GCS Solutions, Inc.

geopressure consulting
services & solutions

RhoVe™ Method

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

A New Empirical Pore Pressure Transform

Marine and Petroleum Geology 86 (2017) 1–24

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

ELSEVIER

Research paper

RhoVe method: A new empirical pore pressure transform

Matt Czerniak

GCS Solutions, Inc., United States

ARTICLE INFO

Article history:
Received 5 January 2016
Received in revised form
28 March 2017
Accepted 17 April 2017
Available online 15 May 2017

Keywords:
Geopressure
Overpressure
Pore pressure

ABSTRACT

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

GCS Solutions, Inc.
geopressure consulting
services & solutions

RhoVe™ Method

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

JIP – seeking $55,000 investment:

- Commercial implementation of RhoVe method as a plug-in to an existing commercial platform, or as a web-based application to include:
  - Real-Time WITSML connectivity,
  - notebook (iPad) capability,
  - 1D temperature modeling,
- Explore AI and Neural Network capabilities,

OVERVIEW

INTRODUCTORY DEMO

PREVIOUS WORK - THEORY

- Mechanical vs Chemical Compaction
- Smectite – Illite Conversion

RHOVE METHOD

- Summary
- Virtual Model
- Alpha – A-Term
- Shale Discrimination

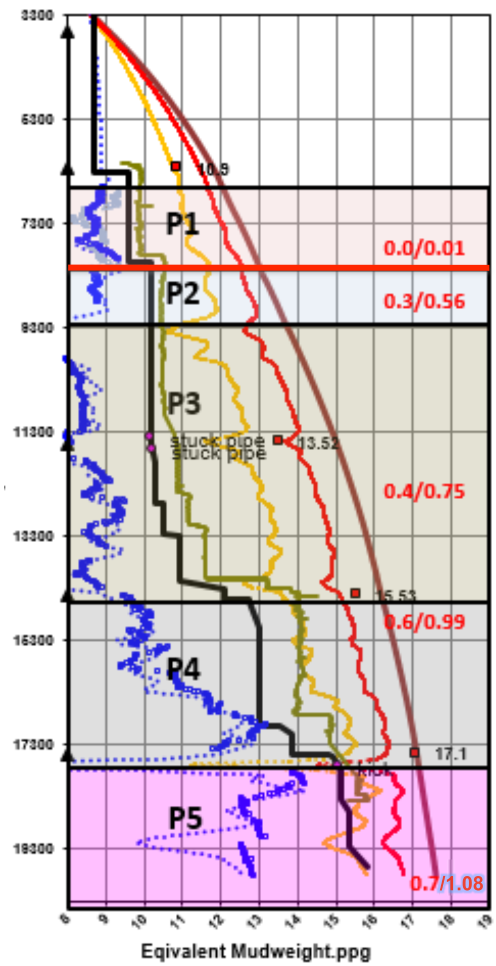
SUMMARY DEMOS

- Untethered Mode
- Tethered Mode

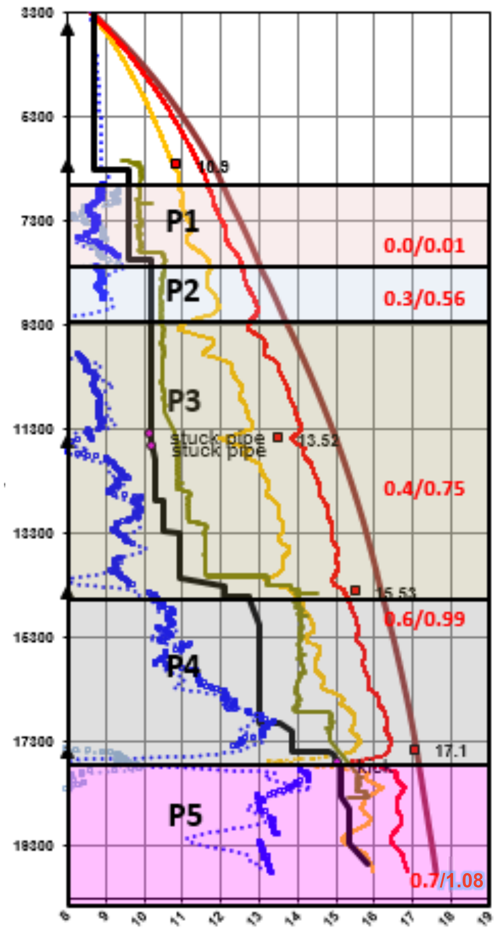
WELL EXAMPLES using RHOVE METHOD

ADVANTAGES of RHOVE Method

AREA: Nova Scotia, Canada H-23



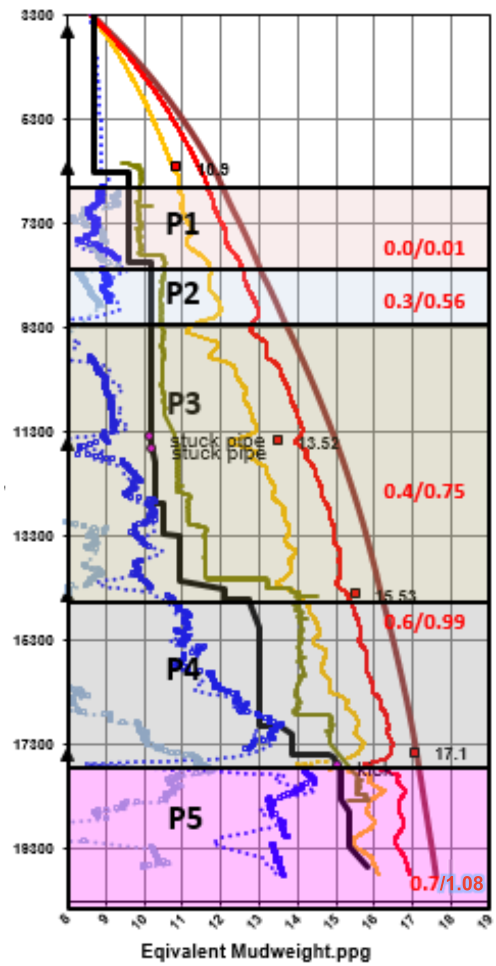
AREA: Nova Scotia, Canada H-23



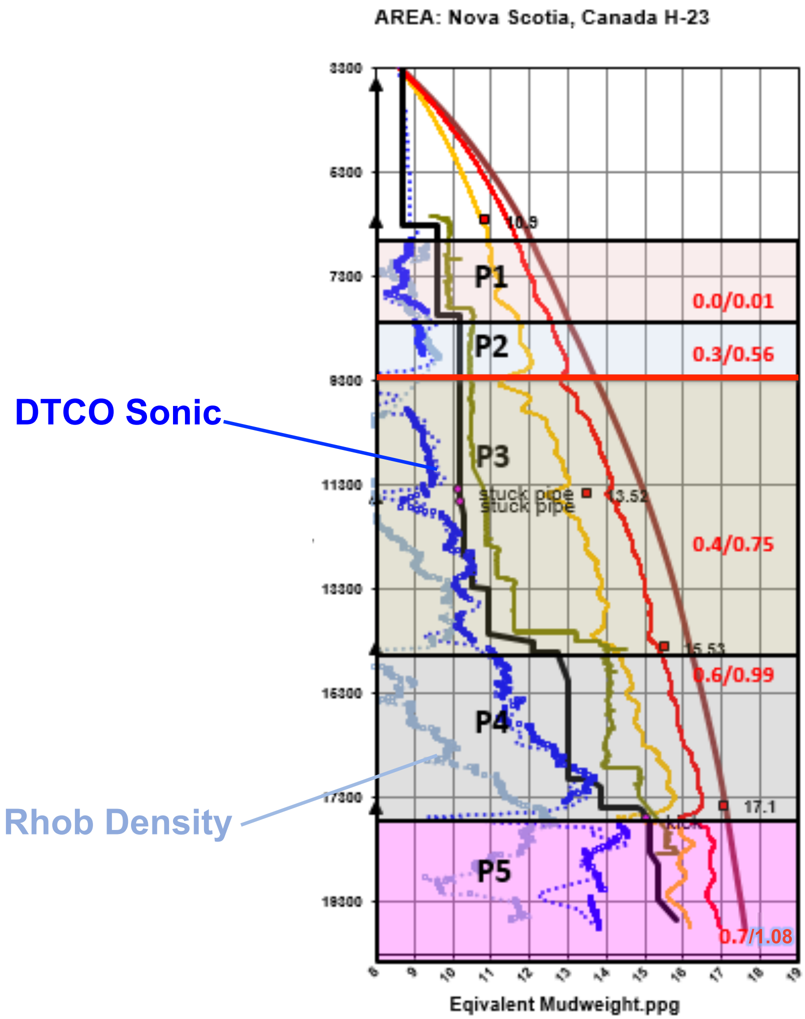
Eqivalent Mudweight.ppg

0.1

AREA: Nova Scotia, Canada H-23

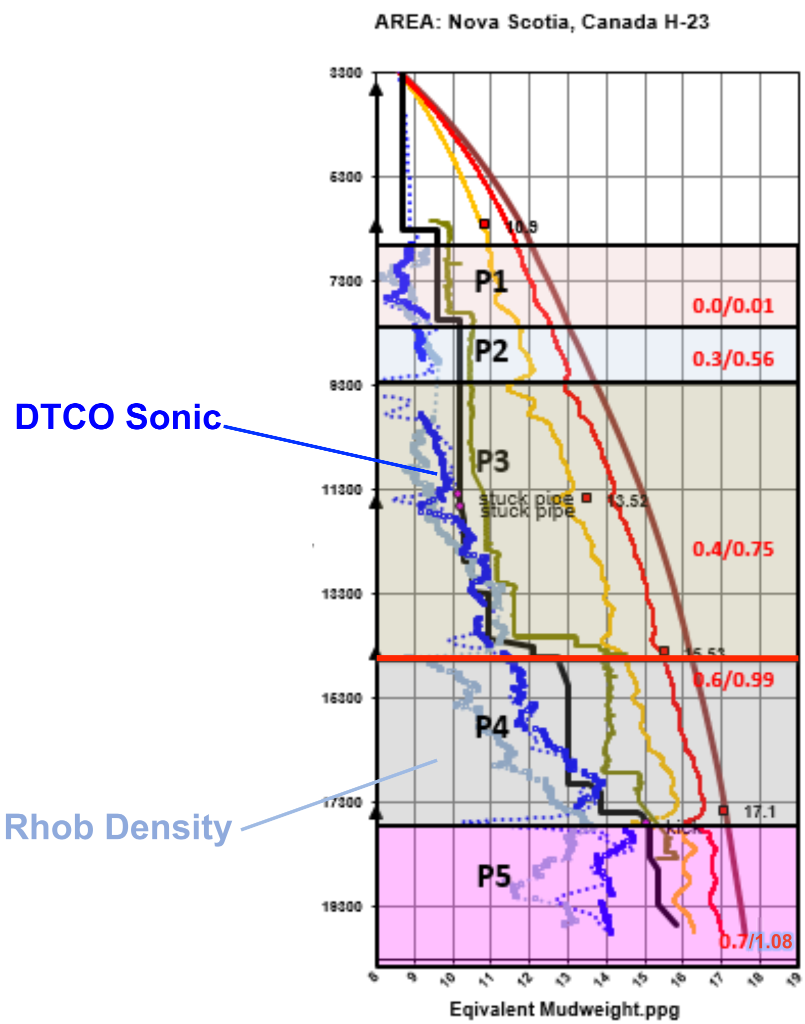


0.2

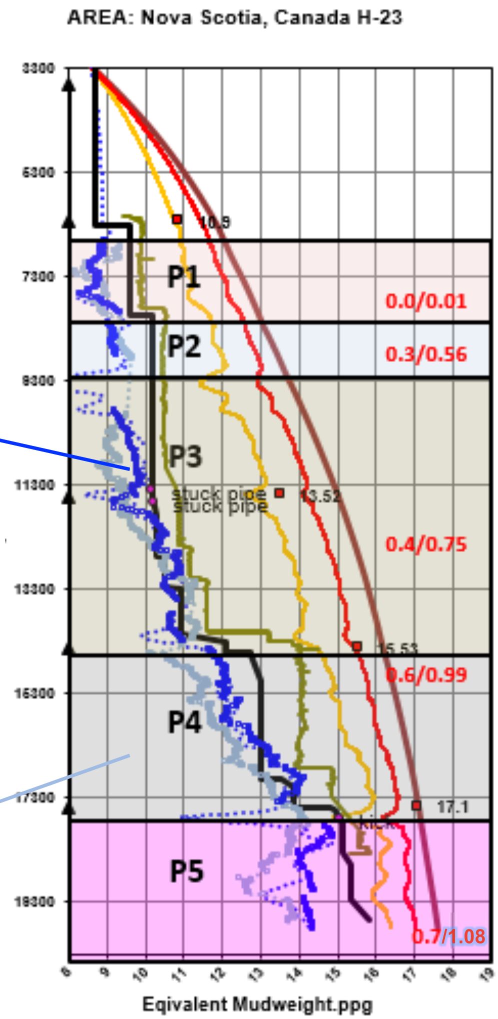


AREA: Nova Scotia, Canada H-23
3300
5300
7300
9300
11300
13300
15300
17300
19300
8
9
10
11
12
13
14
15
16
17
18
19
Eqivalent Mudweight.ppg
P1
P2
P3
P4
P5
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08
10.9
13.52
15.53
17.1
stuck pipe
kick
DTCO Sonic
Rhob Density

