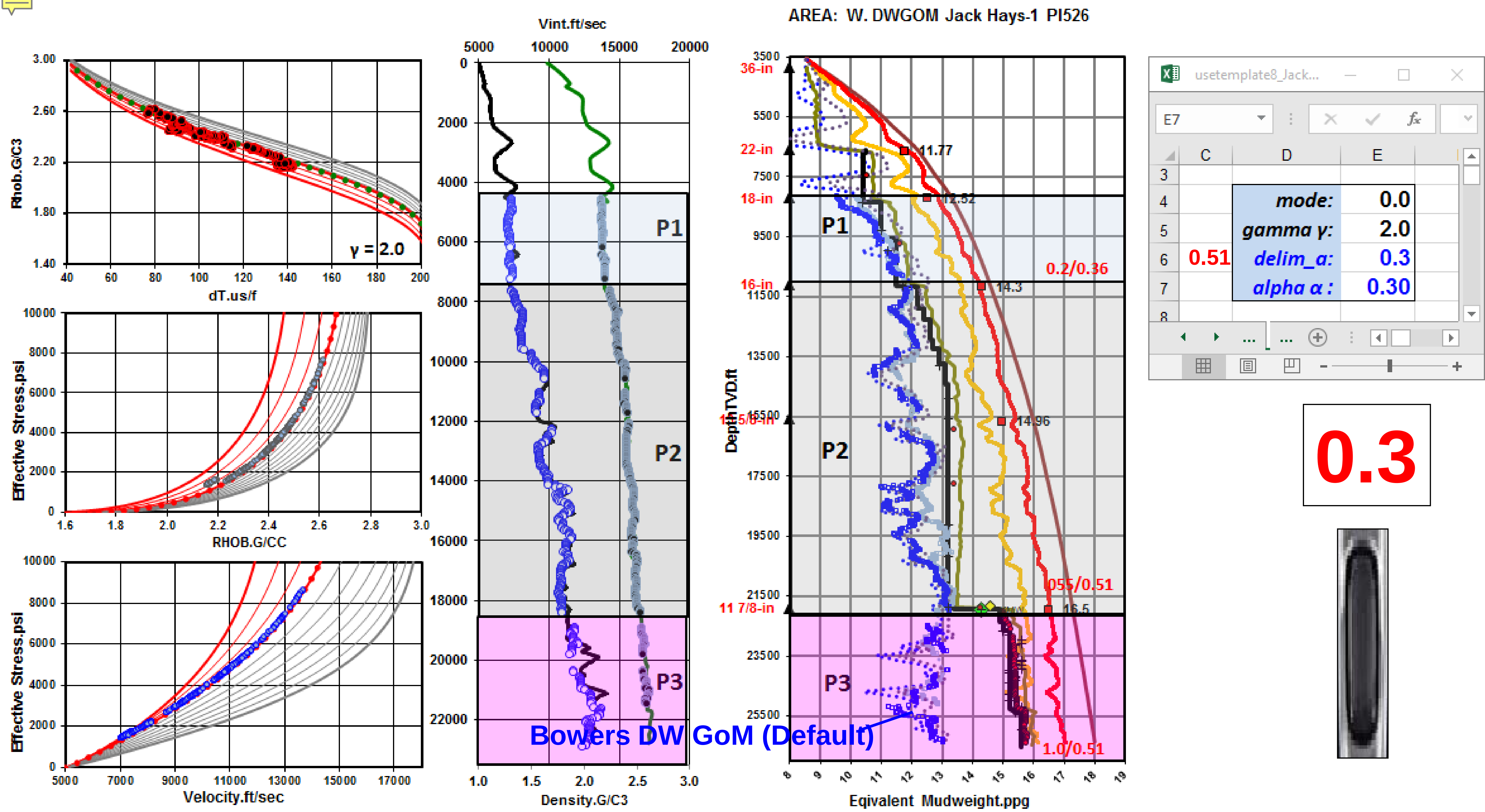


AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
P1
P2
P3
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
dT
rhob
Density.G/C3
Depth TVD.ft
Equivalent Mudweight.ppg
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
055/0.51
1.0/0.51
Bowers DW GoM (Default)
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.00
0.0

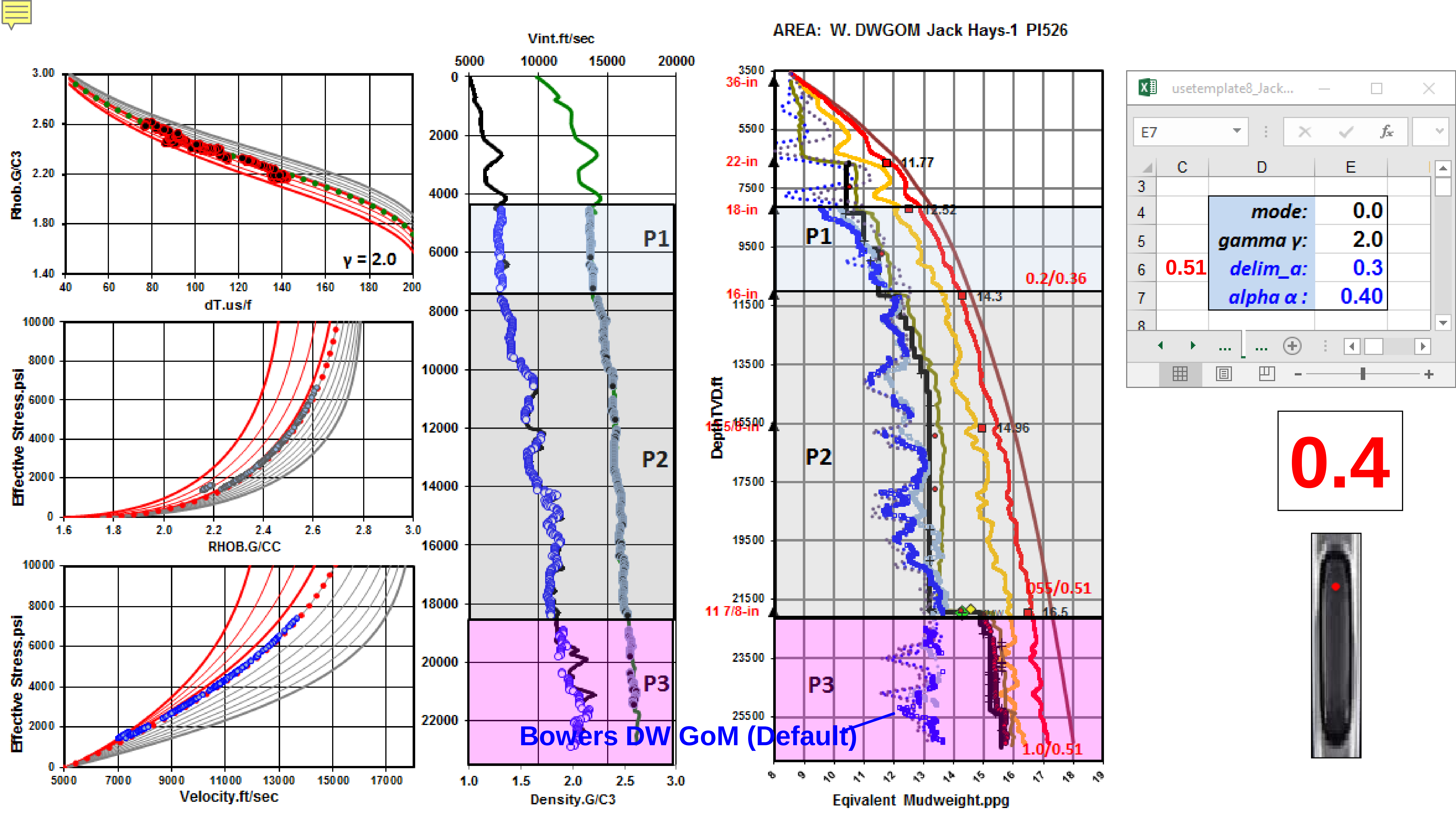

AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Bowers DW GoM (Default)
DepthTVD.ft
Equivalent Mudweight.ppg
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
055/0.51
1.0/0.51
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.10
0.1



AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
γ = 2.0
dT.us/f
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Bowers DW GoM (Default)
DepthTVD.ft
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
055/0.51
1.0/0.51
Eqivalent Mudweight.ppg
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51 delim_a: 0.3
alpha α : 0.20
0.2

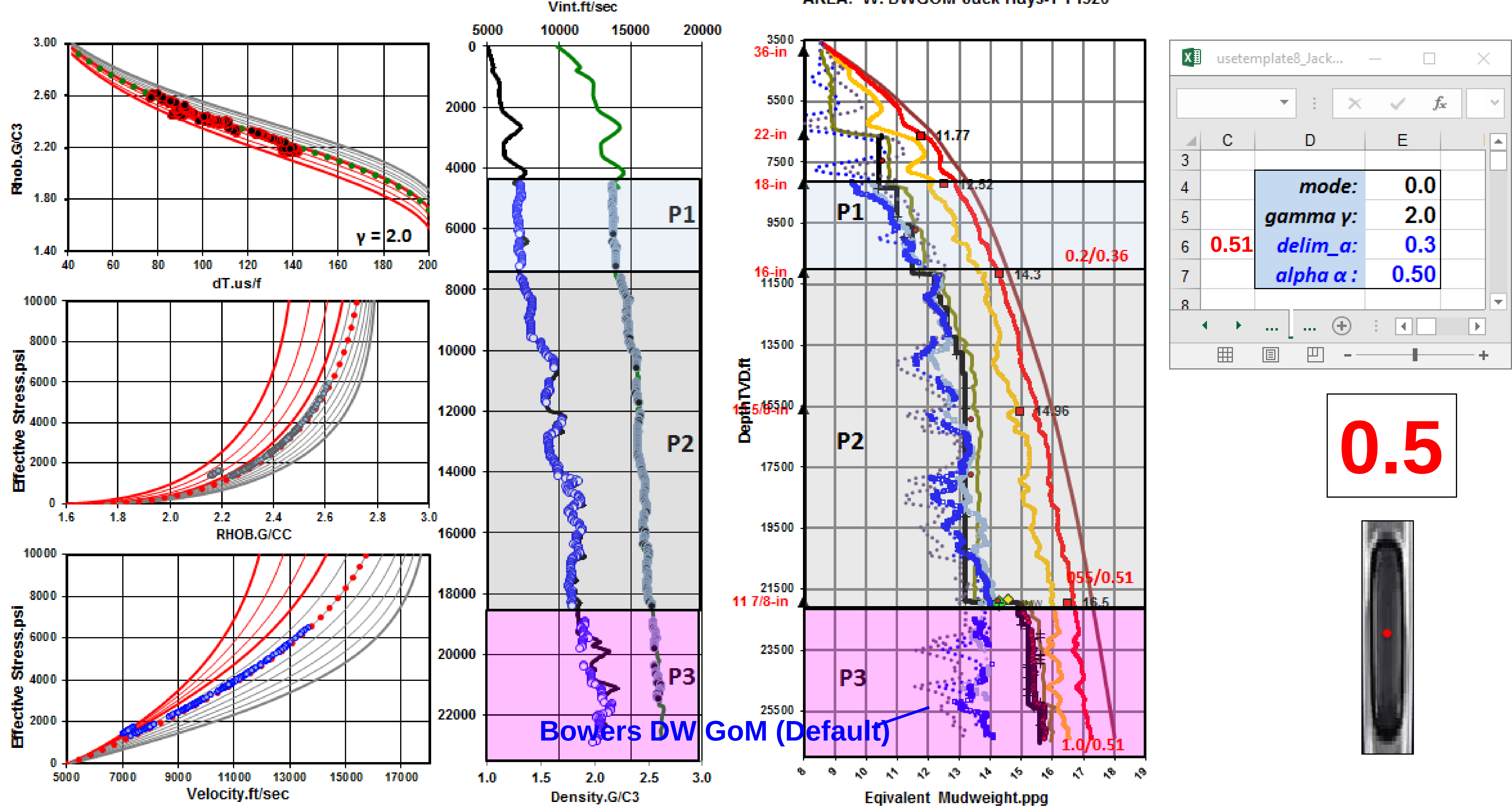


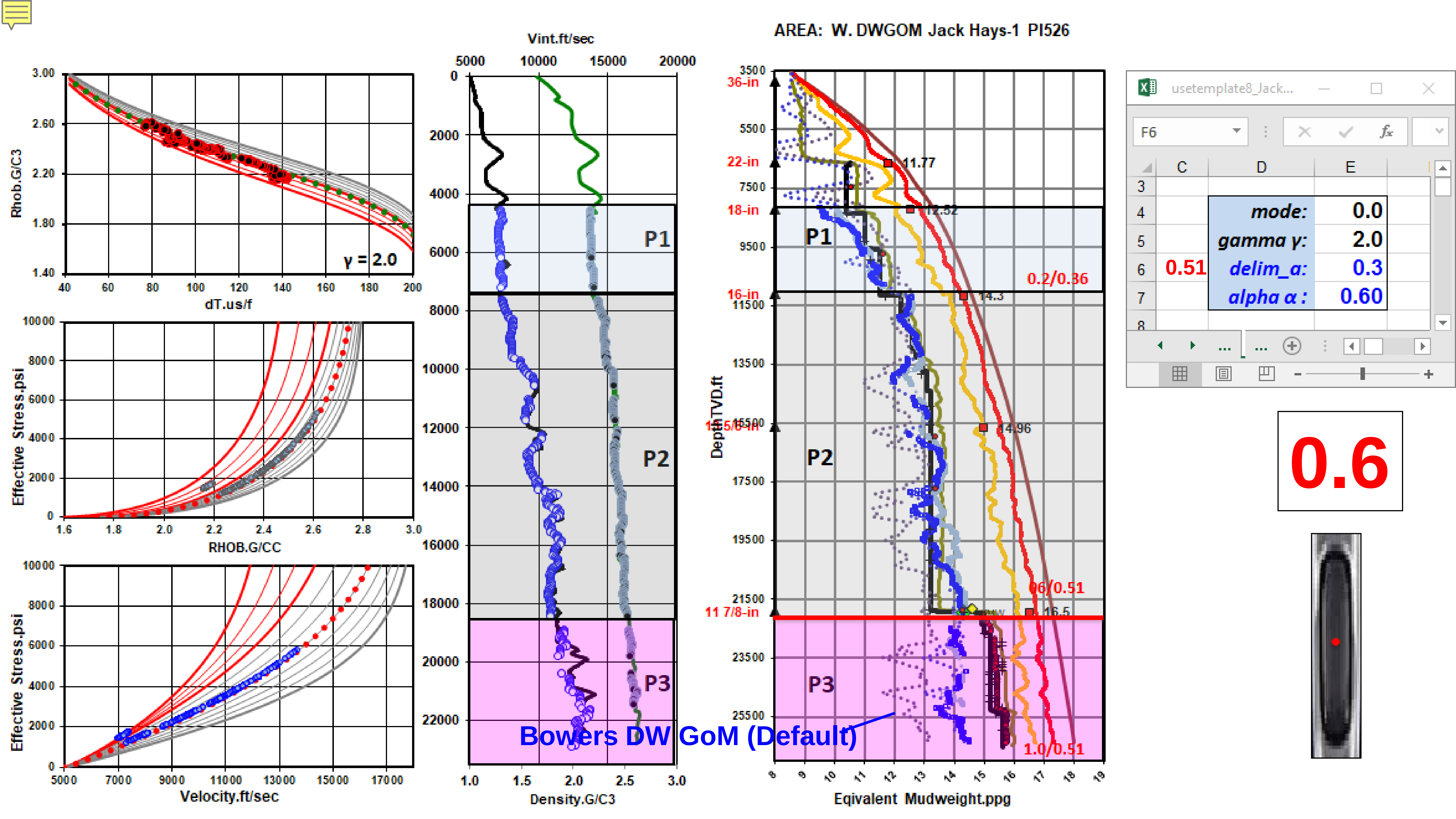
AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Bowers DW GoM (Default)
DepthTVD.ft
Eqivalent Mudweight.ppg
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
055/0.51
1.0/0.51
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.30
0.3



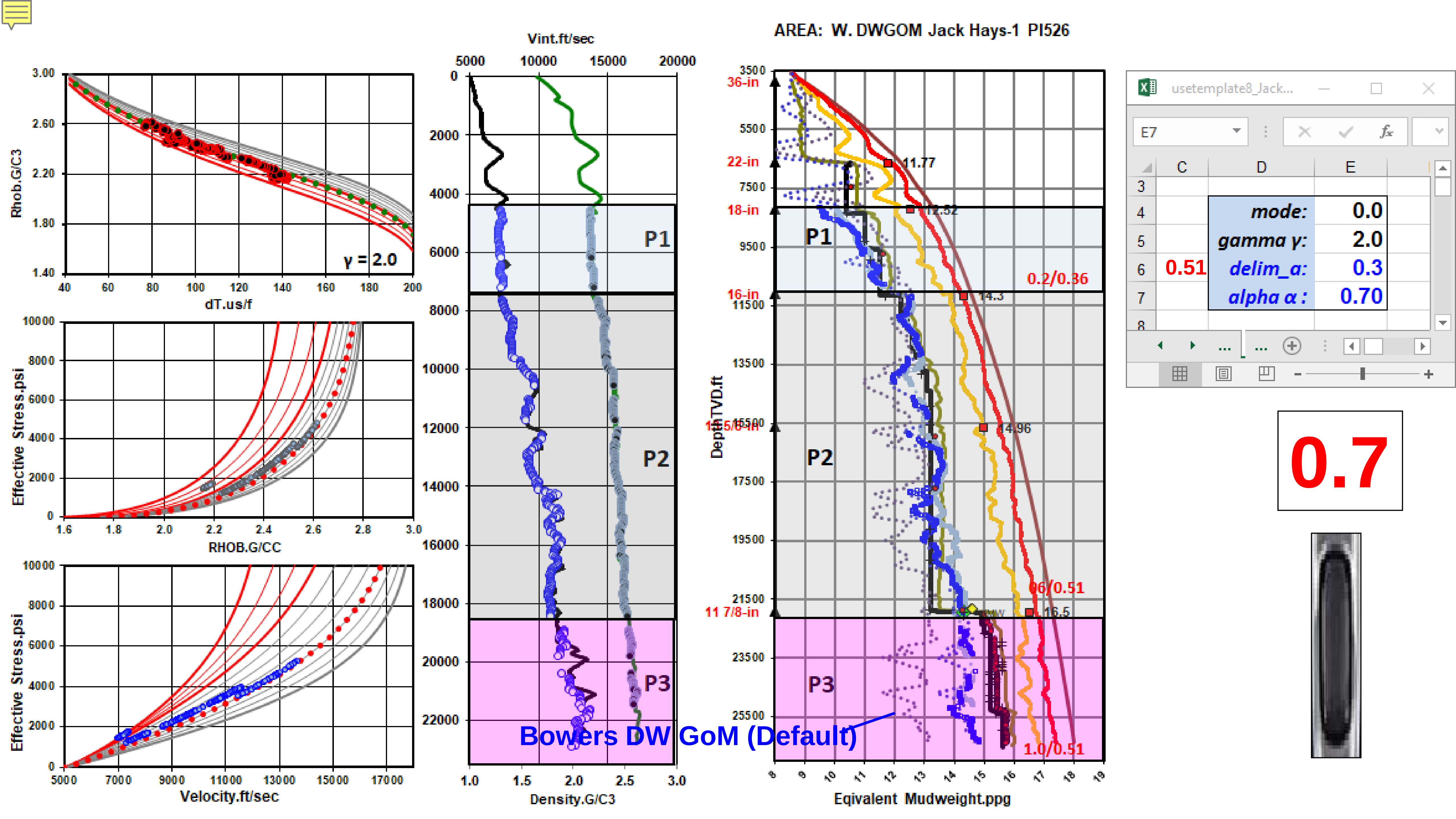
AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Bowers DW GoM (Default)
DepthTVD.ft
36-in
22-in
18-in
16-in
13 5/8-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
0.55/0.51
1.0/0.51
Eqivalent Mudweight.ppg
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
delim_a: 0.3
alpha α : 0.40
0.51
0.4

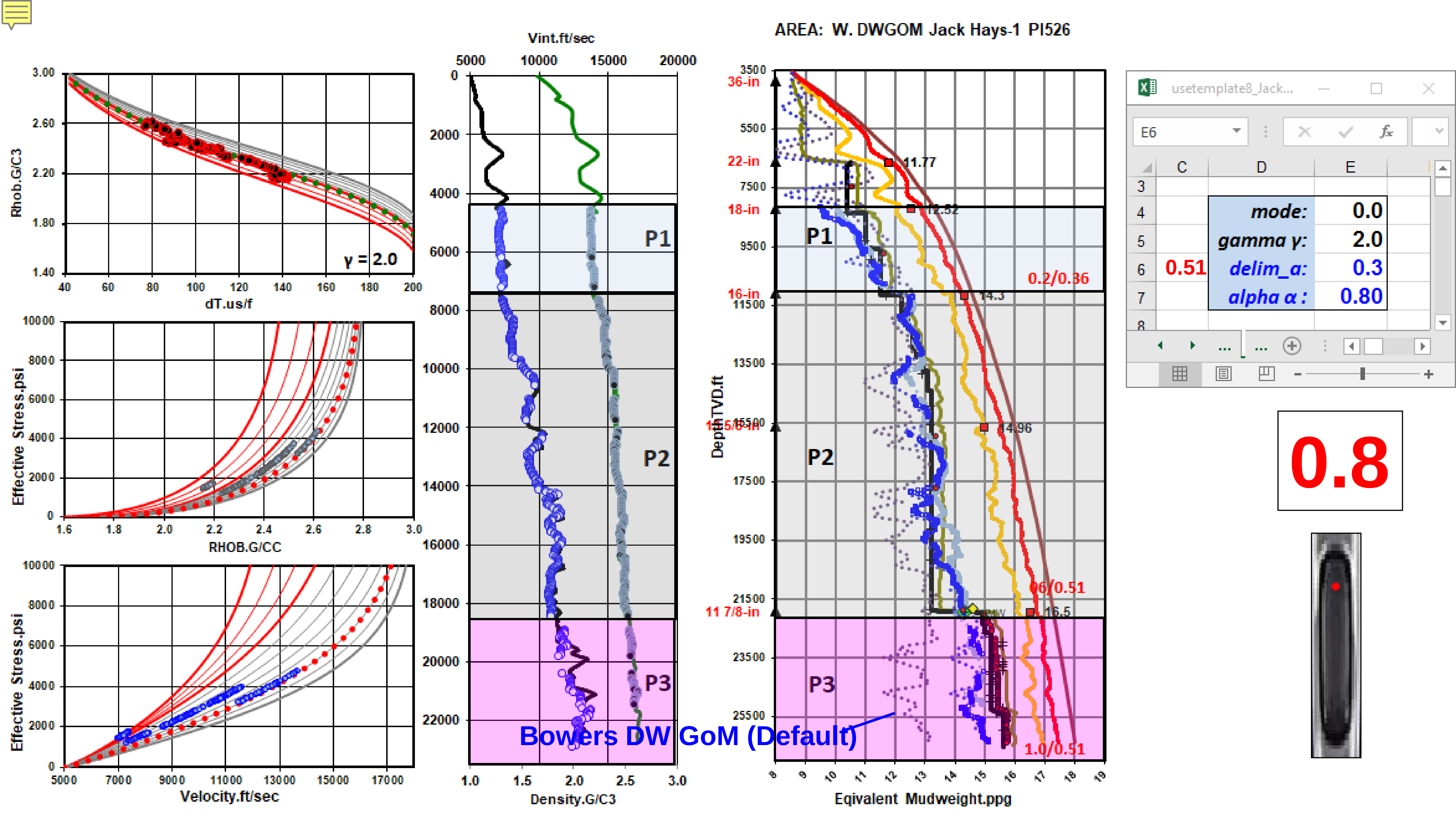
AREA: W. DWGOM Jack Hays-1 PI526

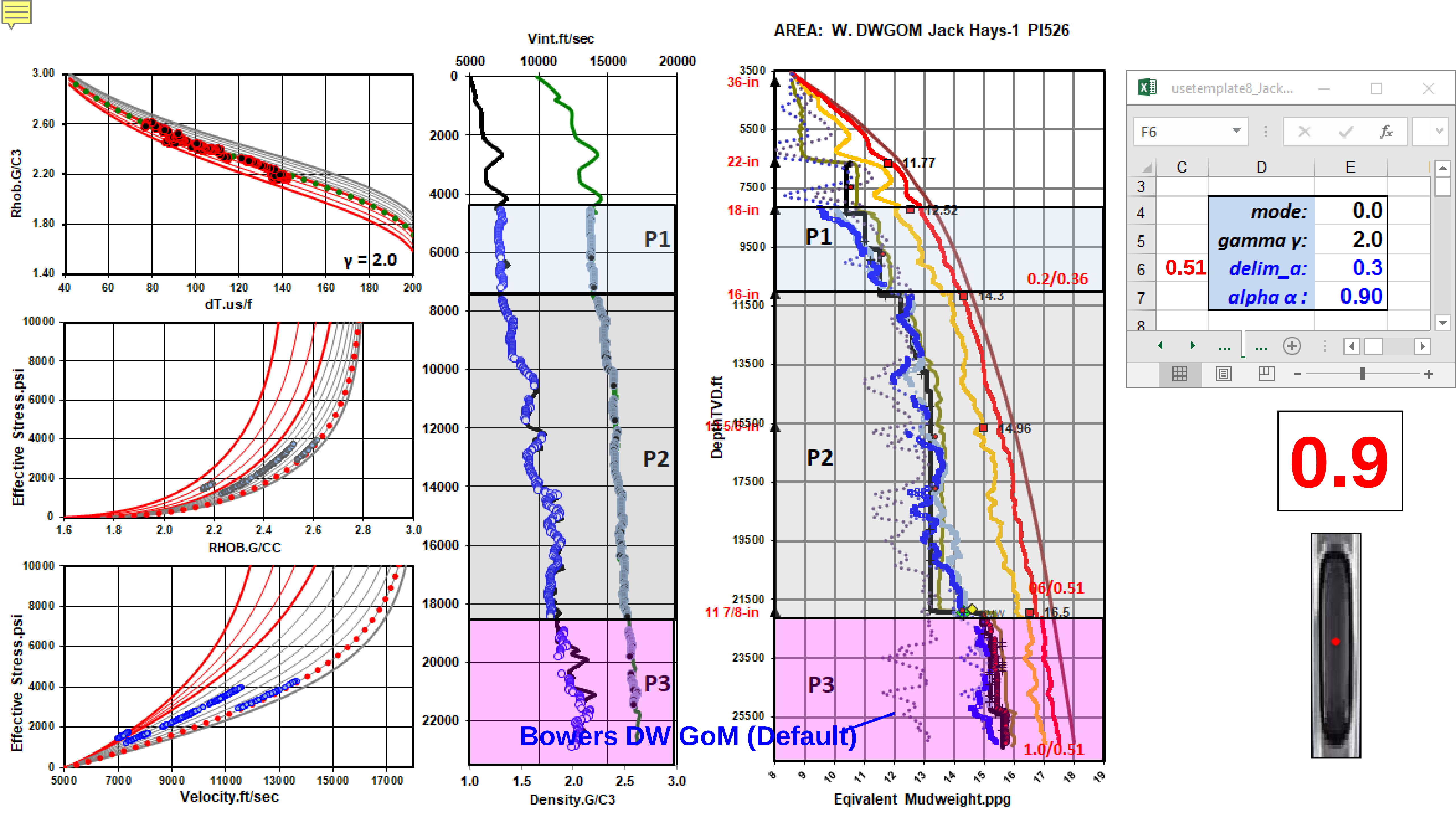




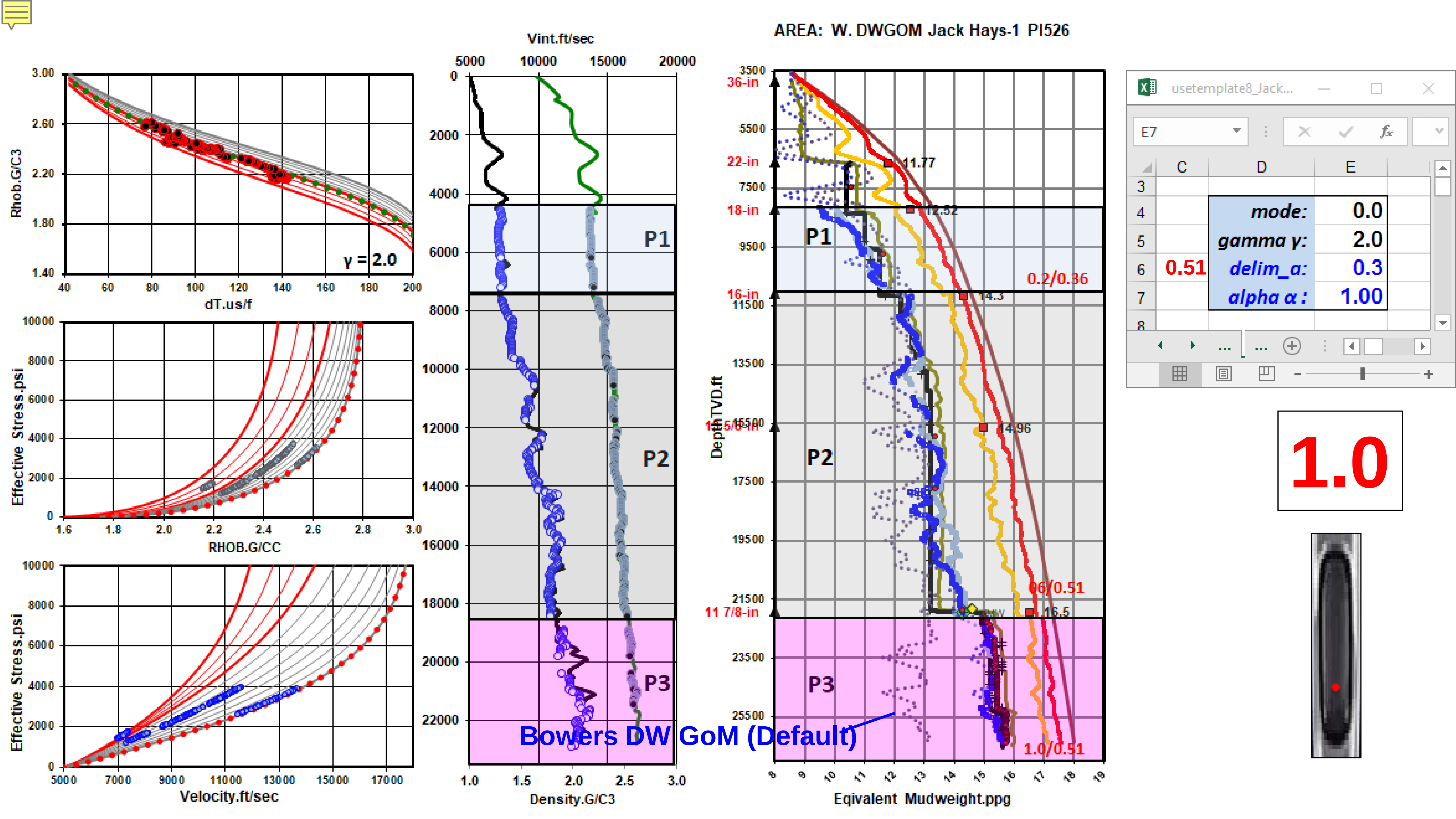
AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
DepthTVD.ft
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
06/0.51
1.0/0.51
Eqivalent Mudweight.ppg
Bowers DW GoM (Default)
usetemplate8_Jack...
F6
mode: 0.0
gamma γ: 2.0
0.51 delim_a: 0.3
alpha α : 0.60
0.6


AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Effective Stress.psi
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
DepthTVD.ft
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
06/0.51
1.0/0.51
Eqivalent Mudweight.ppg
Bowers DW GoM (Default)
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.70
0.7

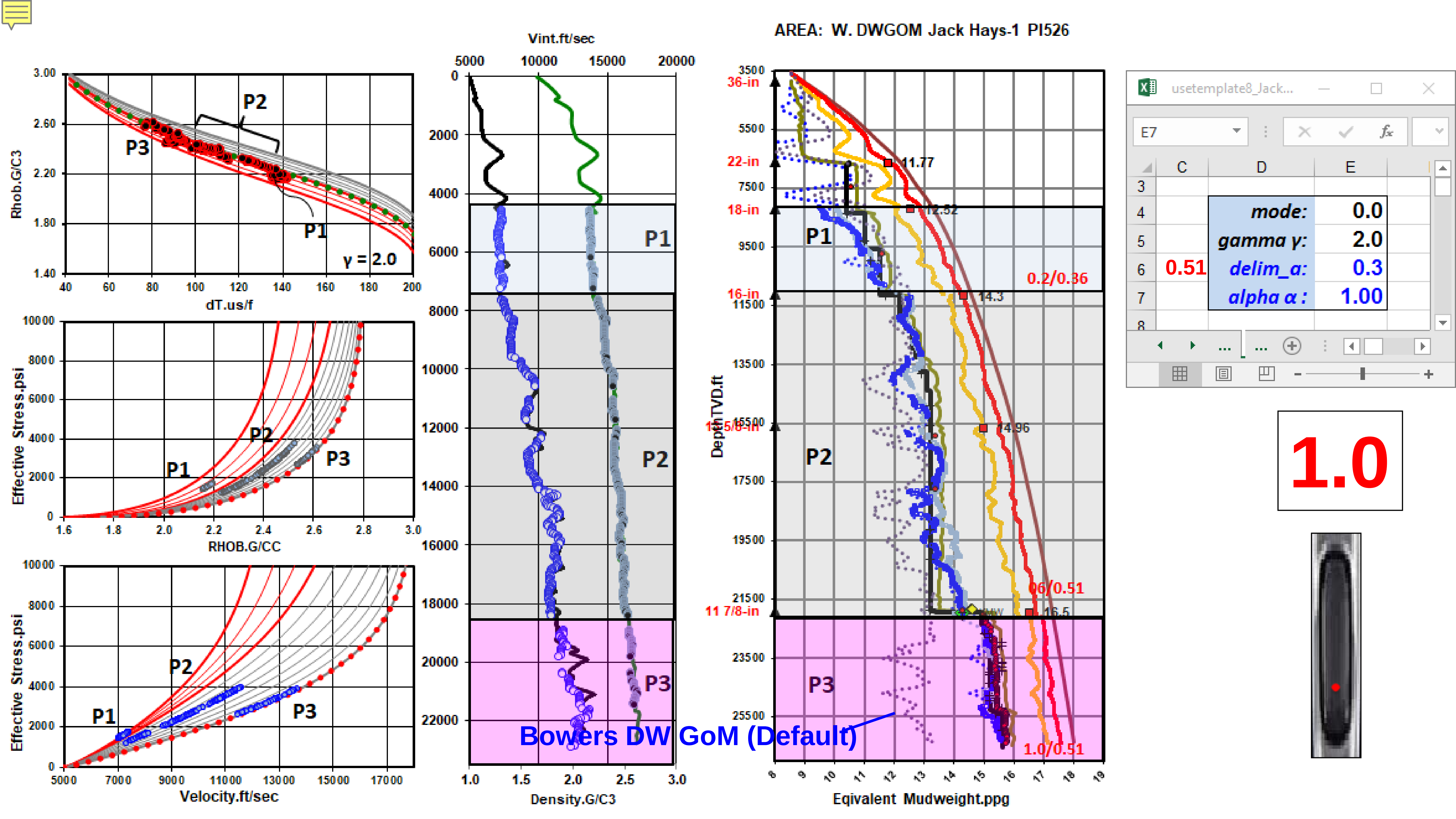

AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Depth TVD.ft
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
06/0.51
1.0/0.51
Eqivalent Mudweight.ppg
Bowers DW GoM (Default)
usetemplate8_Jack...
E6
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.80
0.8



AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
DepthTVD.ft
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
06/0.51
1.0/0.51
Eqivalent Mudweight.ppg
Bowers DW GoM (Default)
usetemplate8_Jack...
F6
mode: 0.0
gamma γ: 2.0
0.51 delim_α: 0.3
alpha α : 0.90
0.9

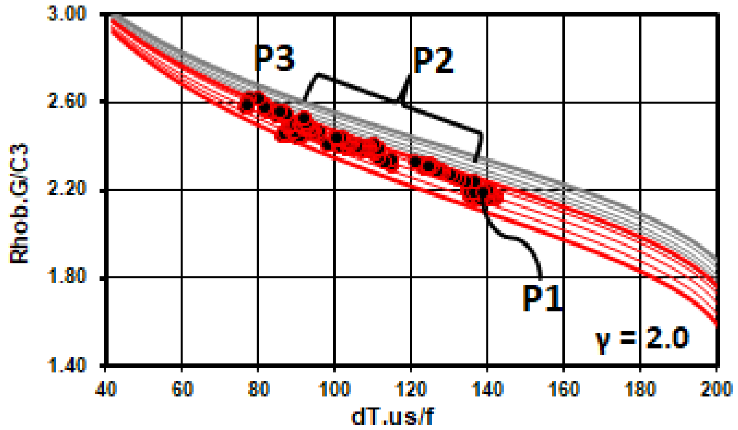


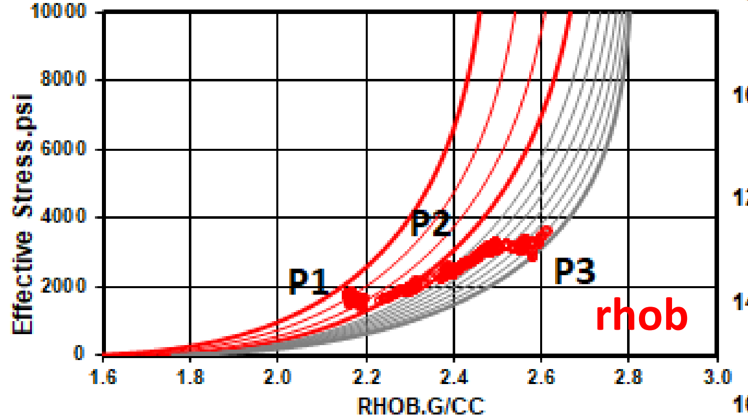
AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Depth TVD.ft
36-in
22-in
18-in
16-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
06/0.51
1.0/0.51
Eqivalent Mudweight.ppg
Bowers DW GoM (Default)
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 1.00
1.0

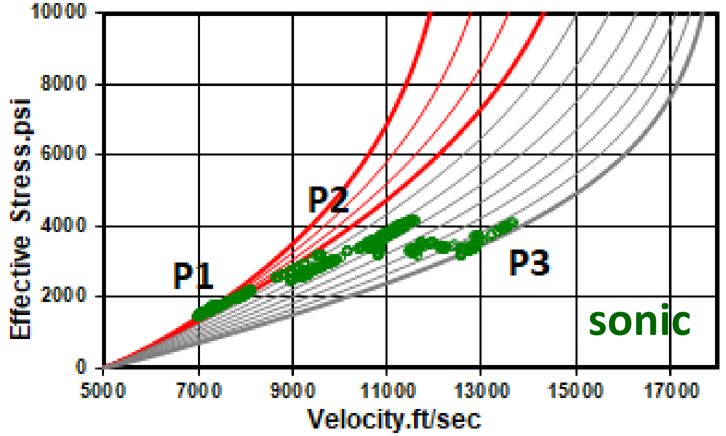


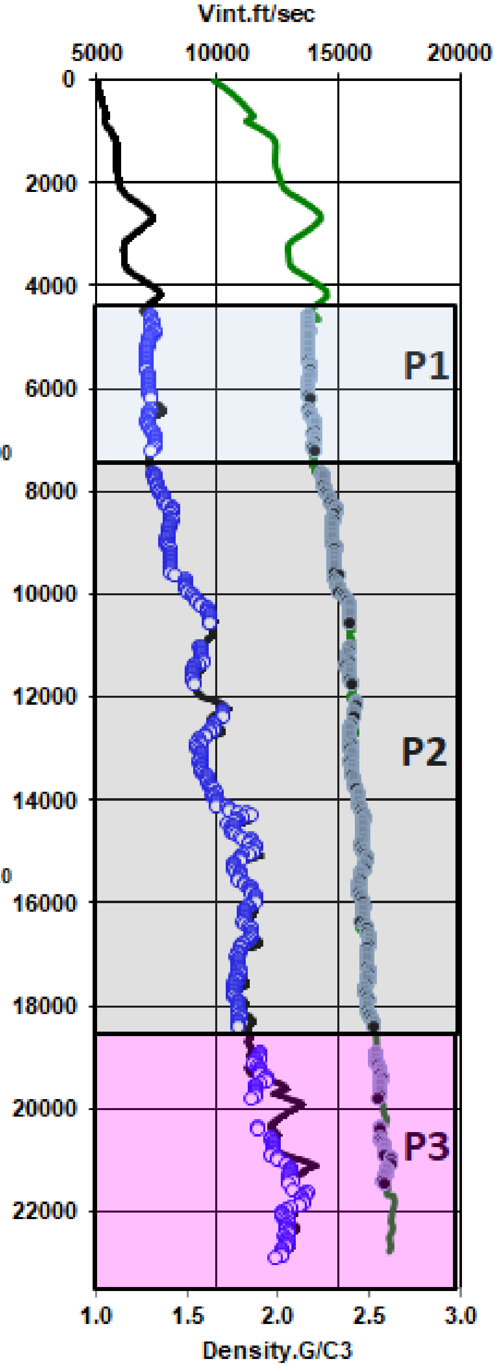
AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
P1
P2
P3
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
DepthTVD.ft
Eqivalent Mudweight.ppg
36-in
22-in
18-in
16-in
13 5/8-in
11 7/8-in
11.77
12.52
14.3
14.96
16.5
0.2/0.36
06/0.51
1.0/0.51
Bowers DW GoM (Default)
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 1.00
1.0

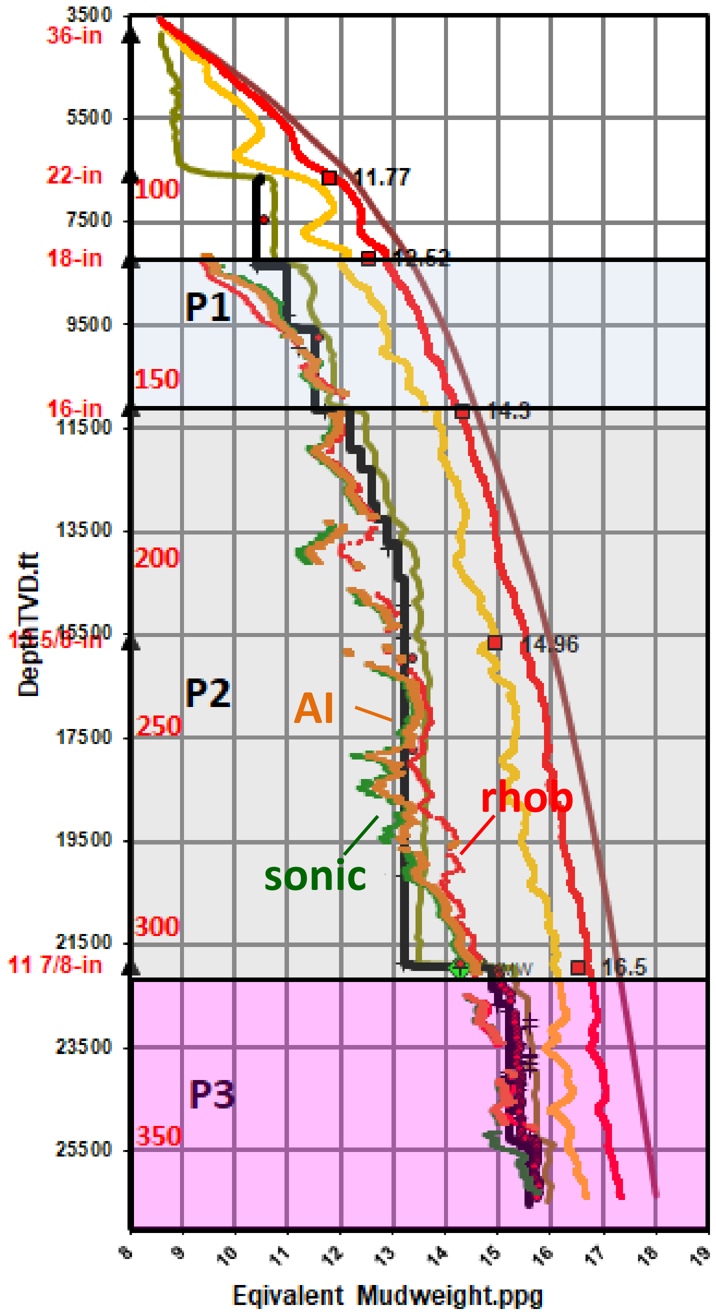
AREA: W. DWGOM Jack Hays-1 PI526



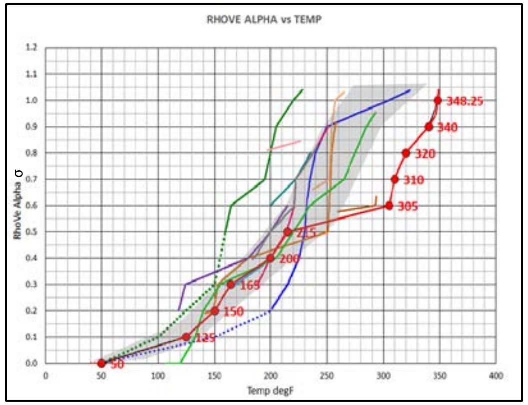




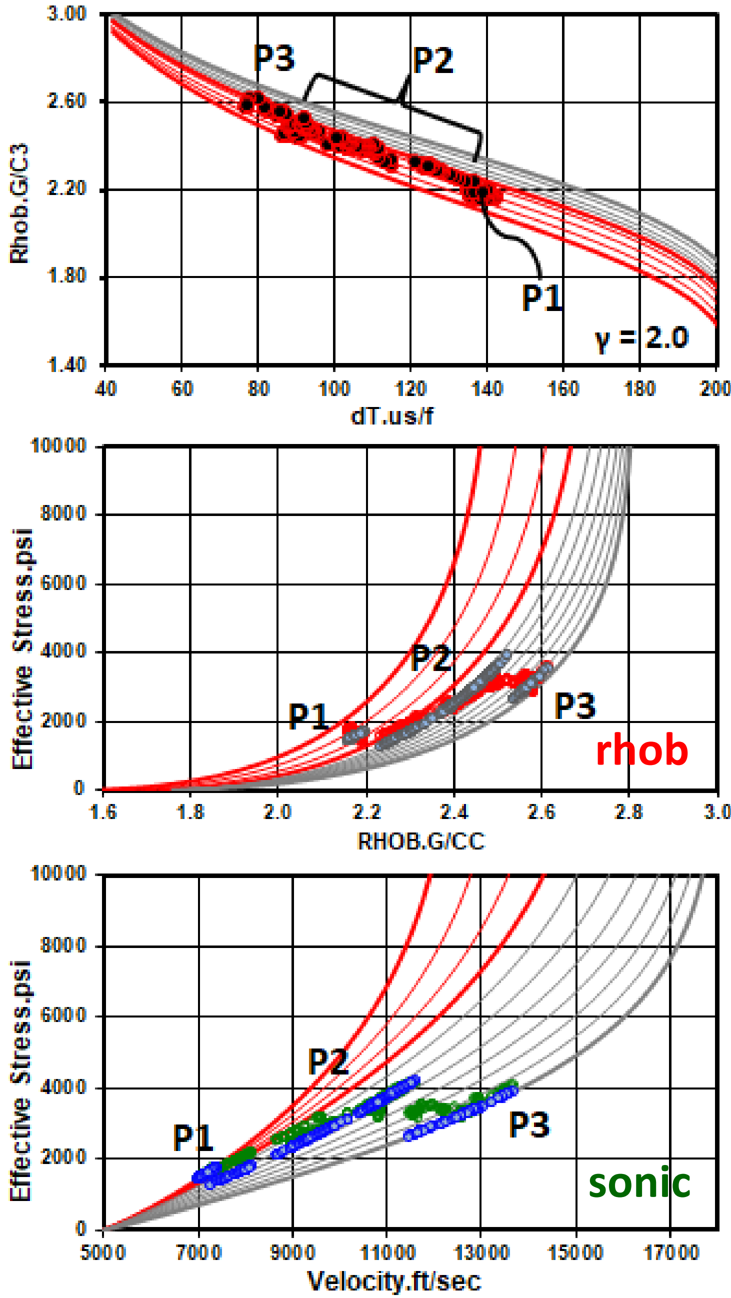


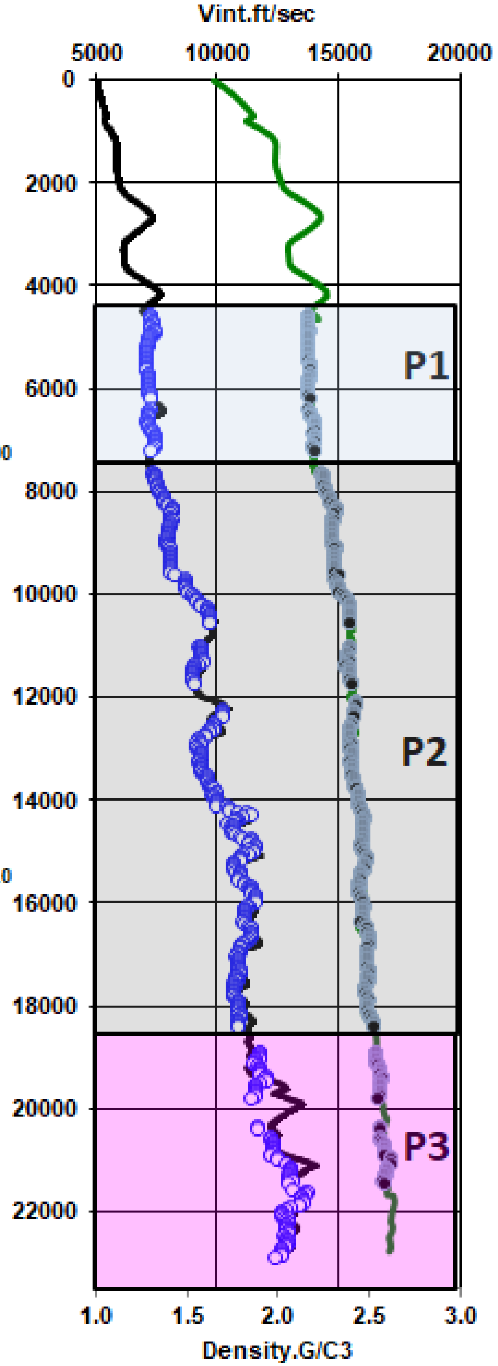


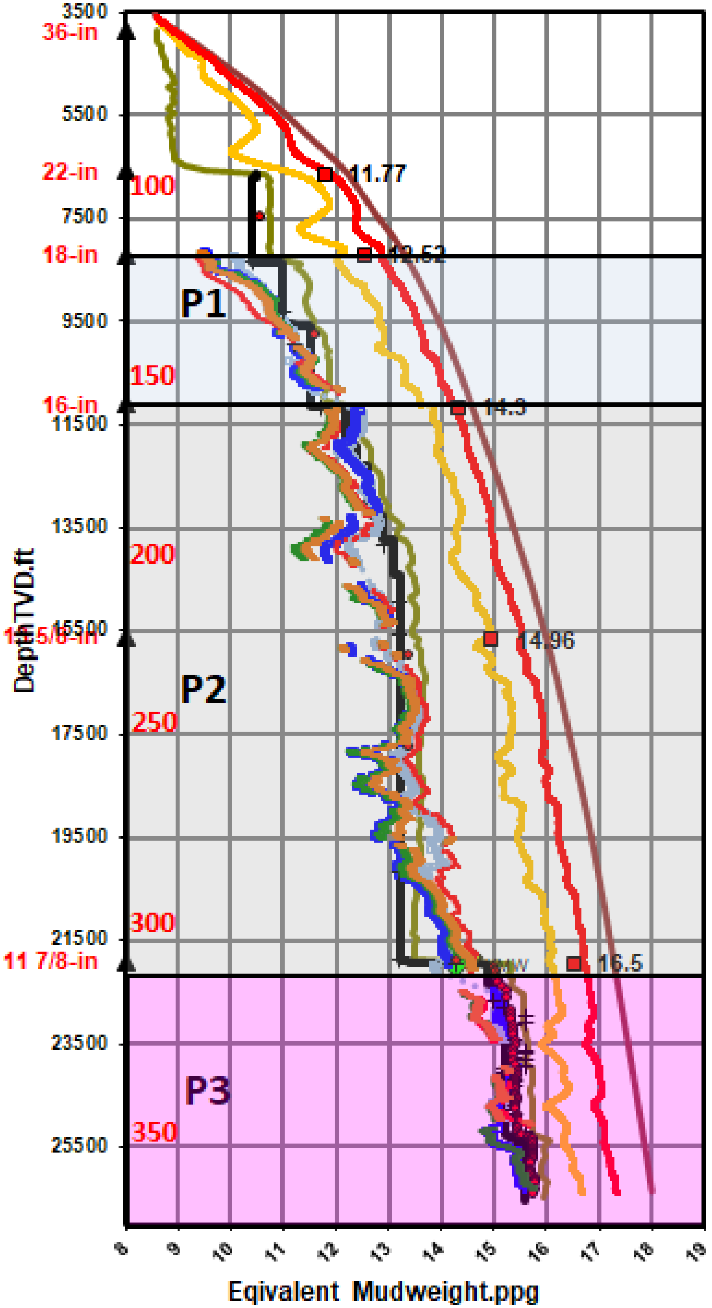
rhob	alpha	TEMPdegF
#N/A	0.0	50
2.16	0.1	125
2.20	0.2	150
2.25	0.3	165
2.39	0.4	200
2.38	0.5	215
2.49	0.6	305
2.53	0.7	310
2.54	0.8	320
2.57	0.9	340
2.60	1.0	347
2.58	1.05	349



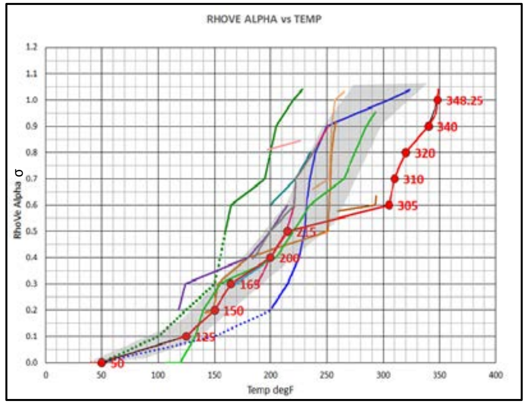
AREA: W. DWGOM Jack Hays-1 PI526

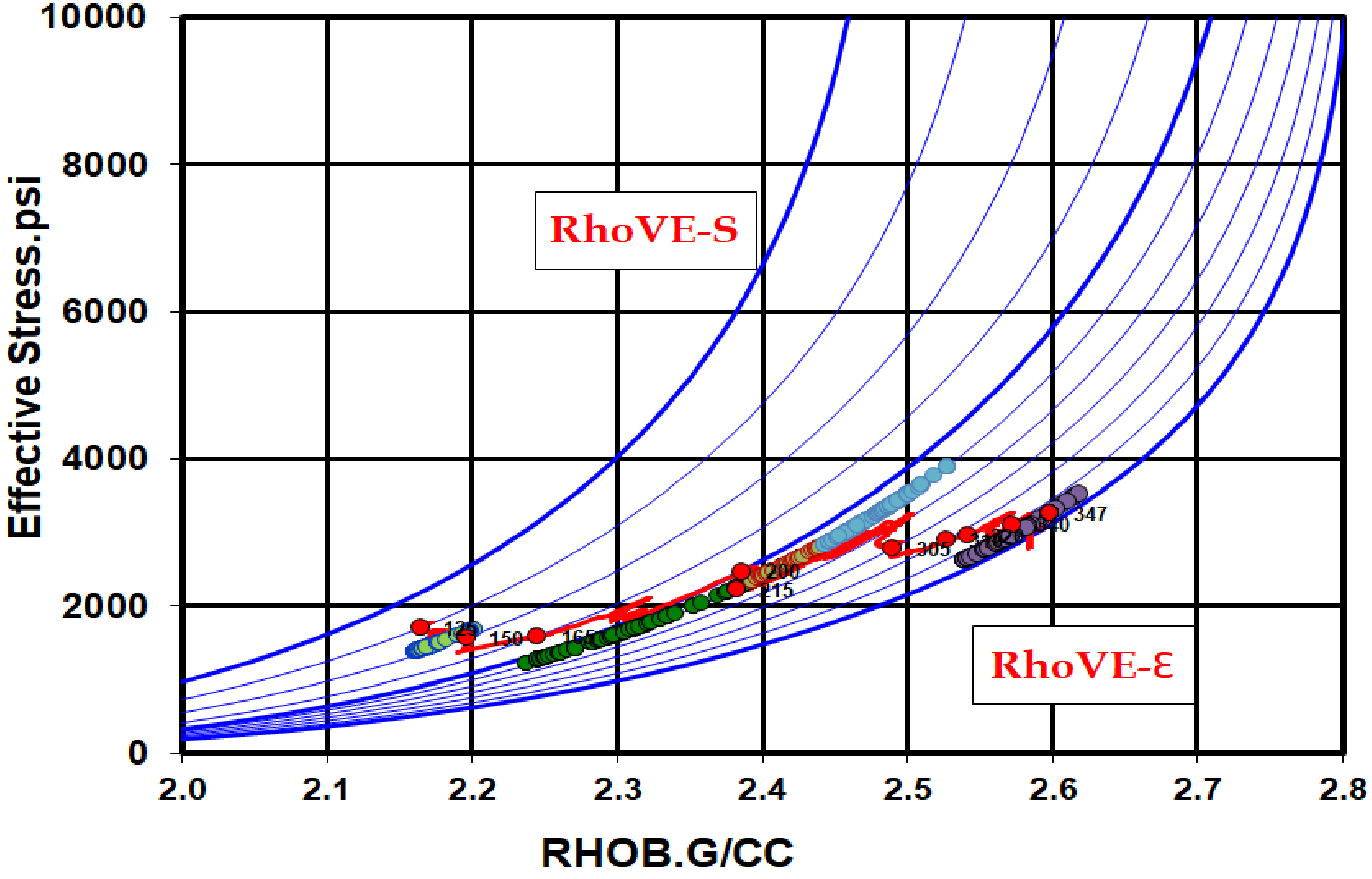




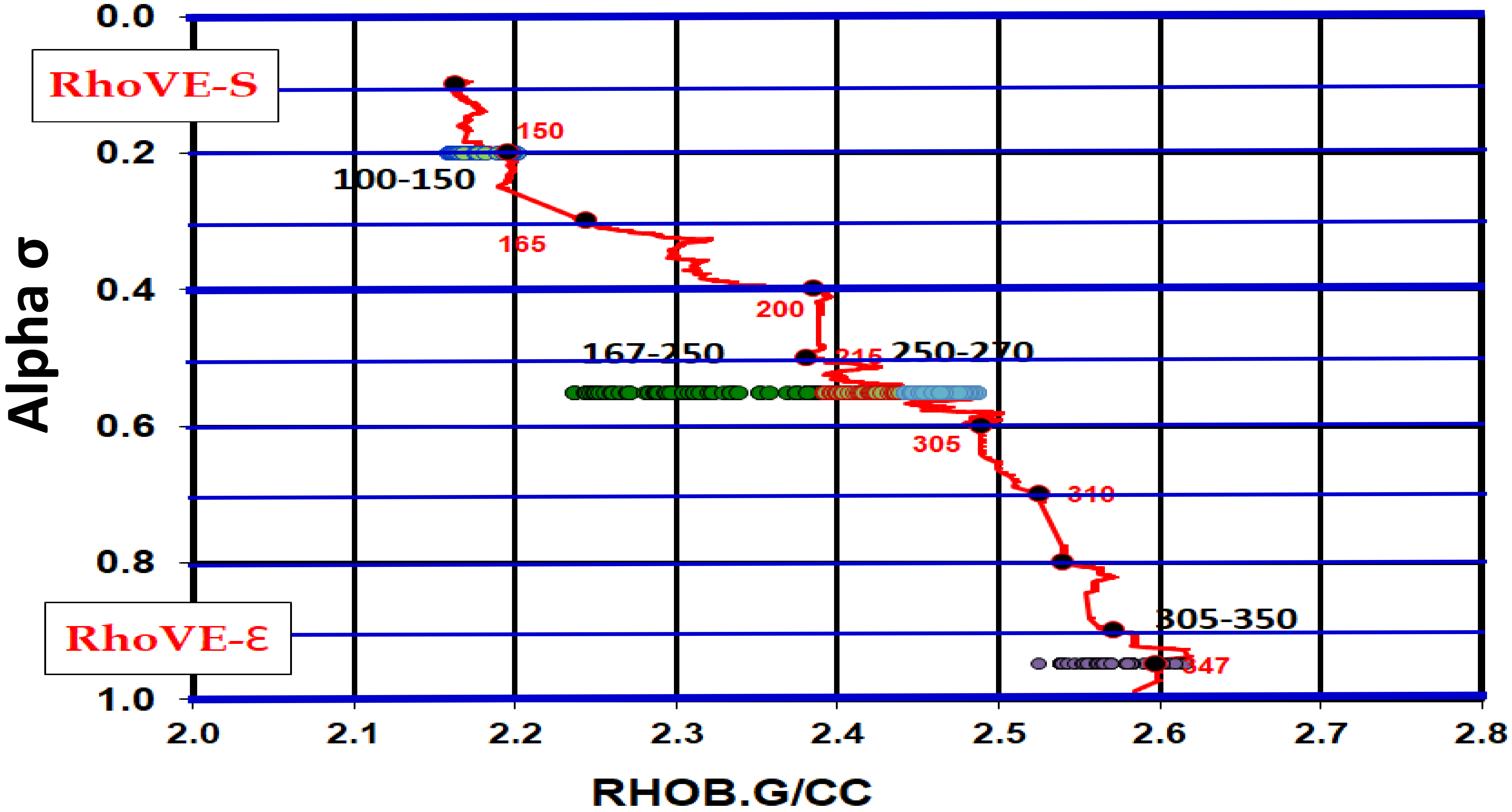


rhob	alpha	TEMPdegF
#N/A	0.0	50
2.16	0.1	125
2.20	0.2	150
2.25	0.3	165
2.39	0.4	200
2.38	0.5	215
2.49	0.6	305
2.53	0.7	310
2.54	0.8	320
2.57	0.9	340
2.60	1.0	347
2.58	1.05	349

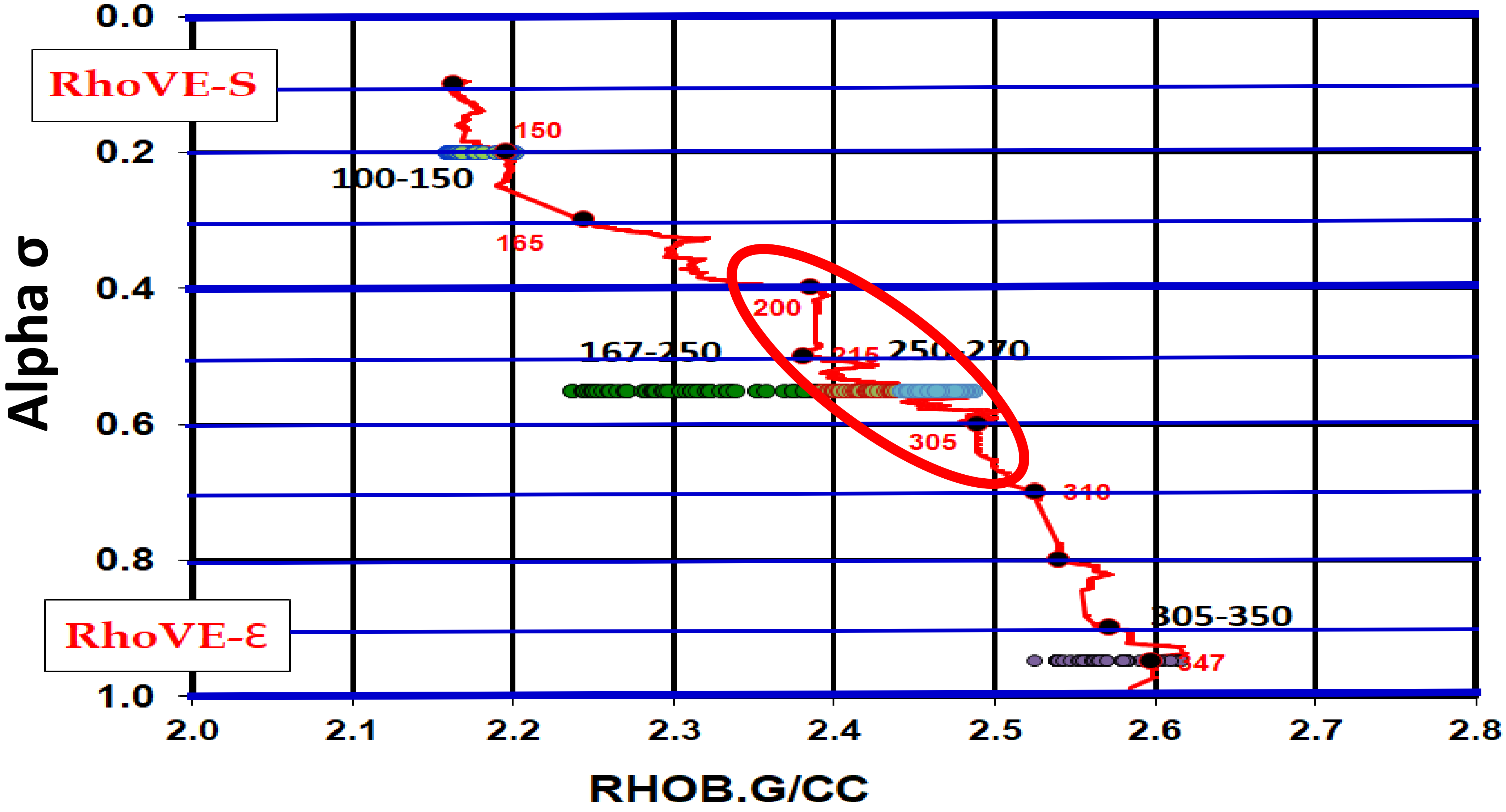




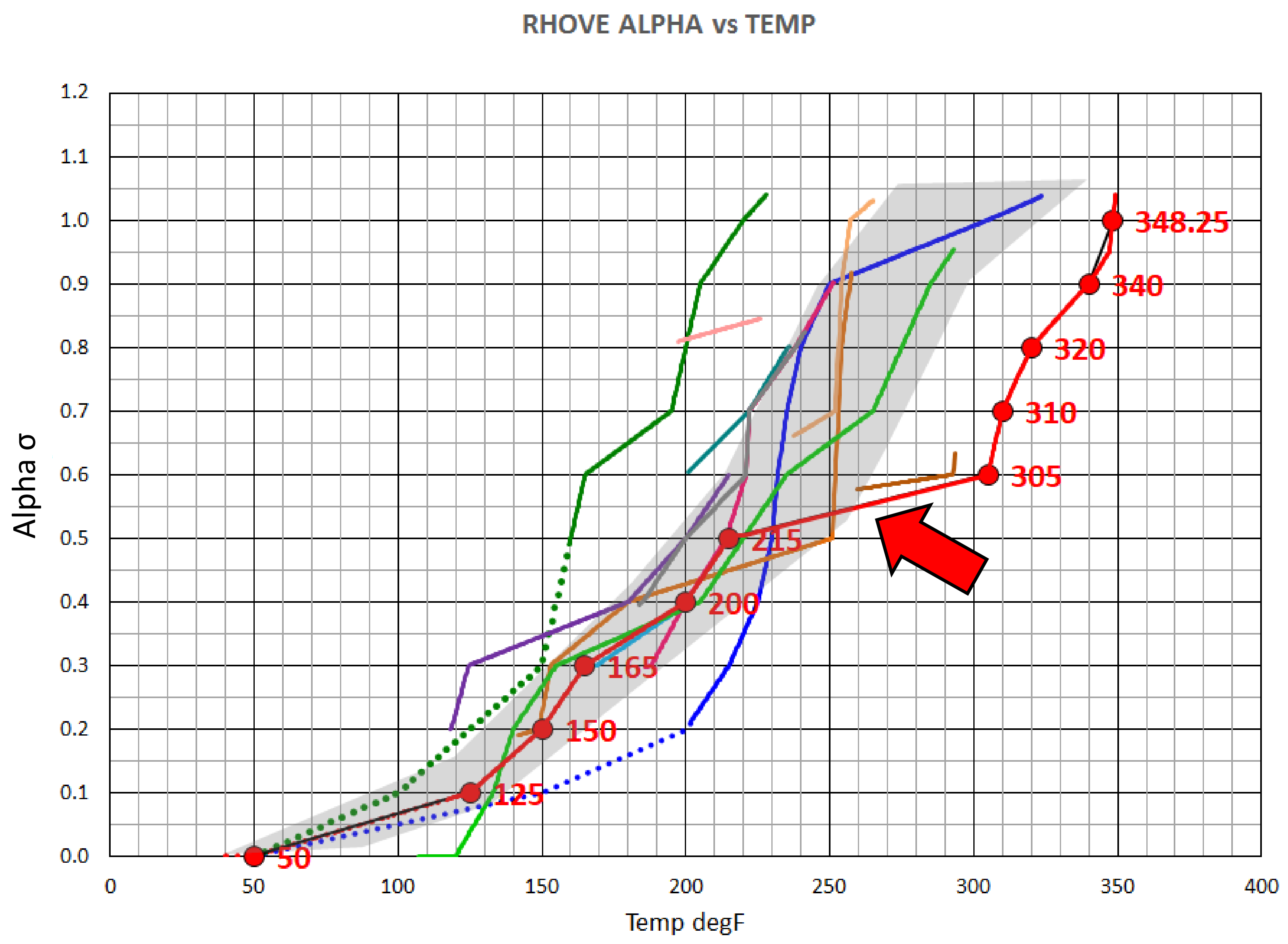
Effective Stress.psi
RHOB.G/CC
10000
8000
6000
4000
2000
0
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
RhoVE-S
RhoVE-Ɛ
150
200
215
305
347



0.0
0.2
0.4
0.6
0.8
1.0
RhoVE-S
RhoVE-Ɛ
Alpha σ
150
100-150
165
200
167-250
215
250-270
305
310
305-350
347
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
RHOB.G/CC

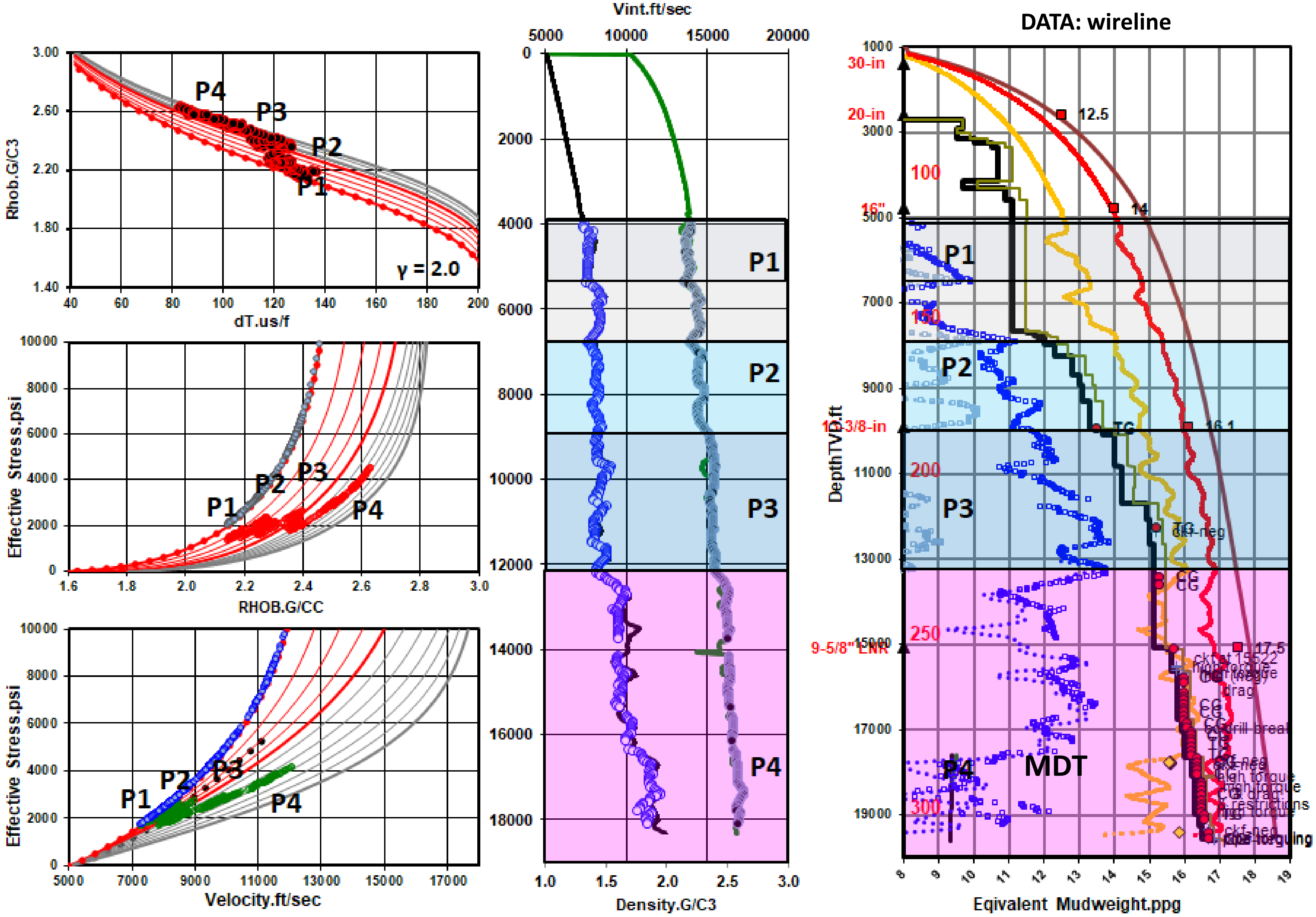


0.0
0.2
0.4
0.6
0.8
1.0
RhoVE-S
RhoVE-Ɛ
Alpha σ
150
100-150
165
200
167-250
215
250-270
305
310
305-350
347
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
RHOB.G/CC

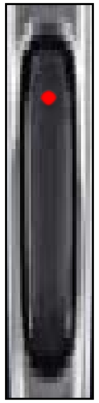

RHOVE ALPHA vs TEMP
Alpha σ
Temp degF
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
348.25
340
320
310
305
215
200
165
150
125
50