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
17.1
stuck pipe
kick
Eqivalent Mudweight.ppg

0.4

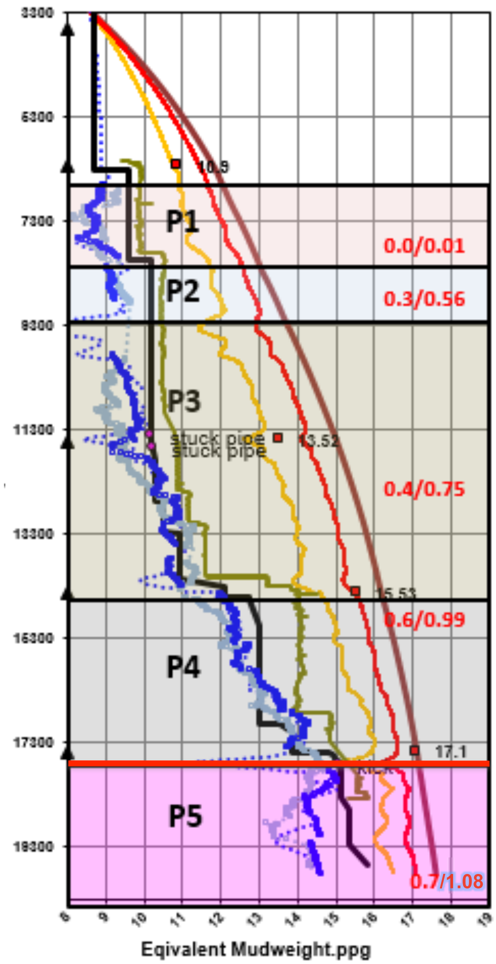


DTCO Sonic

Rhob Density

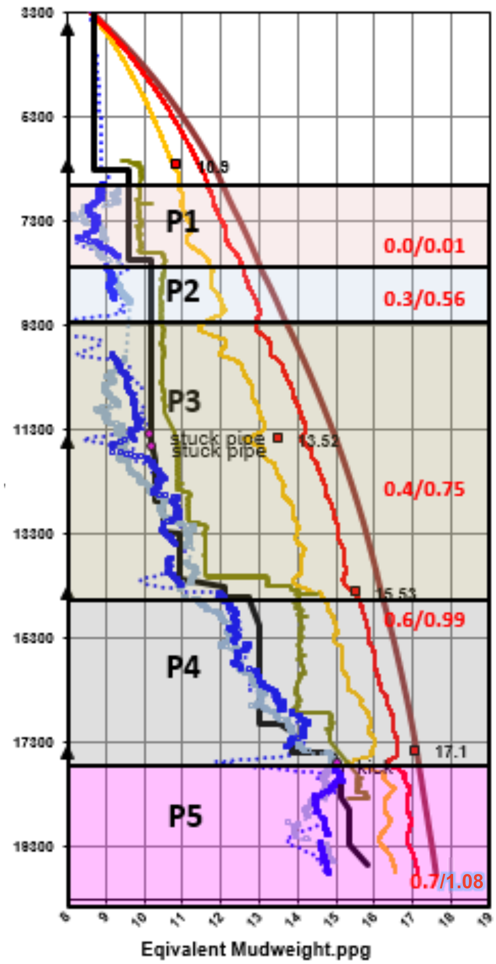
0.5

AREA: Nova Scotia, Canada H-23



0.6

AREA: Nova Scotia, Canada H-23



0.7

OVERVIEW

INTRODUCTORY DEMO

PREVIOUS WORK - THEORY

- Mechanical vs Chemical Compaction
- Smectite – Illite Conversion

RHOVE METHOD

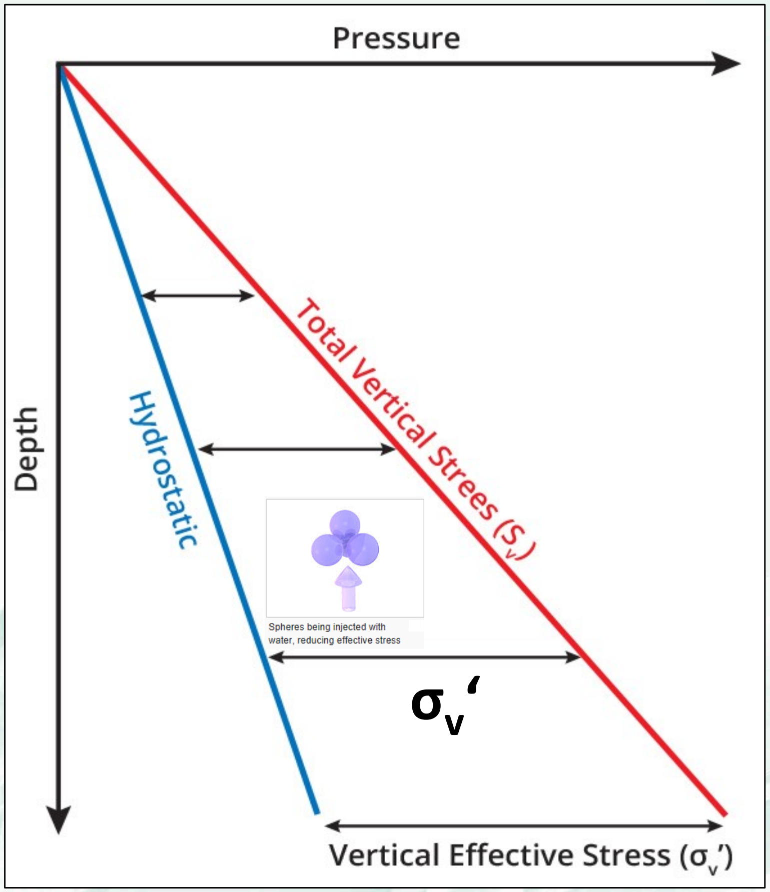
- Summary
- Virtual Model
- Alpha – A-Term
- Shale Discrimination

SUMMARY DEMOS

- Untethered Mode
- Tethered Mode

WELL EXAMPLES using RHOVE METHOD

ADVANTAGES of RHOVE Method



Modified from Swarbrick et al., TLE 2012

Terzaghi’s Relationship

The active pore pressure estimation follows the standard pore pressure protocol workflow using Terzaghi’s (1996) relationship:

$$PP = S_v - \sigma_v'$$

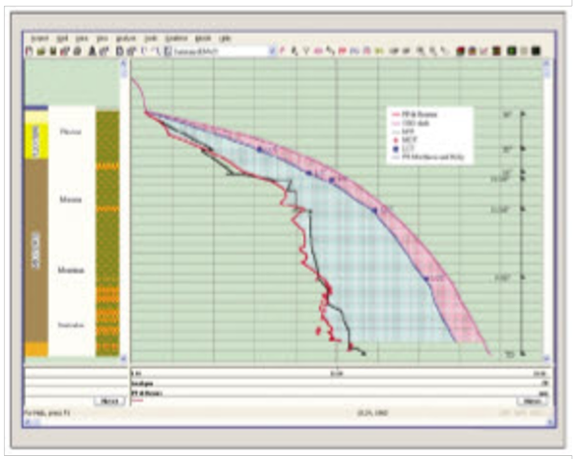
where PP is the pore pressure, S_v is the Total Vertical Stress (overburden) and, σ_v‘ is the Vertical Effective Stress.

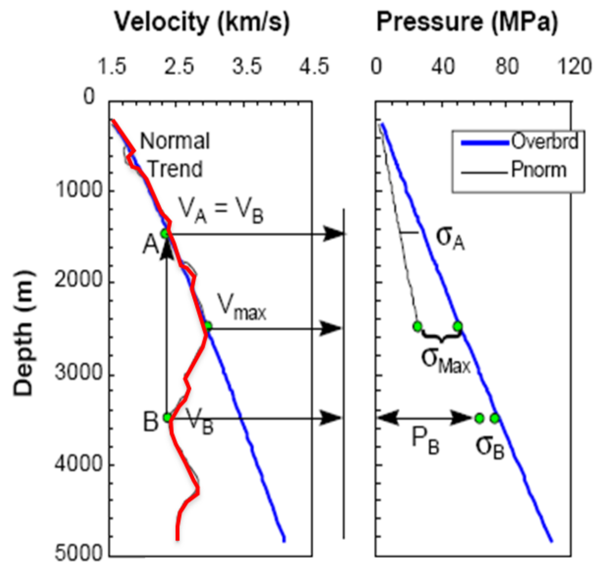
Joint Industry Project - DEA 119

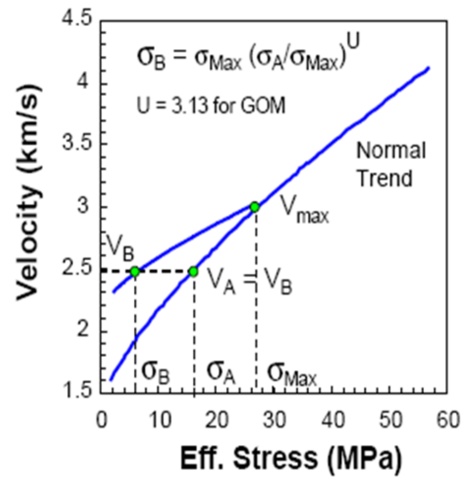
An Improved Methodology to Predict Predrill Pore Pressure in Deepwater Gulf of Mexico - KSI

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

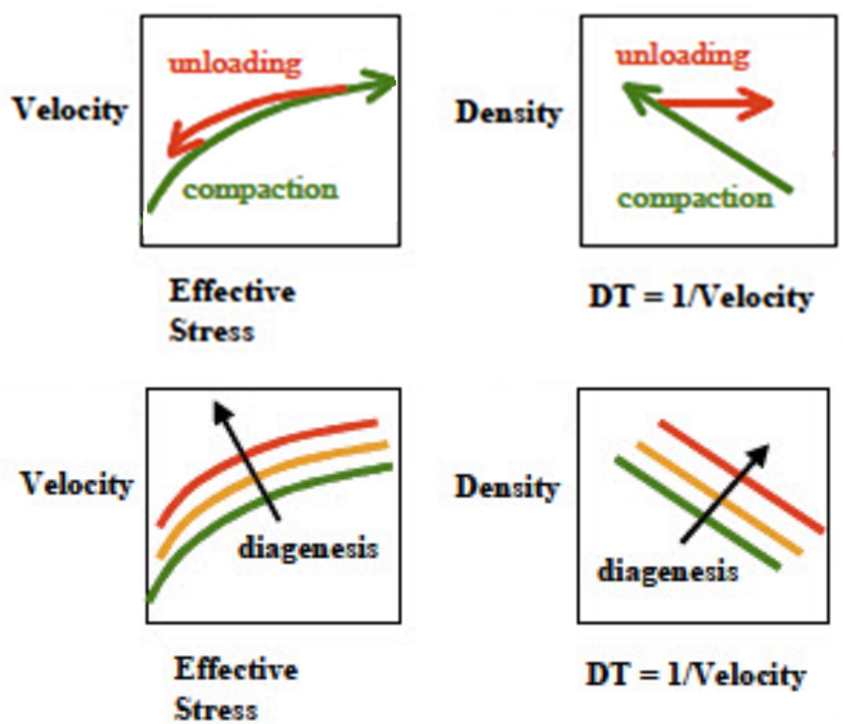
1) Vertical Methods
2) Horizontal Methods
3) Other