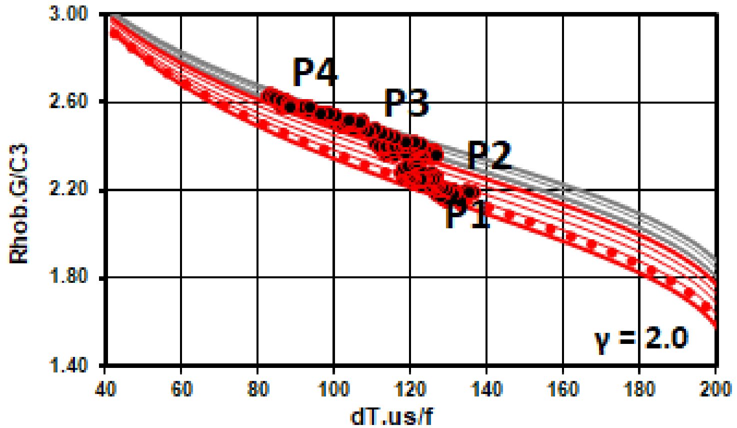
Rhob

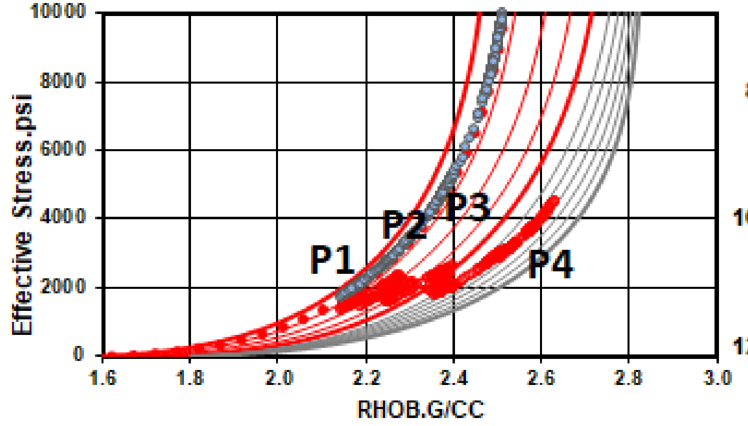
AREA: Viosca Knoll
DATA: wireline

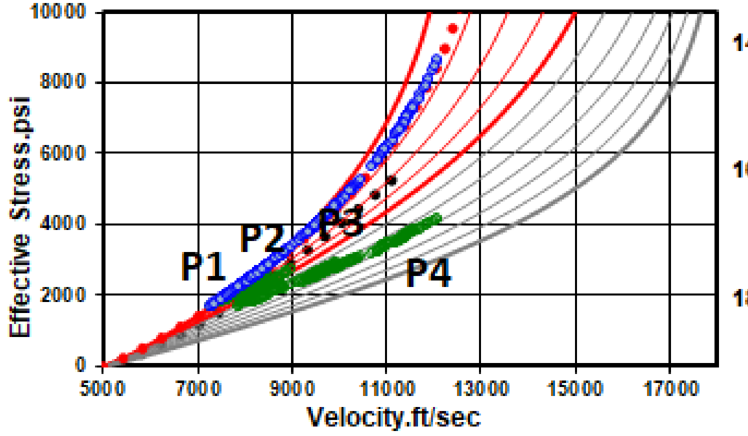


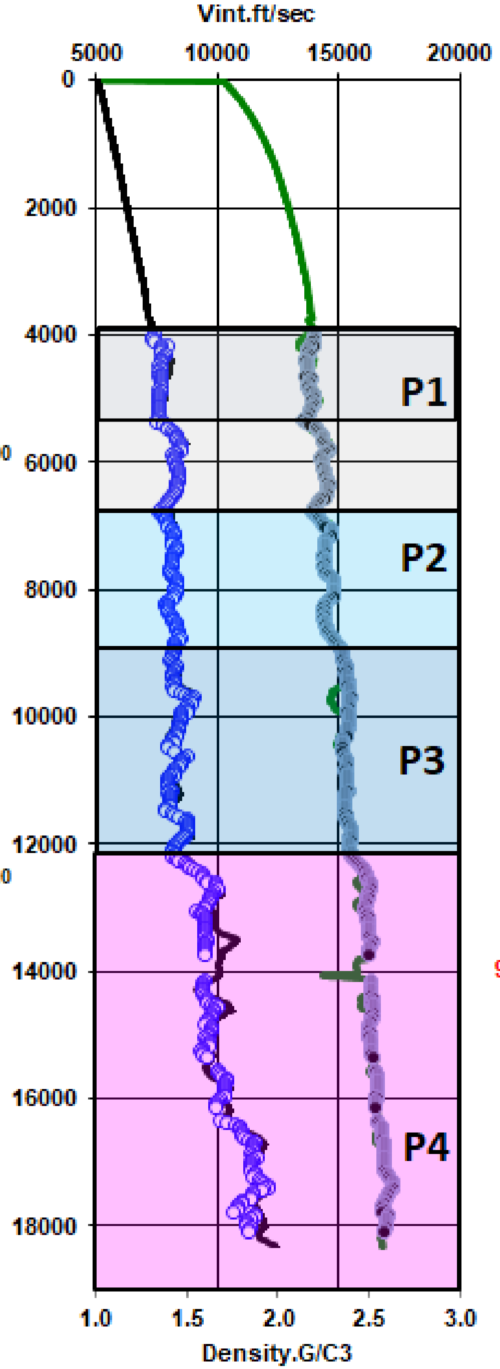
0.00



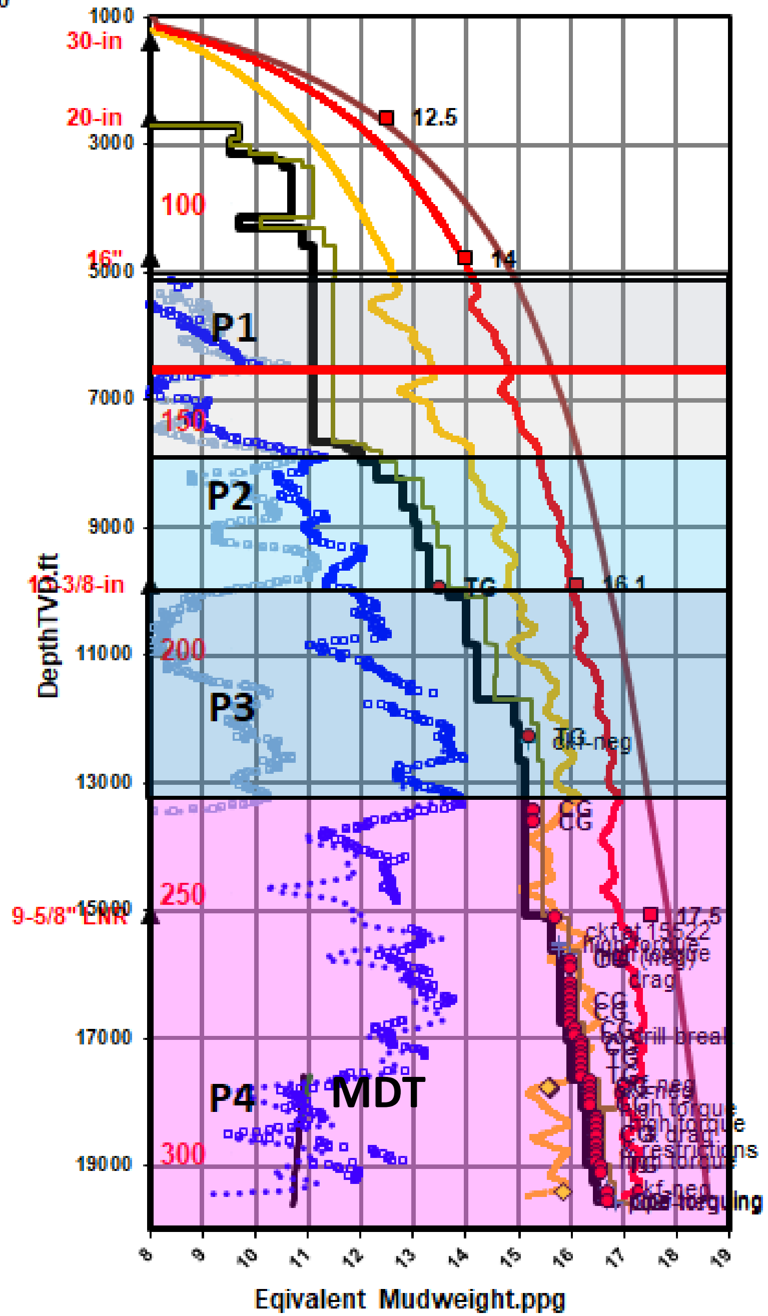








AREA: Viosca Knoll
DATA: wireline



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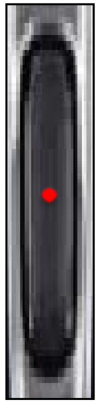
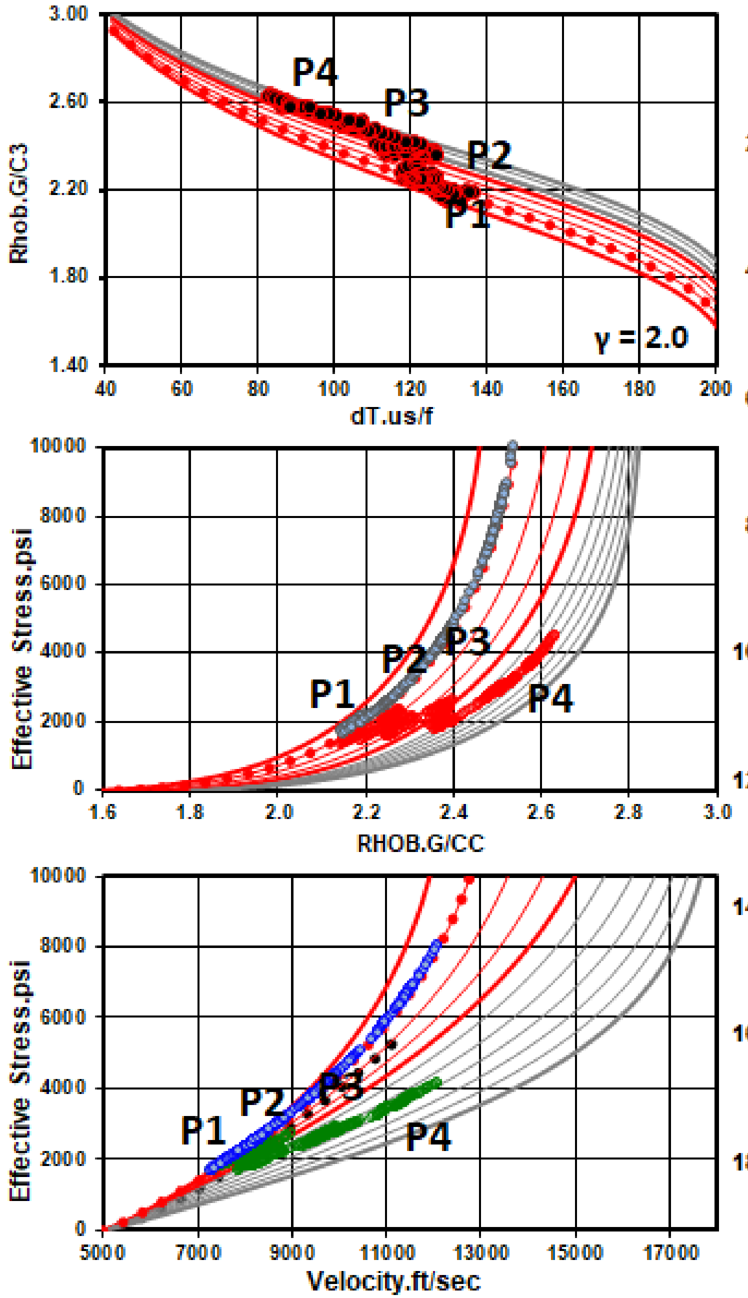
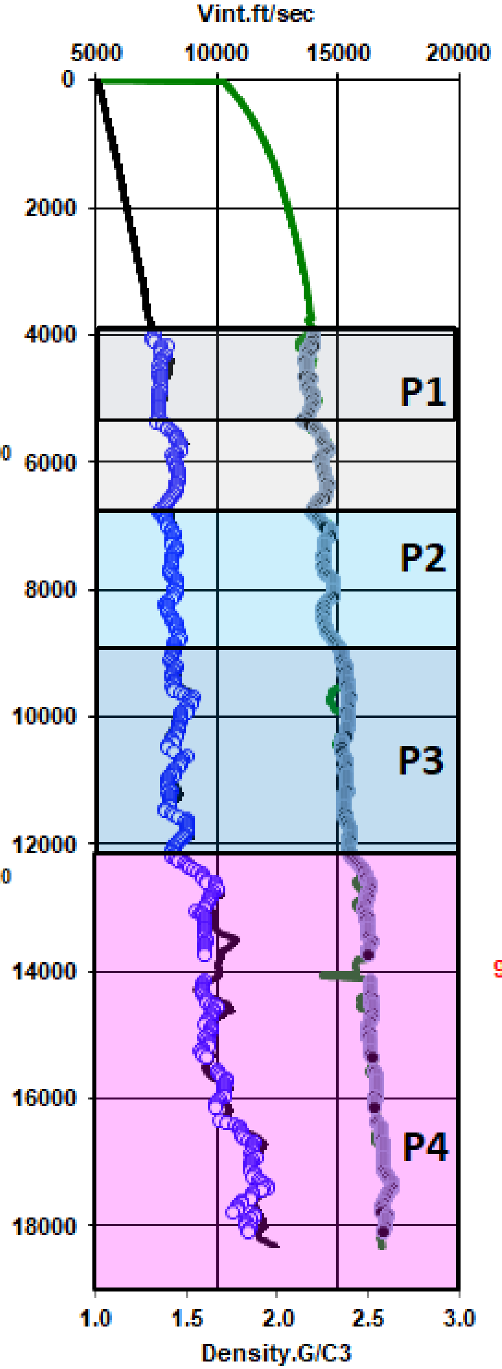
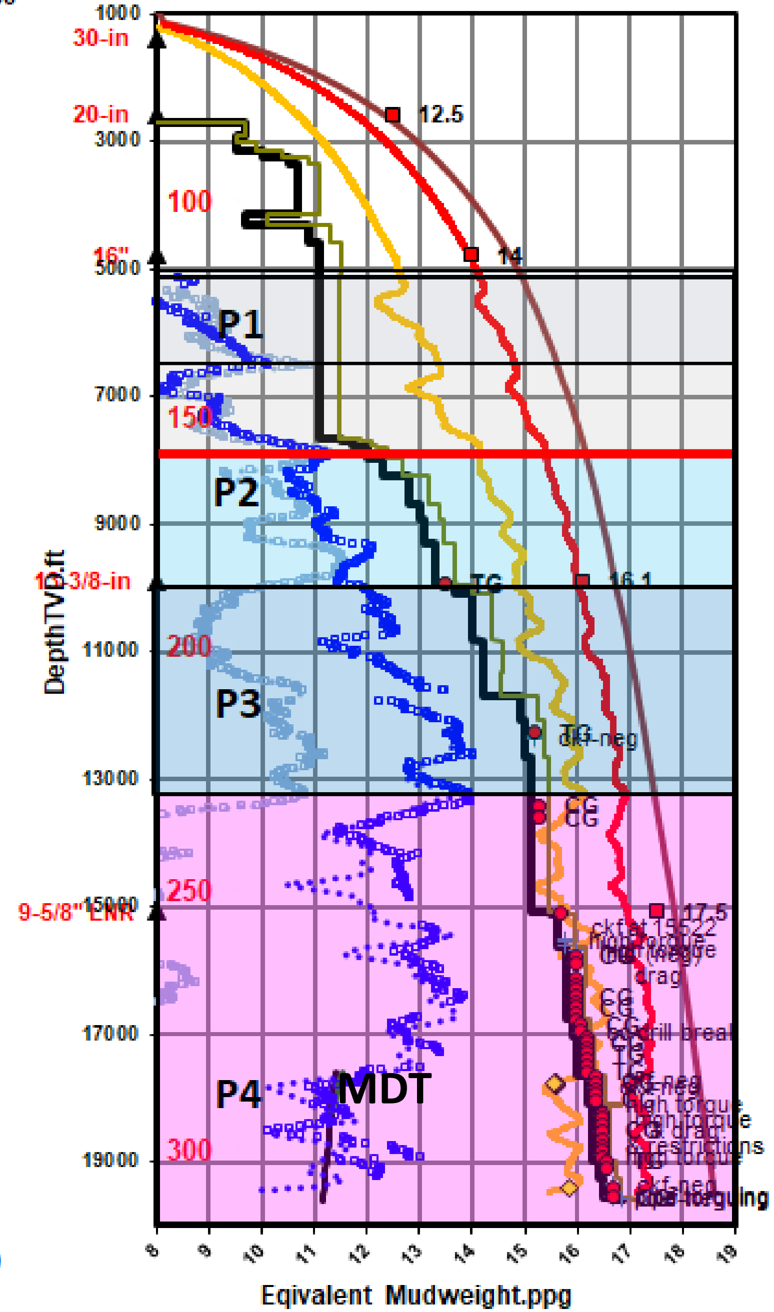


AREA: Viosca Knoll
DATA: wireline







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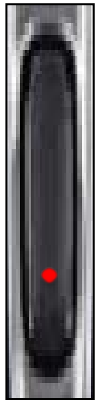
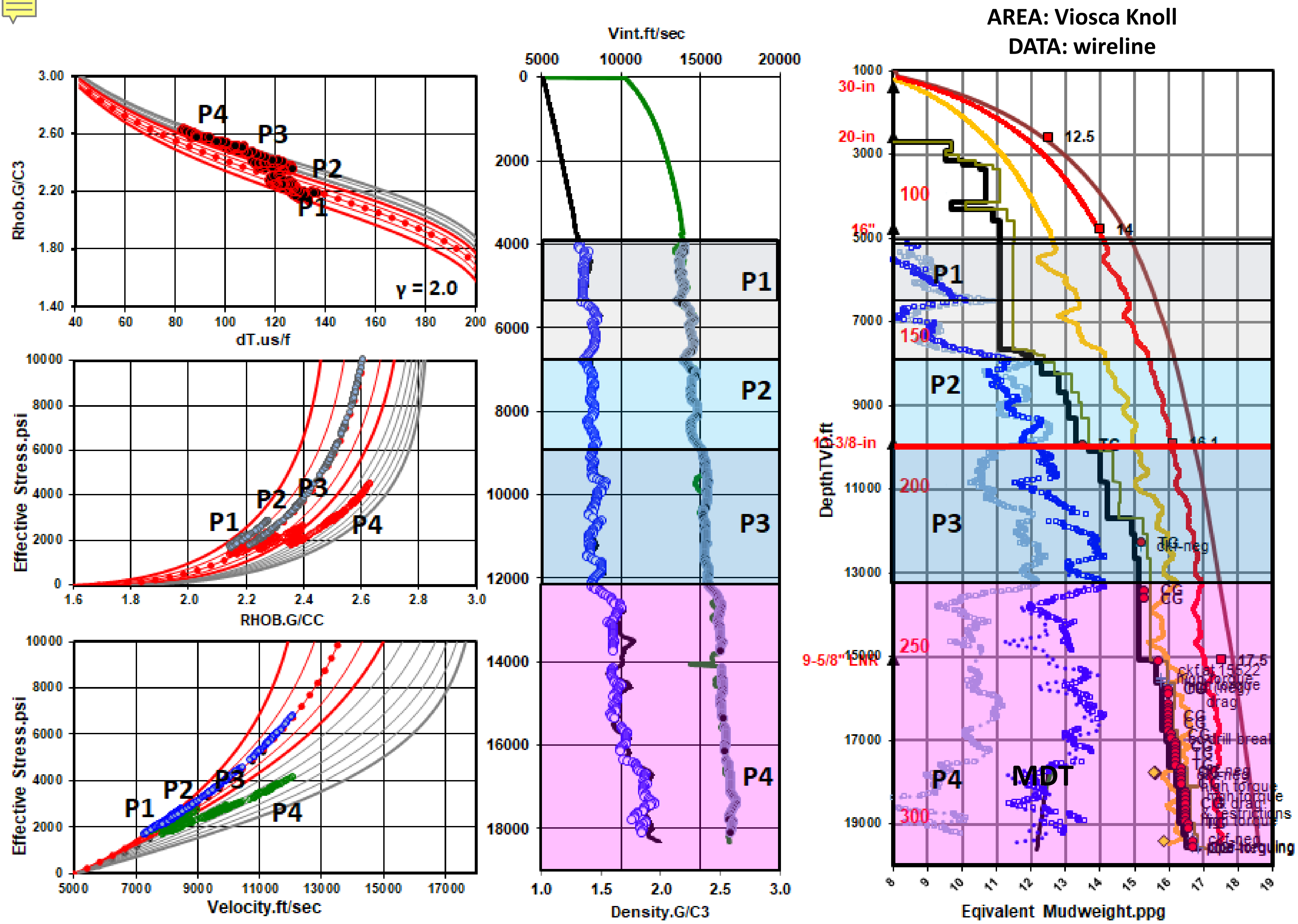
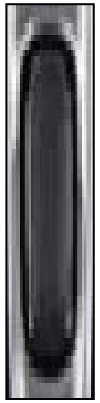
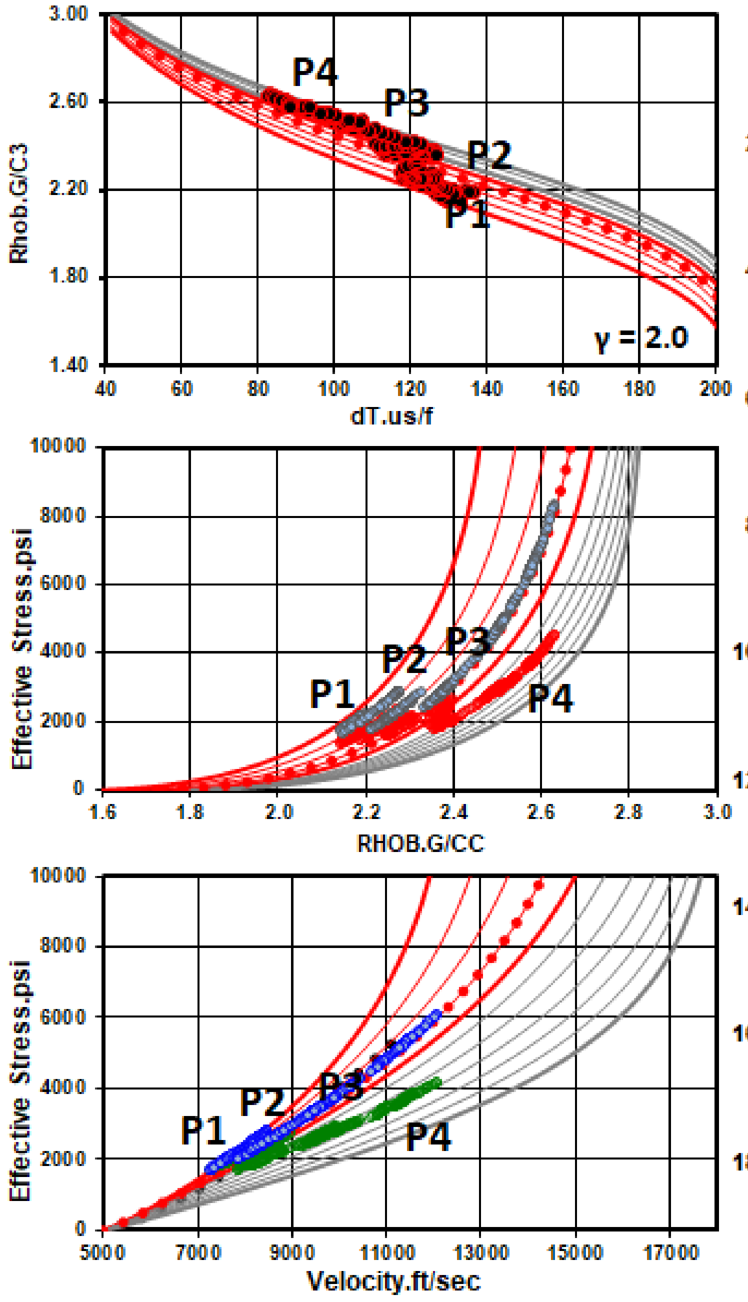
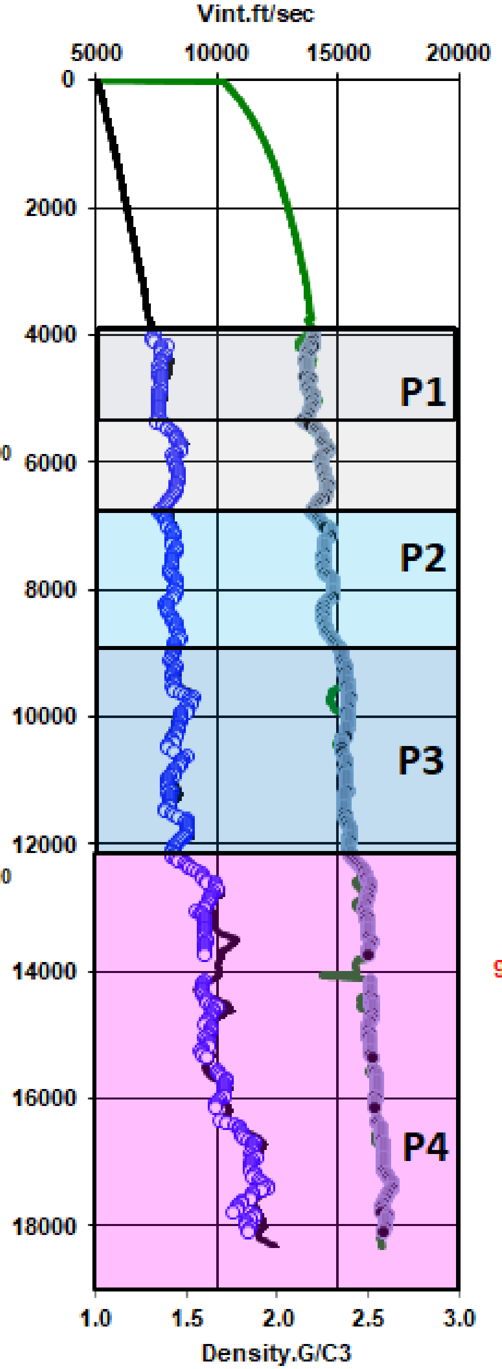



AREA: Viosca Knoll
DATA: wireline
Rhob.G/C3
dT.us/f
γ = 2.0
P1
P2
P3
P4
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
DepthTVD.ft
Eqivalent Mudweight.ppg
30-in
20-in
16"
13-3/8-in
9-5/8" LNR
100
150
200
250
300
12.5
14
17.5
MDT