Mechanical vs. Chemical

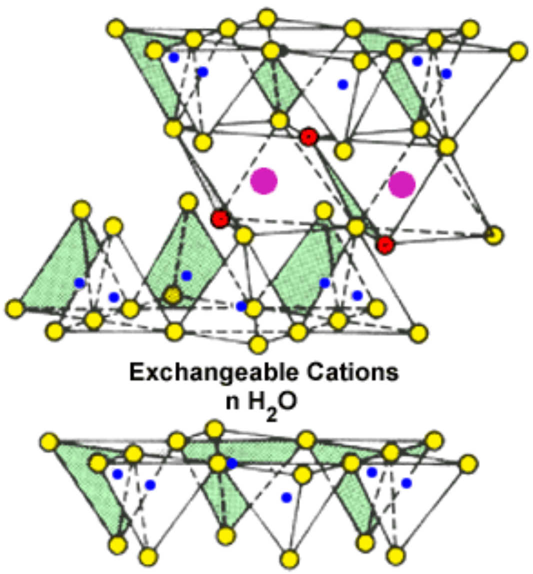


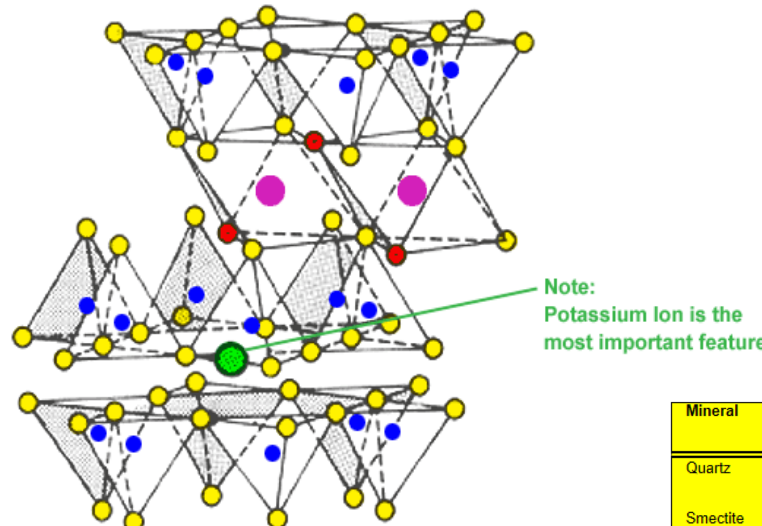
Modified after Katahara, 2003 OTC

Montmorillonite (Smectite): $Al_2\ Si_4\ O_{10}\ (OH)_2$

• n H_2O

Illite:$K_2\ Al_4\ (Si_6\ Al_2)\ O_{20}\ (OH)_4$



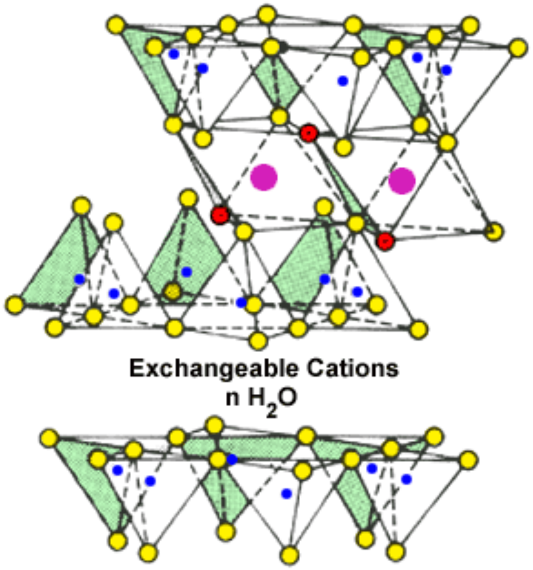


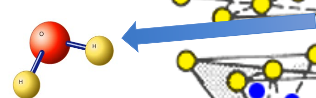
Mineral	Surface Area
Quartz	0.15 cm^2/gm*
Smectite	752 m^2/gm
Illite	113 m^2/gm
Chlorite	42 m^2/gm
Kaolinite	23 m^2/gm
* Depends on grain size and distribution	

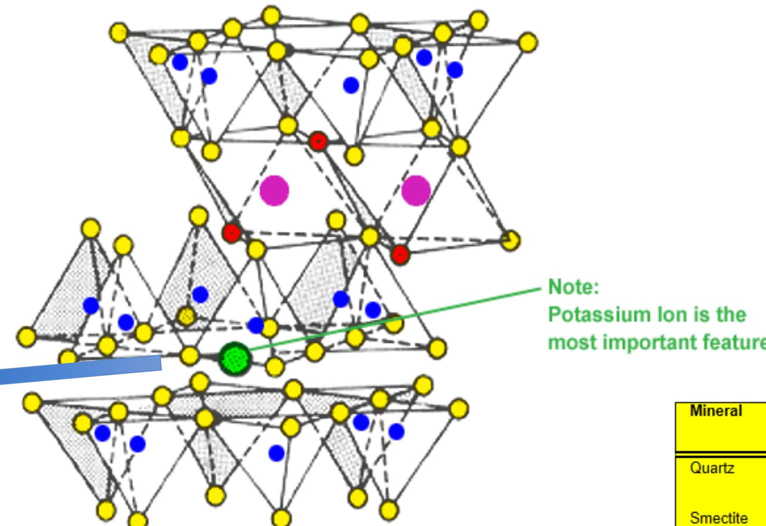
https://www.ihrdc.com/els/ipims-demo/t26/offline_IPIMS_s23560/resources/data/G4105.htm

Montmorillonite (Smectite): $Al_2\ Si_4\ O_{10}\ (OH)_2$ • n H_2O

Illite: $K_2\ Al_4\ (Si_6\ Al_2)\ O_{20}\ (OH)_4$





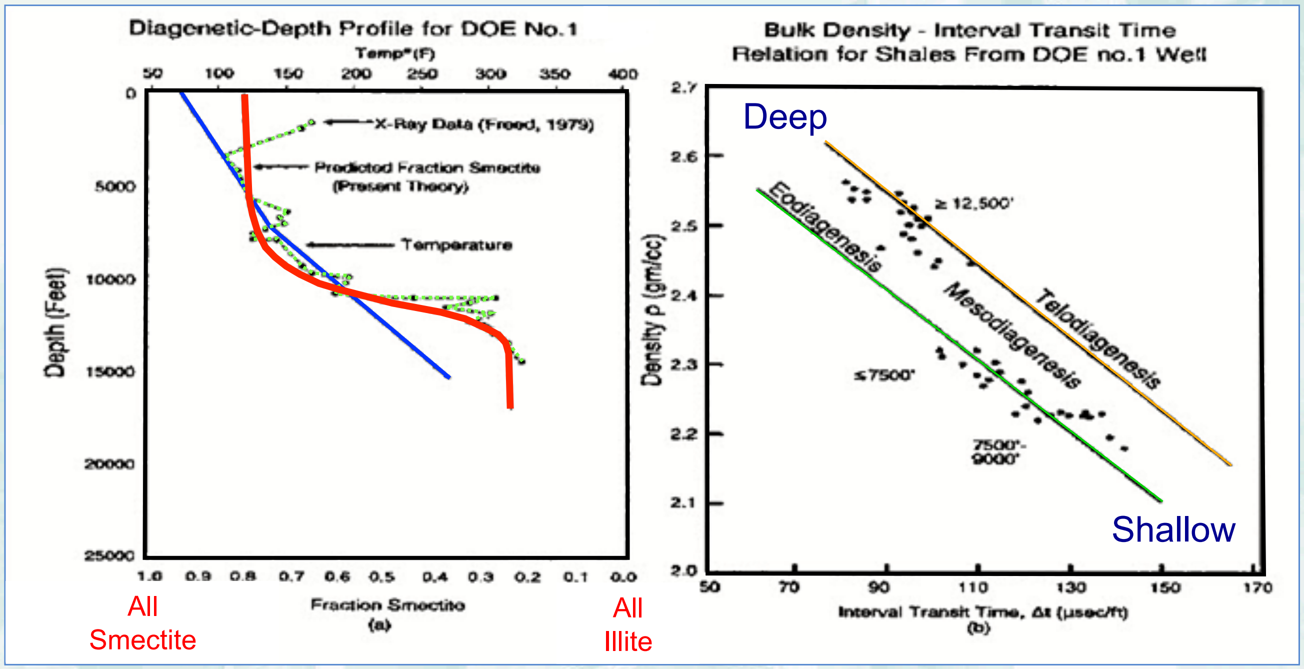


Mineral	Surface Area
Quartz	0.15 cm^2/gm*
Smectite	752 m^2/gm
Illite	113 m^2/gm
Chlorite	42 m^2/gm
Kaolinite	23 m^2/gm
* Depends on grain size and distribution	

https://www.ihrdc.com/els/ipims-demo/t26/offline_IPIMS_s23560/resources/data/G4105.htm

Dutta

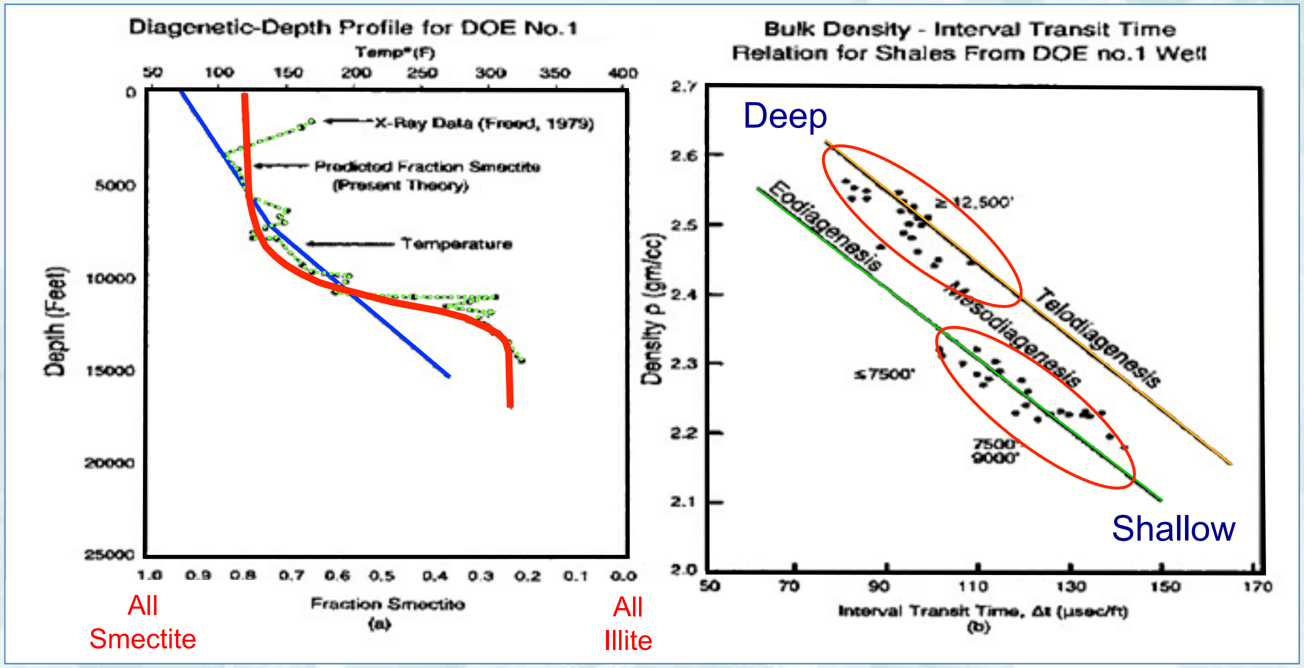
Dutta 2002 TLE



after Dutta, 2002 TLE

Dutta

Dutta 2002 TLE



after Dutta, 2002 TLE

Arrhenius Law

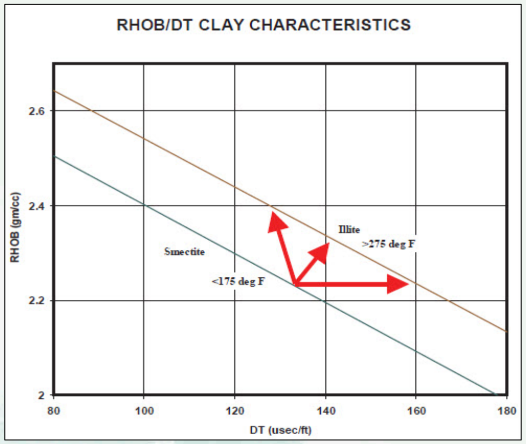
$$k_i = A_i\, e^{-E_i}\,\mathrm{RT}$$

Describes the controls of temperature and time on the rate and extent of chemical reaction (Roaldset et al., 1998).