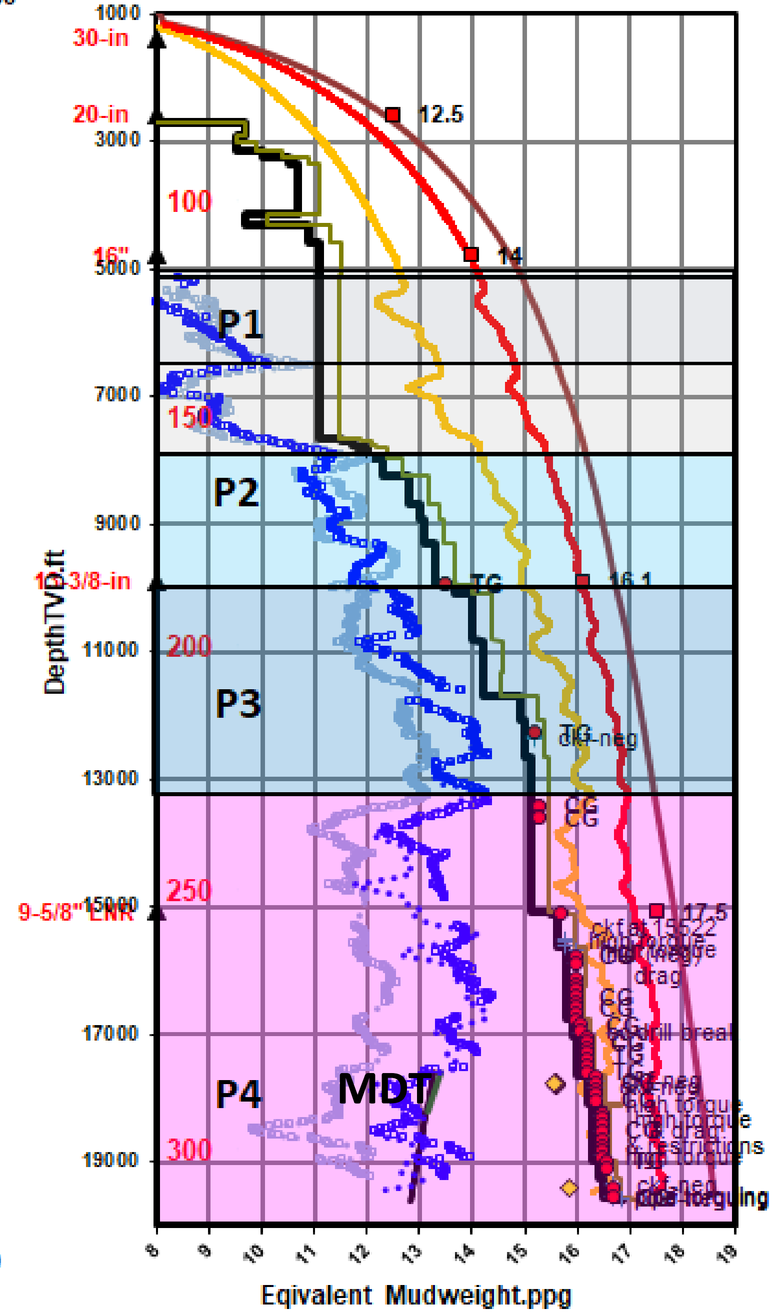
0.20



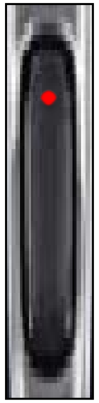


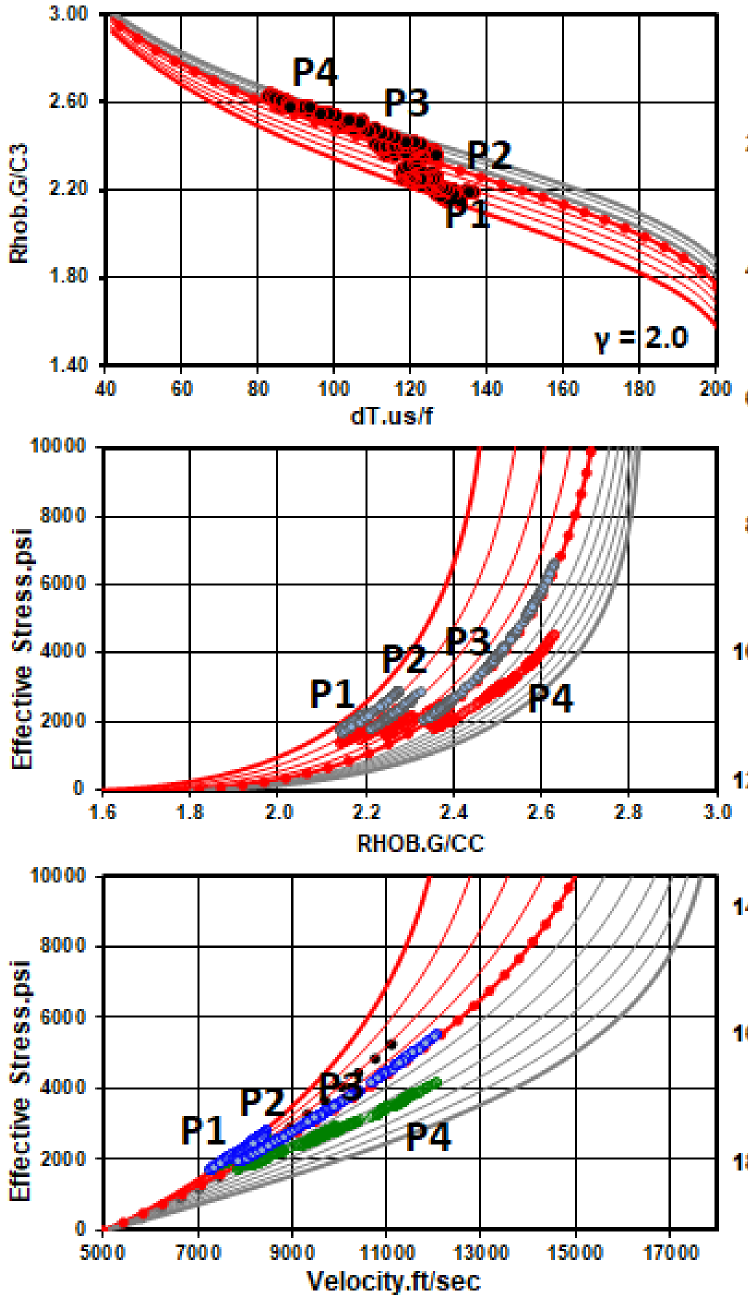


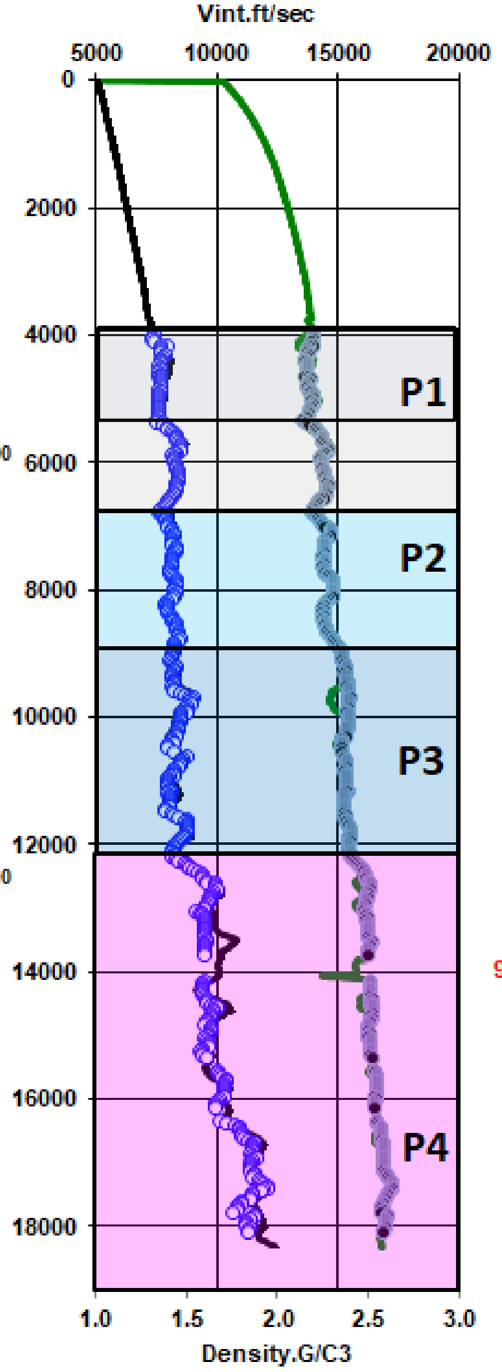
AREA: Viosca Knoll
DATA: wireline



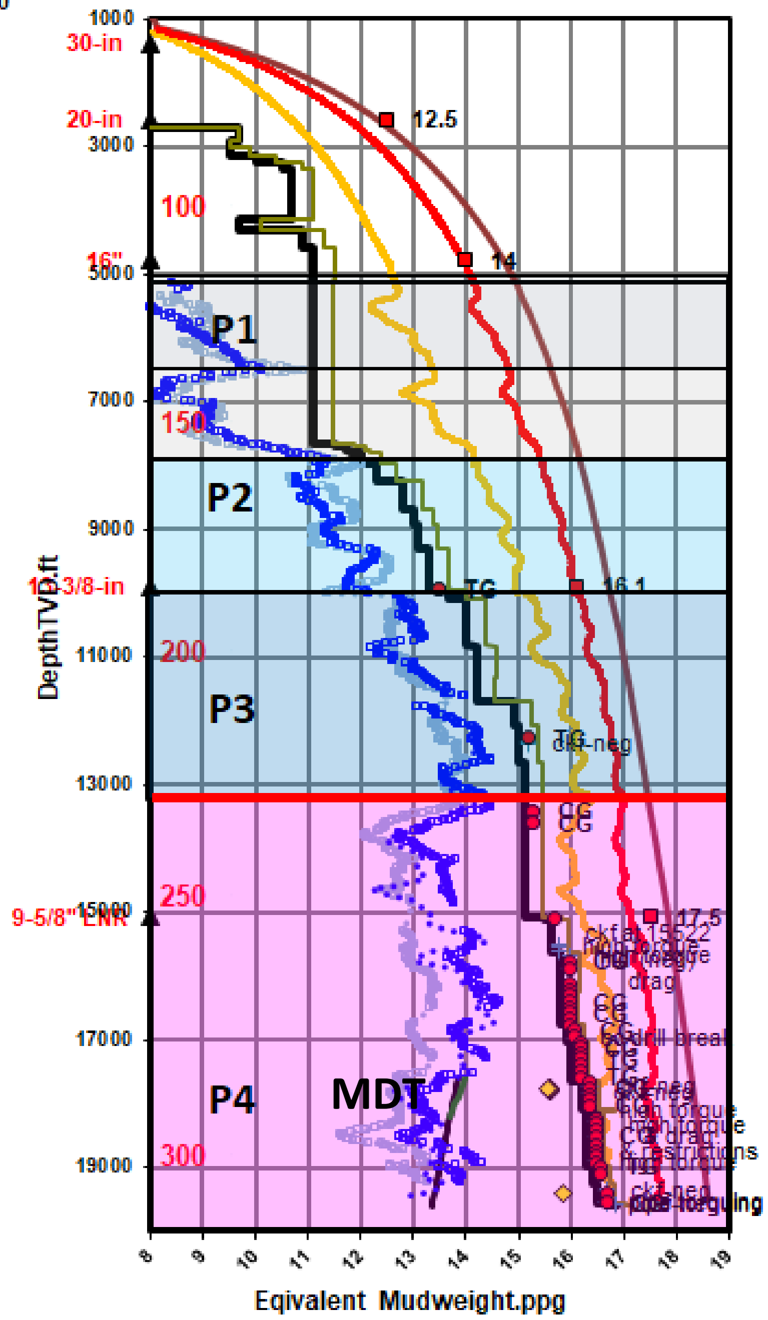
0.30



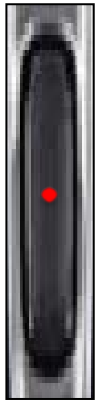




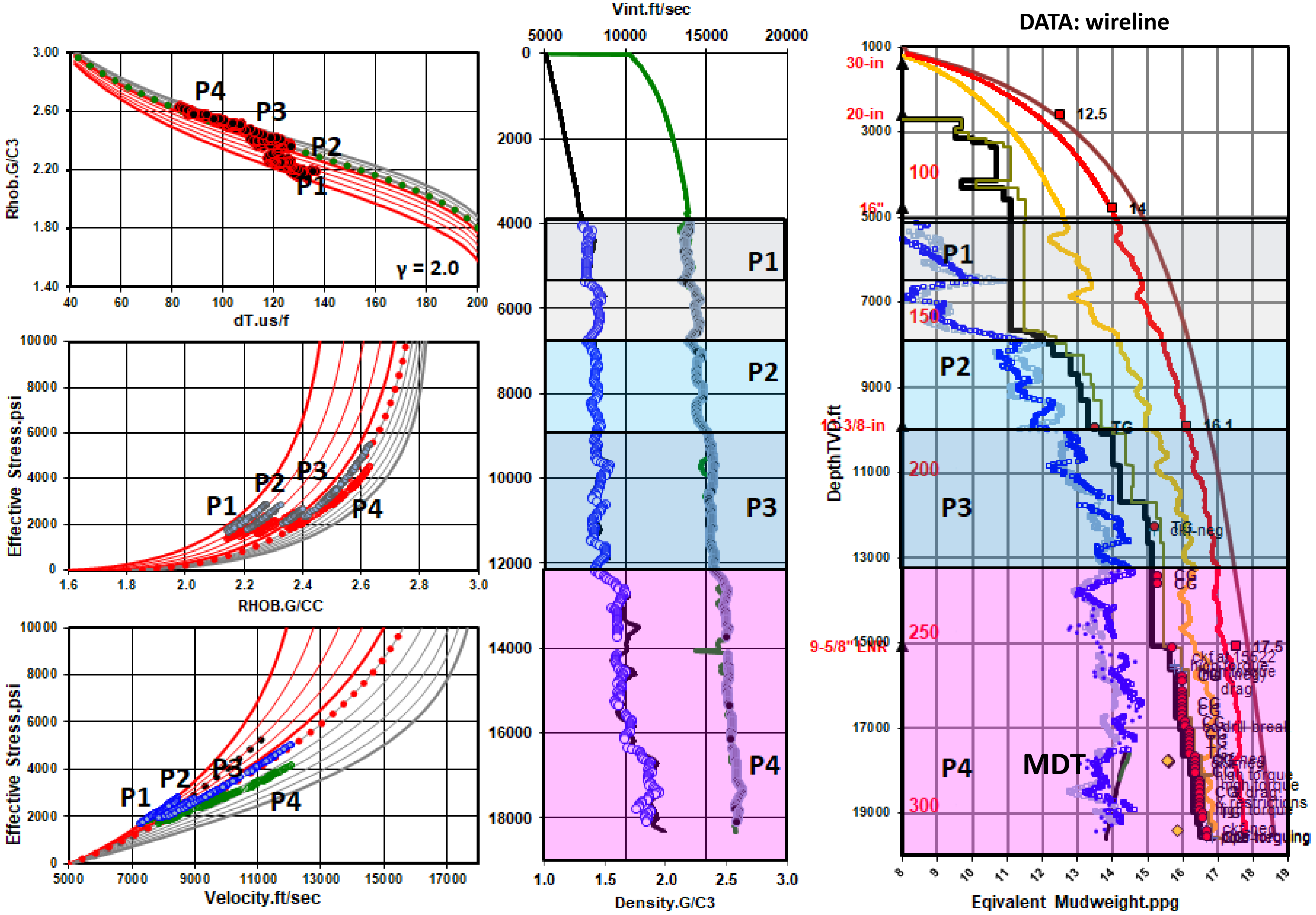
AREA: Viosca Knoll
DATA: wireline



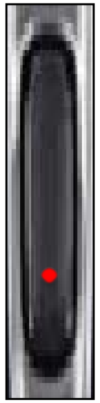
0.40

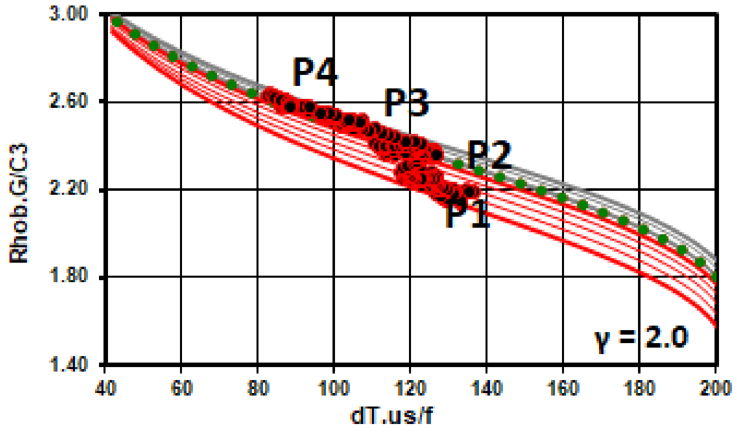


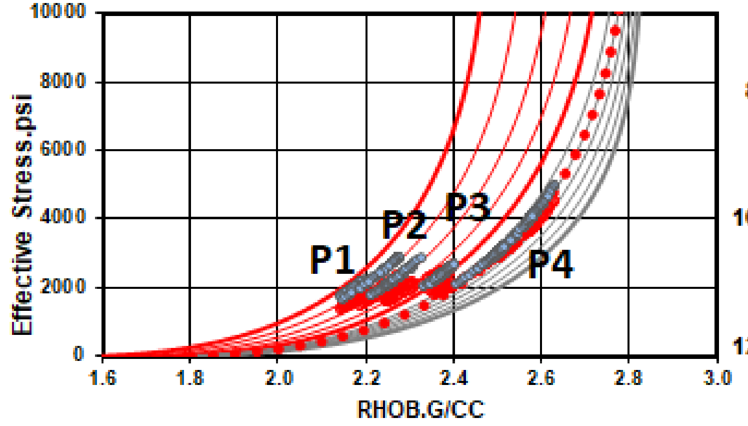
AREA: Viosca Knoll
DATA: wireline

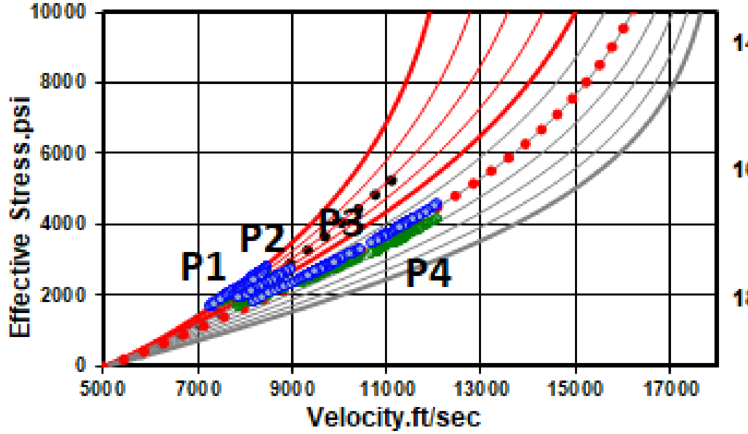


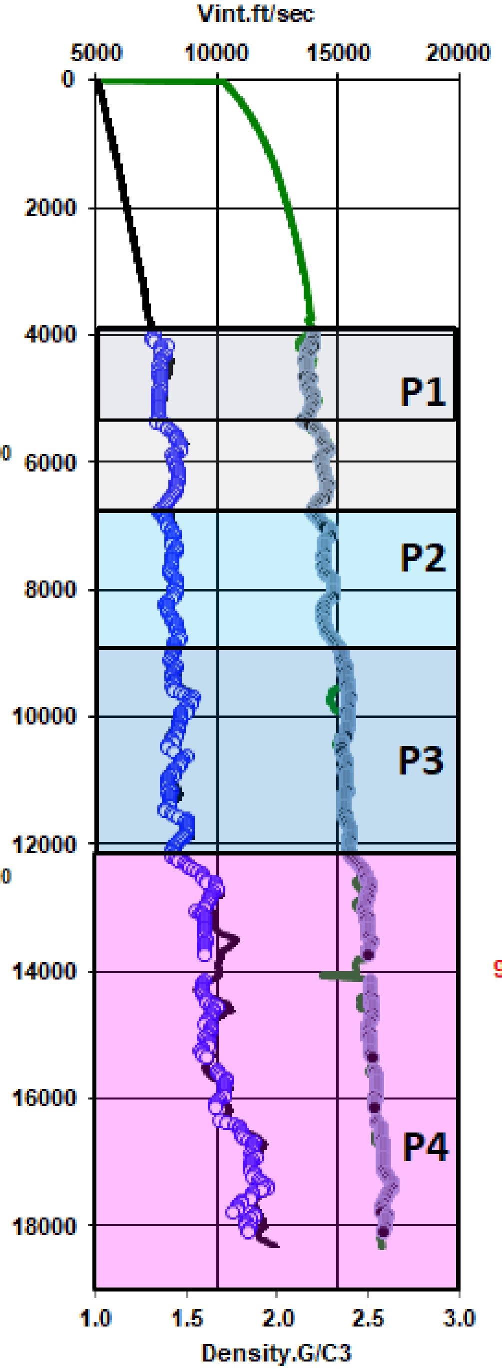
0.50



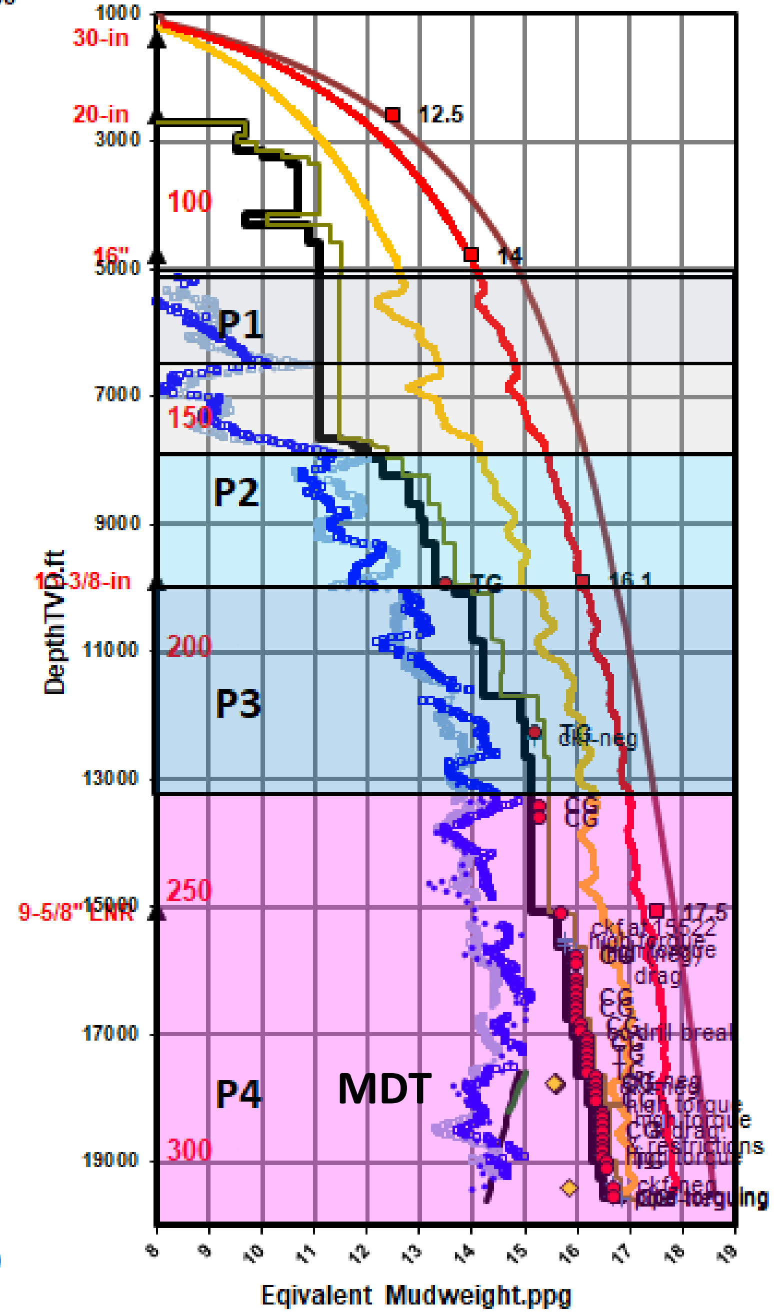




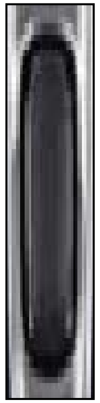




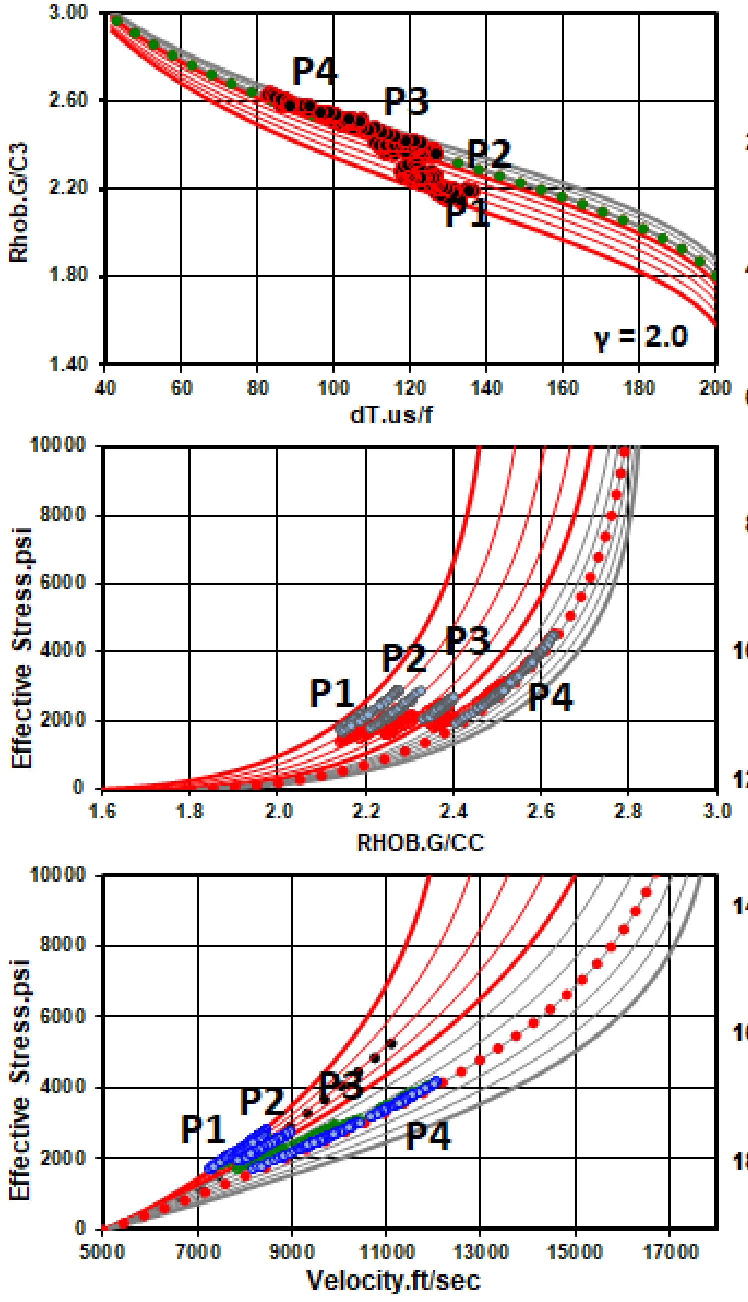
AREA: Viosca Knoll
DATA: wireline

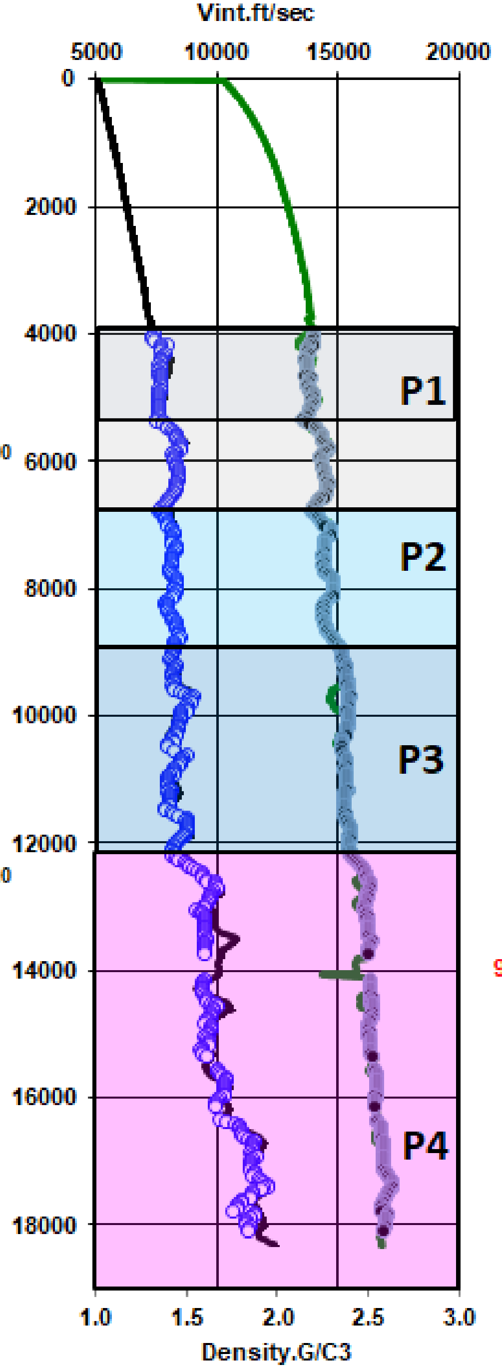


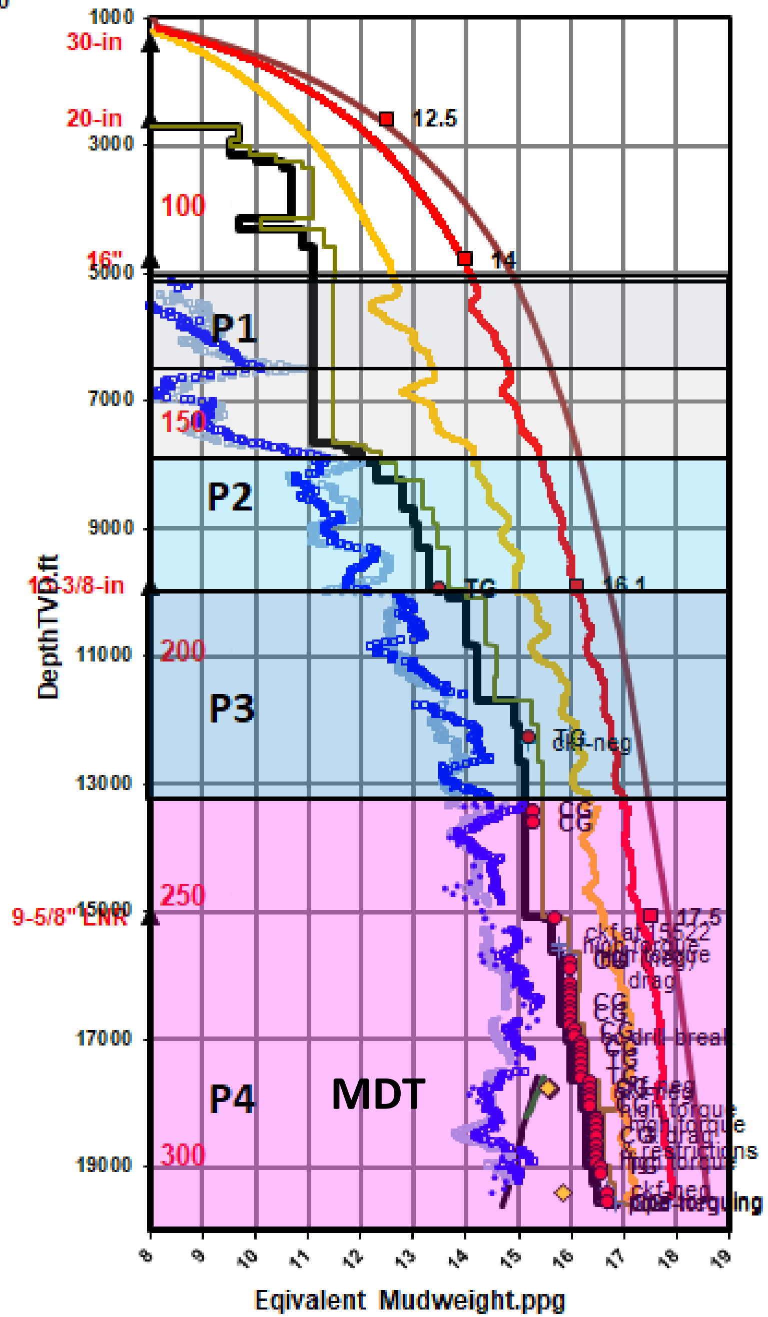
0.60



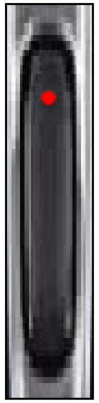
AREA: Viosca Knoll
DATA: wireline



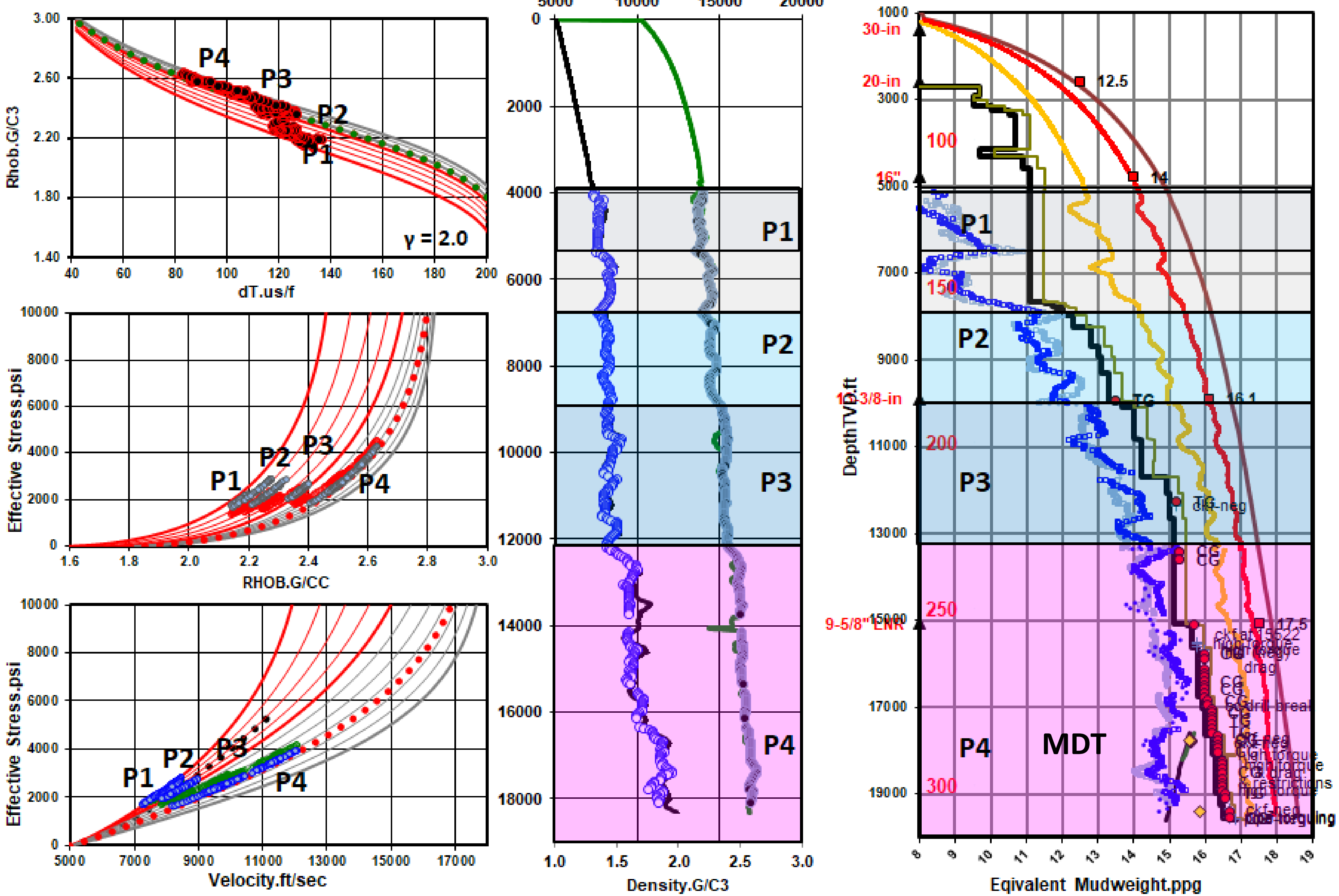




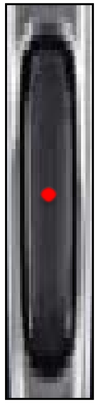
0.70

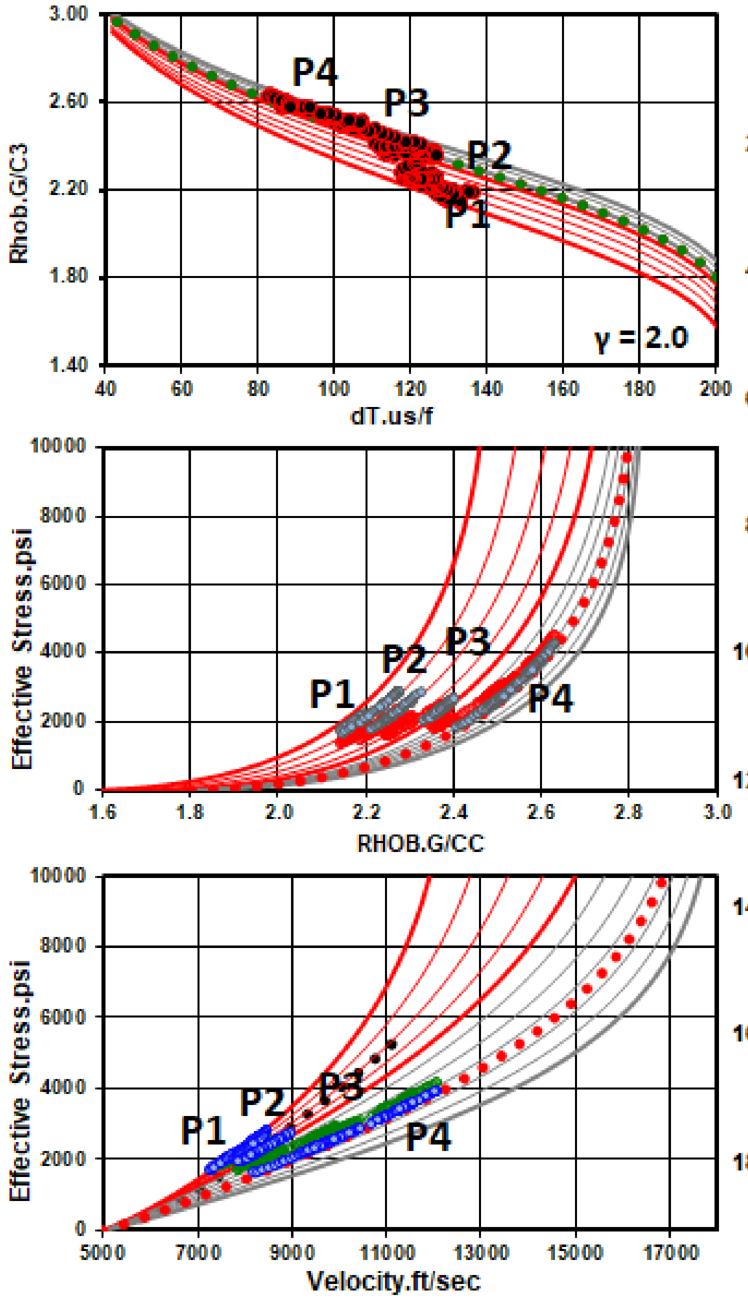


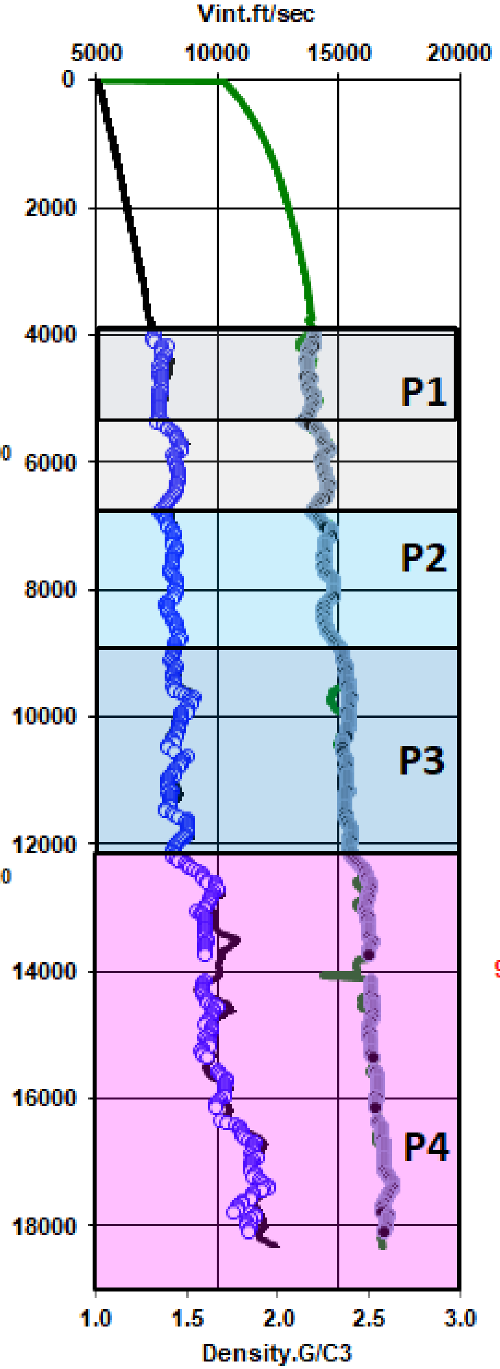
AREA: Viosca Knoll
DATA: wireline



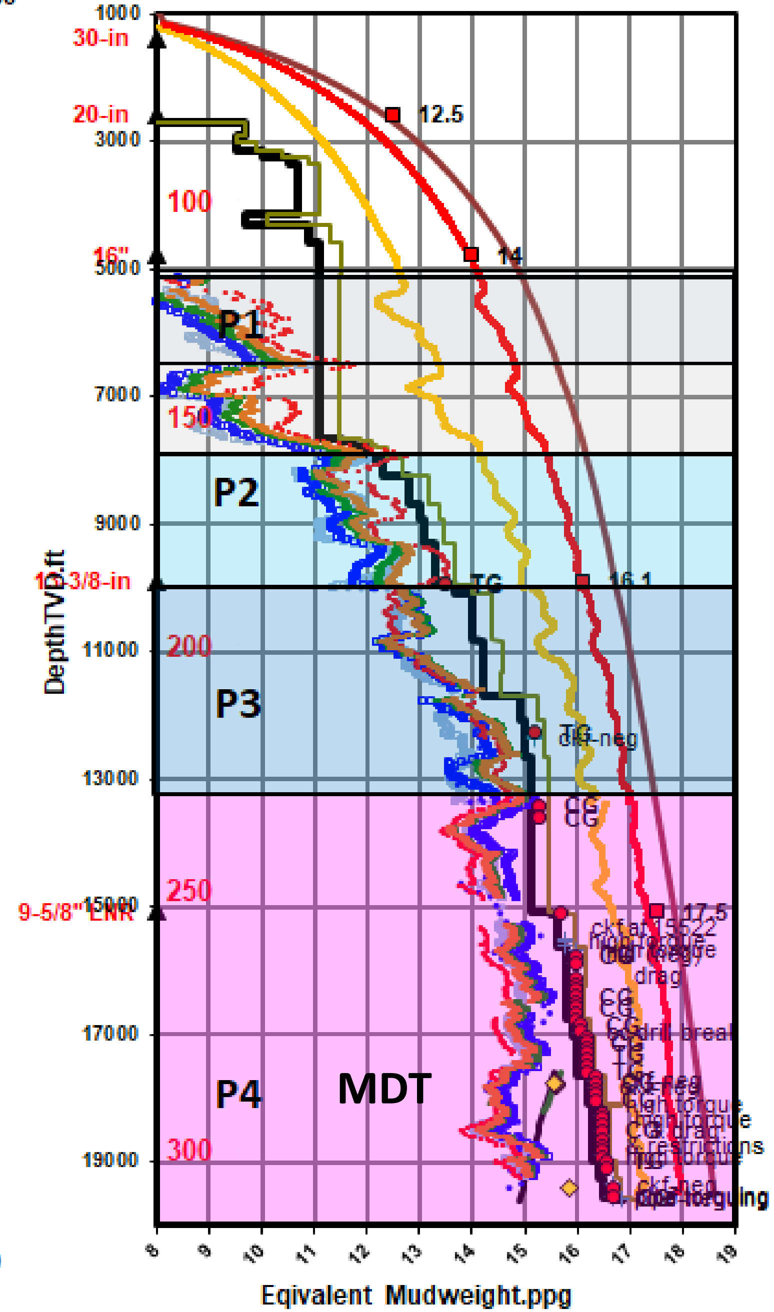
0.75



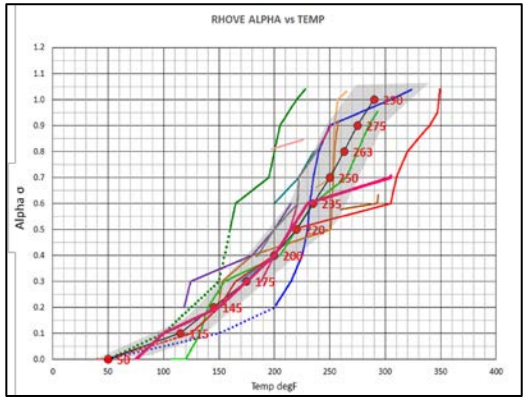




AREA: Viosca Knoll
DATA: wireline



rhob	alpha	15b
#N/A	0.0	75
#N/A	0.1	100
2.26	0.2	150
2.30	0.3	175
2.39	0.4	200
2.38	0.5	215
2.39	0.6	230
2.58	0.7	305
#N/A	0.8	310
#N/A	0.9	320
#N/A	1.0	340
#N/A	1.05	347



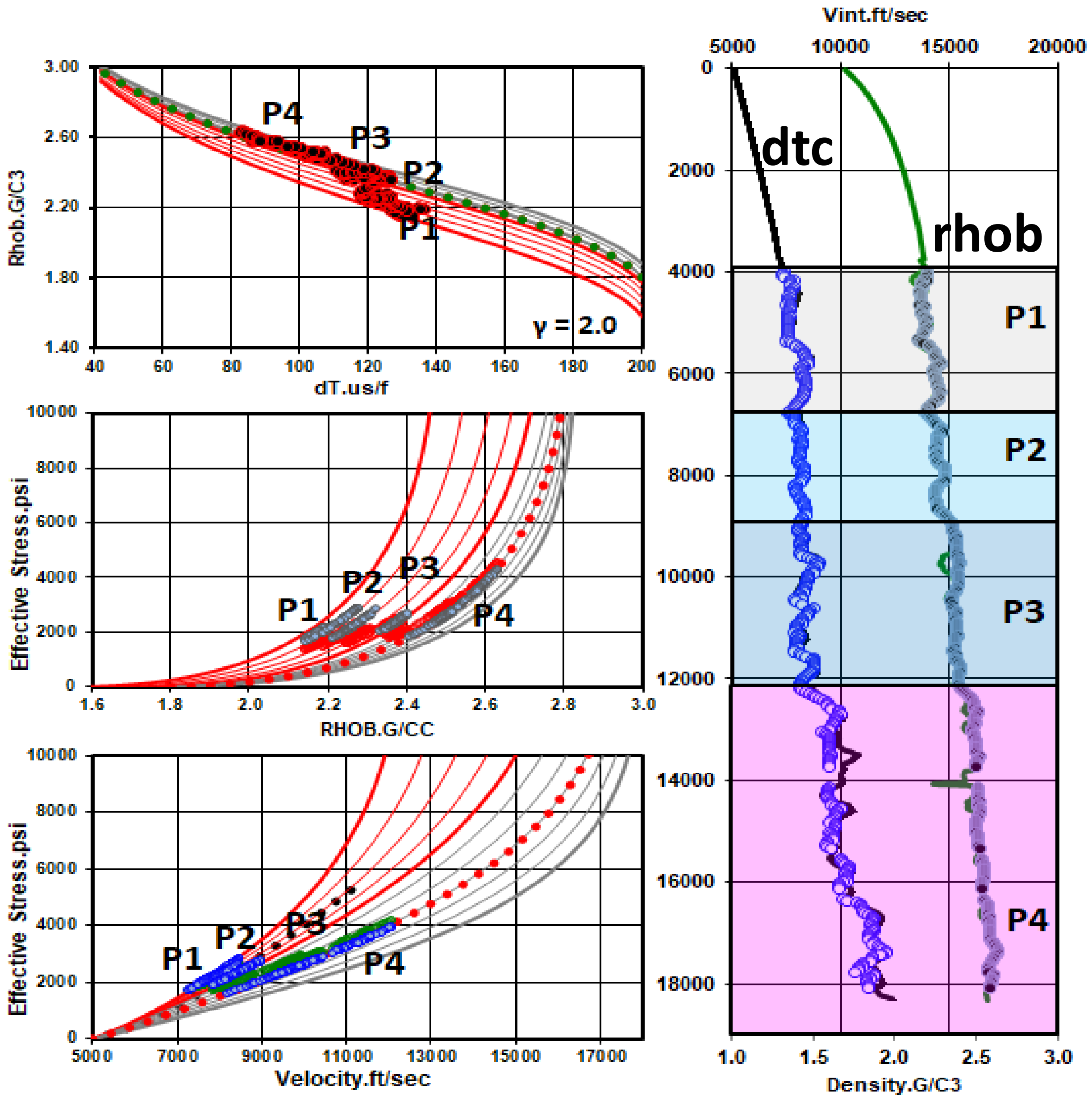
GCS Solutions, Inc.

geopressure consulting services & solutions

RhoVe™ Method

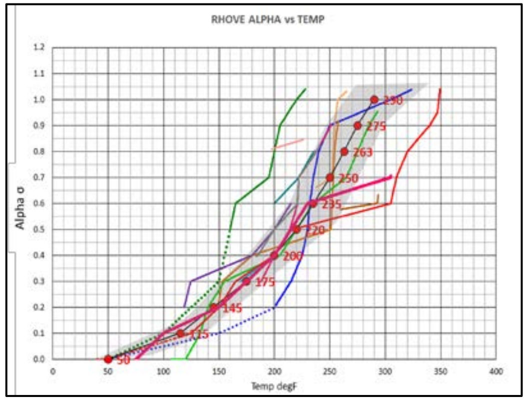
(U.S. patent pending - copyright © 2016)

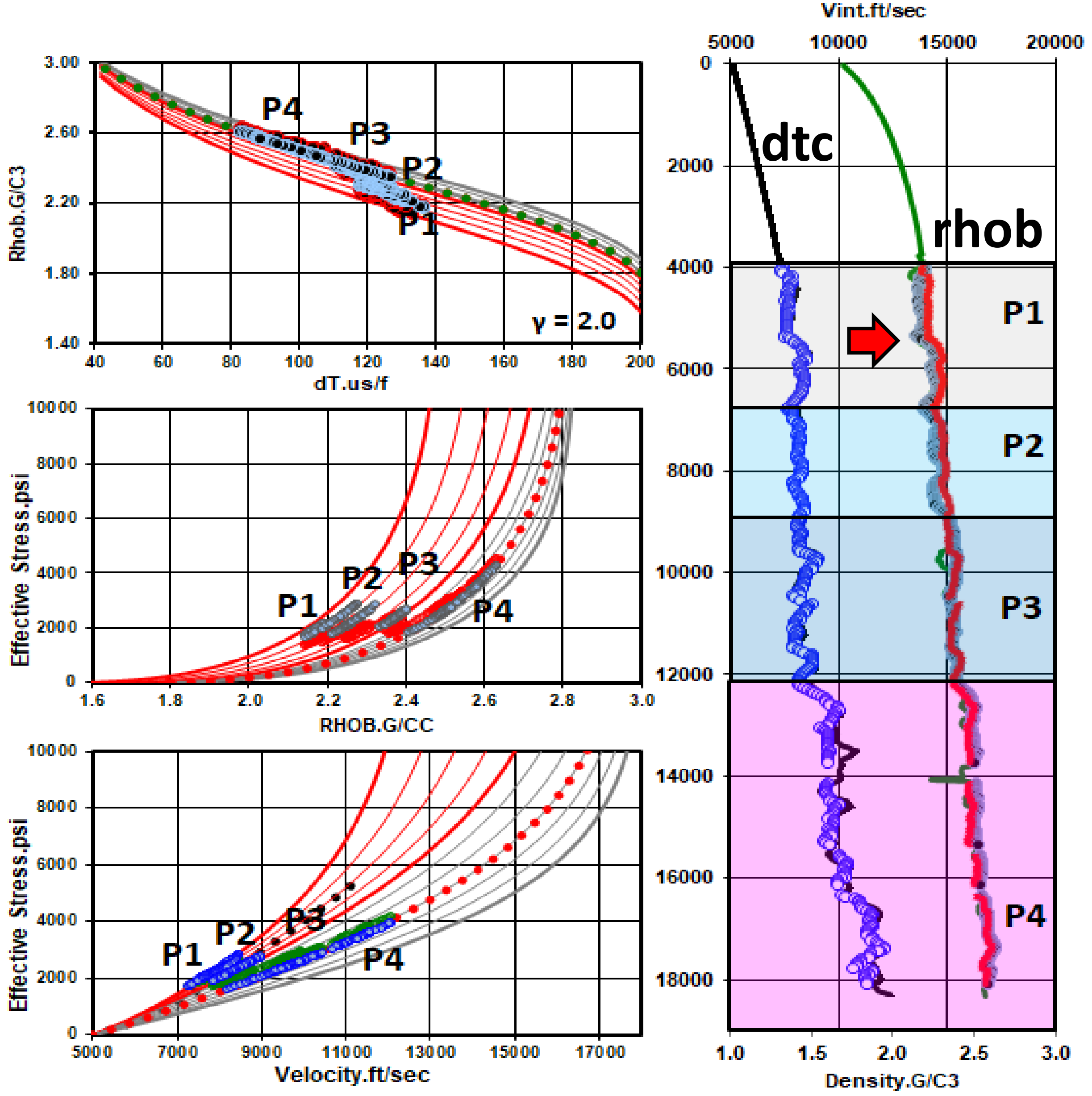
Predrill PPFG Estimation RhoVe T



- pseudorhob from dtc
- more accurate OBG & FG estimation from seismic
- improved sub-regional PPG calibration for predrill estimates

rhob	alpha	15b
#N/A	0.0	75
#N/A	0.1	100
2.26	0.2	150
2.30	0.3	175
2.39	0.4	200
2.38	0.5	215
2.39	0.6	230
2.58	0.7	305
#N/A	0.8	310
#N/A	0.9	320
#N/A	1.0	340
#N/A	1.05	347





- pseudorhob from dtc
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rhob	alpha	15b
#N/A	0.0	75
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2.26	0.2	150
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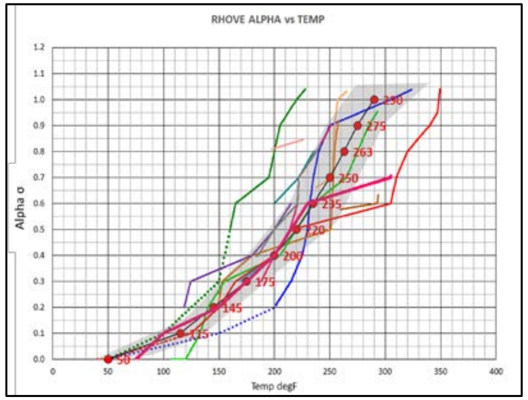
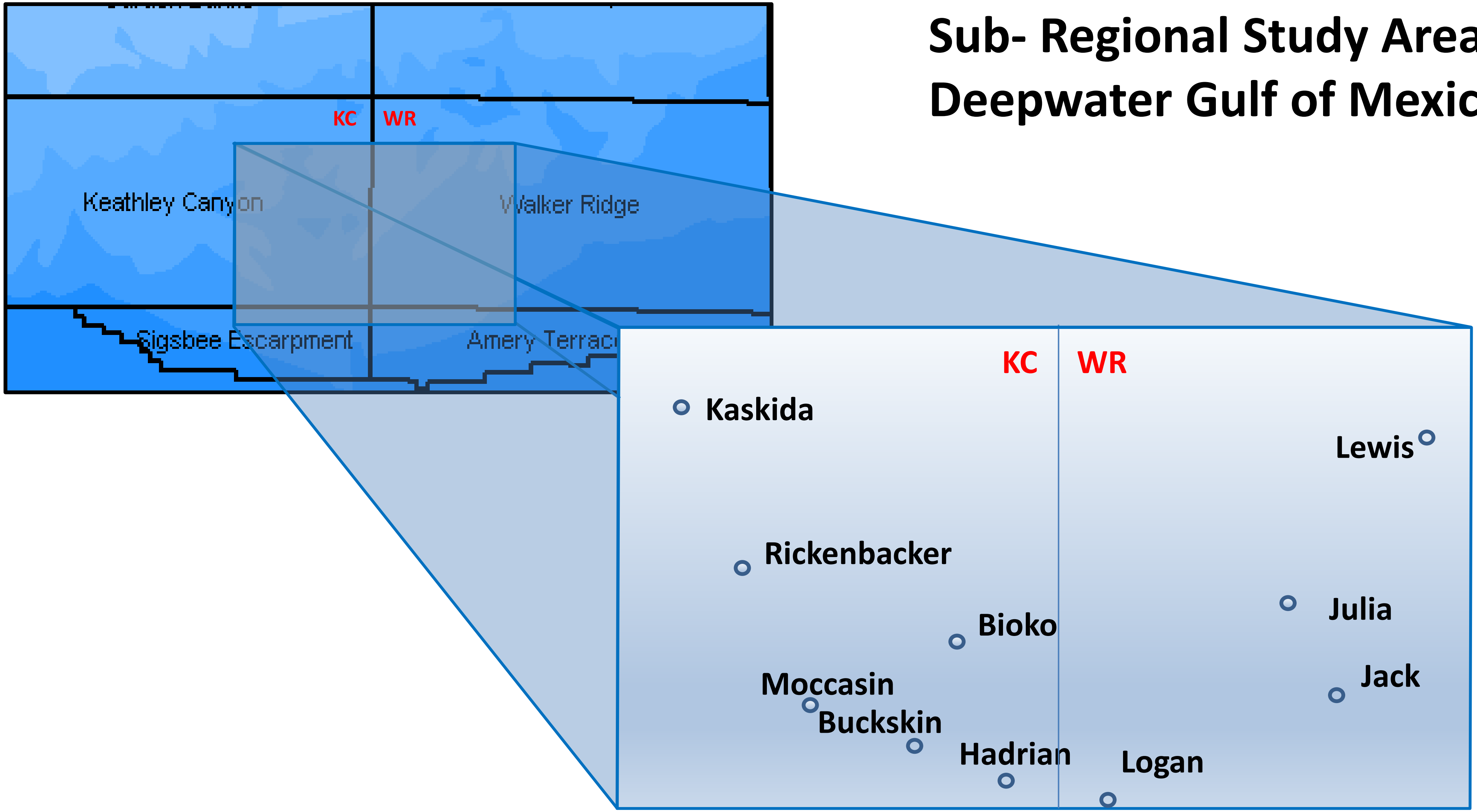
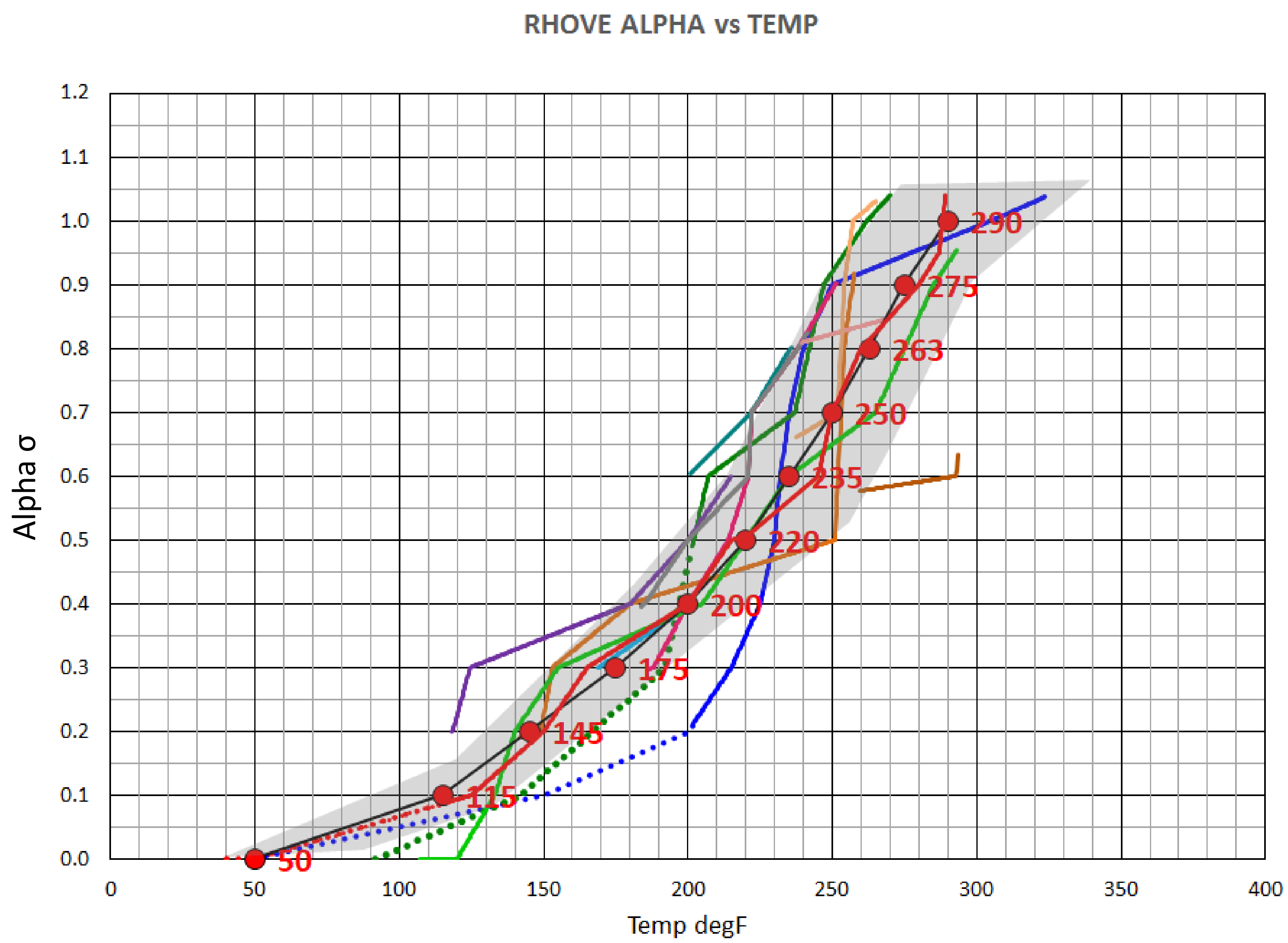
#N/A	1.0	340
#N/A	1.05	347



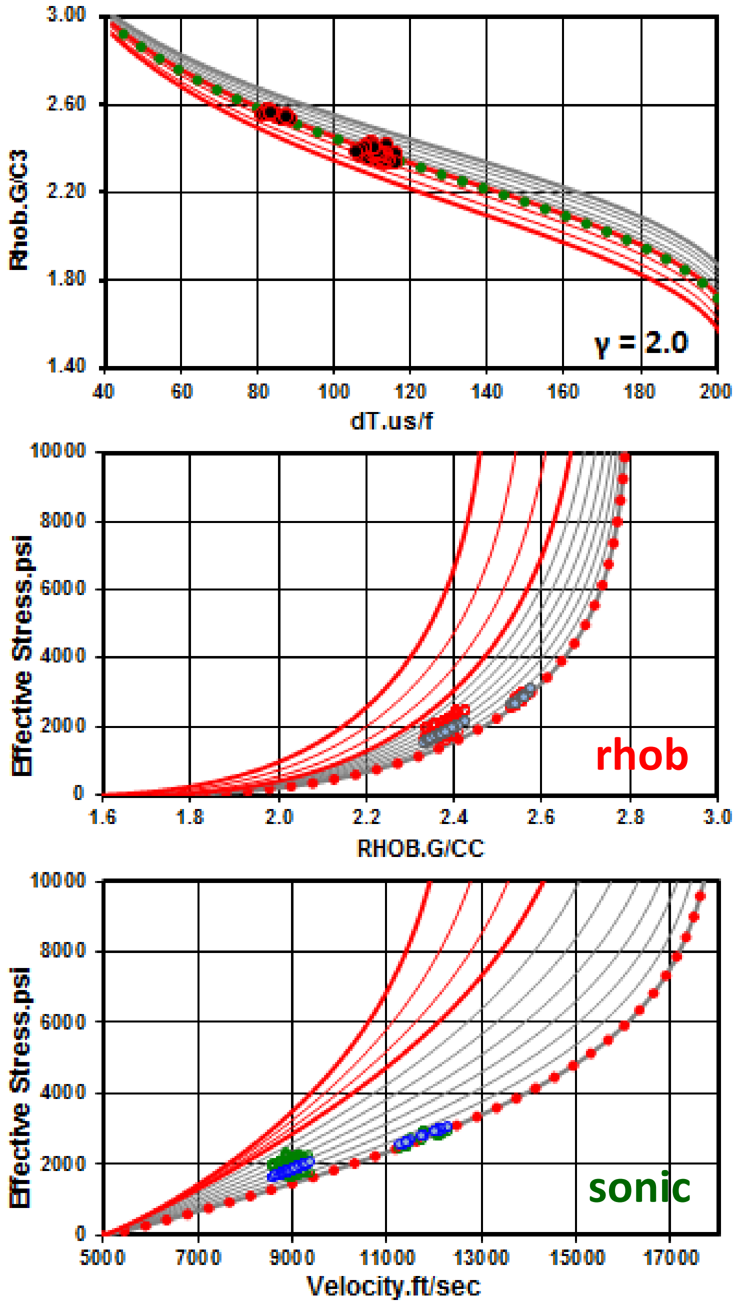
Sub- Regional Study Area
Deepwater Gulf of Mexico

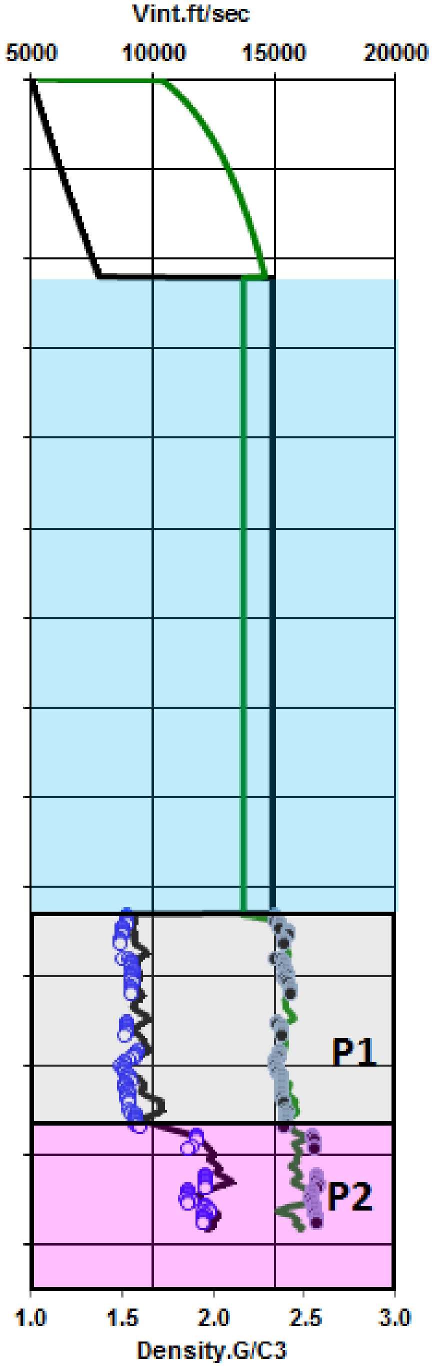


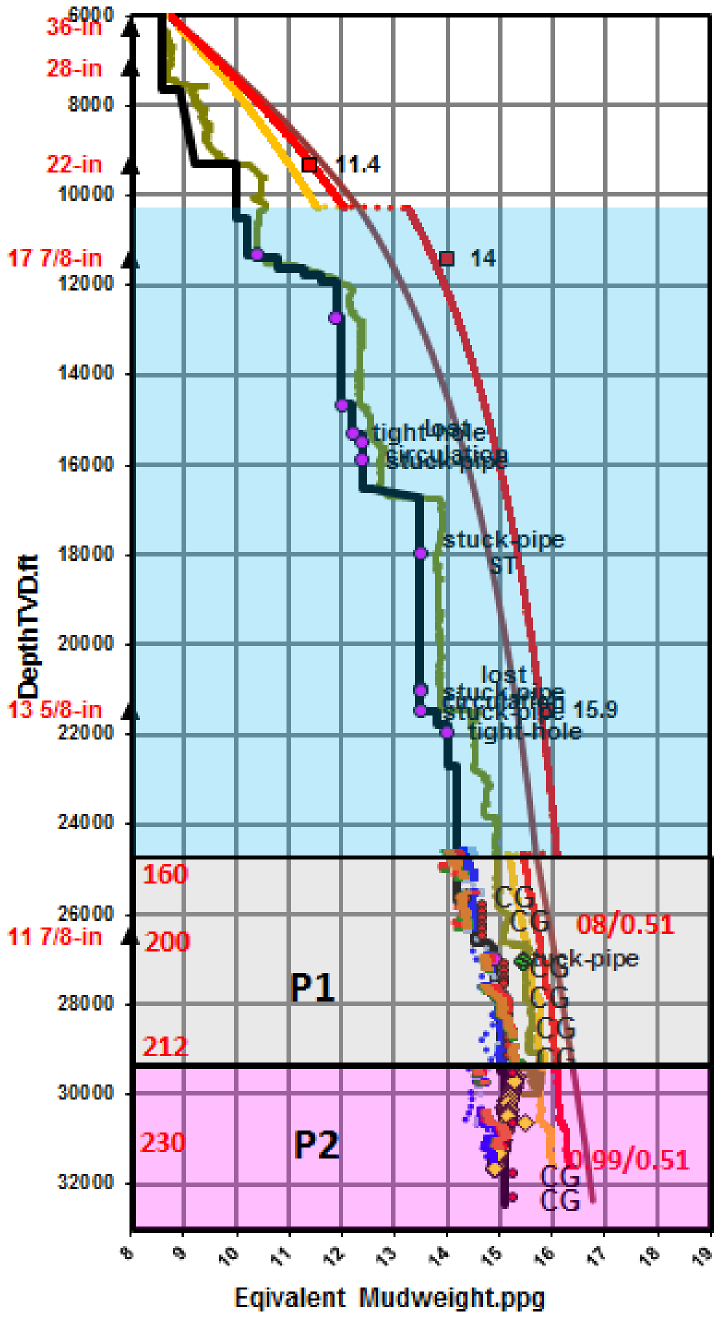

RHOVE ALPHA vs TEMP
Alpha σ
Temp degF
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
290
275
263
250
235
220
200
175
145
115
50

Rhob

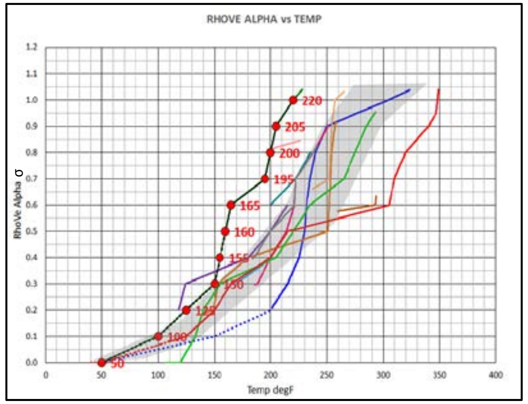
AREA: DW GOM KC292-1BP2 KASKIDA

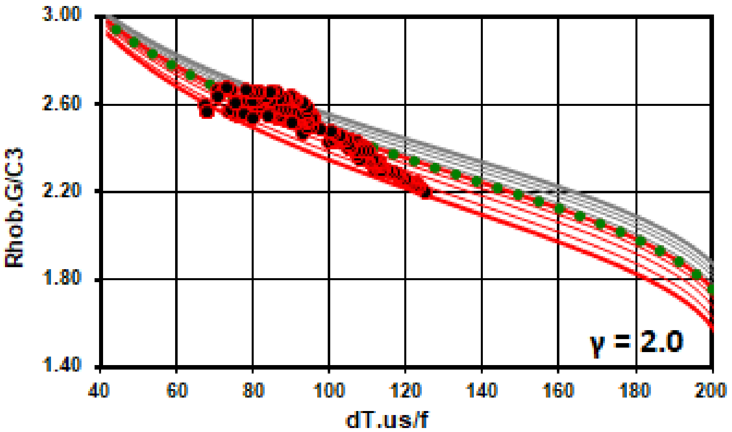


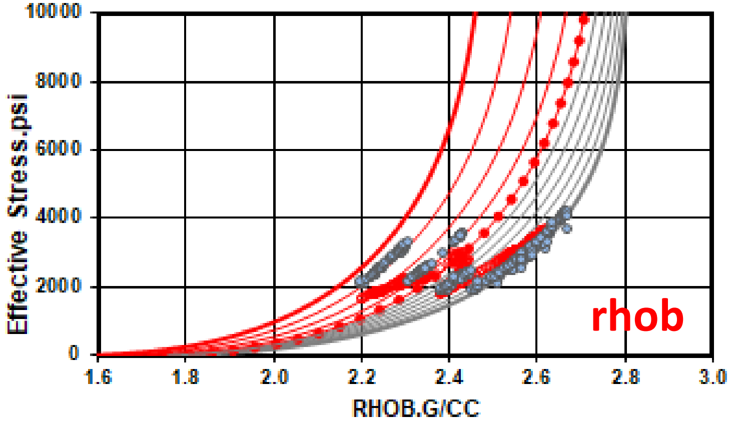


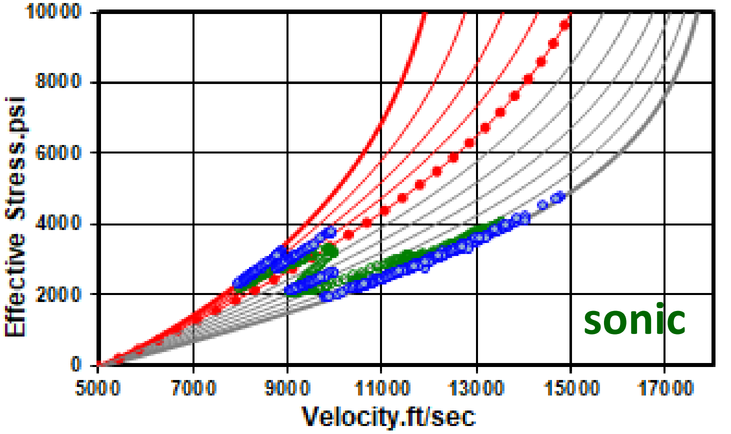


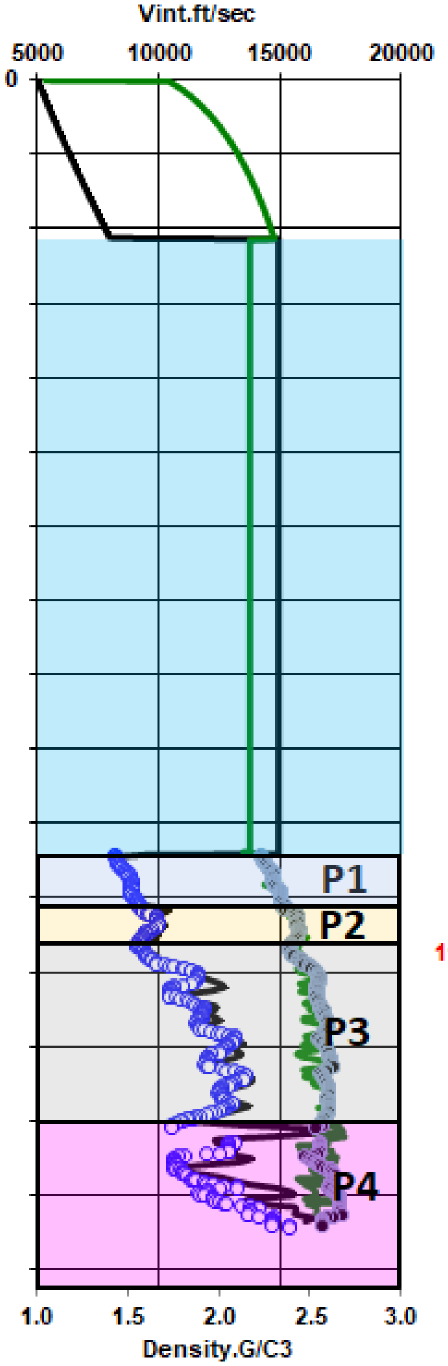
rhob	alpha	TEMPdegF
#N/A	0.0	50
#N/A	0.1	100
#N/A	0.2	125
#N/A	0.3	150
#N/A	0.4	155
#N/A	0.5	160
2.41	0.6	165
2.34	0.7	195
2.38	0.8	200
2.39	0.9	205
#N/A	1.0	220
2.56	1.05	230

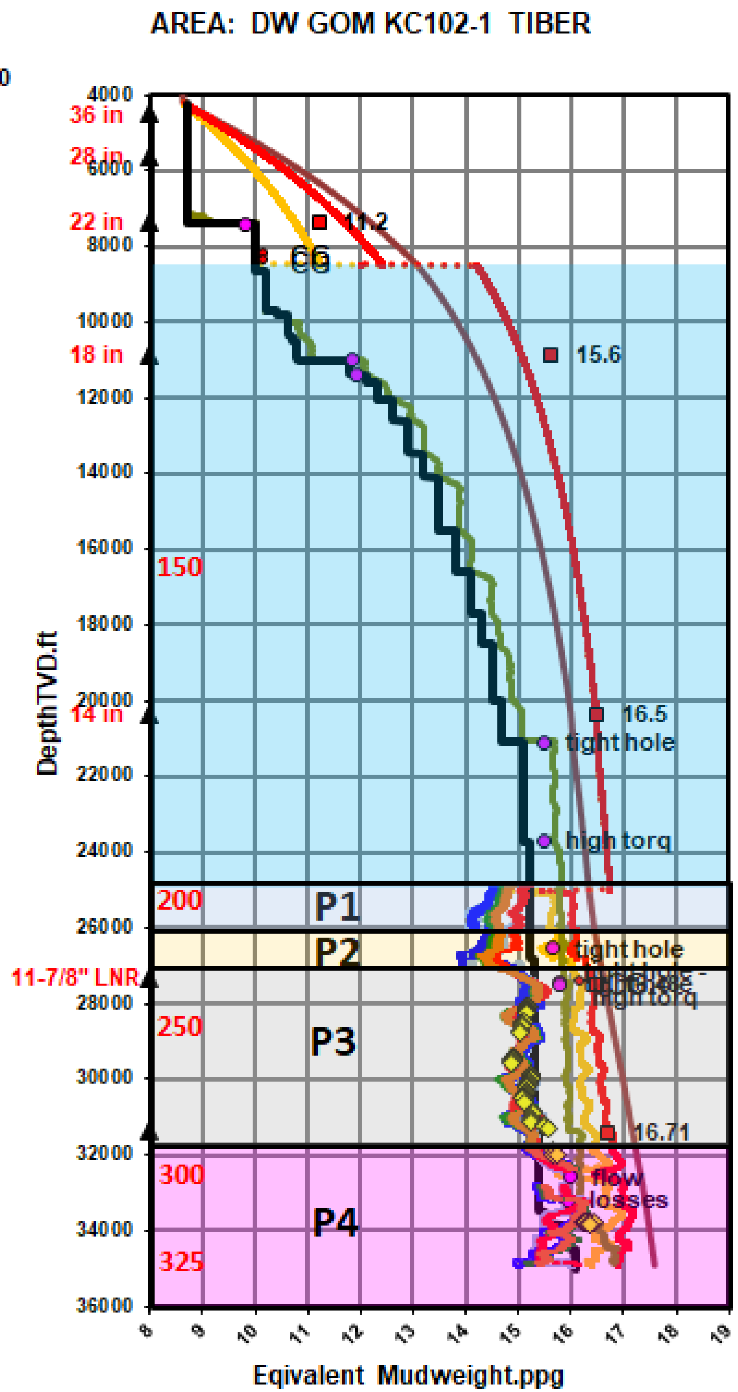




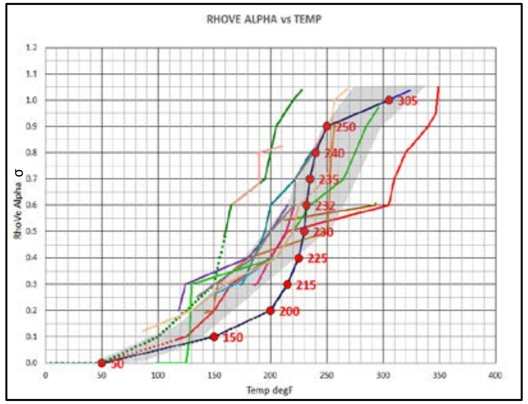




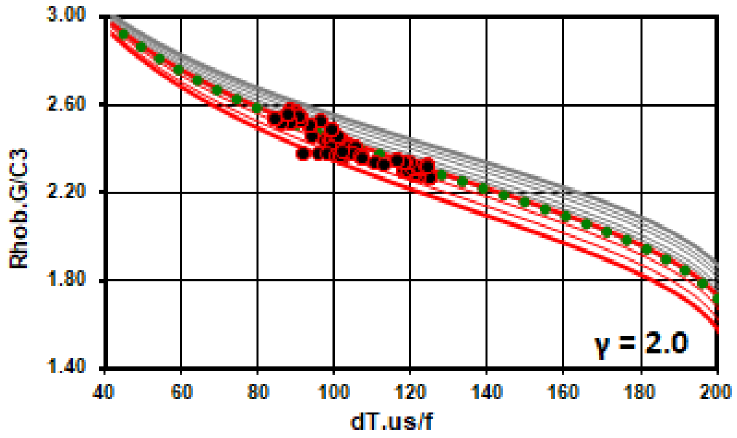


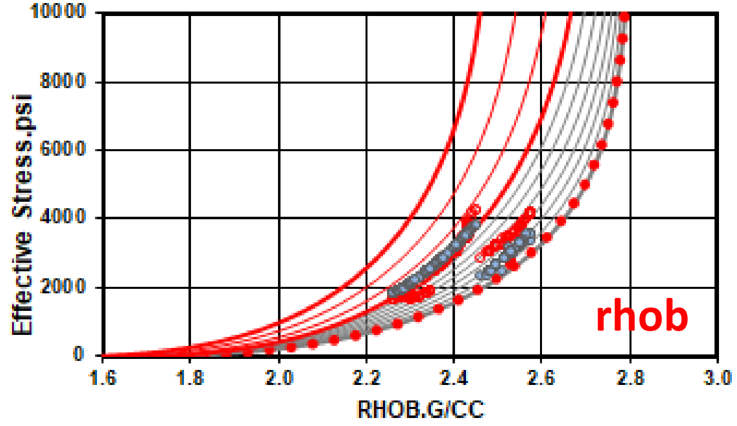


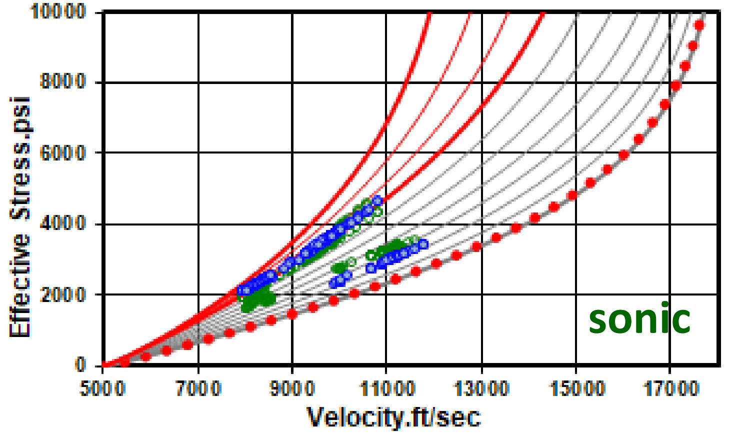
rhob	alpha	TEMPdegF
#N/A	0.0	50
#N/A	0.1	150
#N/A	0.2	200
2.30	0.3	215
2.42	0.4	225
2.43	0.5	230
2.44	0.6	232
2.40	0.7	235
2.41	0.8	240
2.54	0.9	250
2.48	1.0	305
2.57	1.05	330

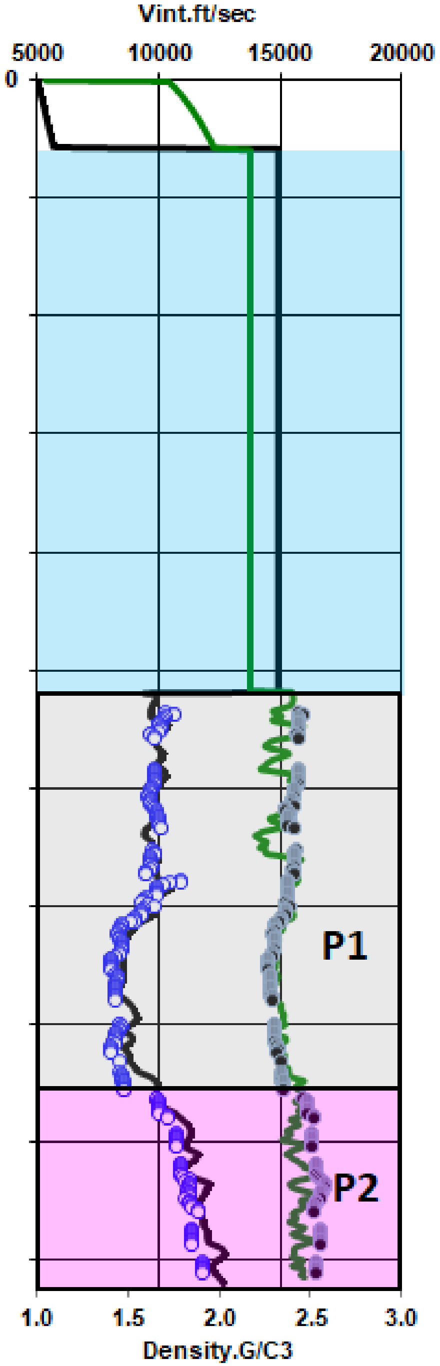


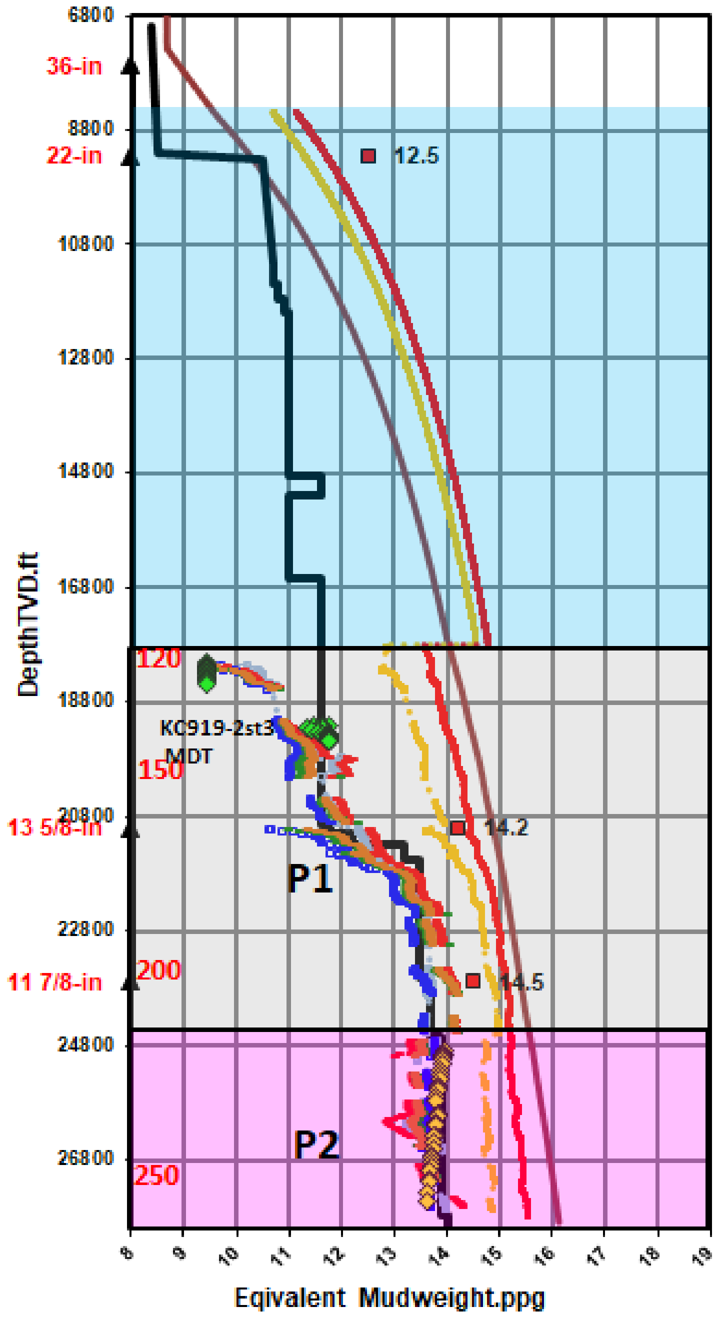
AREA: DW GOM KC919-1 HADRIAN



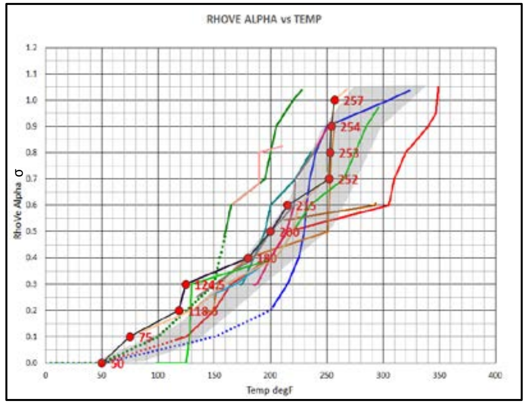




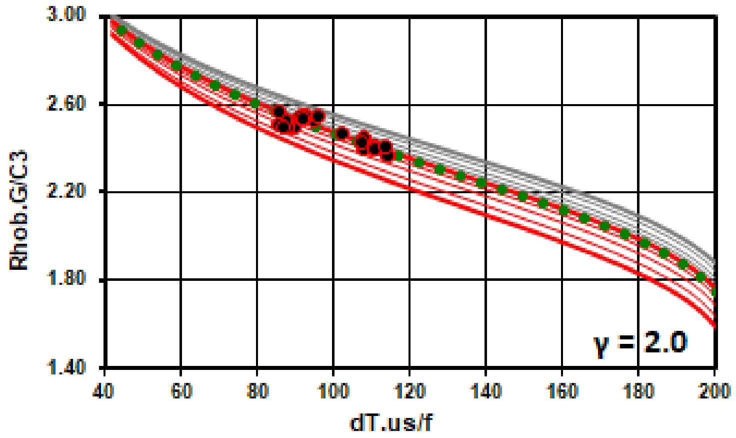


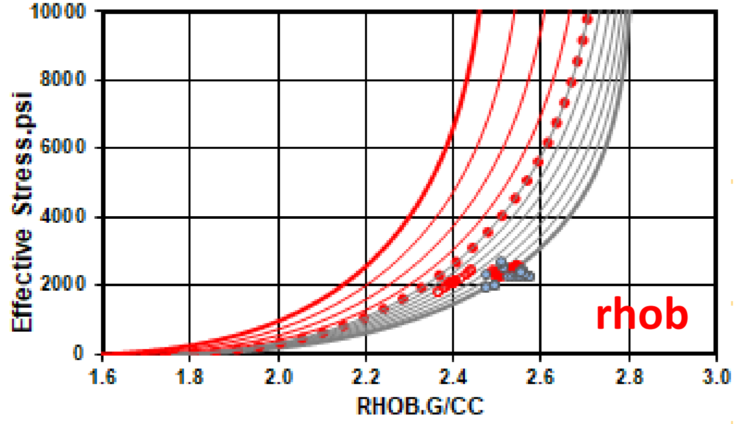


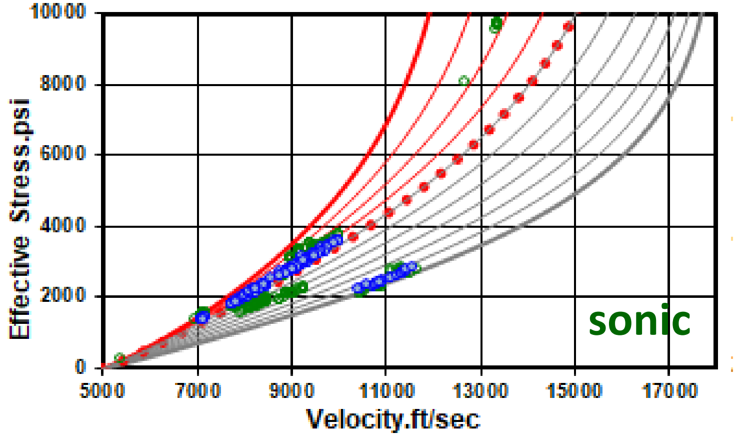
rhob	alpha	TEMPdegF
#N/A	0.0	50
#N/A	0.1	75
2.40	0.2	118.5
2.45	0.3	124.5
2.30	0.4	180
2.30	0.5	200
2.35	0.6	215
#N/A	0.7	252
#N/A	0.8	253
#N/A	0.9	254
#N/A	1.0	257
#N/A	1.05	270

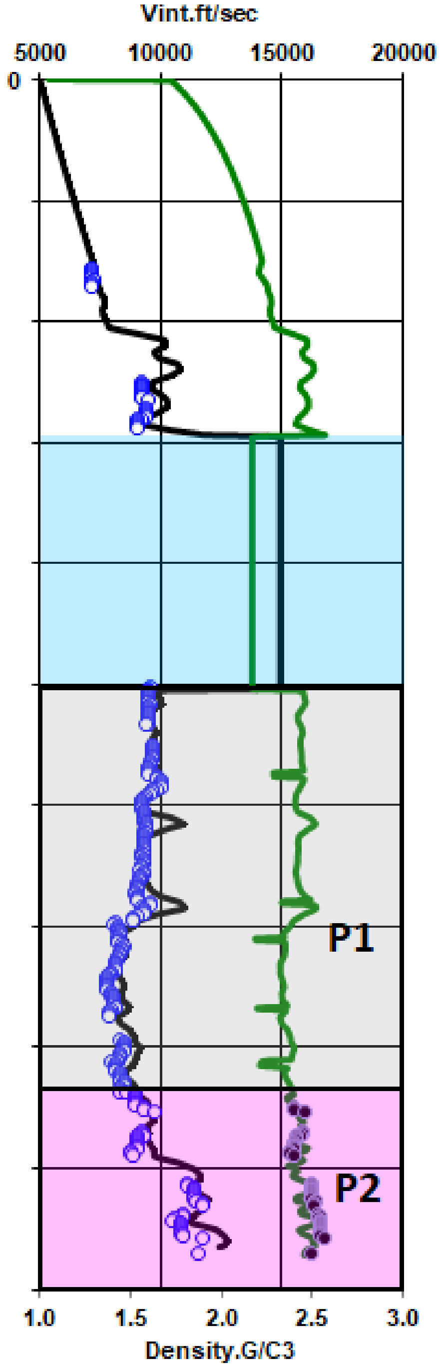


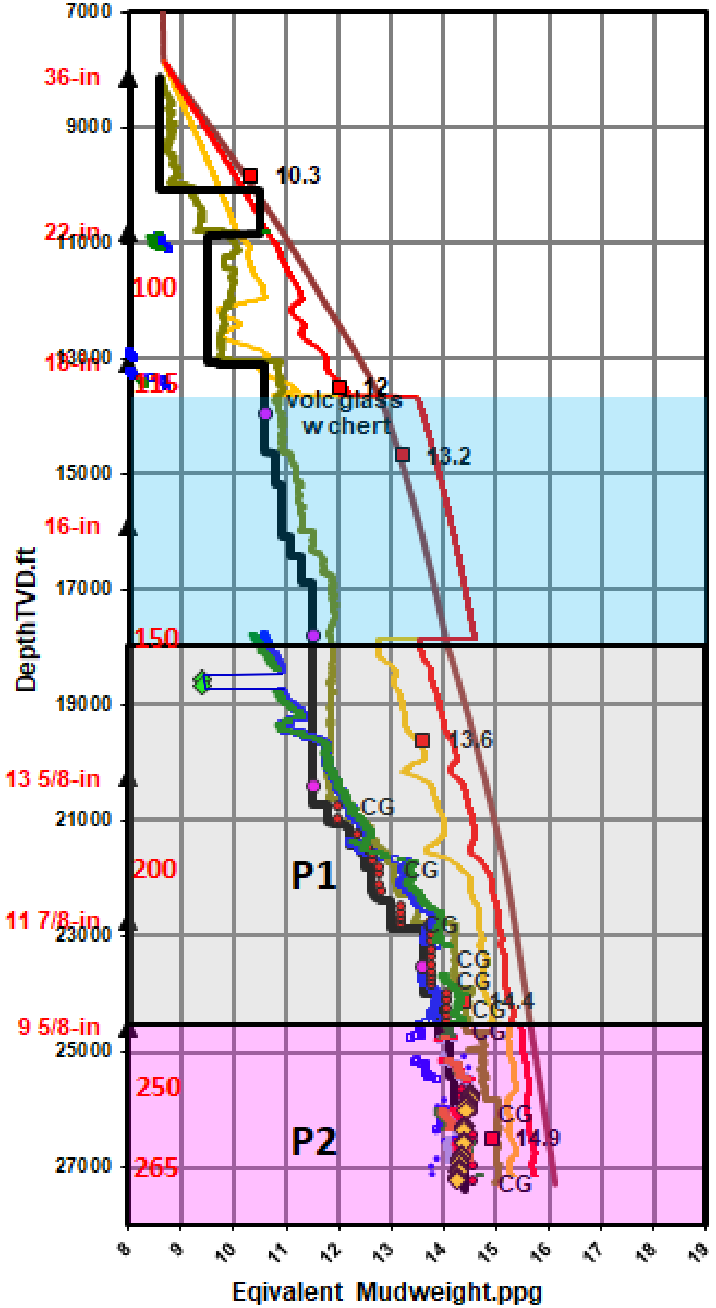
AREA: DW GOM WR969-1 LOGAN



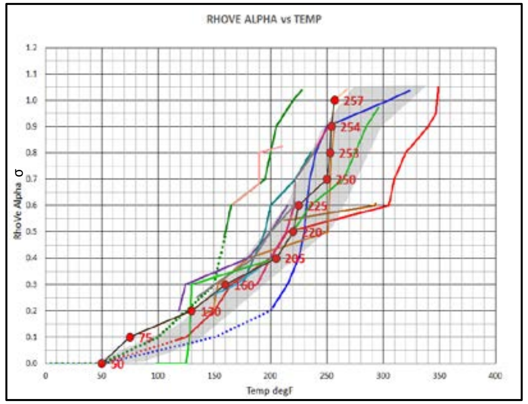




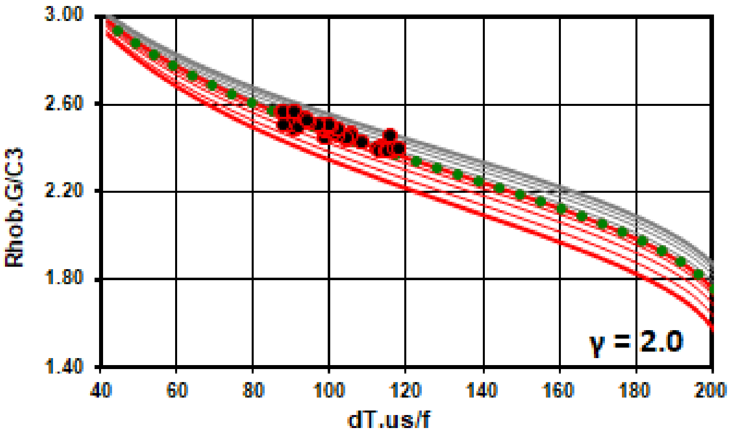


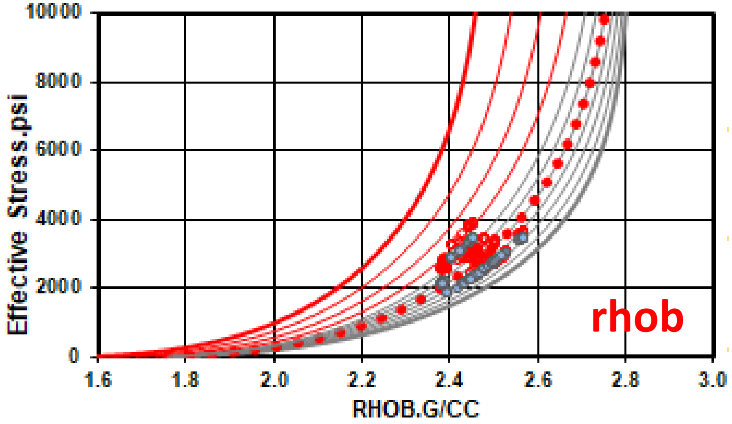


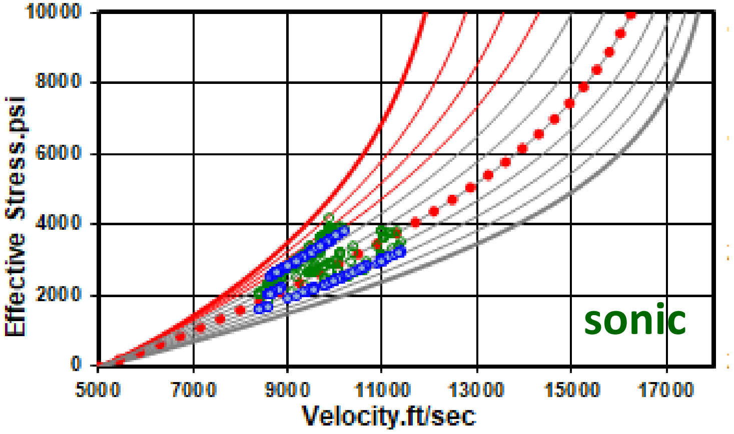
rhob	alpha	TEMPdegF
#N/A	0.0	50
#N/A	0.1	75
#N/A	0.2	118.5
#N/A	0.3	124.5
#N/A	0.4	180
#N/A	0.5	200
#N/A	0.6	215
#N/A	0.7	252
#N/A	0.8	253
2.50	0.9	254
2.52	1.0	257
#N/A	1.05	270