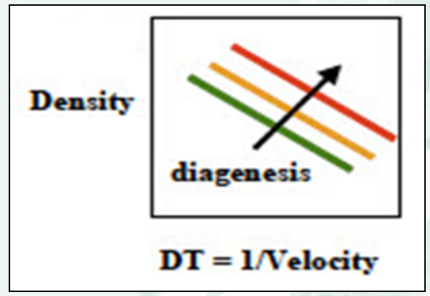
**note: subscript $_i$ denotes a parallel reaction

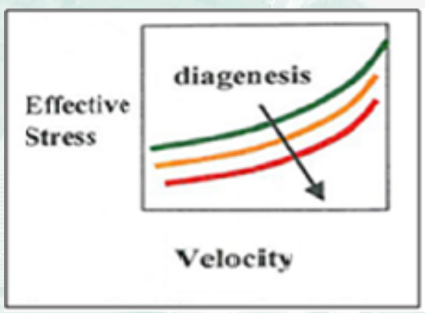
$$\text{Smectite}: 2\ Na_{0.4}(Al_{1.47}Fe_{0.18}Mg_{0.29})Si_4O_{10}(OH)_2 + 0.85K^{+} + 1.07\ H^{+}$$
$$\rightarrow \text{Illite}: 1.065K_{0.80}(Al_{1.98}Mg_{0.02})(Si_{3.22}Al_{0.78})O_{10}(OH)_2 + 4.6\ SiO_2$$
$$+ 0.36\ Fe(OH)_3 + 0.56\ Mg^{2+} + 0.8\ Na^{+} + 0.9\ H_2O.$$

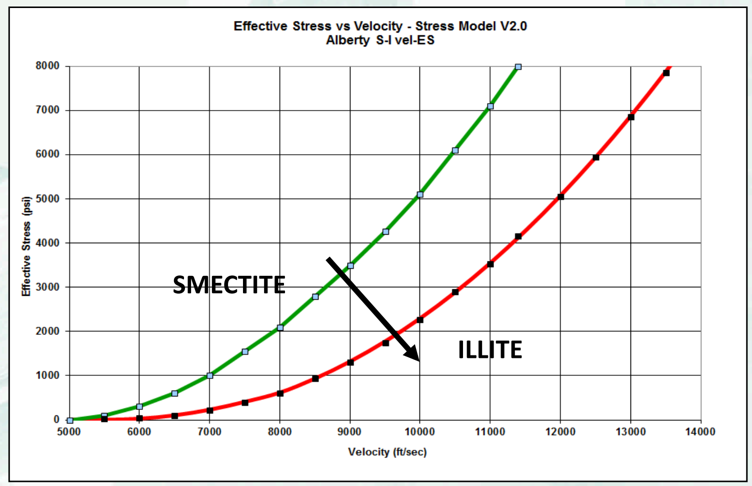
Alberty



Alberty-McLean, OTC 2003

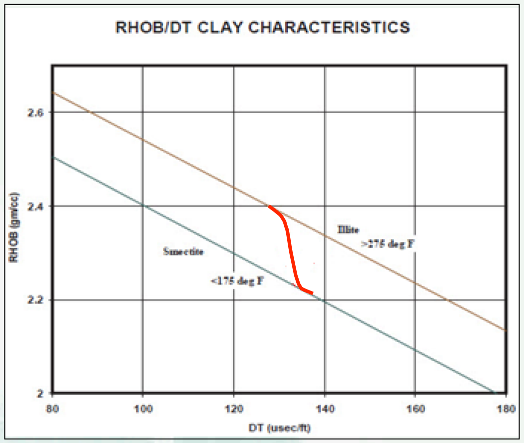




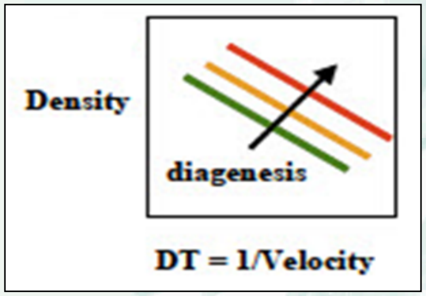


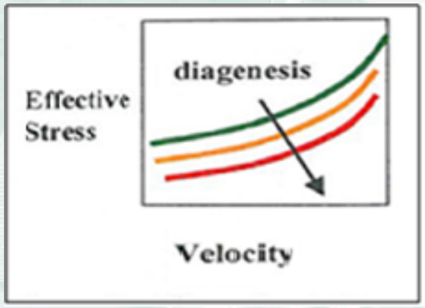
after Alberty, SPE DL Series, 2004

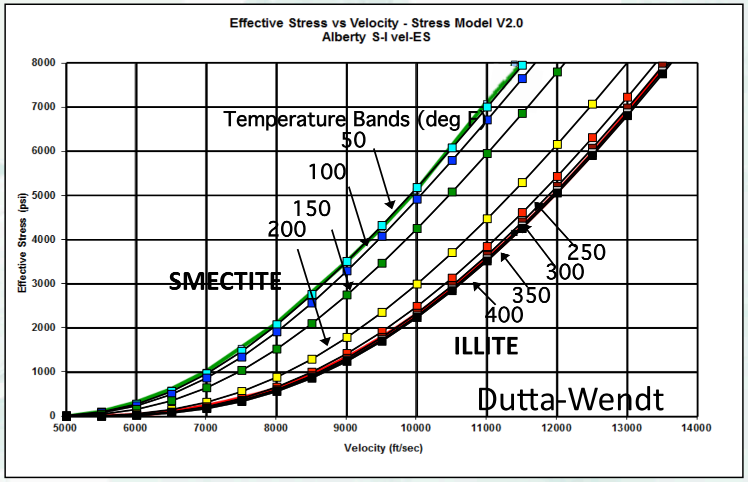
Alberty



Alberty-McLean, OTC 2003

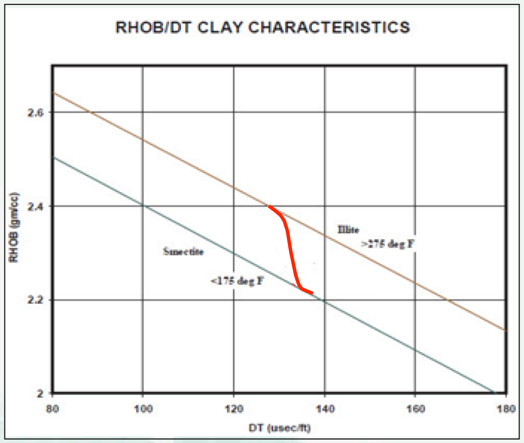




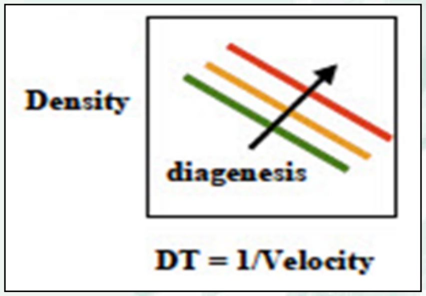


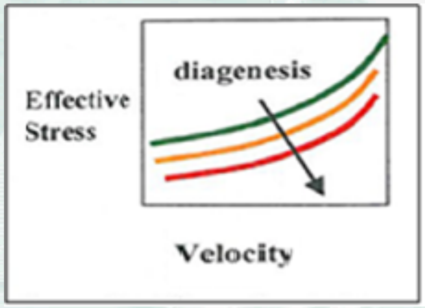
after Alberty, SPE DL Series, 2004

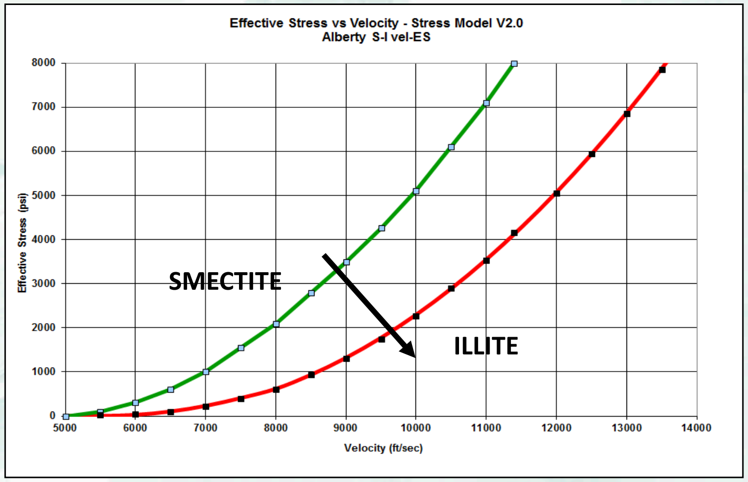
Alberty



Alberty-McLean, OTC 2003

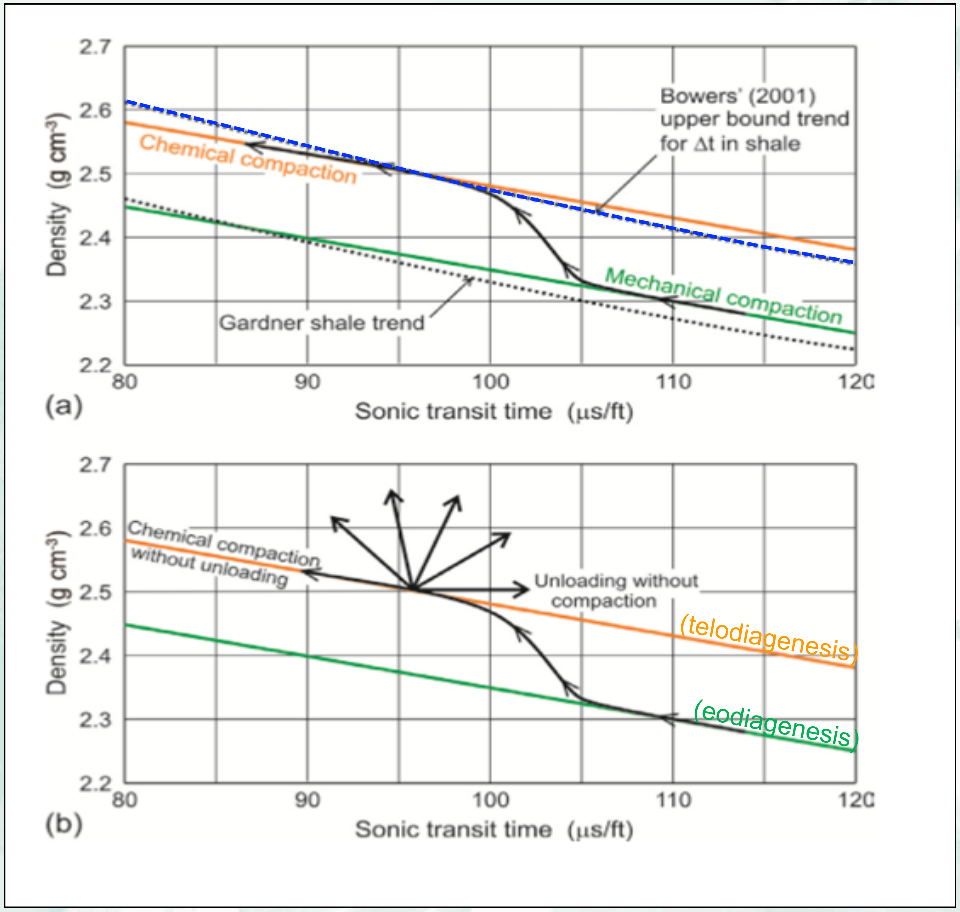






after Alberty, SPE DL Series, 2004

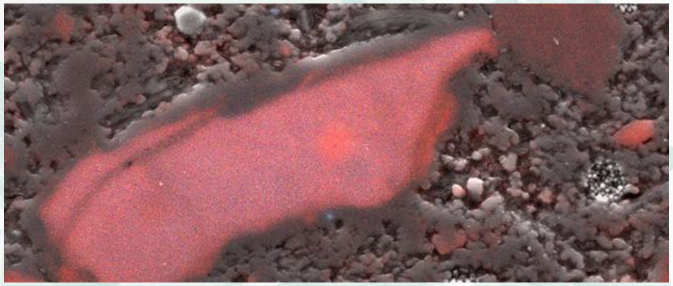
Sargent



after Sargent et al., 2015

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.

OVERVIEW

INTRODUCTORY DEMO

PREVIOUS WORK - THEORY

- Mechanical vs Chemical Compaction
- Smectite – Illite Conversion

RHOVE METHOD

- Summary
- Virtual Model
- Alpha – A-Term
- Shale Discrimination

SUMMARY DEMOS

- Untethered Mode
- Tethered Mode

WELL EXAMPLES using RHOVE METHOD

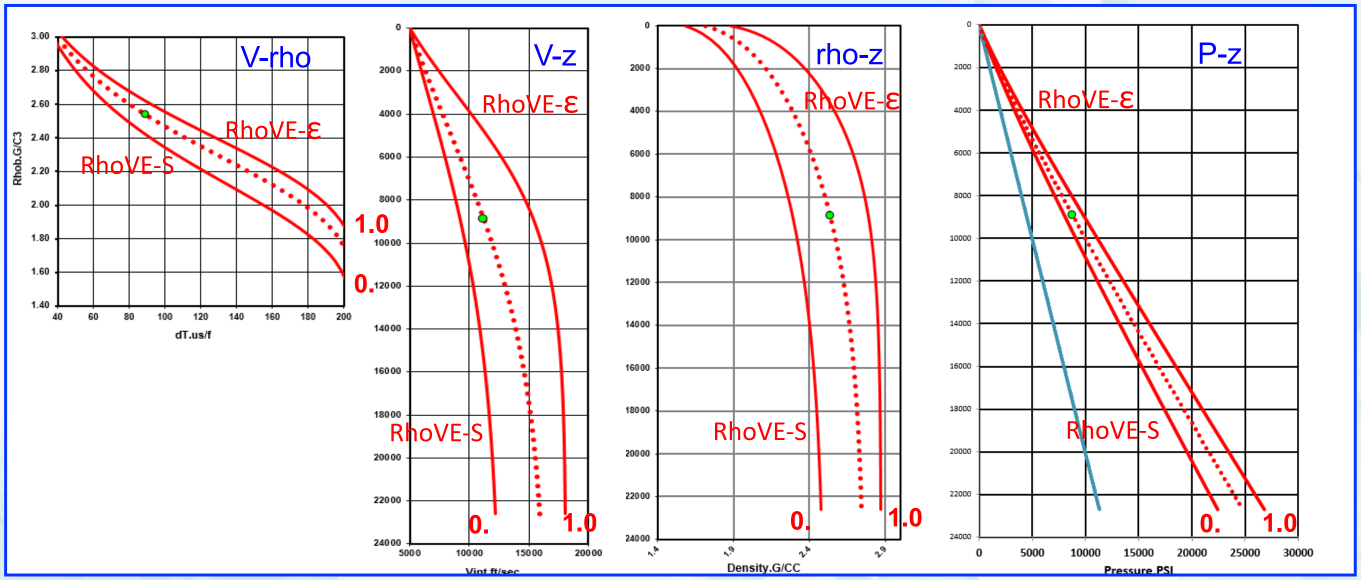
ADVANTAGES of RHOVE Method

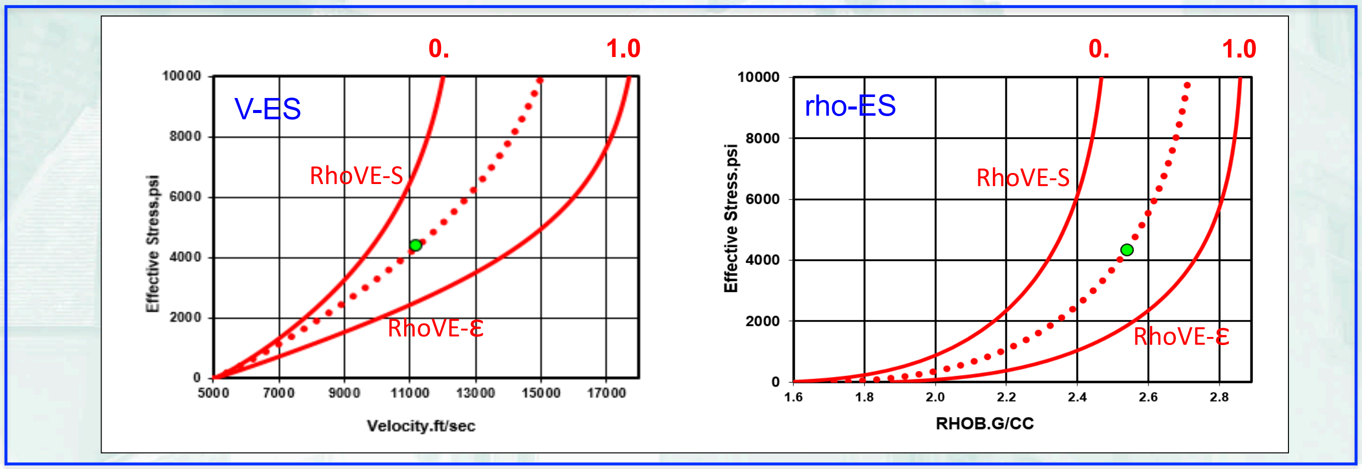
RhoVe™ Method

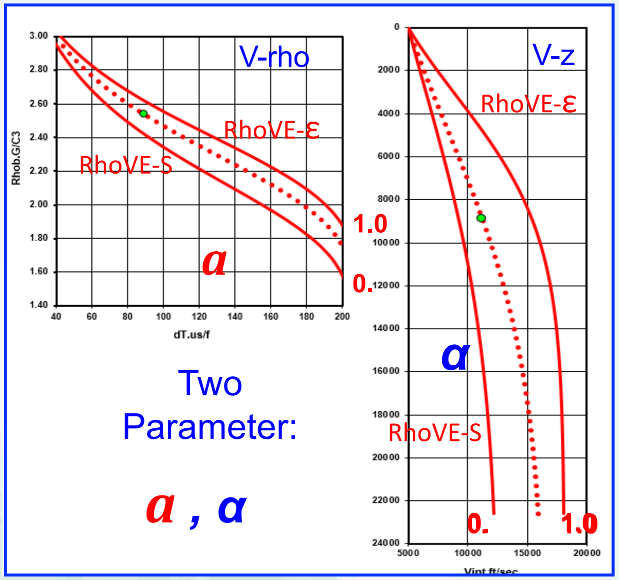
(U.S. patent pending - copyright © 2016)

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 –
- Handles varying shale lithologies with multiple NCTs in a predictive manner.
- 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.
- Consistent with Bower’s Method solutions for DWGoM fine-grained clastics.


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

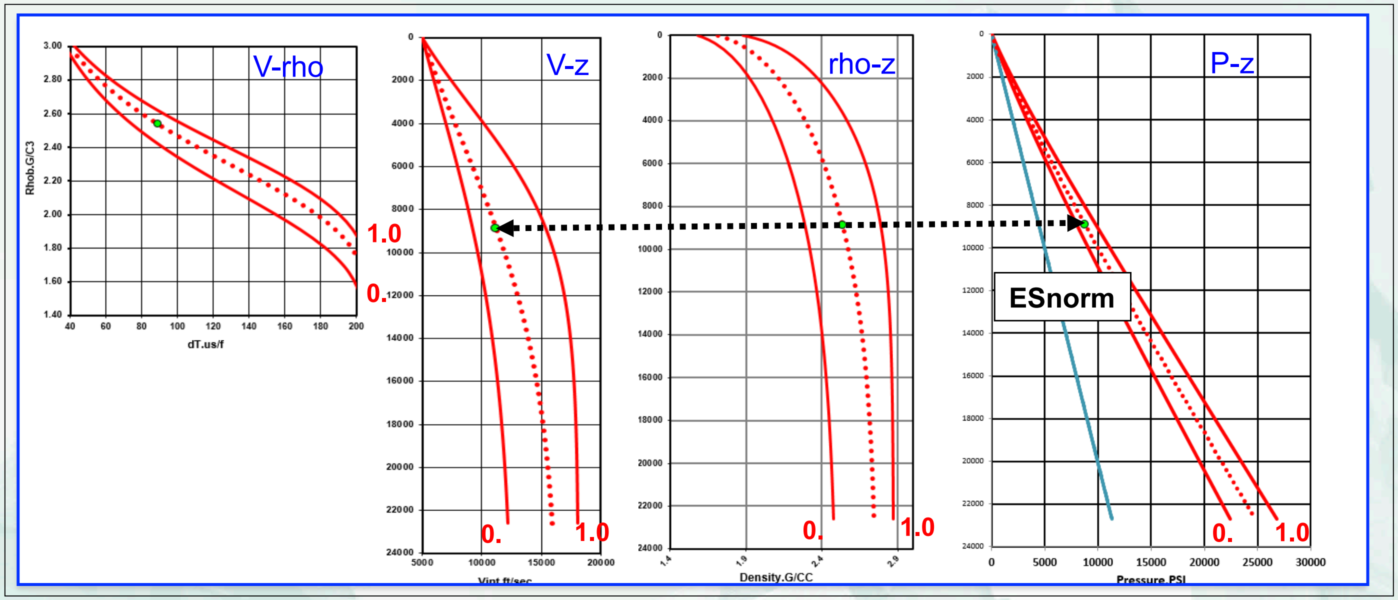

V-ES
0.
1.0
RhoVE-S
RhoVE-Ɛ
Effective Stress.psi
Velocity.ft/sec
rho-ES
0.
1.0
RhoVE-S
RhoVE-Ɛ
Effective Stress.psi
RHOB.G/CC