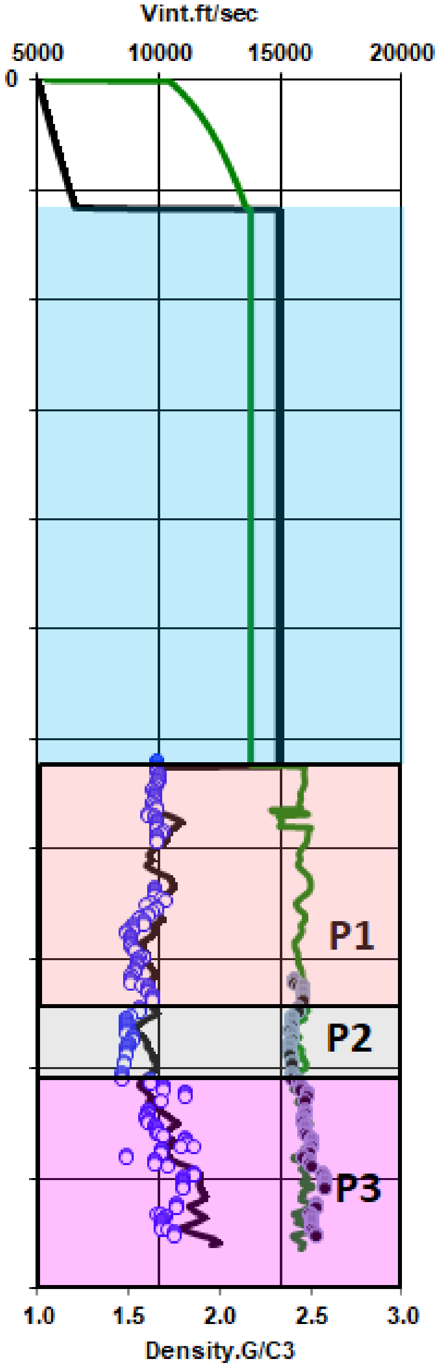


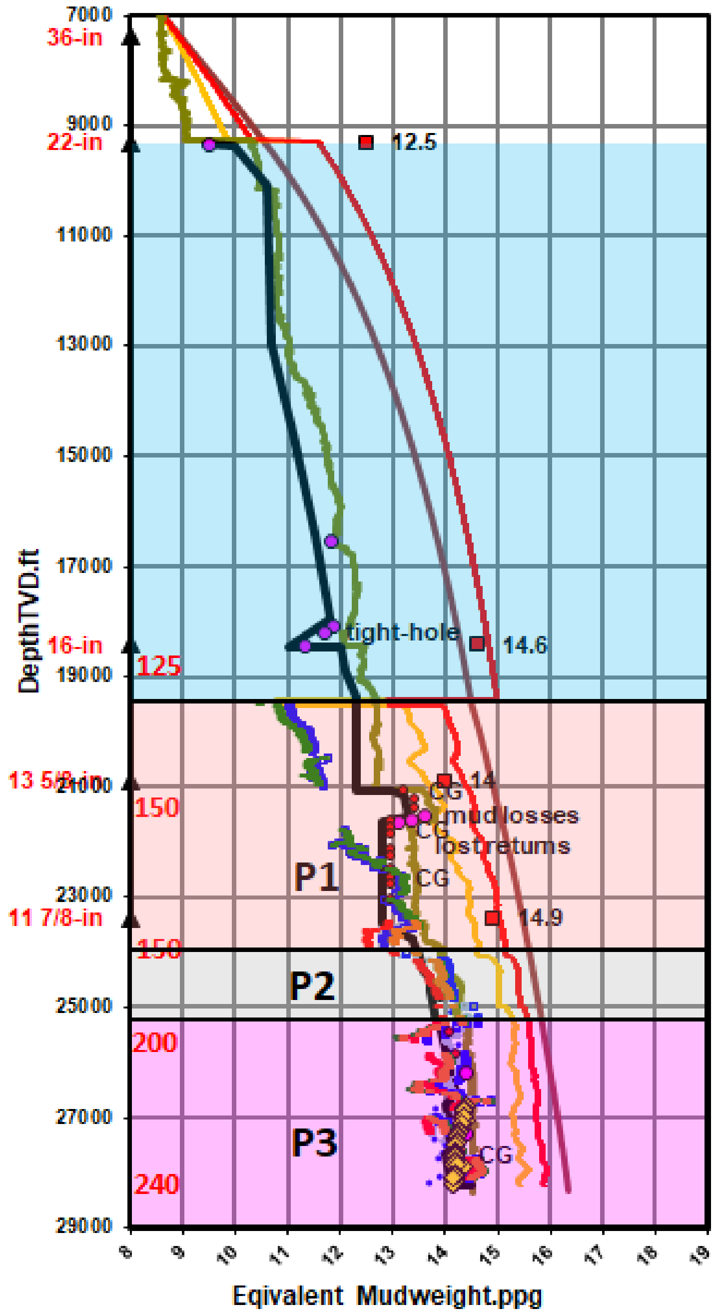
AREA: DW GOM KC872-1 BUCKSKIN



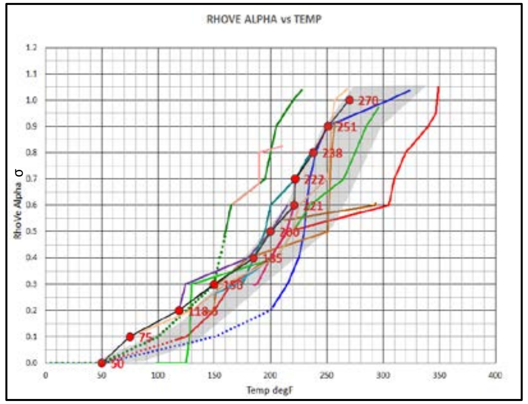




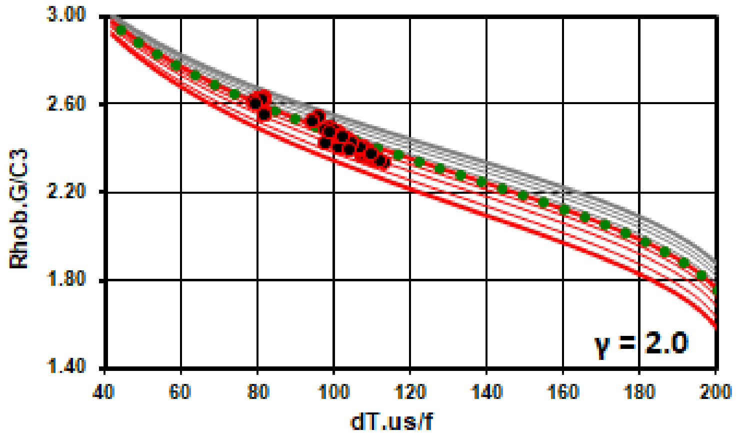


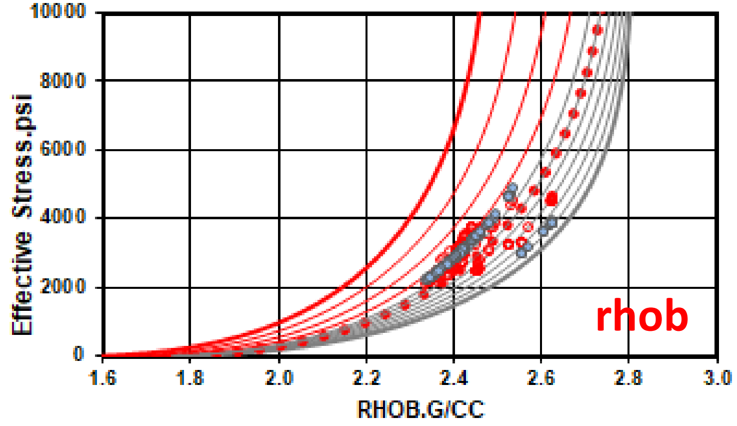


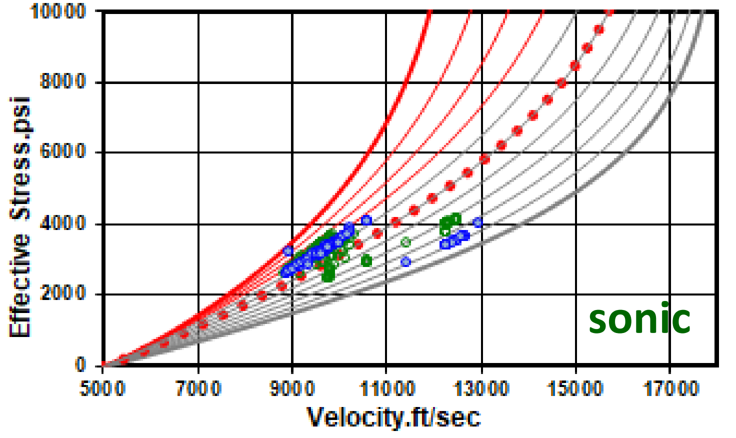
rhob	alpha	TEMPdegF
#N/A	0.0	50
#N/A	0.1	75
#N/A	0.2	118.5
#N/A	0.3	150
2.42	0.4	185
2.39	0.5	200
2.51	0.6	221
2.49	0.7	222
2.50	0.8	238
#N/A	0.9	251
#N/A	1.0	270
#N/A	1.05	275

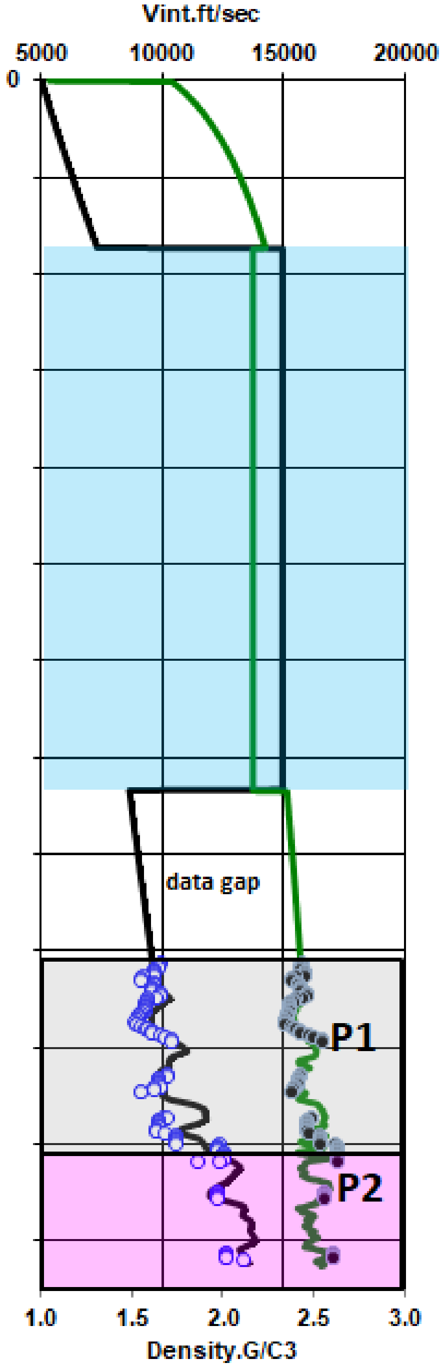


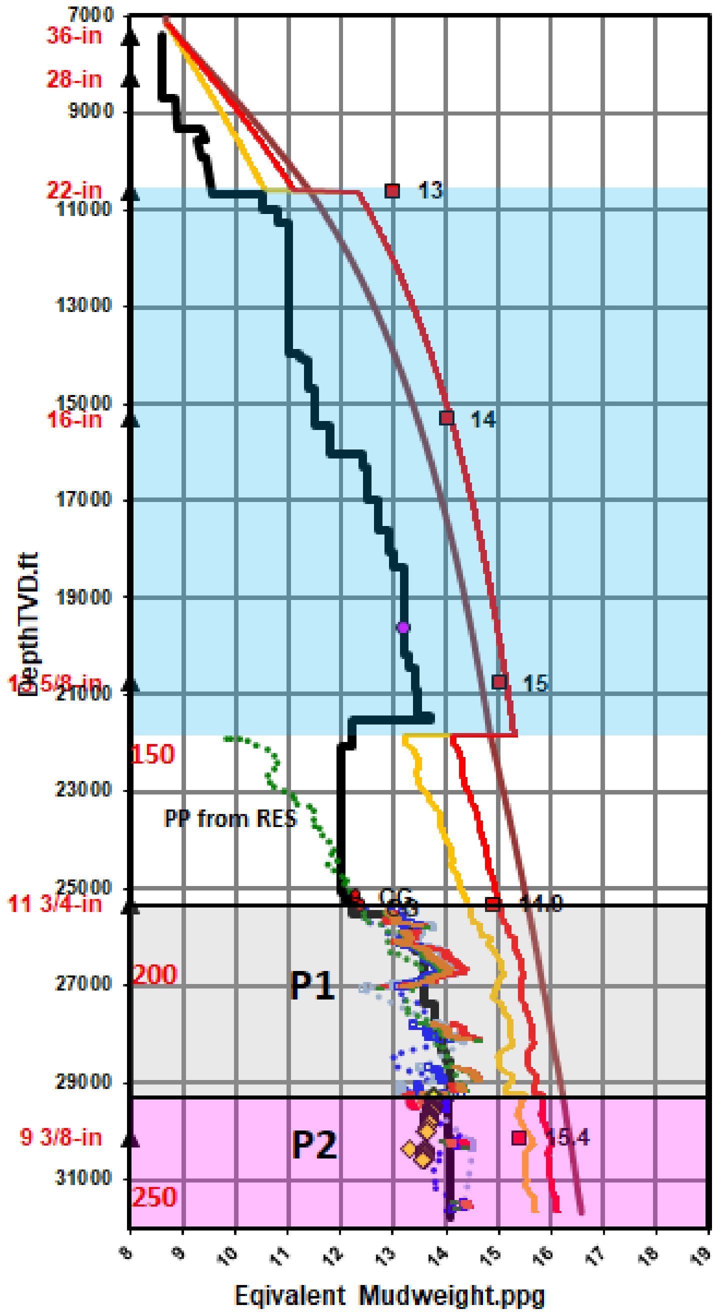
AREA: DW GOM WR627-1 JULIA



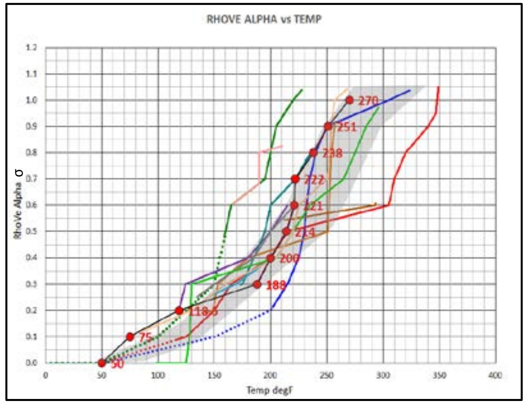


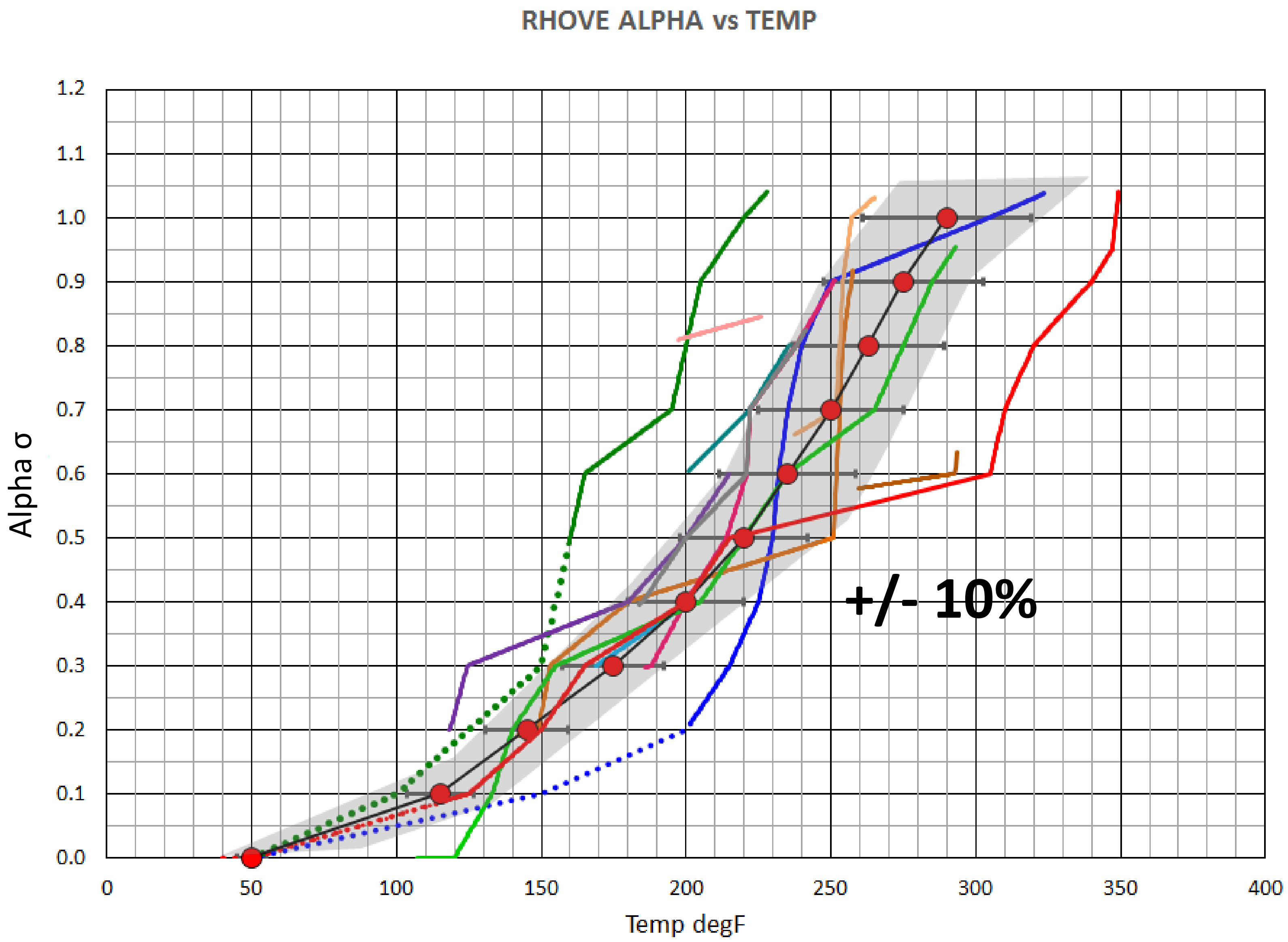






rhob	alpha	TEMPdegF
#N/A	0.0	50
#N/A	0.1	75
#N/A	0.2	118.5
2.45	0.3	188
2.38	0.4	200
2.39	0.5	214
2.46	0.6	221
2.46	0.7	222
2.56	0.8	238
2.61	0.9	251
#N/A	1.0	270
#N/A	1.05	275



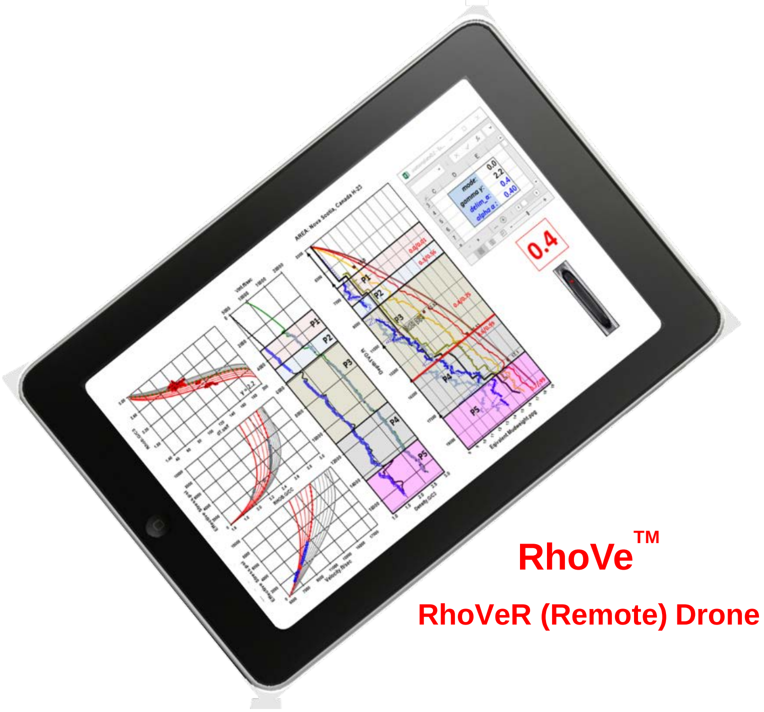

RHOVE ALPHA vs TEMP
Alpha σ
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
Temp degF
+/- 10%

Rhob

Advantages

- Efficiency through simplicity –

- RhoVe™ method has universal application -
- RhoVe™ method provides interactive solutions for:
  - Prospect Exploration
  - Prospect Maturation
  - Operations



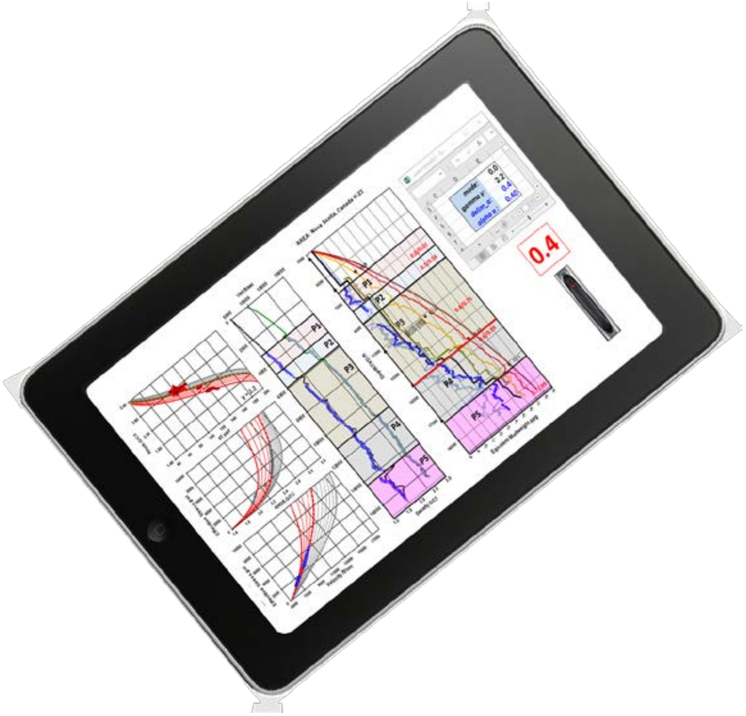
RhoVe™

RhoVeR (Remote) Drone

- Rhob density transformed to effective stress and pore pressure provides a rationale for subdivision of major flow units.
- Automate pore pressure solutions related to compositional changes using **RhoVe™ Auto**
- Thermodynamic transition from mudstone to shale utilize **RhoVe™ T**; applicable to unconventional shale reservoir plays.

GCS Solutions, Inc.

geopressure consulting
services & solutions



RhoVe™ Method

(U.S. patent pending - copyright © 2016)

JIP – seeking $55,000 investment for:

- Commercial implementation of RhoVe method as a plug-in or web-based application to include:
  - Real-Time WITSML connectivity,
  - notebook (iPad) capability,
  - 1D temperature modeling,
- Explore automation capabilities,

GCS Solutions, Inc.
geopressure consulting
services & solutions

Chemical Compaction

Late Diagenesis

JIP – (future work) $40,000 investment for:

- EMI (electron microbeam instrumentation) project to study the effects of late stage diagenesis (temperature, pH) on effective stress and pore pressure (2+ wells),
- Sample collection, preparation, analysis & reporting [1]

[1] Bureau of Economic Geology, The University of Texas, Austin

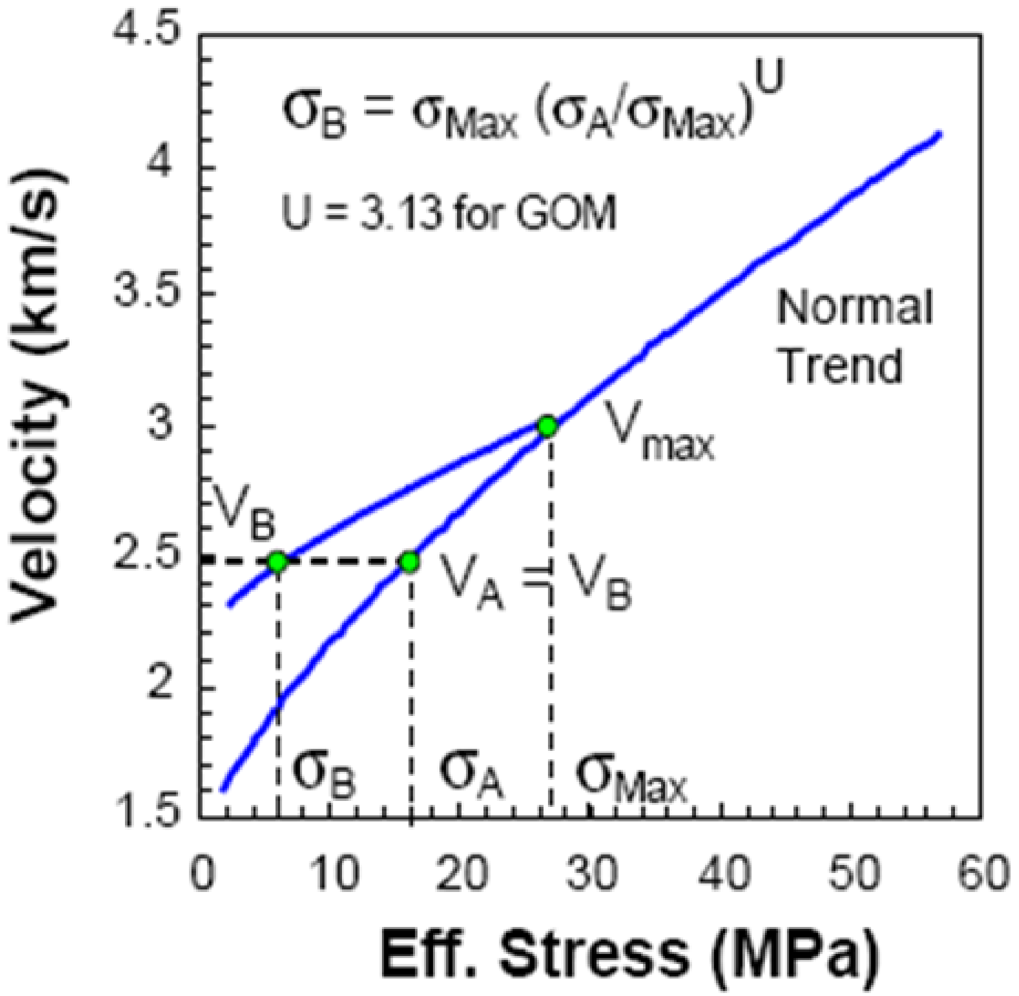
Additional References

- Alberty, M.W. [2011]. SPE Distinguished Lecturer Series, Pore Pressure Detection: Moving from an Art to a Science.
- Real-Time Downhole pH Measurement Using Optical Spectroscopy, Raghuraman, B. et al. 2007, SPE-93057-PA
- Mudrocks (shales, mudstones) at the Scale of Grains and Pores: Current Understanding, Milliken, K., 2017, Bureau of Economic Geology The University of Texas, Austin.
- Jahren, J, Thyberg, B, Marcussen, O, Winje, T, Bjorlykke, K. and Faleide, J.I., 2009, From Mud to Shale: The Role of Microquartz Cementation, AAPG Annual Convention.
- Sargent, C., Goulty, N.R., Cicchino, A.M.P., Ramdhan, A.M. [2015] Budge-Fudge method of PorePressure Estimation from Wireline Logs with Application to Cretaceous Mudstones at Haltenbanken. Petroleum Geoscience, 21, 219-232.

BACKUP SLIDES

GCS Solutions, Inc.
geopressure consulting
services & solutions

RhoVe versus Bowers



$$V = V_0 + A\,\sigma^{B}$$

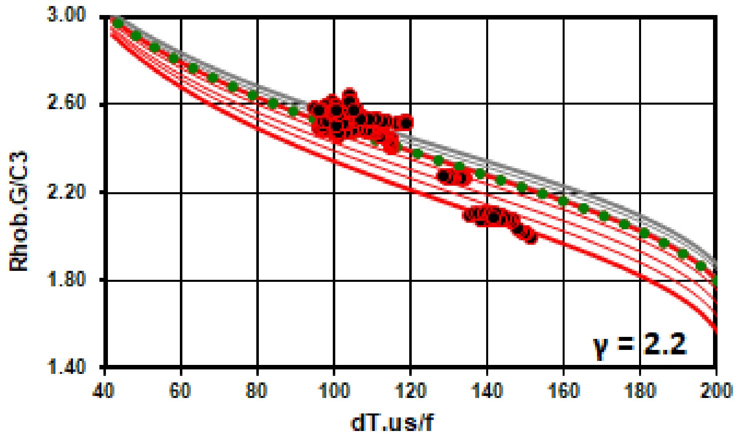
DWGOM

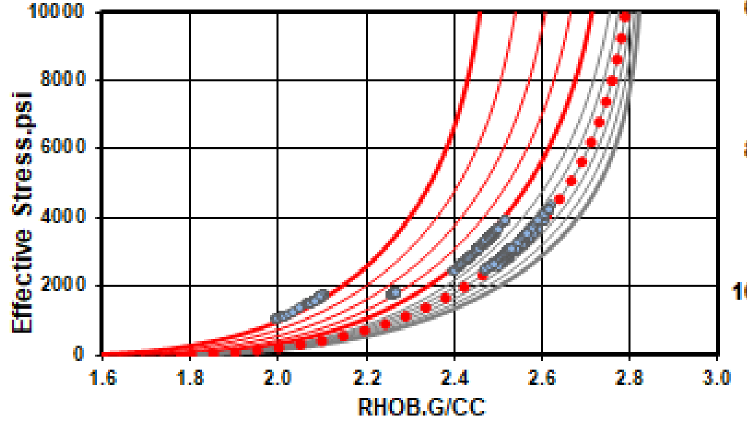
V_o: 4930

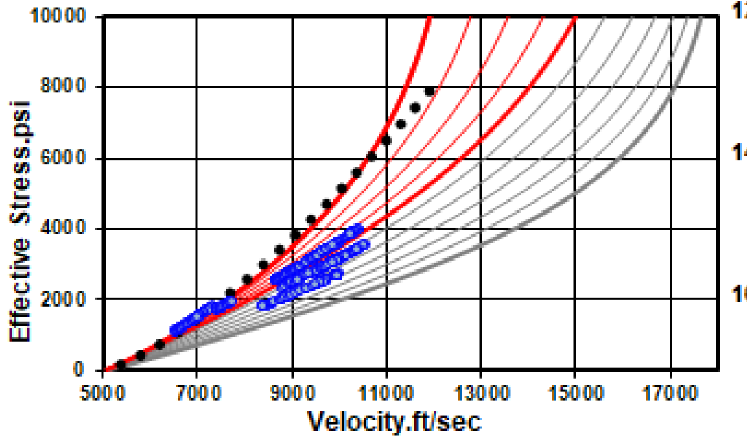
A: 14.2

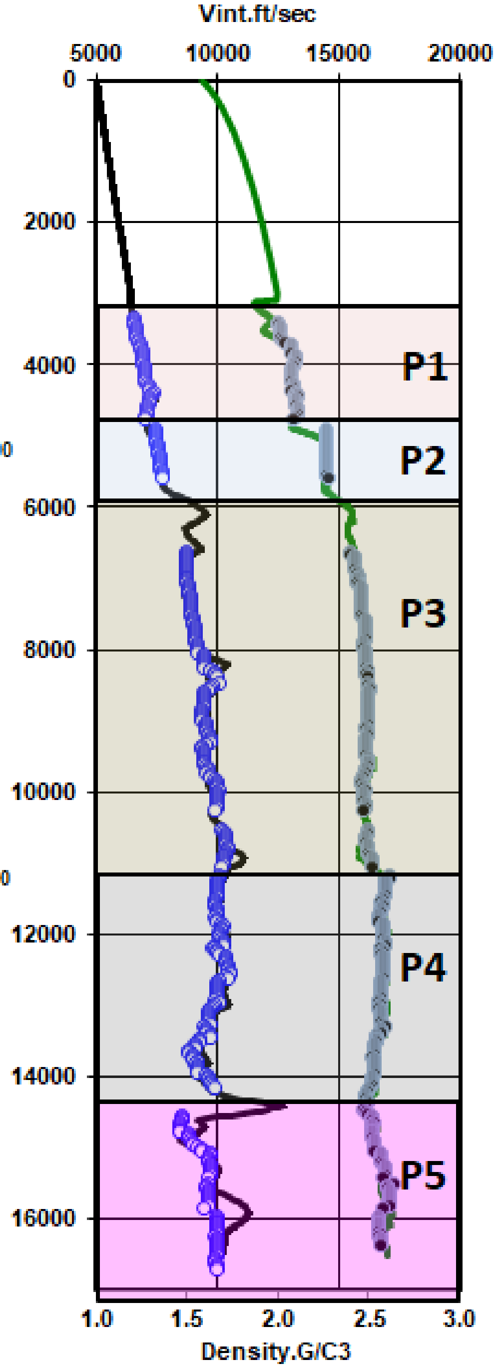
B: 0.724

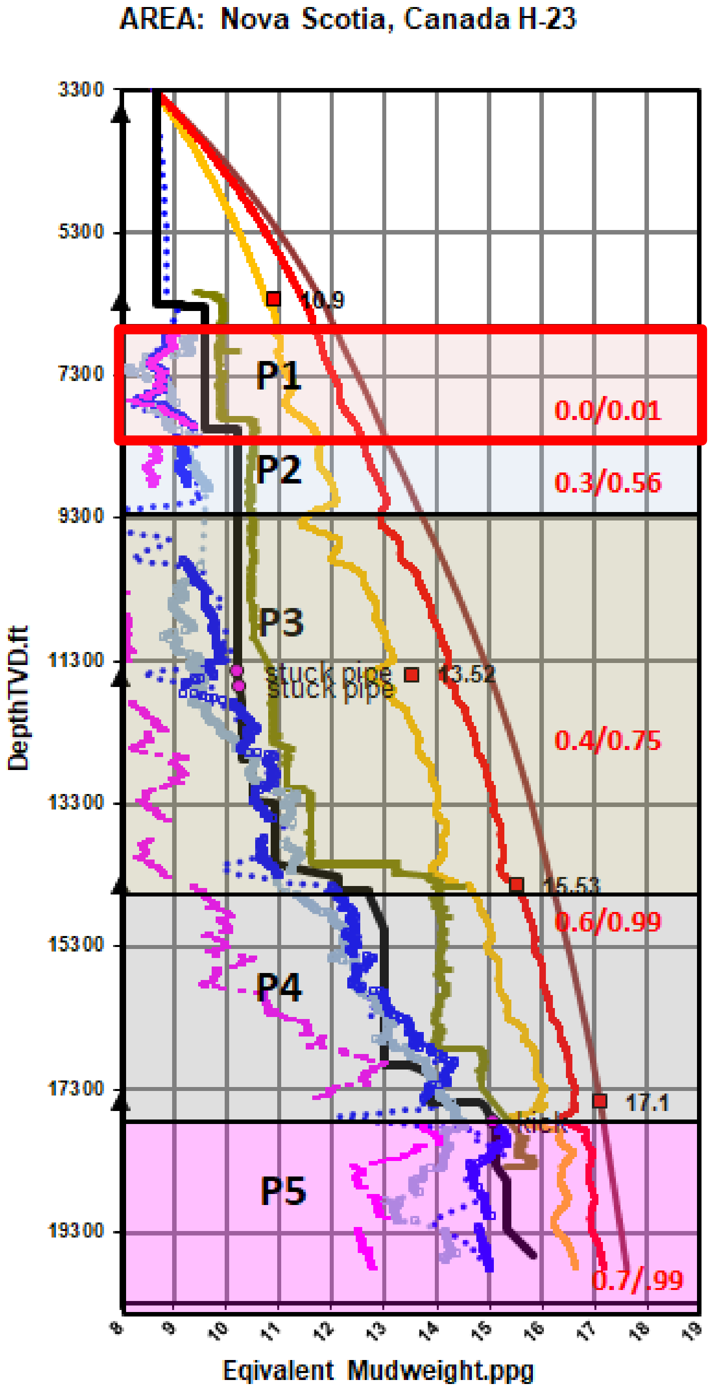
Bowers - 1995 SPE; 2001 OTC


Rhob.G/C3
dT.us/f
γ = 2.2
3.00
2.60
2.20
1.80
1.40
40
60
80
100
120
140
160
180
200

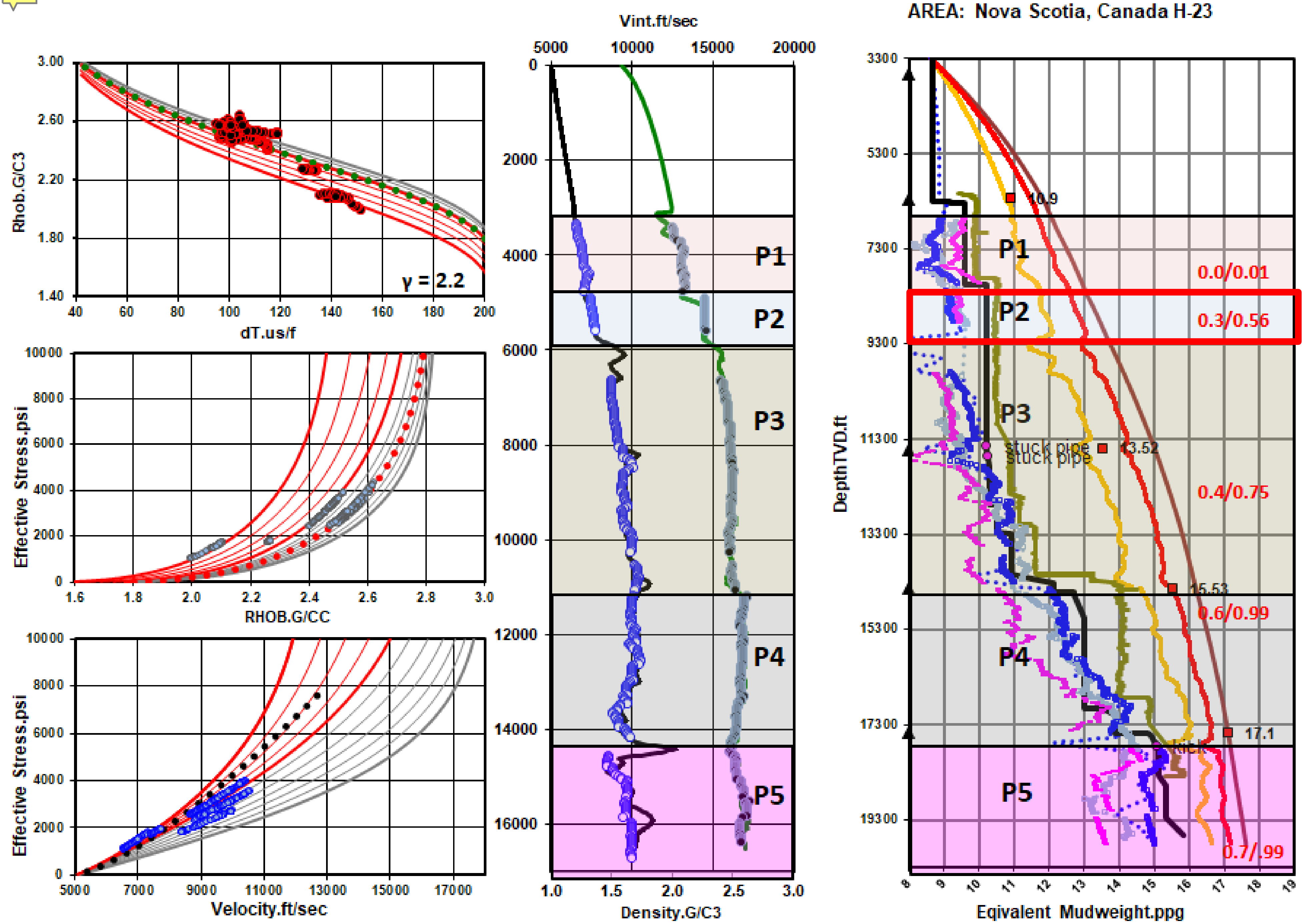

Effective Stress.psi
RHOB.G/CC
10000
8000
6000
4000
2000
0
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0