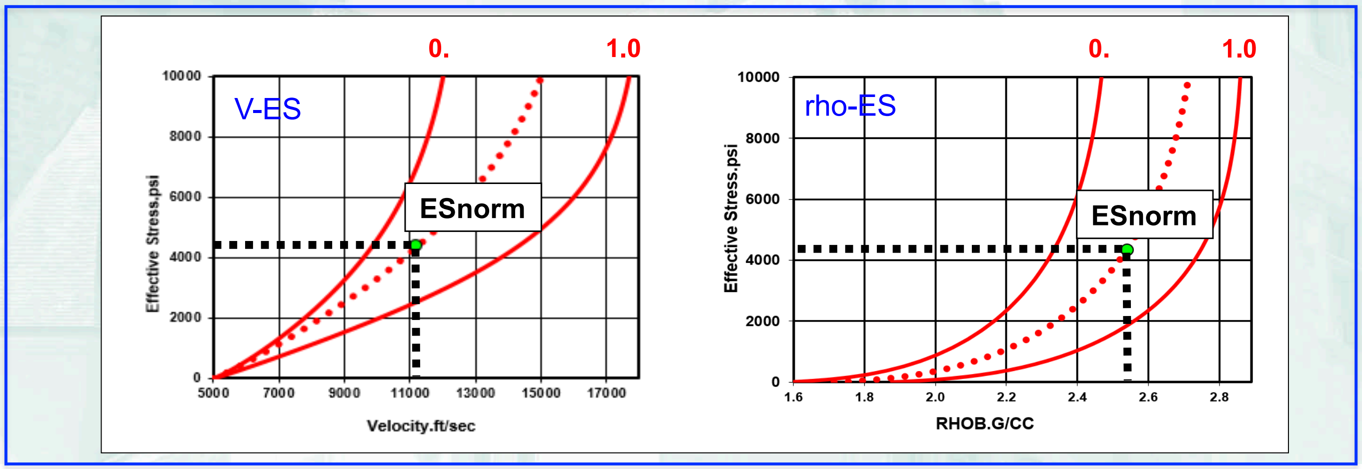


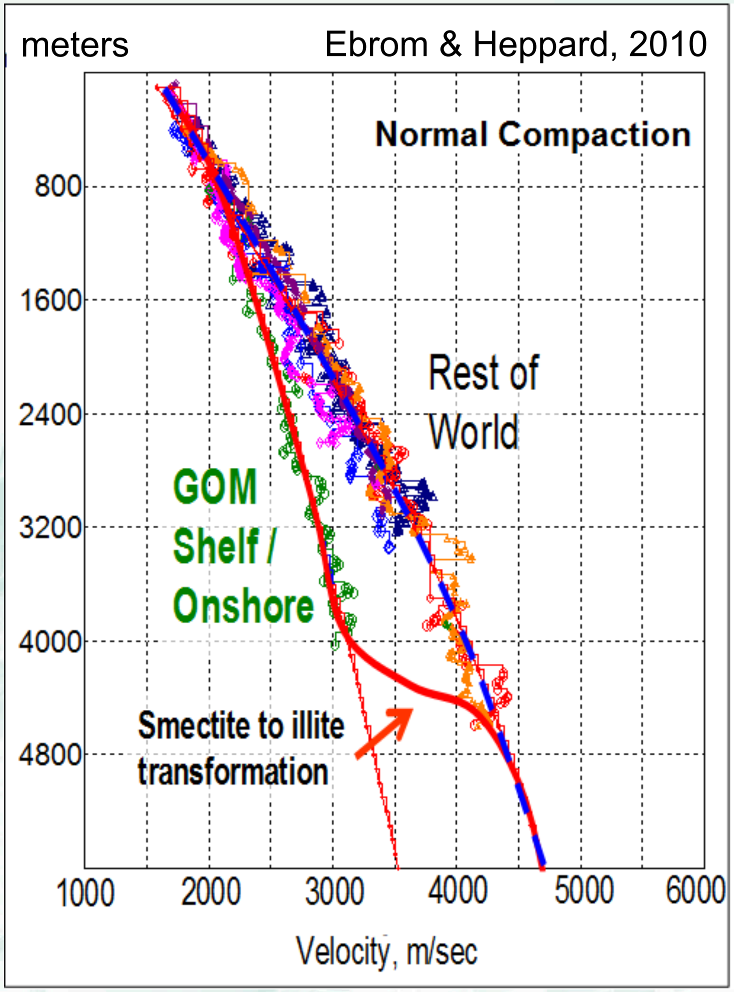
a : fractional distance

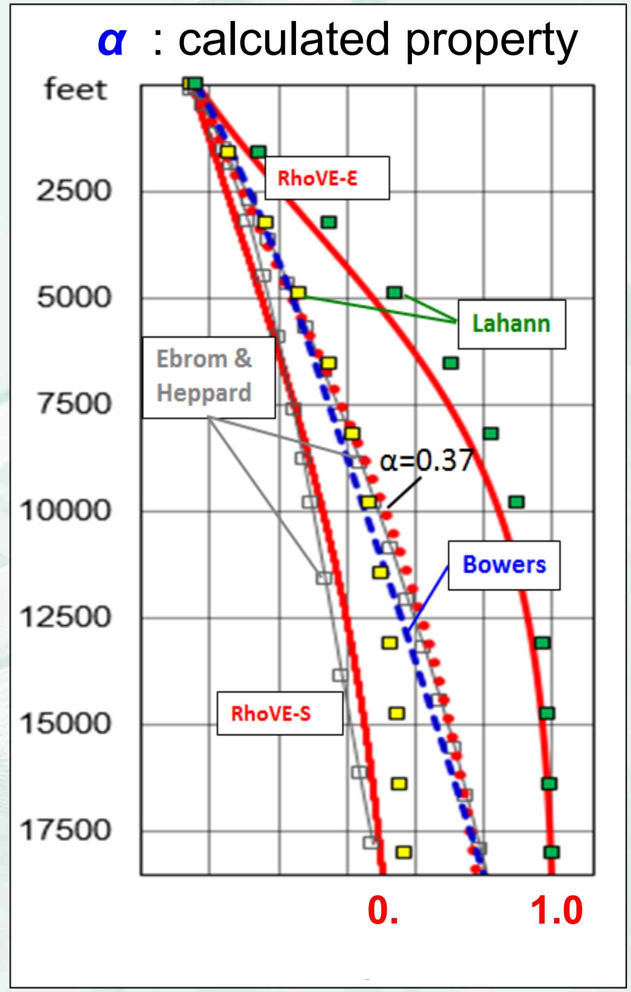
α : calculated property

0.37

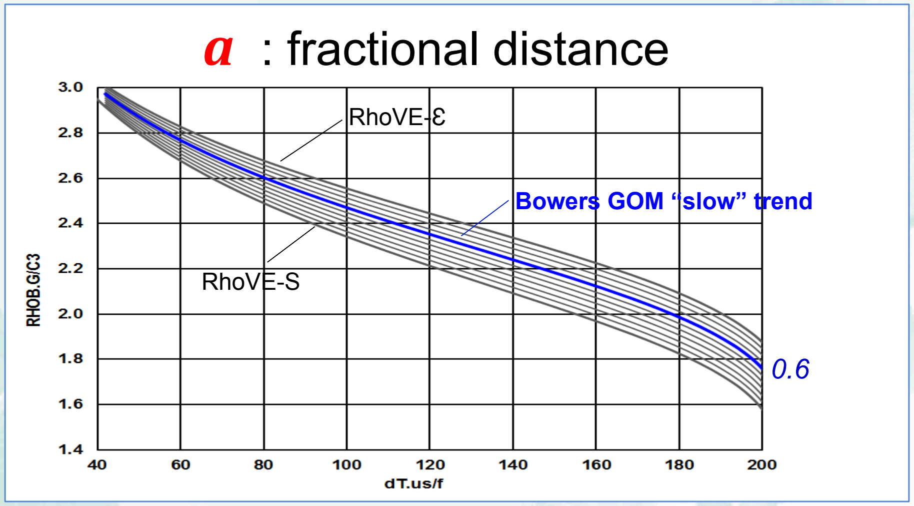

V-rho
Rhob.G/C3
dT.us/f
1.0
0.
V-z
Vint.ft/sec
0.
1.0
rho-z
Density.G/CC
0.
1.0
P-z
ESnorm
Pressure PSI
0.
1.0


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


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



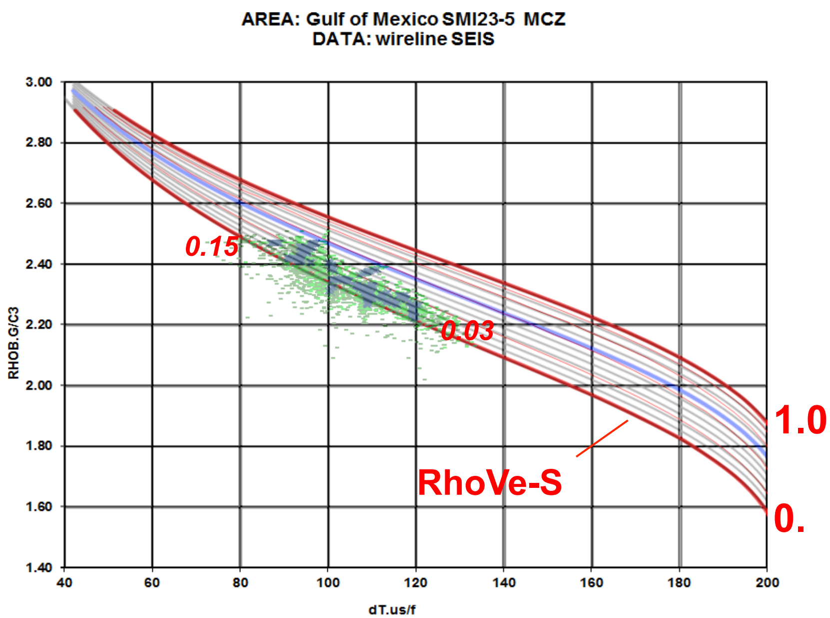
V-Rho equation (Bowers, OTC 2001) :

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

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

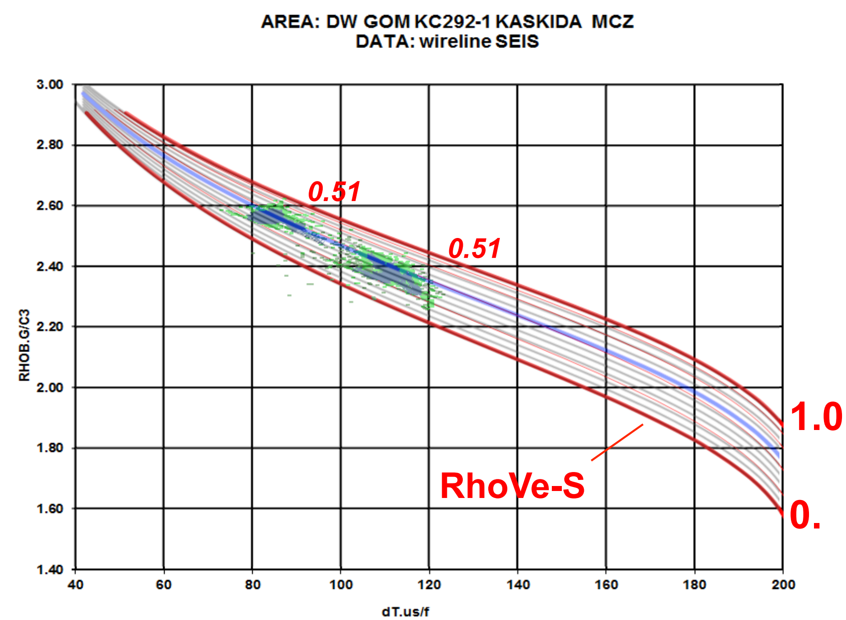
RhoVE interm: *α* * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S

Examples



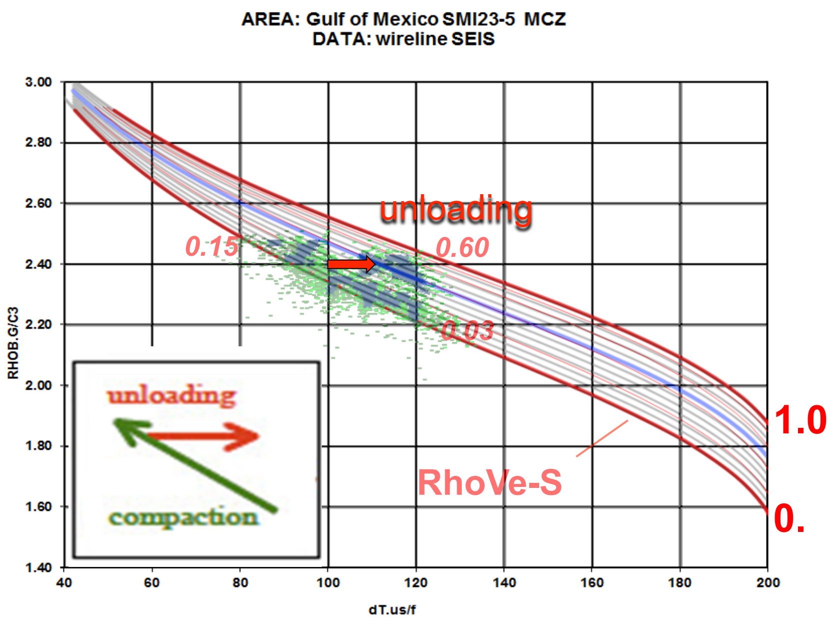
Smectite Dominated

a : fractional distance



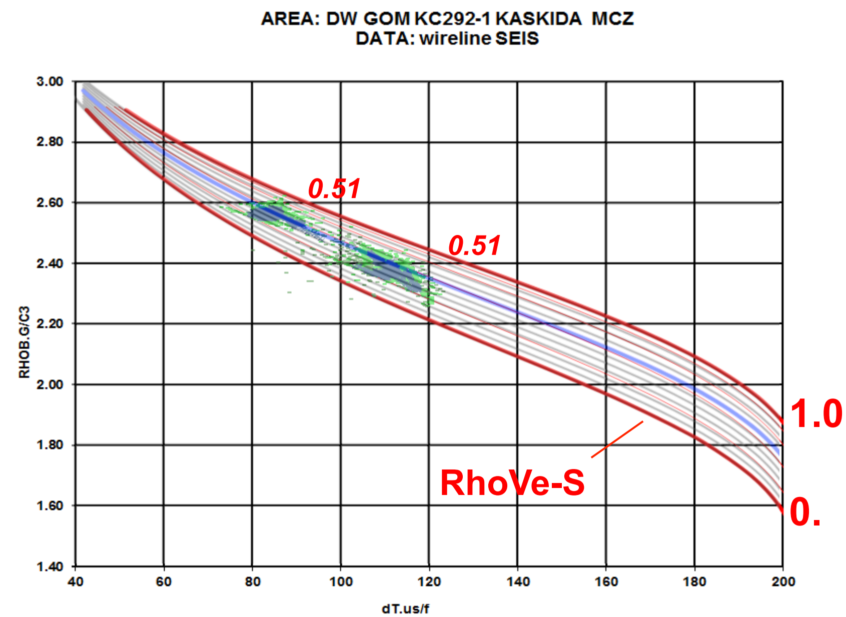
Delimited

Examples



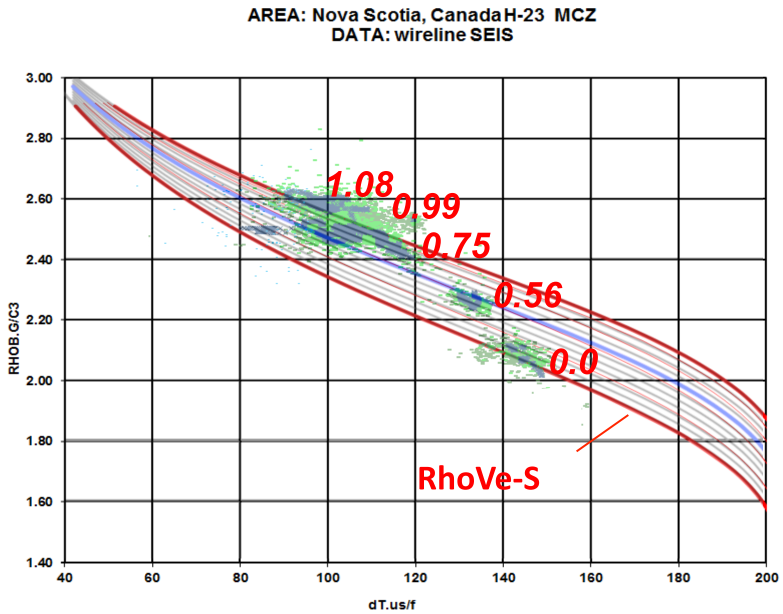
Smectite Dominated

a : fractional distance

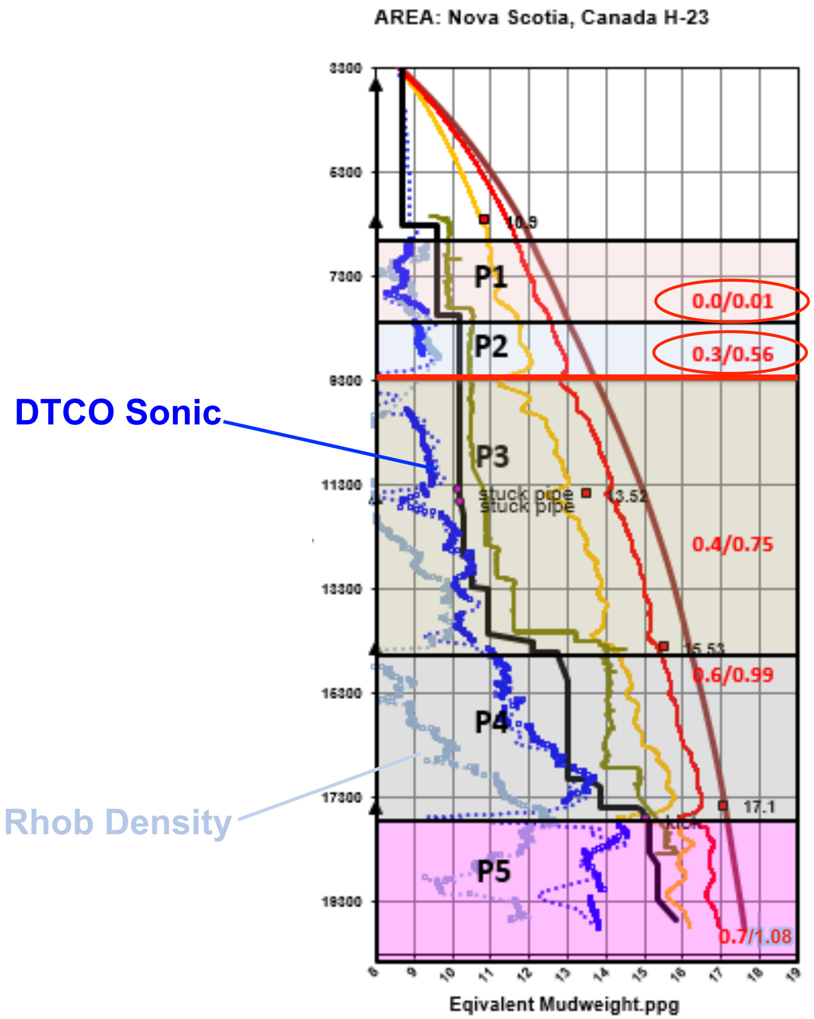


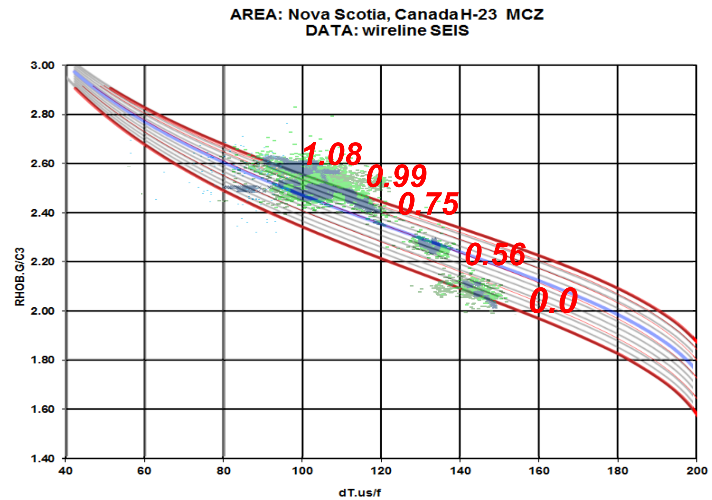
Delimited

Examples

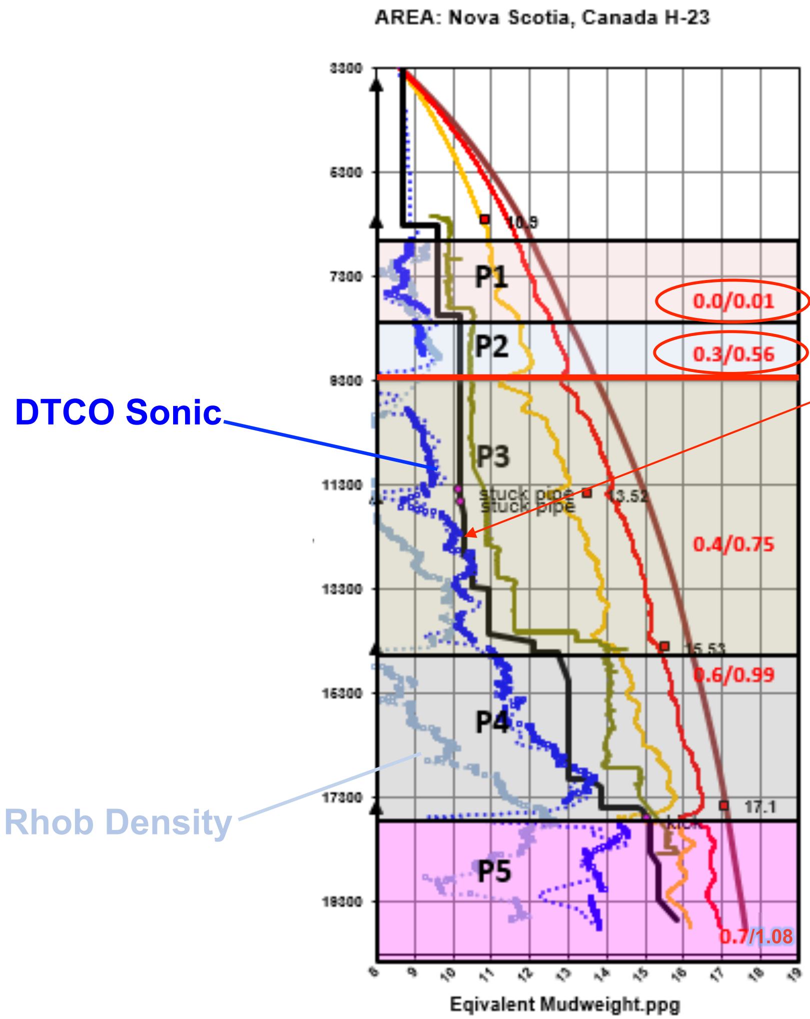


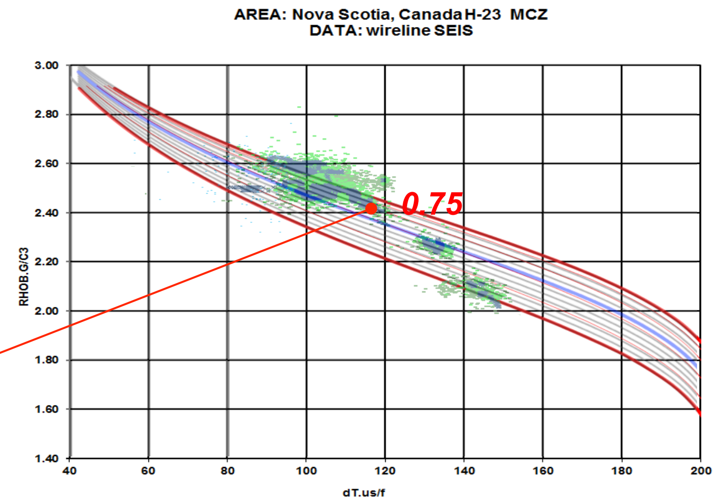
a : fractional distance


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
kick
3300
5300
7300
9300
11300
13300
15300
17300
19300
8
9
10
11
12
13
14
15
16
17
18
19
Eqivalent Mudweight.ppg

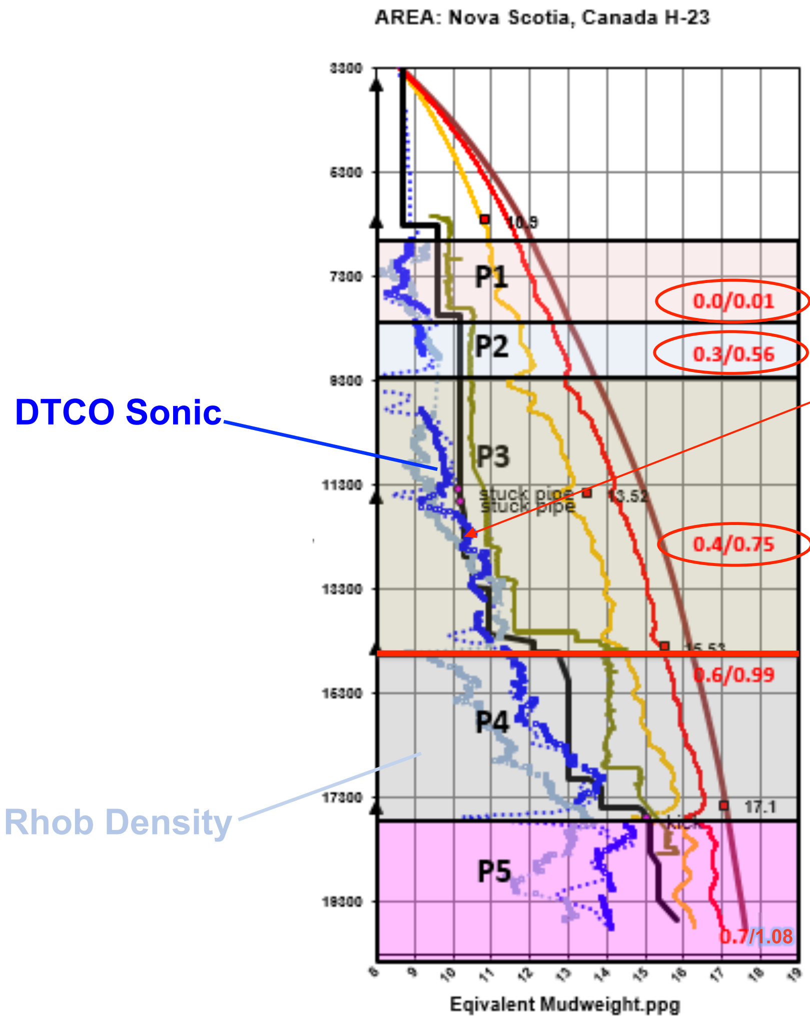

AREA: Nova Scotia, Canada H-23 MCZ
DATA: wireline SEIS
1.08
0.99
0.75
0.56
0.0
RHOB.G/C3
dT.us/f
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
40
60
80
100
120
140
160
180
200

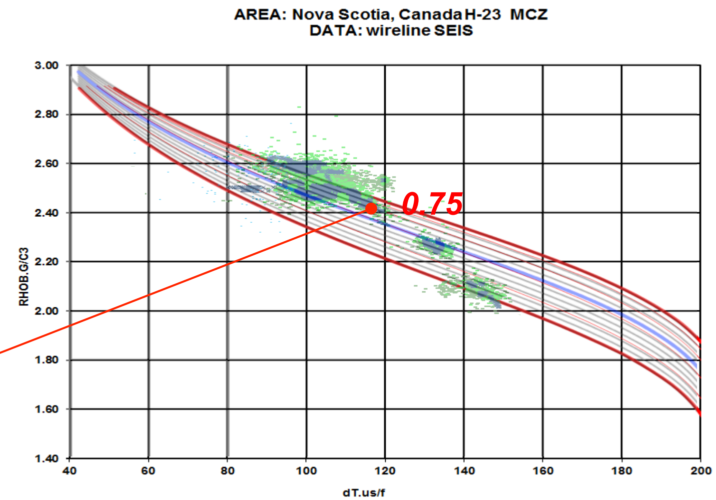
0.3


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
stuck pipe
13.52
15.53
17.1
kick
Eqivalent Mudweight.ppg