Effective Stress.psi
Velocity.ft/sec
10000
8000
6000
4000
2000
0
5000
7000
9000
11000
13000
15000
17000

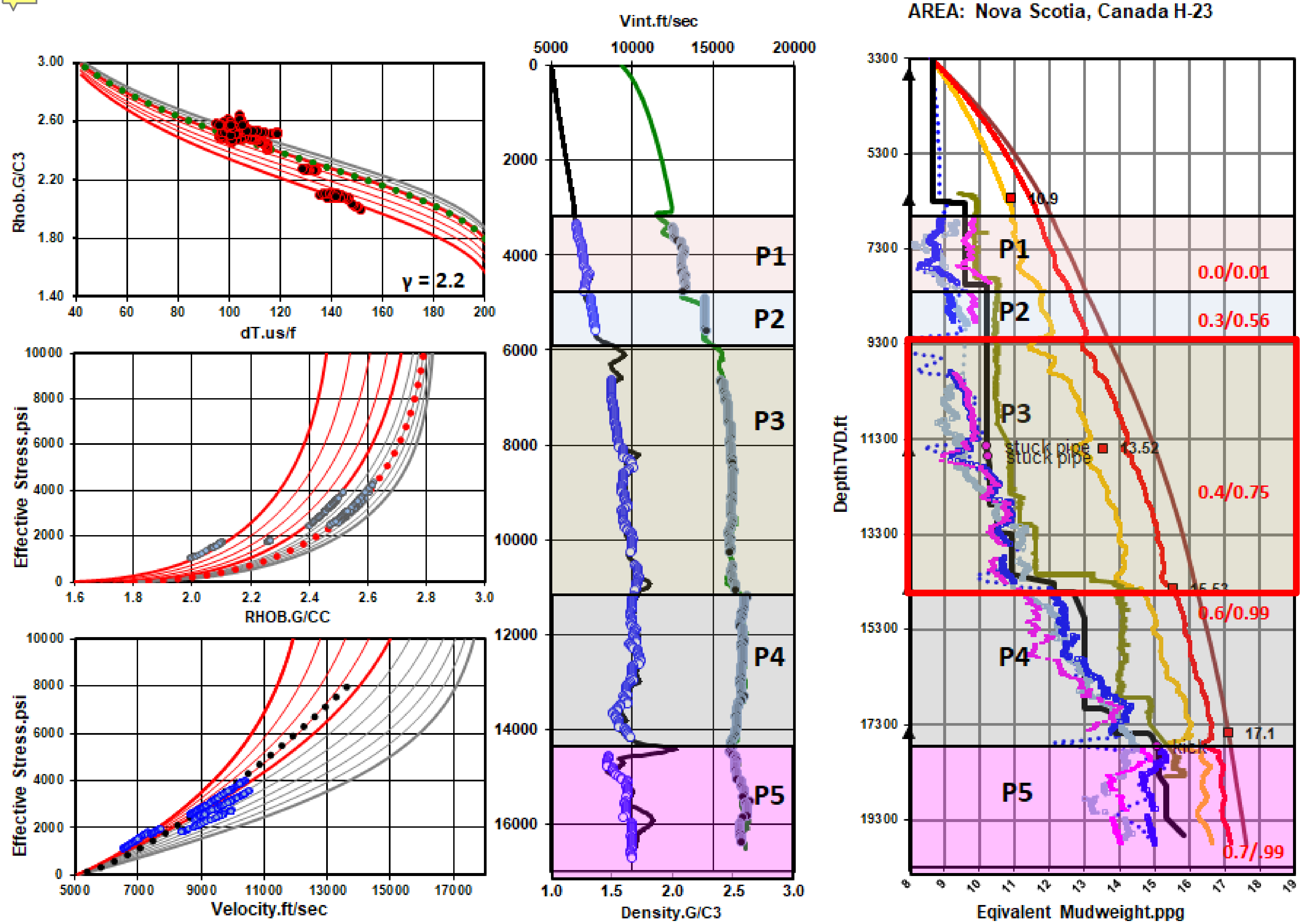

Vint.ft/sec
5000
10000
15000
20000
0
2000
4000
6000
8000
10000
12000
14000
16000
P1
P2
P3
P4
P5
1.0
1.5
2.0
2.5
3.0
Density.G/C3


AREA: Nova Scotia, Canada H-23
DepthTVD.ft
3300
5300
7300
9300
11300
13300
15300
17300
19300
P1
P2
P3
P4
P5
10.9
stuck pipe
13.52
15.53
17.1
kick
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/.99
8
9
10
11
12
13
14
15
16
17
18
19
Eqivalent Mudweight.ppg

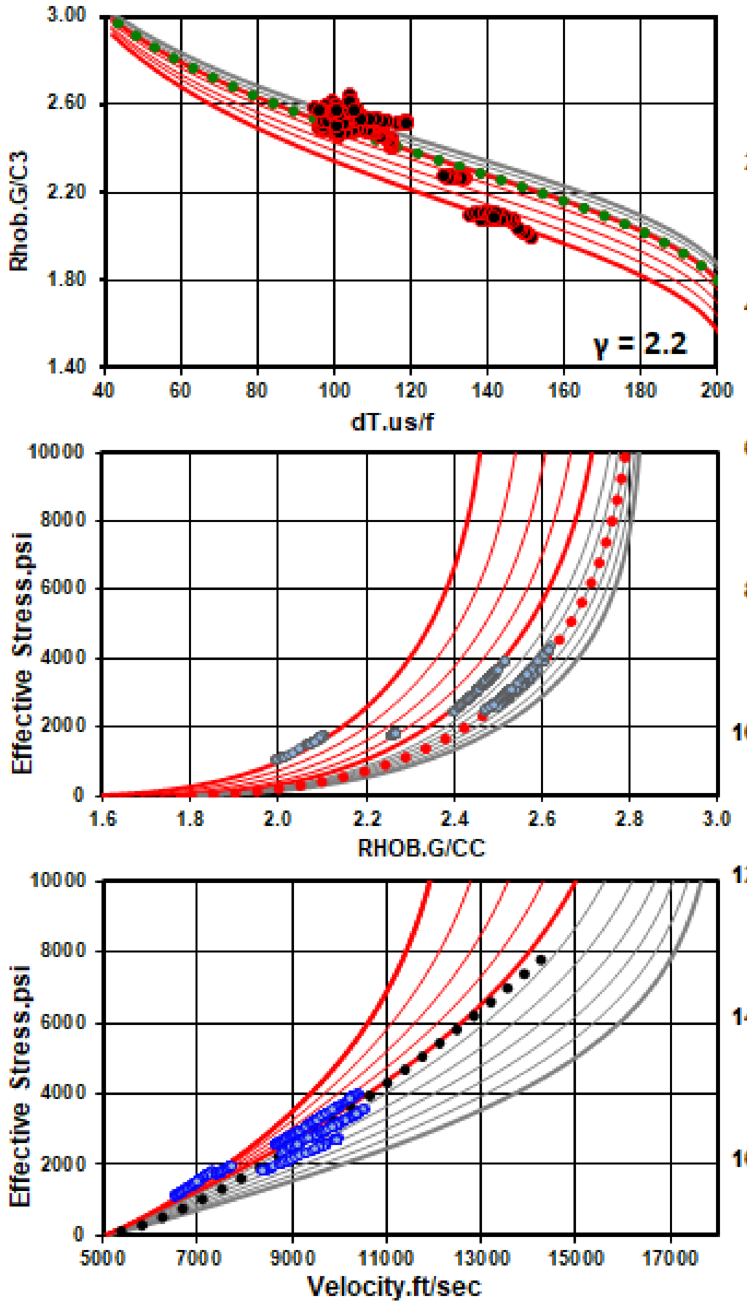
A = 10.5

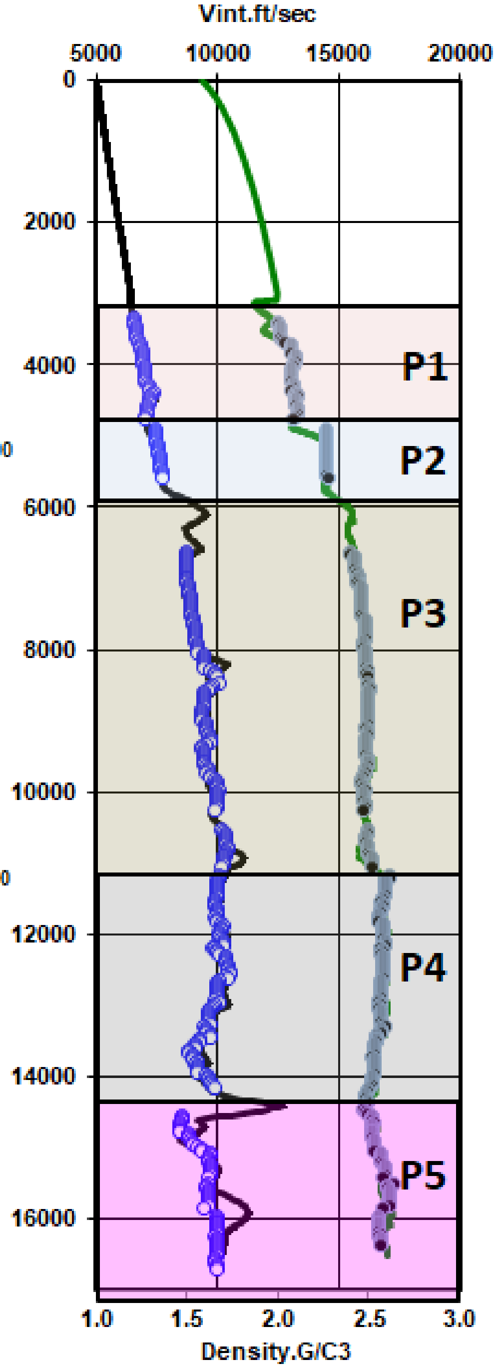

AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
10.9
13.52
15.53
17.1
stuck pipe
kick
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/.99

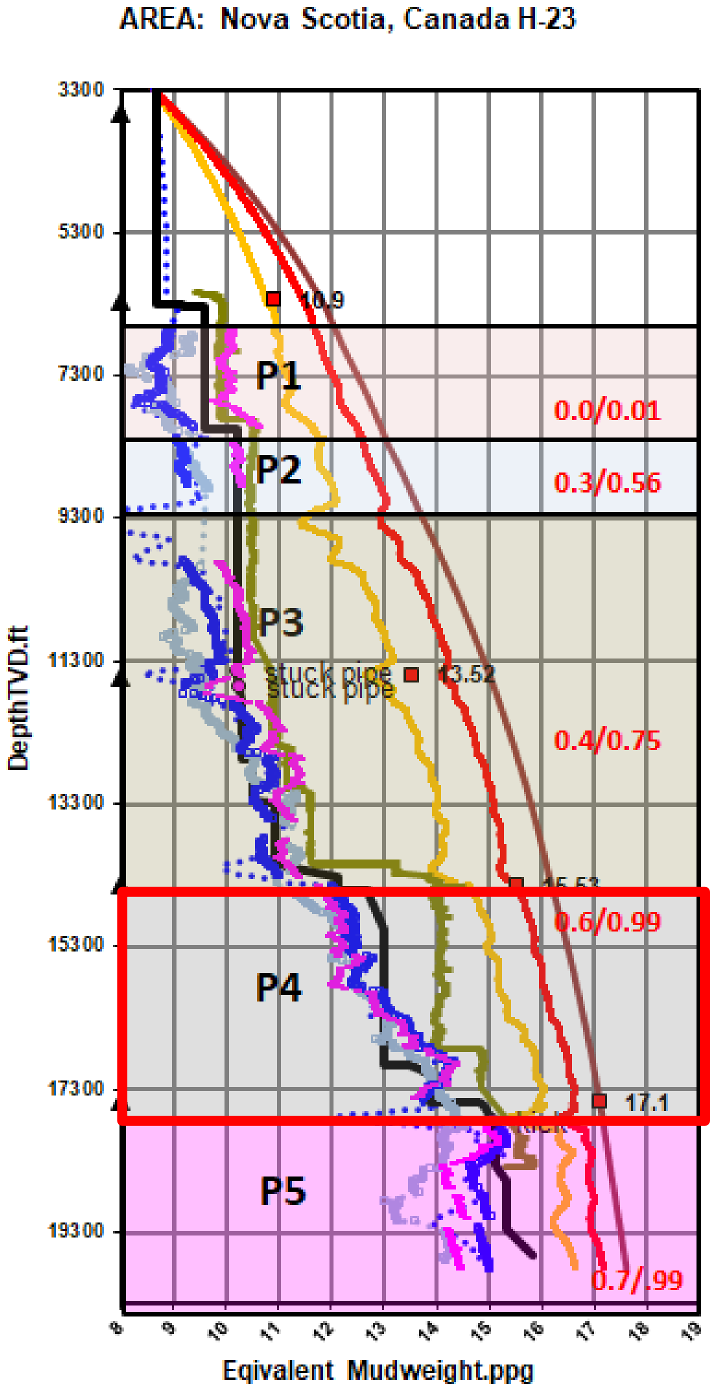
A = 12


AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
10.9
13.52
17.1
stuck pipe
kick
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/.99

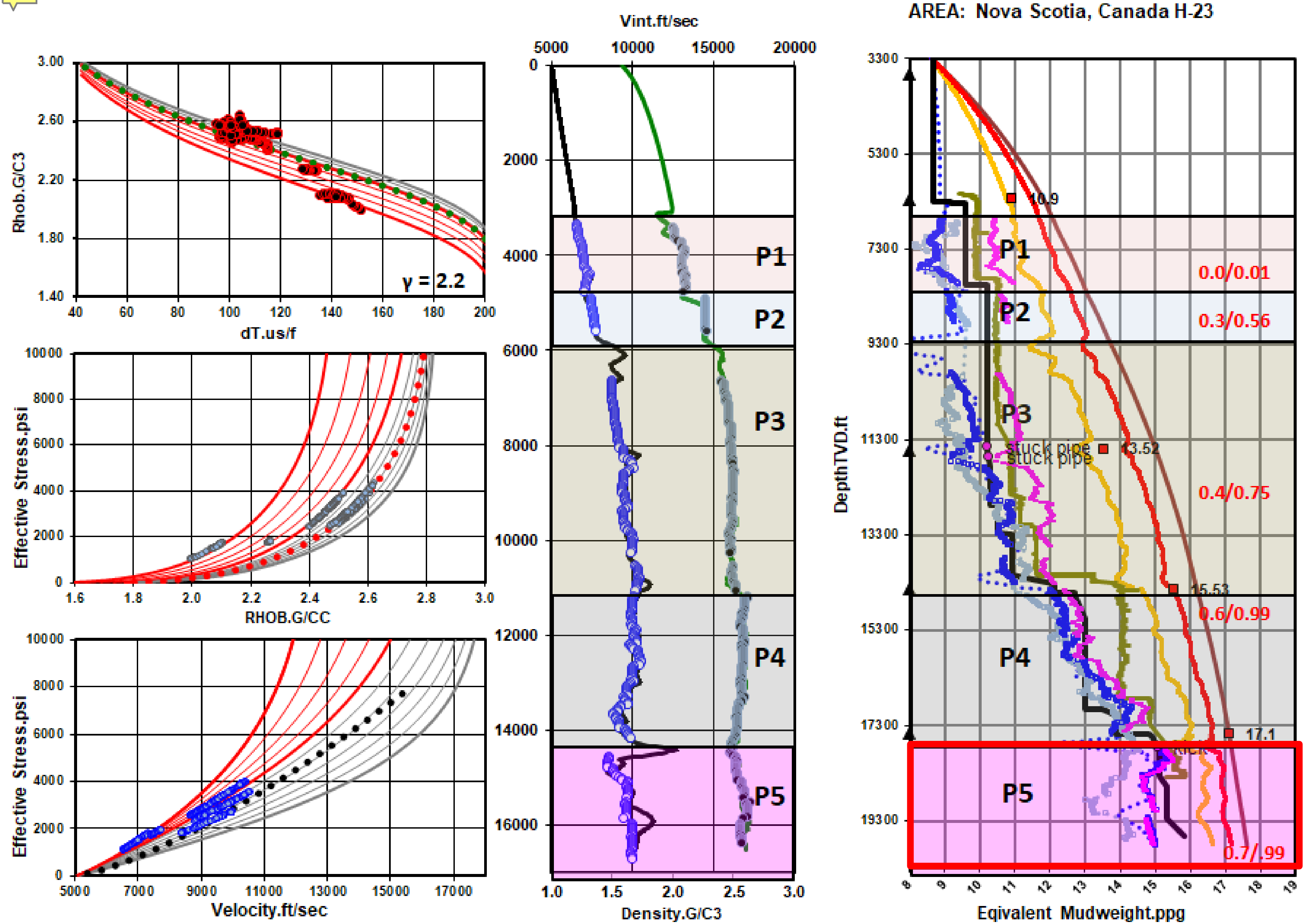
A = 13.0


Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Effective Stress.psi
Velocity.ft/sec

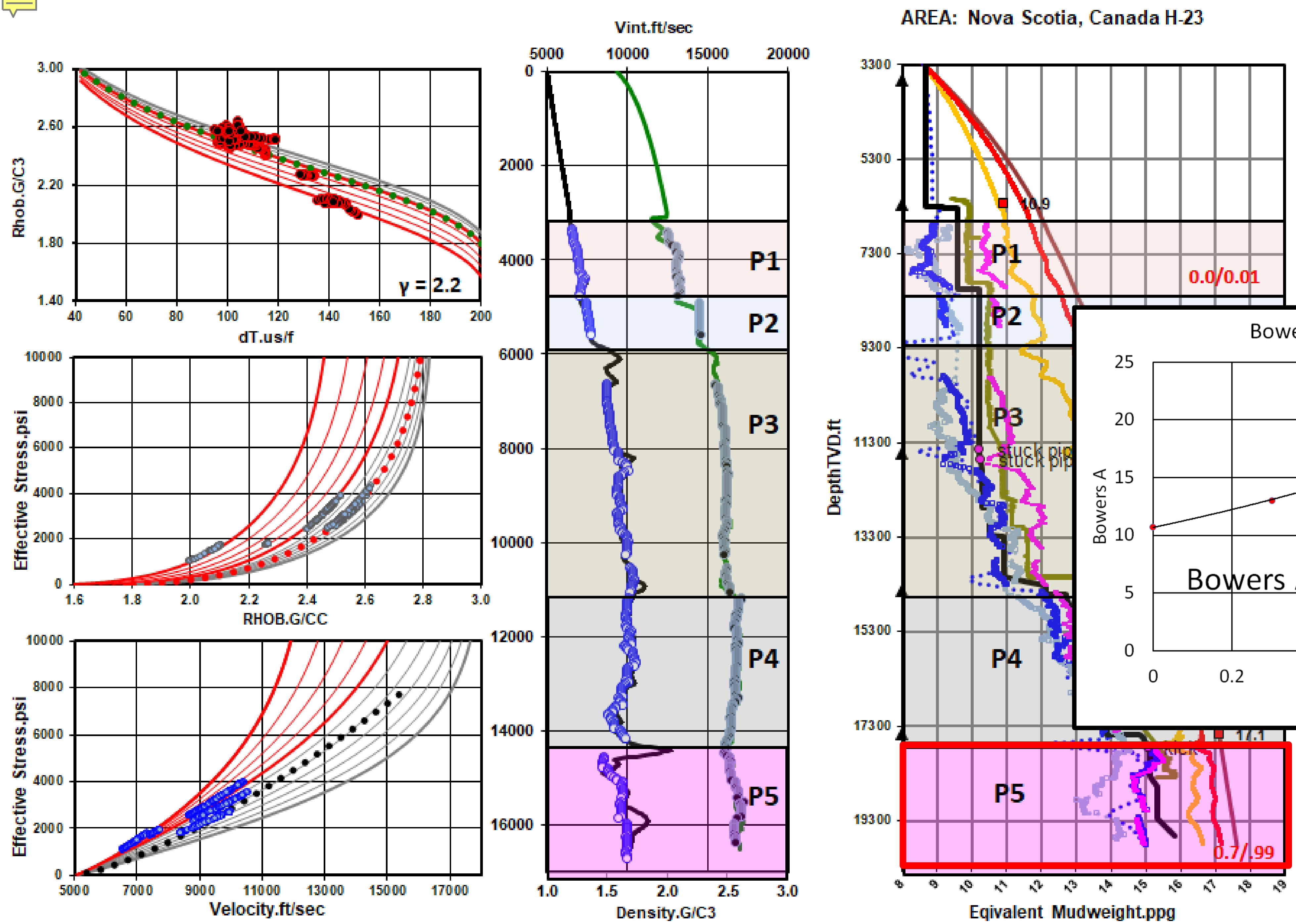

Vint.ft/sec
P1
P2
P3
P4
P5
Density.G/C3

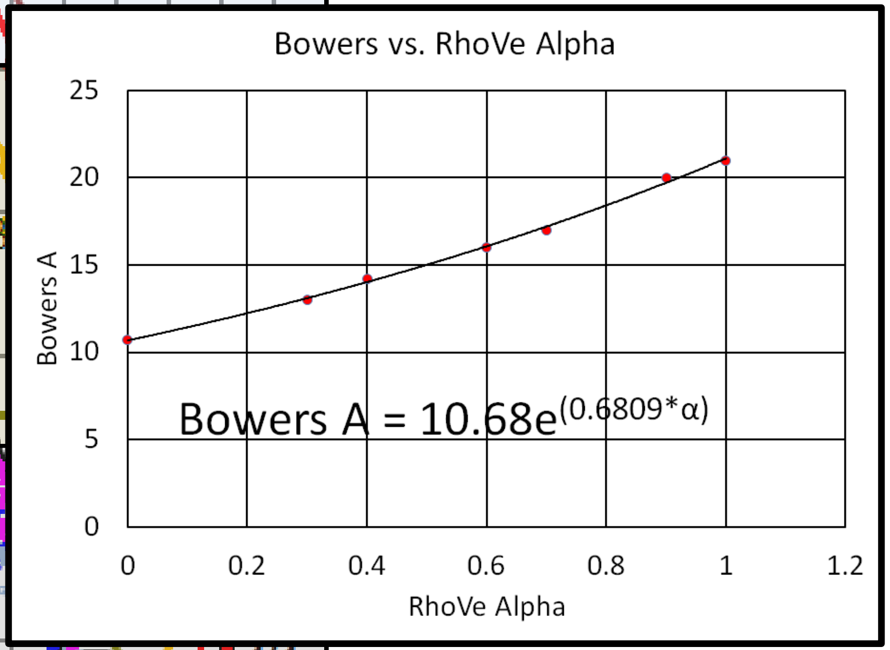

AREA: Nova Scotia, Canada H-23
DepthTVD.ft
10.9
P1
0.0/0.01
P2
0.3/0.56
P3
stuck pipe
13.52
0.4/0.75
0.6/0.99
P4
17.1
P5
0.7/.99
Eqivalent Mudweight.ppg

A = 14.2

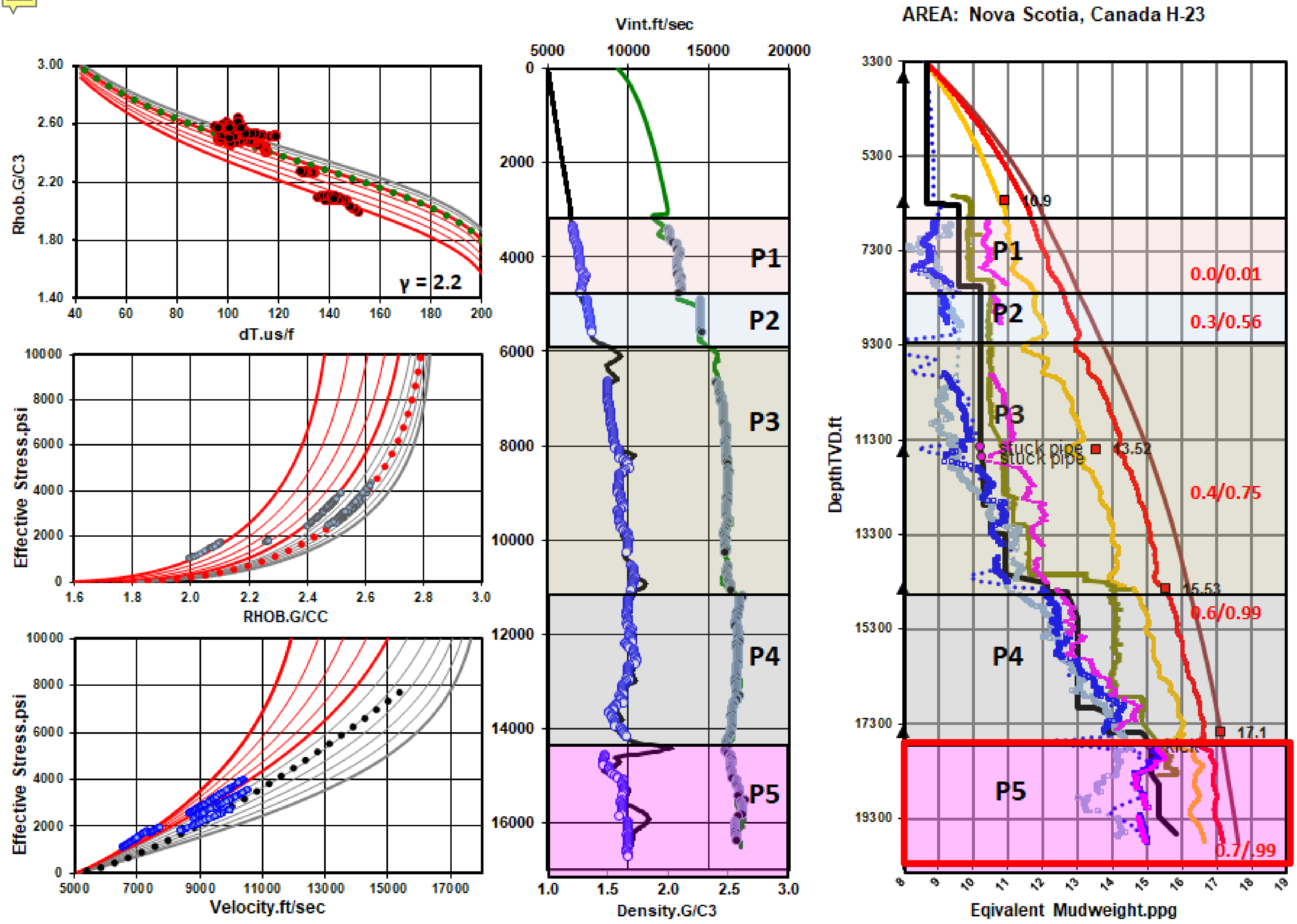

AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
10.9
13.52
15.53
17.1
stuck pipe
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/.99

A = 16.0


AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
10.9
0.0/0.01
stuck pip
17.1
0.7/.99

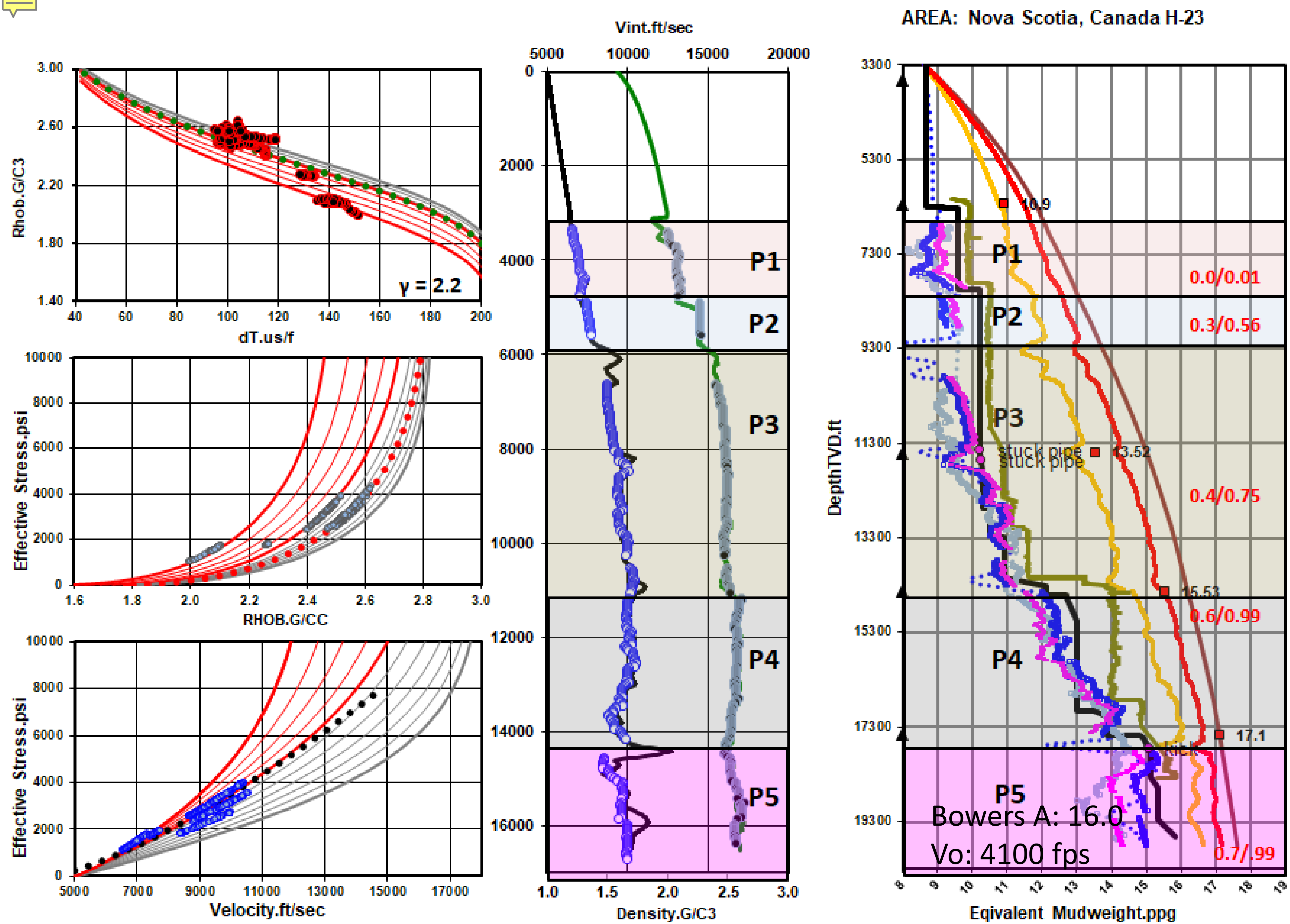

Bowers vs. RhoVe Alpha
Bowers A
RhoVe Alpha
Bowers A = 10.68e(0.6809*α)

A = 16.0



AREA: Nova Scotia, Canada H-23
Rhob.G/C3
dT.us/f
γ = 2.2
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
P4
P5
DepthTVD.ft
Eqivalent Mudweight.ppg
10.9
13.52
15.53
17.1
stuck pipe
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/.99

A = 16.0



$$V = V_0 + A\,\sigma^B$$

DWGOM

V_o: 4100 fps

A: 16.0

B: 0.724

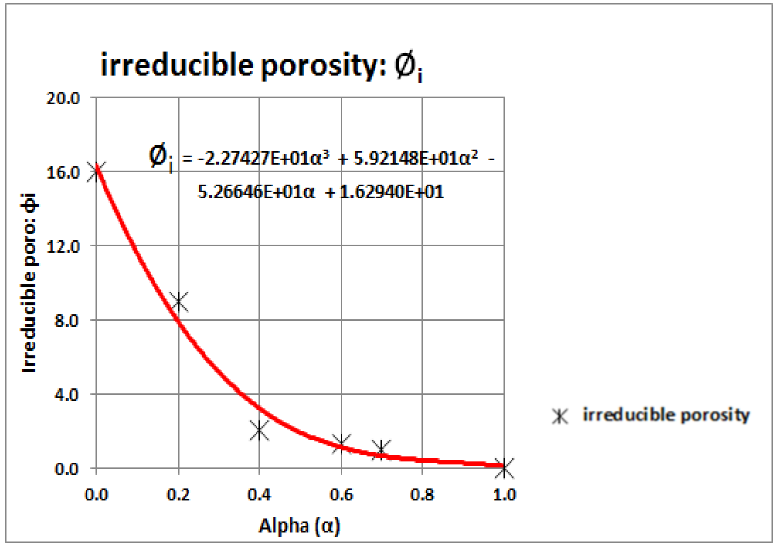
RhoVe Method

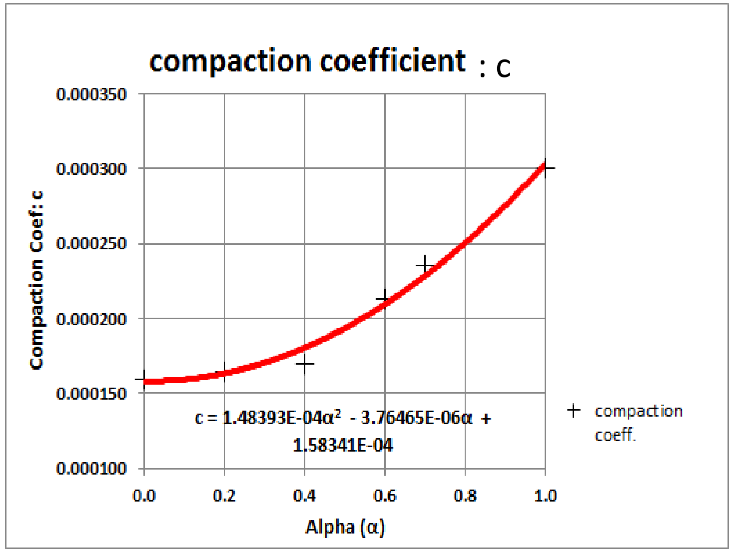
dT Compaction Trend:

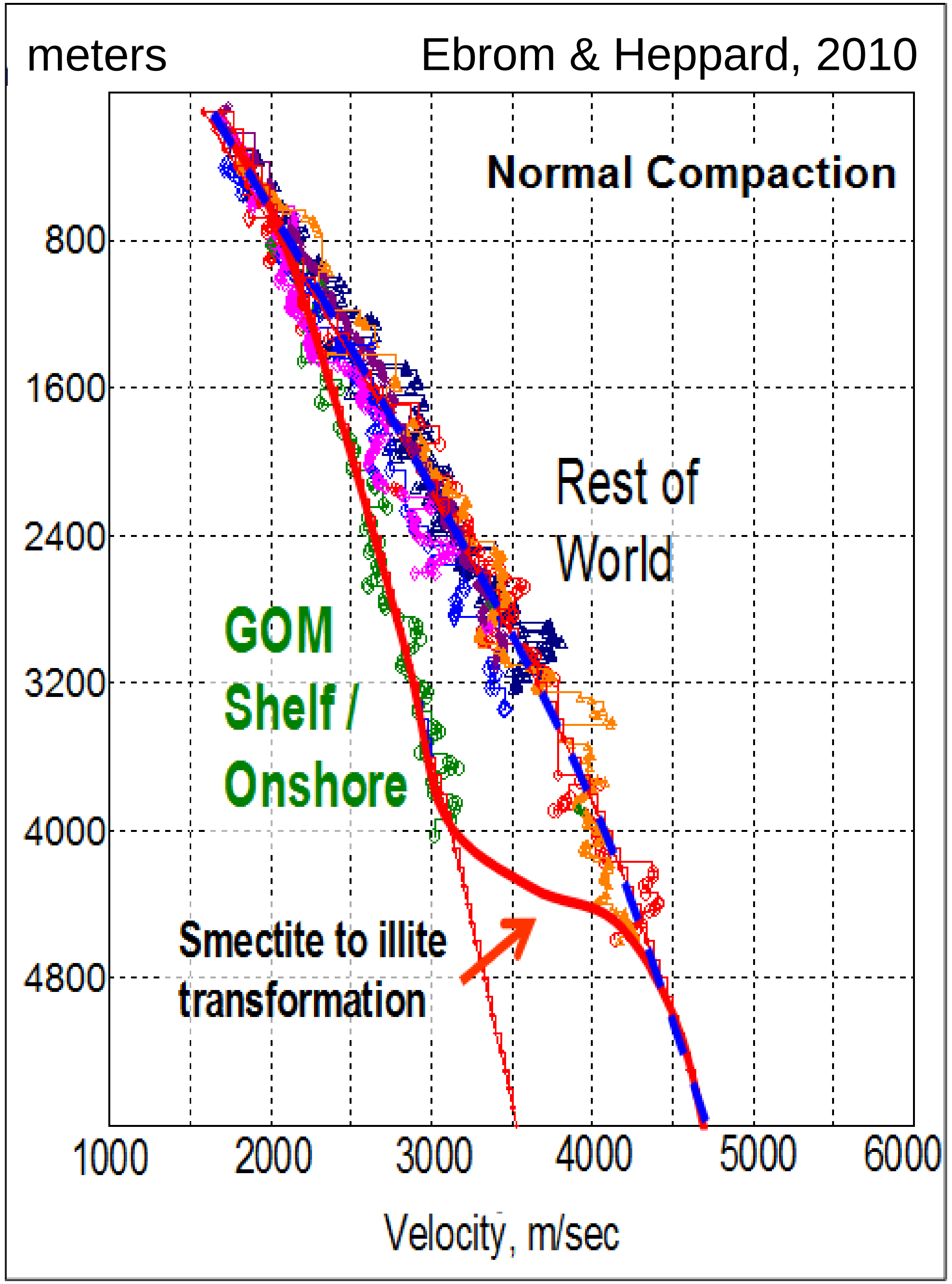
$$\Delta t_n = (\Delta t_{ml} - \Delta t_i)\, e^{-cz} + \Delta t_i$$

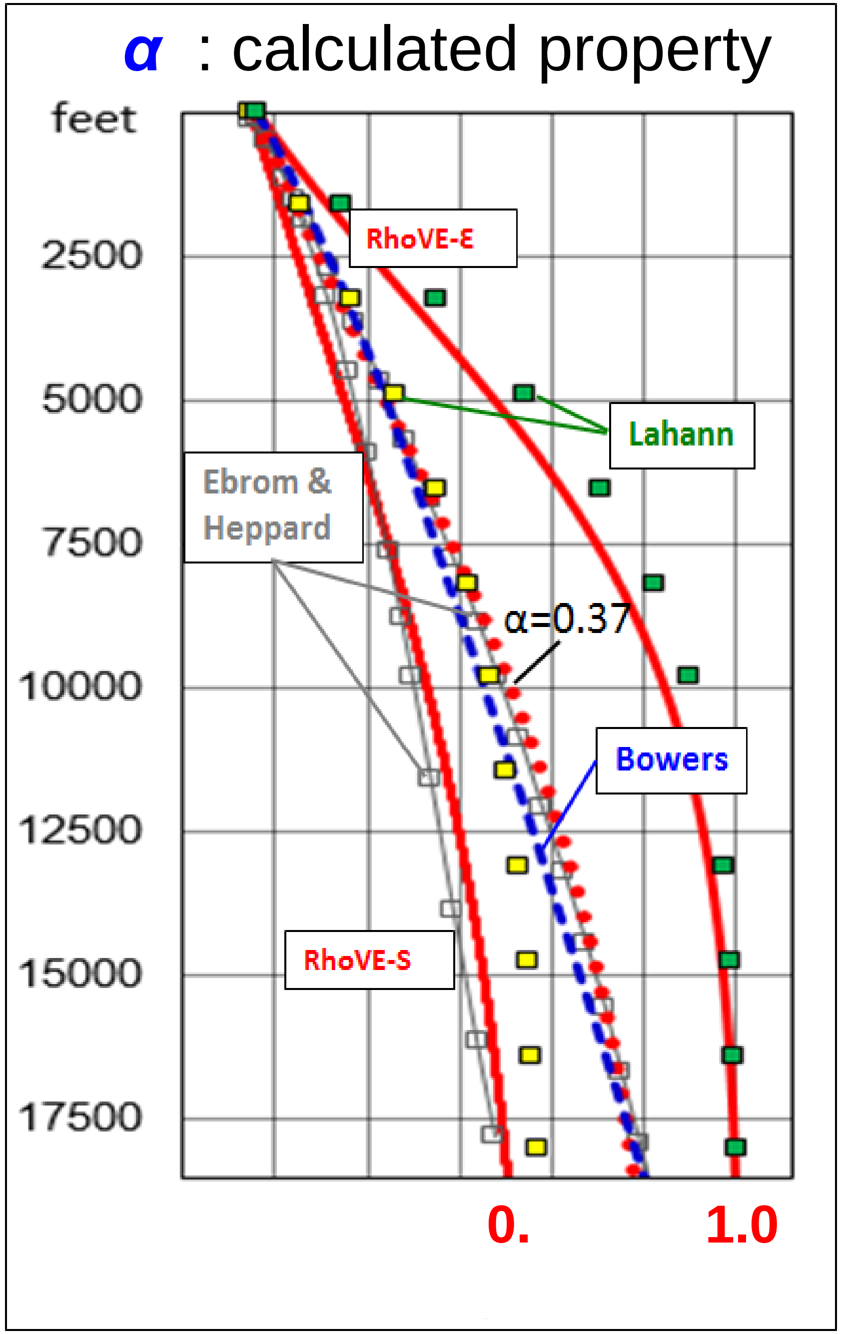
$$\Delta t_i = \varnothing_i (\Delta t_{ml} - \Delta t_{mx}) + \Delta t_{mx}$$

Δt_{mx}: : dT matrix: 55 usec/ft
Δt_{ml} : dT mudline 200 usec/ft
c compaction coeff: 0.00016 - 0.00030
z: depth below mudline
$\varnothing_i$: irreducible porosity (fractional)

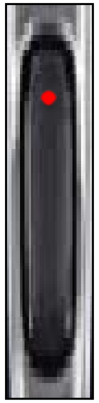


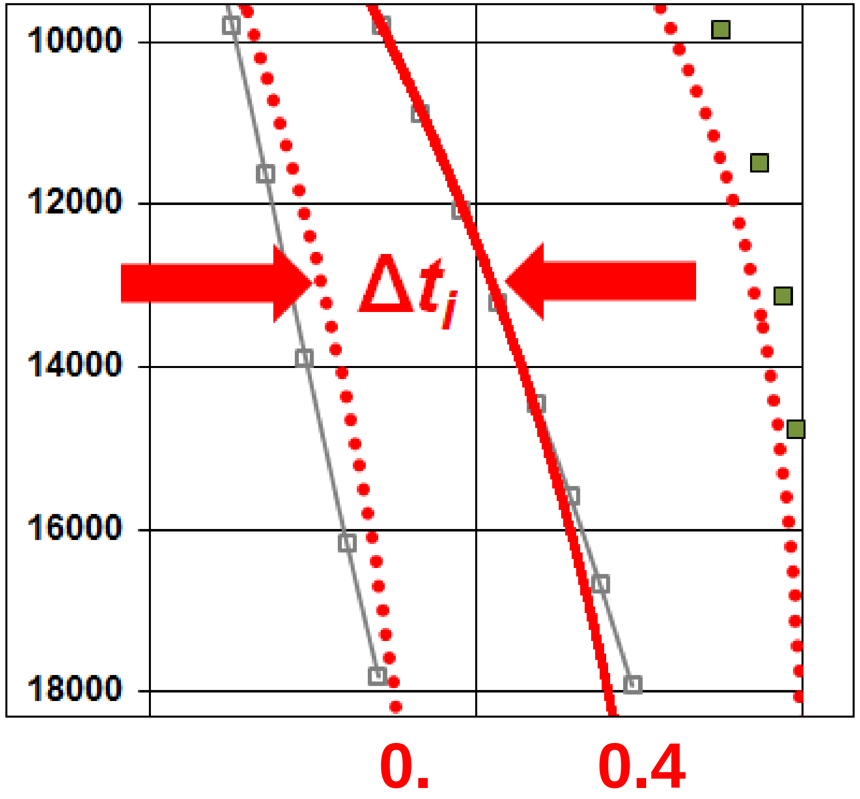


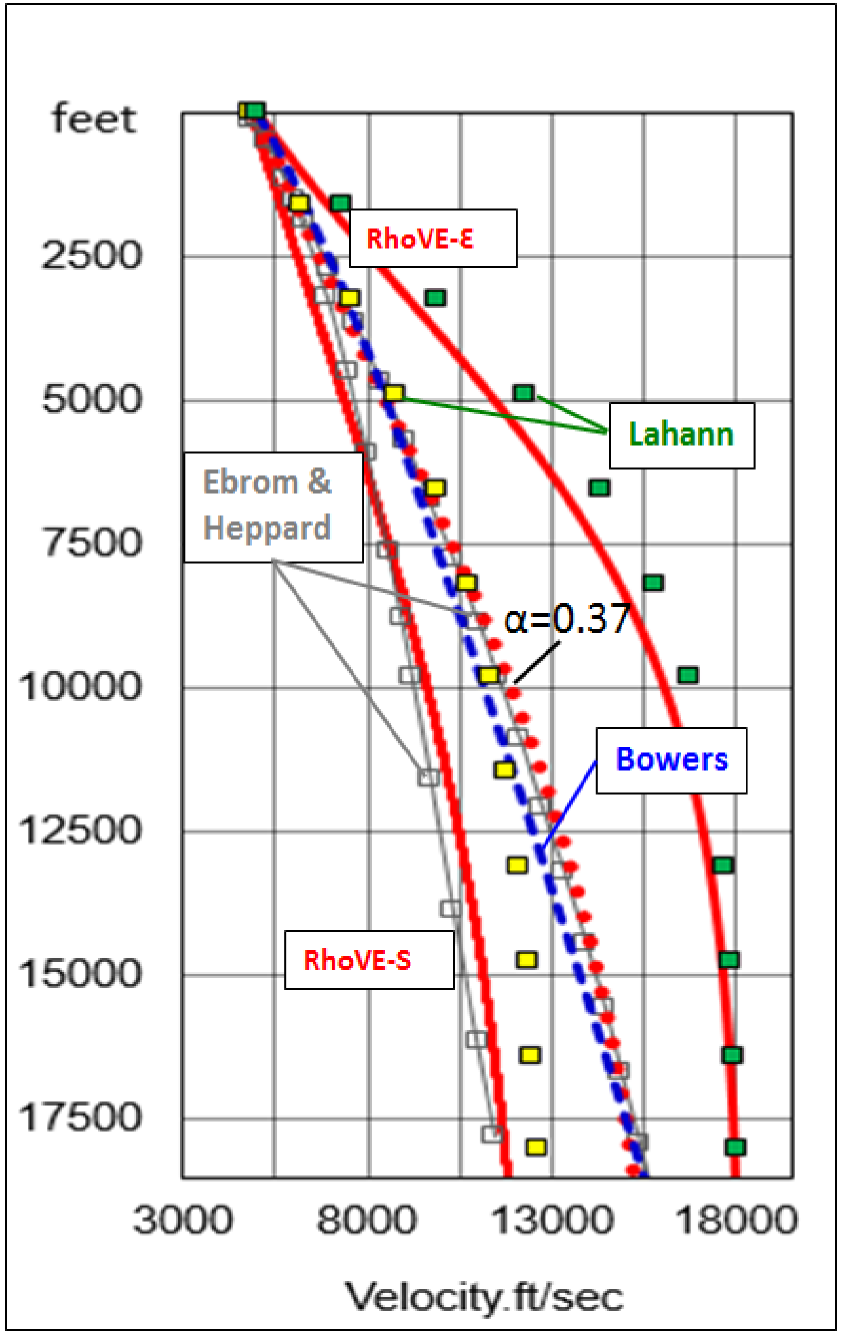

meters
Ebrom & Heppard, 2010
Normal Compaction
800
1600
2400
3200
4000
4800
Rest of
World
GOM
Shelf /
Onshore
Smectite to illite
transformation
1000
2000
3000
4000
5000
6000
Velocity, m/sec


α : calculated property
feet
2500
5000
7500
10000
12500
15000
17500
RhoVE-E
Lahann
Ebrom &
Heppard
α=0.37
Bowers
RhoVE-S
0.
1.0

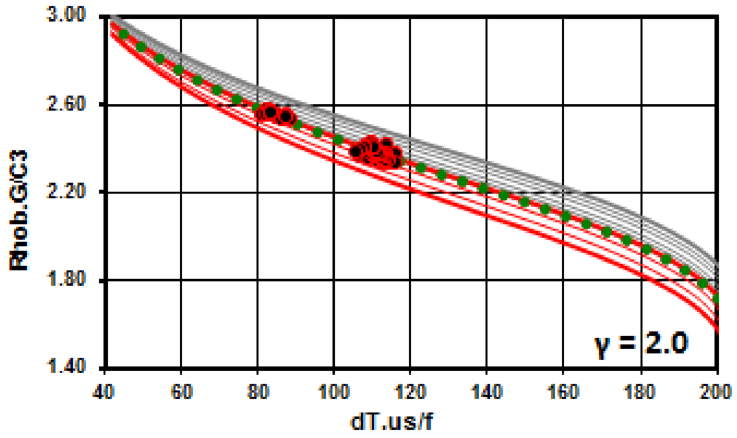
0.37

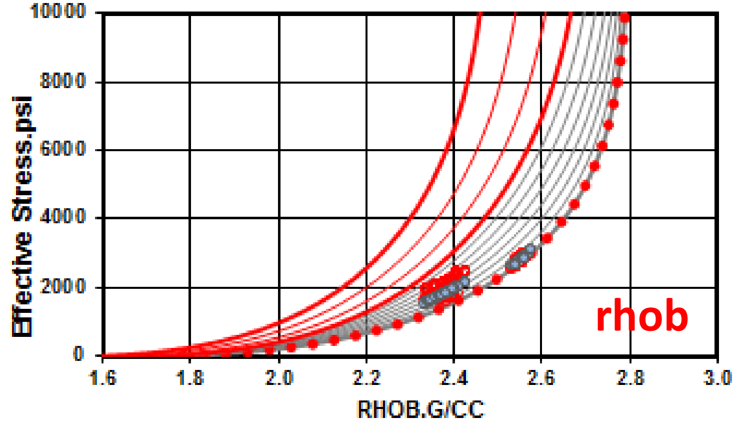


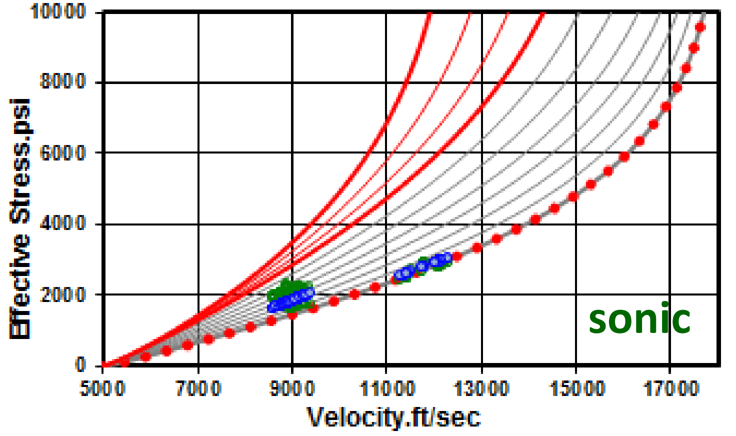

10000
12000
14000
16000
18000
Δt
0.
0.4

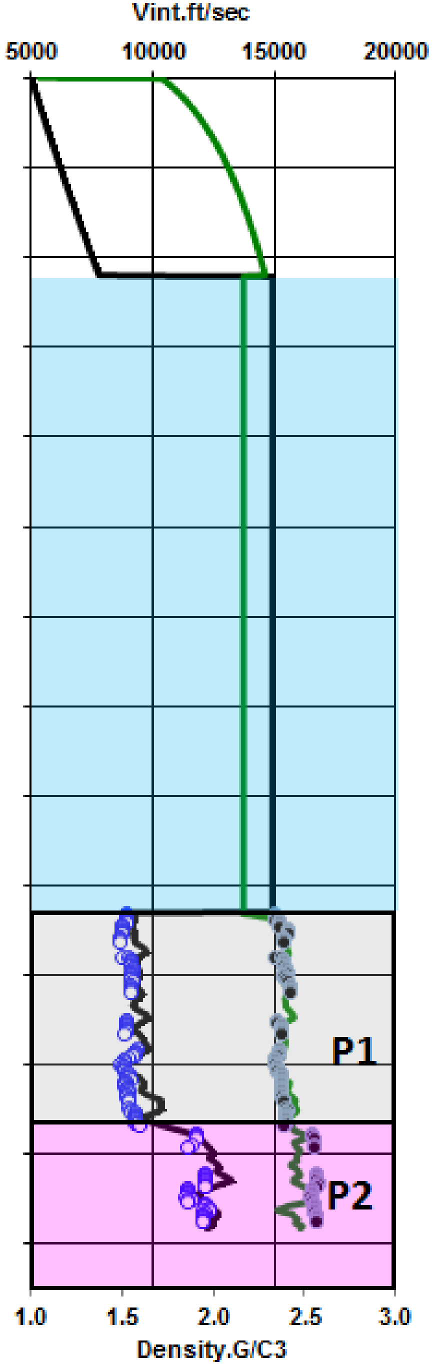

feet
2500
5000
7500
10000
12500
15000
17500
3000
8000
13000
18000
Velocity.ft/sec
RhoVE-E
Lahann
Ebrom &
Heppard
α=0.37
Bowers
RhoVE-S

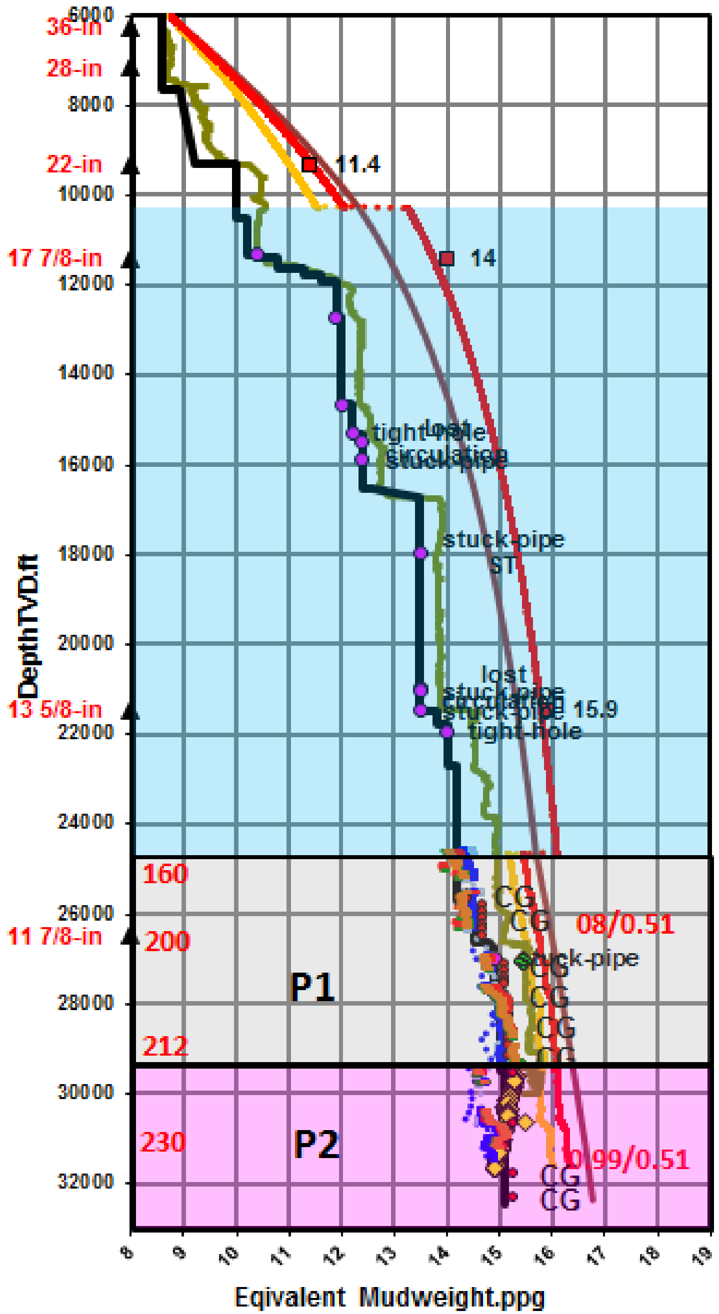
AREA: DW GOM KC292-1BP2 KASKIDA



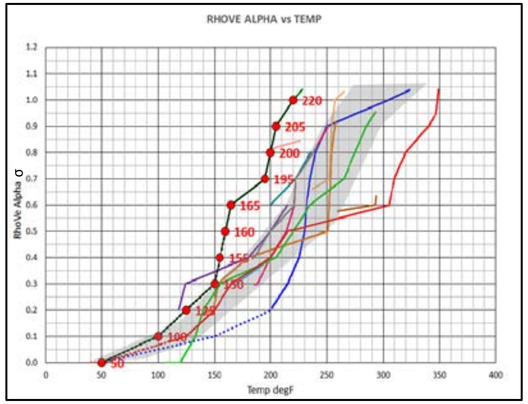




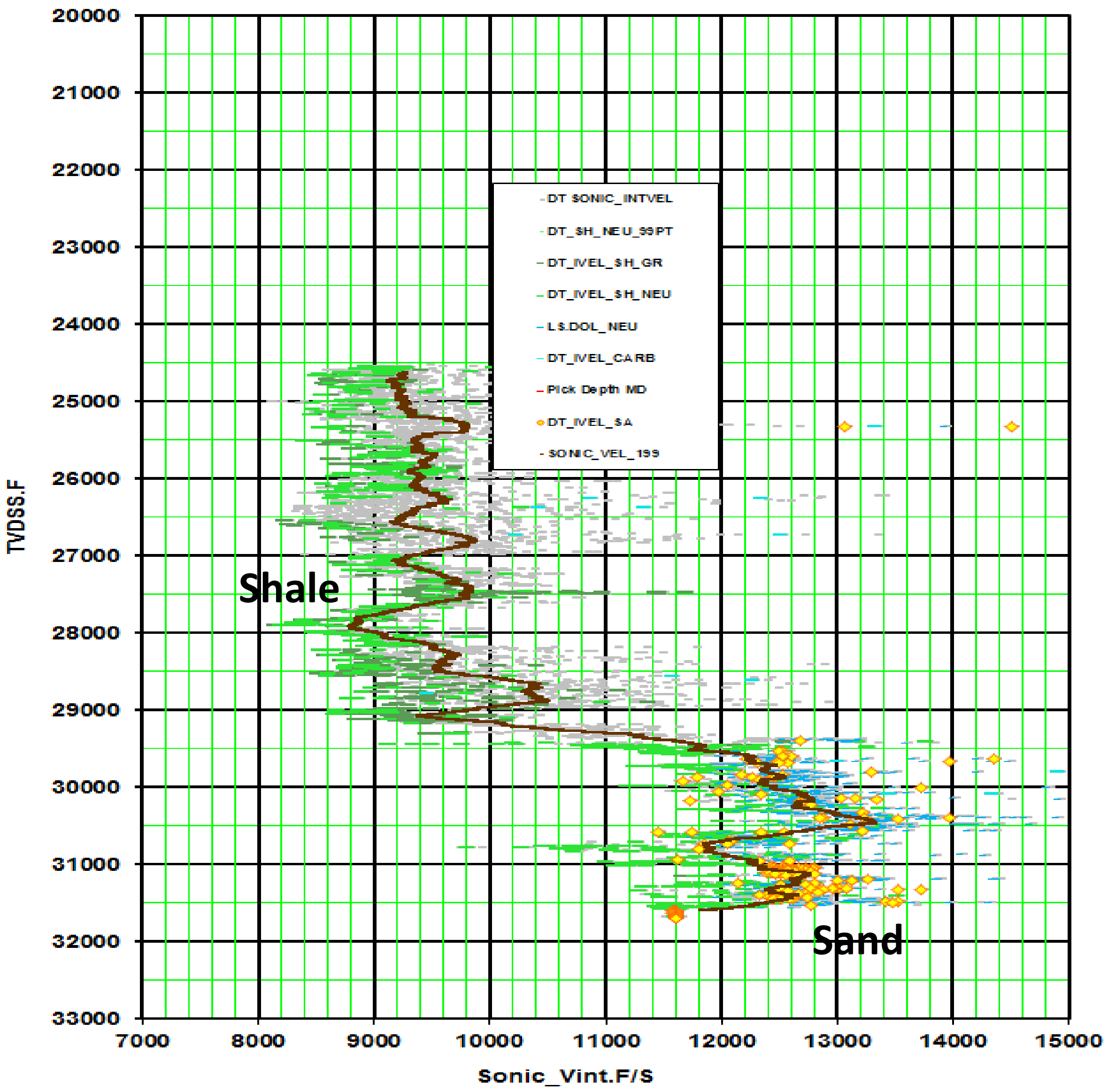


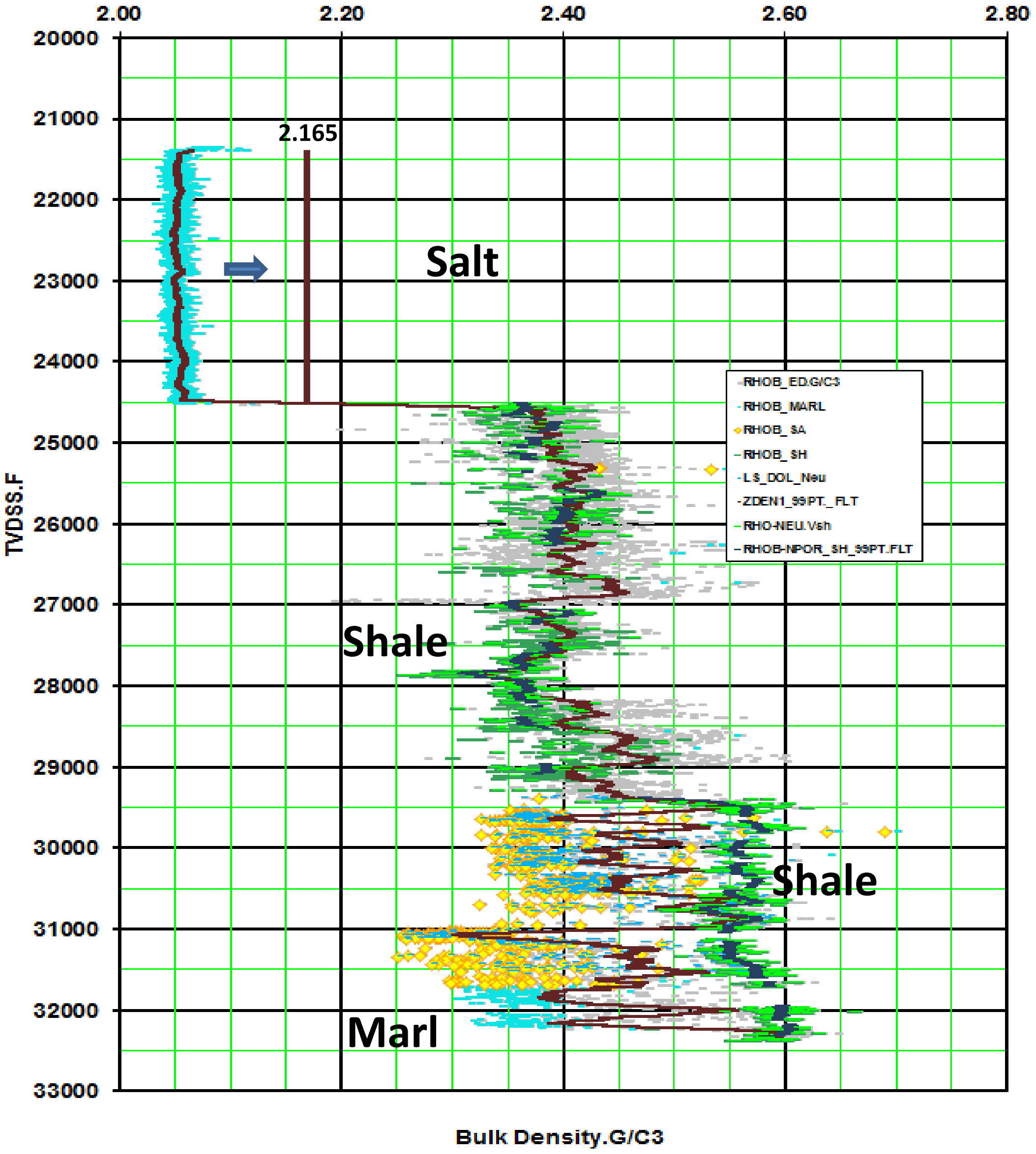


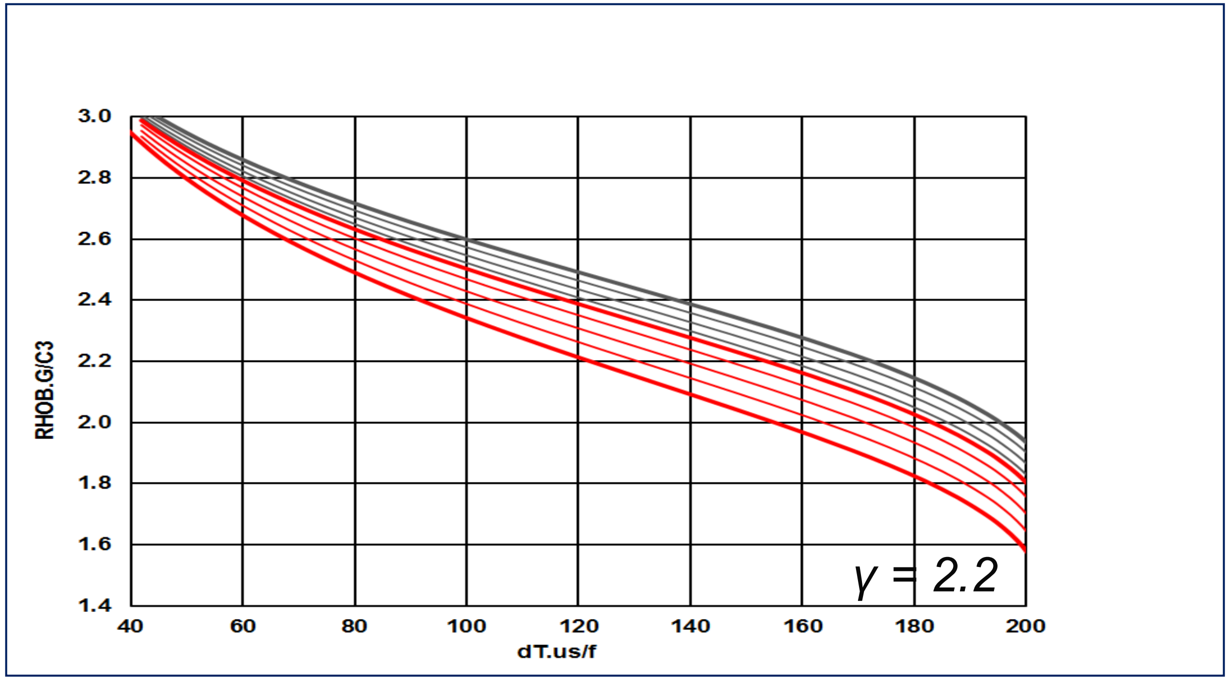
rhob	alpha	TEMPdegF
#N/A	0.0	50
#N/A	0.1	100
#N/A	0.2	125
#N/A	0.3	150
#N/A	0.4	155
#N/A	0.5	160
2.41	0.6	165
2.34	0.7	195
2.38	0.8	200
2.39	0.9	205
#N/A	1.0	220
2.56	1.05	230

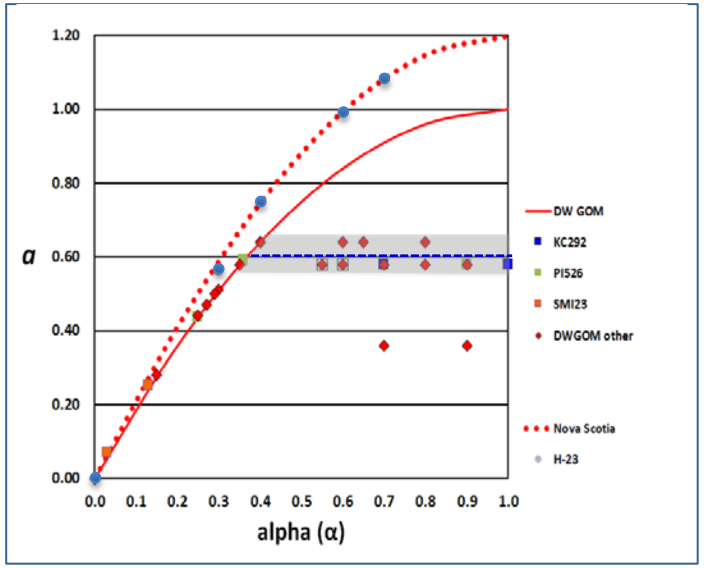


AREA: DW GOM KC292-1
KASKIDA MCZ
DATA: wireline SEIS









$$a = \gamma\alpha - \alpha^{\gamma}$$

V-Rho equation (Bowers, OTC 2001) :

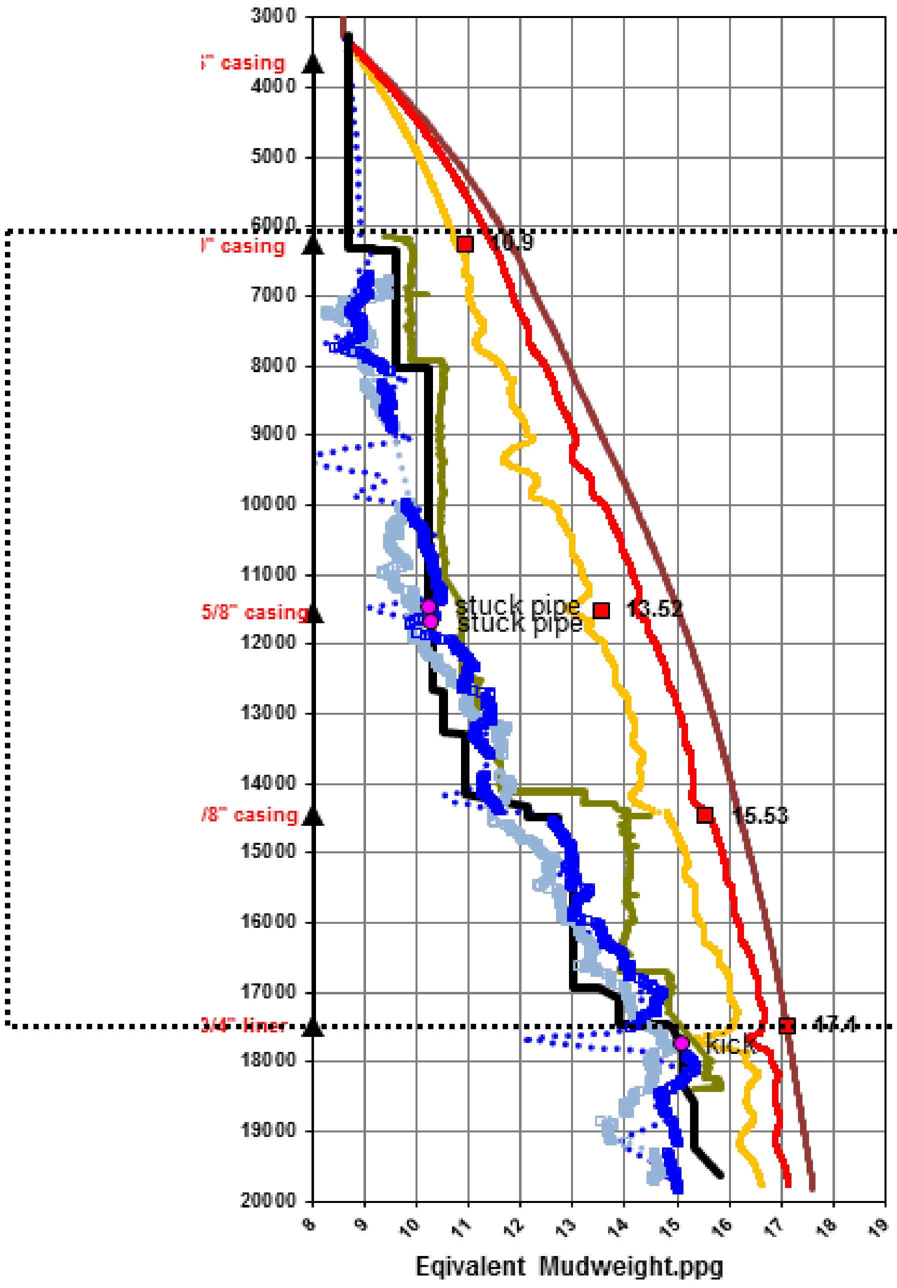
$$V = V_0 + A\,(\rho - \rho_o)^{B}$$

BOWERS GOM "Slow" Trend		RhoVE-Ɛ	RhoVE-S
Vo:	4790	4800	4900
A:	2953	2000	4500
B:	3.57	4.2	3
ρ_o:	1.3	1.3	1.3

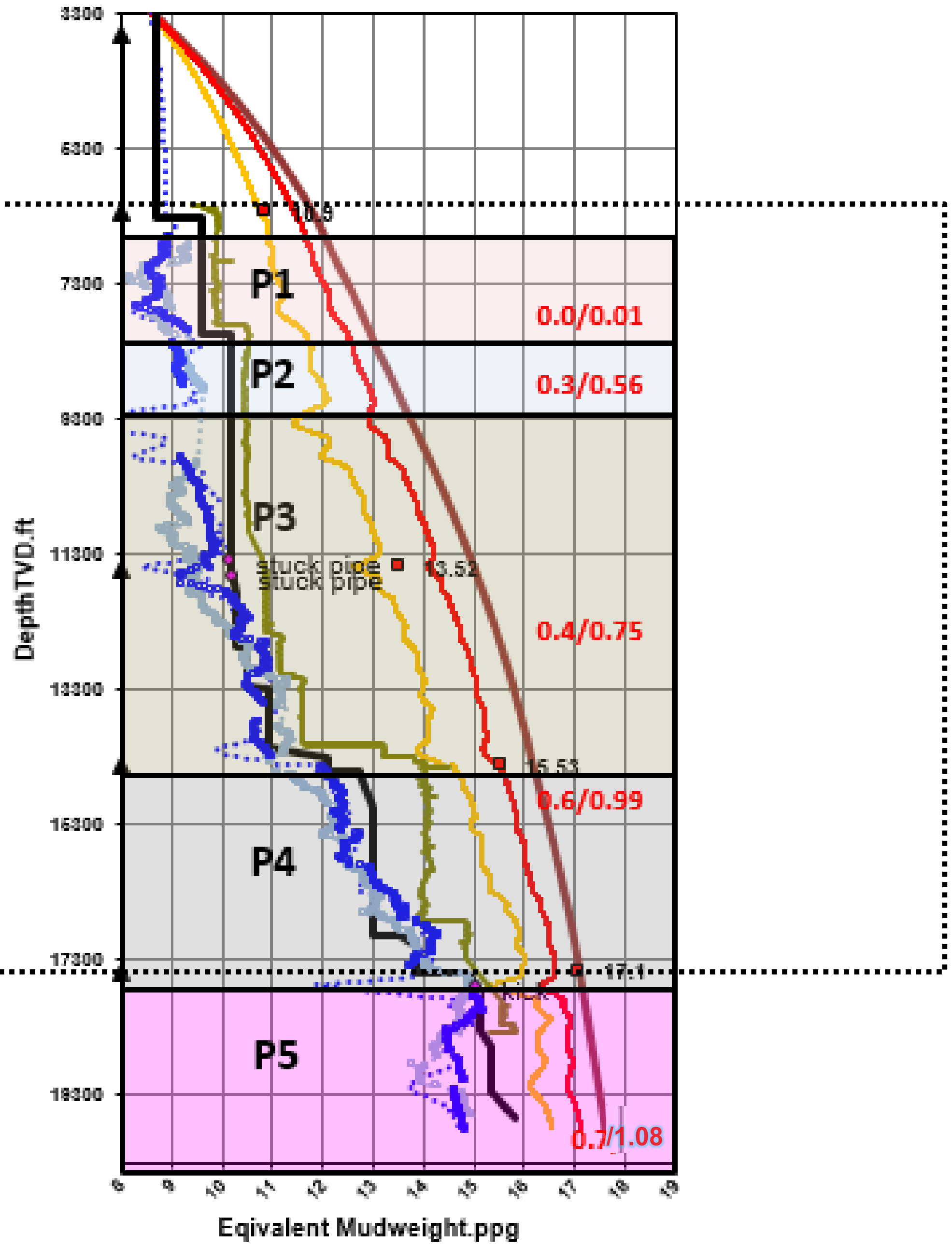
RhoVE interm: *f*(α) * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S

H-23 CVX
Offshore Nova Scotia, Canada

Offshore Nova Scotia $\gamma = 2.0$



Offshore Nova Scotia $\gamma = 2.2$



From Mud to Shale: The Role of Microquartz Cementation*

Jens Jahren,[1] Brit Thyberg,[1] Øyvind Marcussen,[1] Turid Winje,[1] Knut Bjørlykke, [1] and Jan Inge Faleide[1]

Search and Discovery Article #50206 (2009)
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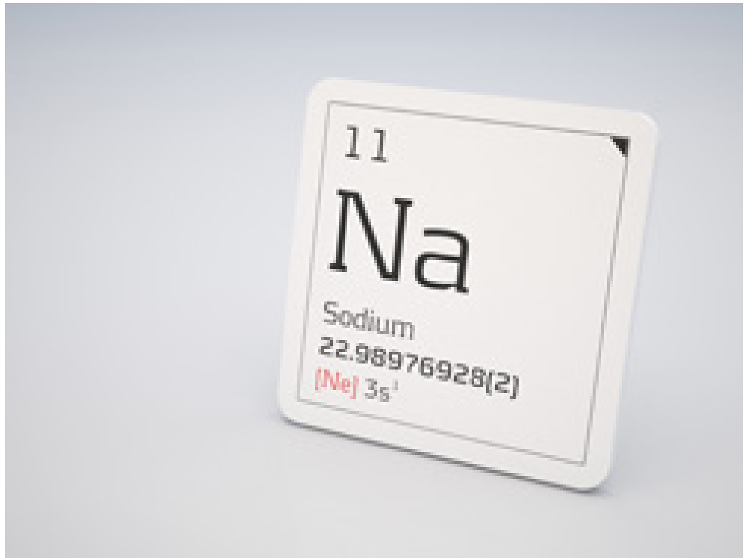
Abstract

The important mud to shale transformation is well known in sedimentary basins and is identified by changes in physical rock properties observed in well log velocity and density measurements. The transformation processes is, however, poorly understood. New discoveries of fine-grained micropore filling quartz cement found in Upper Cretaceous mudstones offshore Norway containing reactive silica releasing phases like opal-CT and smectite reveal the importance of microquartz cementation and its impact on petrophysical properties. Based on direct petrographic evidence of microquartz crystals with CL-responses indicating authigenic origin a microquartz cementation process that may explain how mudstones originally containing smectite stiffen to shale is proposed. The fine-grained quartz released in the clay mineral reaction smectite to illite within the micropores of the shale precipitate as 1-3 µm sub-spherical discrete grains, short chains, and small clusters interpreted to be parts of larger interconnected microquartz networks and interlocking aggregates of several microquartz and authigenic clay (illite-smectite and illite) crystals. A significant increase in the velocity is recorded at a burial depth around 2500 m /80-85°C, reflecting formation of a pervasive microquartz cement network at this depth in smectite rich mudstones. The smectite to illite reaction will commence between 60 and 70°C in mudstones, indicating that the temperature (80-85°C) where the velocity increase takes place reflects formation of a critical amount of interlocking complexes of interconnected microquartz networks and aggregates stiffening and strengthening the mudstones. The sluggish nature of the illitization process in mudstones reflected by the wide temperature range (60-100°C) that smectite is found in mudstones result in a progressive formation of microquartz crystals. This will, in most mudstones with less smectite than the ones studied herein, most probably only result in a slow continuous progressive stiffening of the mudstone framework. This may explain why this important cementing process in smectite containing mudstones has been overlooked in the past.

What is pH?

pH is the measurement of a liquids level of acidity or alkalinity. The pH scale runs from 0.0 to 14.0 with 7.0 being neutral. Acids have low pH values with anything lower than a 7 and alkaline solutions have high pH with anything above a 7. If the solution has an equal amount of acidic and alkaline molecules, the pH is considered neutral.



What are the chemical properties of salt?

Sodium chloride, more commonly known as salt, is one of the most common mineral compounds found in the world. It is required for the human body to function normally because the sodium-potassium exchange is an integral part in the human heart beat. Salt absorbs water from its surroundings, hence why it dissolves when you pour it in a glass of water.

There is a general rule in chemistry as to how salts affect solution pH. If the salt of a strong base and weak acid is dissolved in water it will form an alkaline solution, whereas, the salt of a weak base and strong acid will form an acidic solution. The salts of a strong acid and strong base or a weak acid and weak base will both form a neutral or near neutral solution. For example, sodium sulfate (Na2SO4) will form a neutral solution when dissolved in water because it is the salt of a strong base and strong acid, whereas, tri-sodium phosphate (Na3PO4) will form an alkaline solution because it is the salt of a strong base and weak acid. Sodium chloride is table salt and when it is added to water it breaks down into ions of sodium and chloride. Neither of them reacts to water so adding it to water will only change the volume, not the pH. In order for a type of salt to affect the pH it has to react with water to release or bind the hydrogen atoms from the water.

VK988-1
RHOB vs. Temp deg F