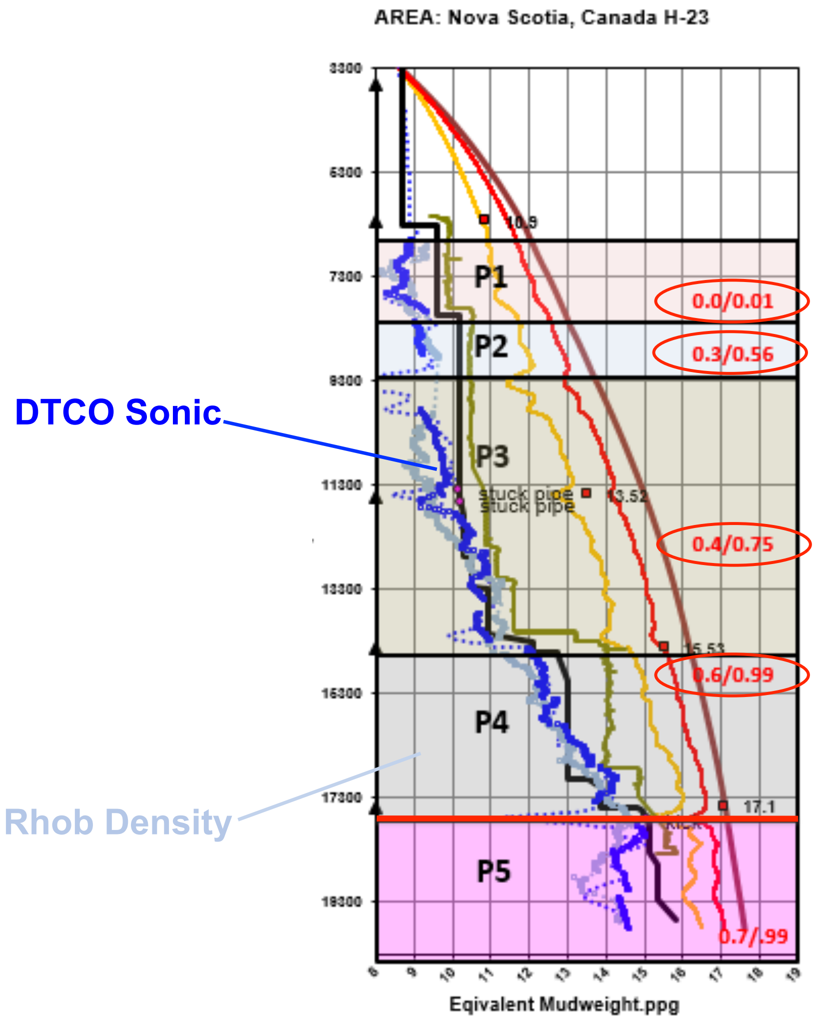

AREA: Nova Scotia, Canada H-23 MCZ
DATA: wireline SEIS
0.75
RHOB.G/C3
dT.us/f

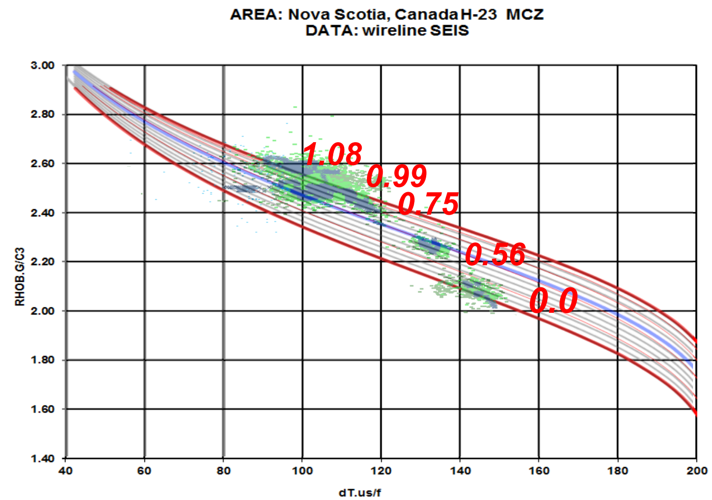
0.3


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
DTCO Sonic
Rhob Density
Eqivalent Mudweight.ppg

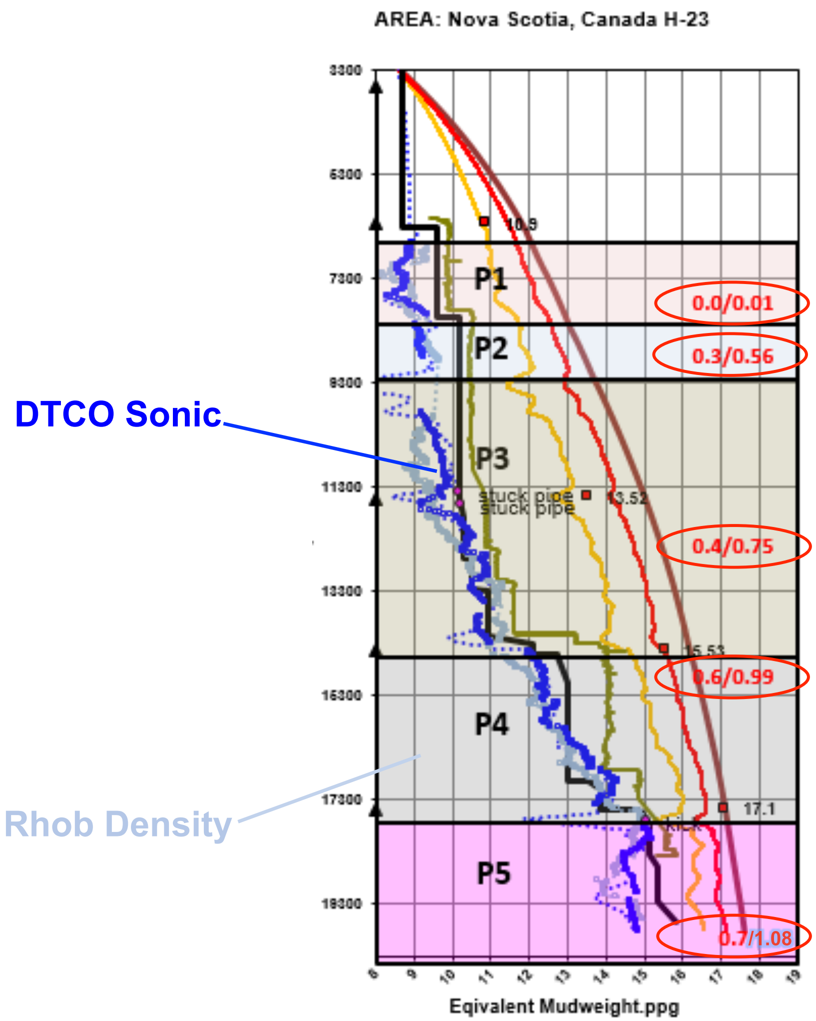

AREA: Nova Scotia, Canada H-23 MCZ
DATA: wireline SEIS
0.75
RHOB.G/C3
dT.us/f

0.4

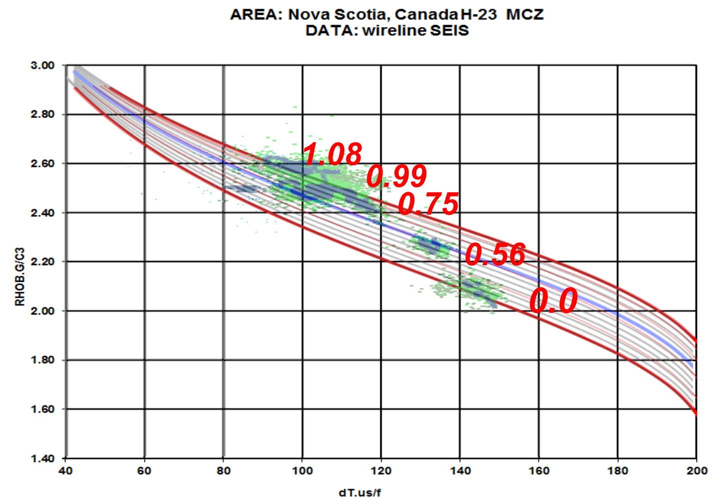

AREA: Nova Scotia, Canada H-23
DTCO Sonic
Rhob Density
P1
P2
P3
P4
P5
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/.99
10.9
13.52
15.53
17.1
stuck pipe
Eqivalent Mudweight.ppg


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

0.6

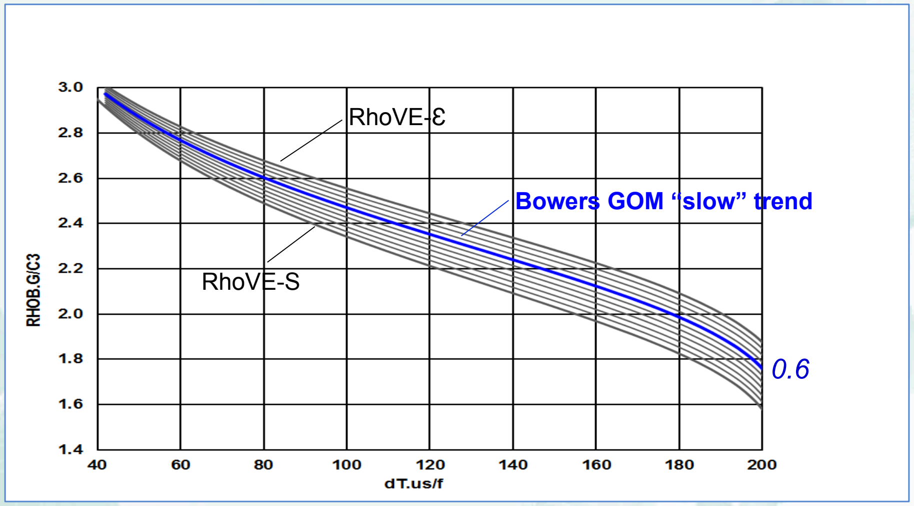


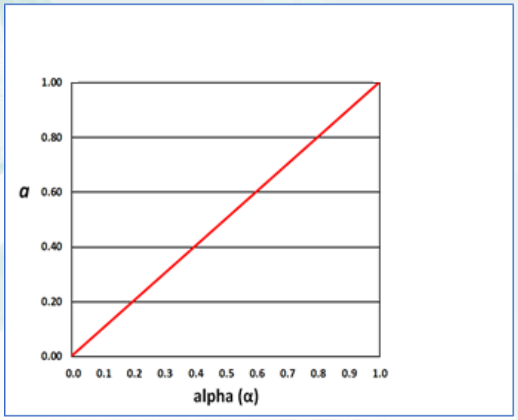
AREA: Nova Scotia, Canada H-23
DTCO Sonic
Rhob Density
P1
P2
P3
P4
P5
0.0/0.01
0.3/0.56
0.4/0.75
0.6/0.99
0.7/1.08
10.9
13.52
15.53
17.1
stuck pipe
7300
11300
13300
17300
Eqivalent Mudweight.ppg



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

0.7





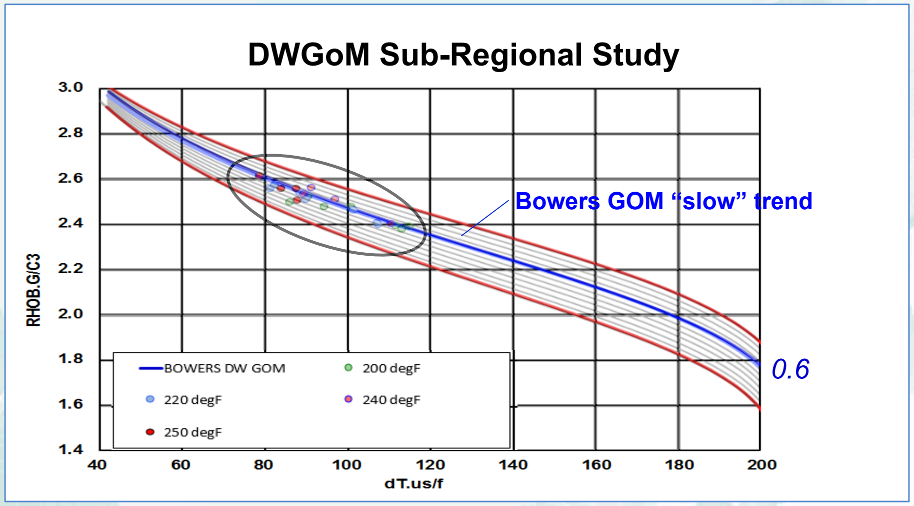
$\alpha = \alpha$

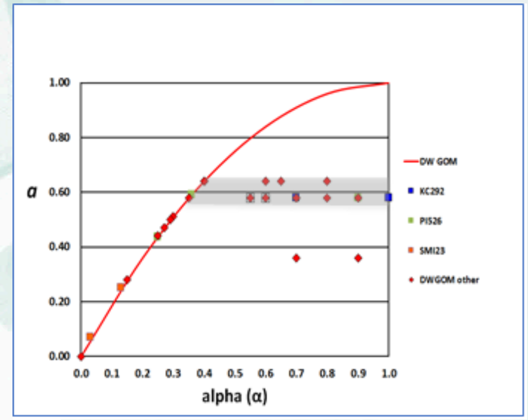
V-Rho equation (Bowers, OTC 2001) :

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

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: α * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S





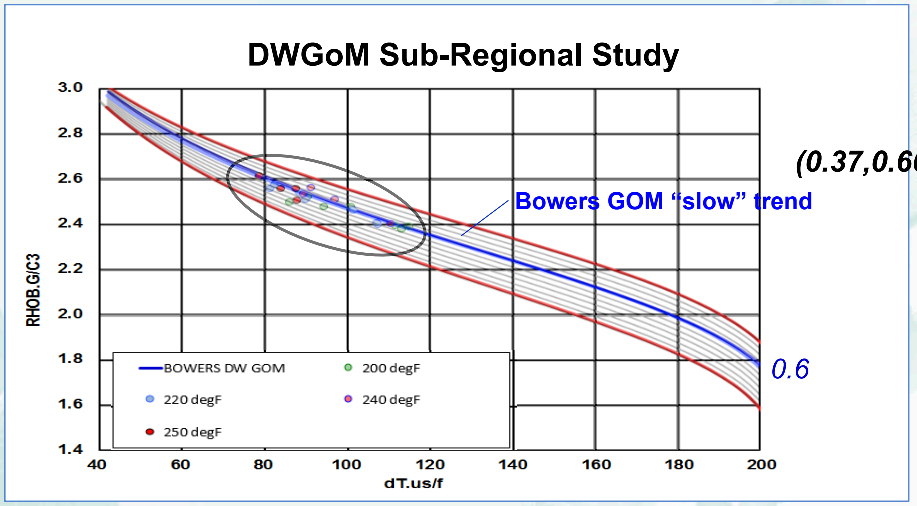
$$a = 2\alpha - \alpha^2$$

V-Rho equation (Bowers, OTC 2001) :

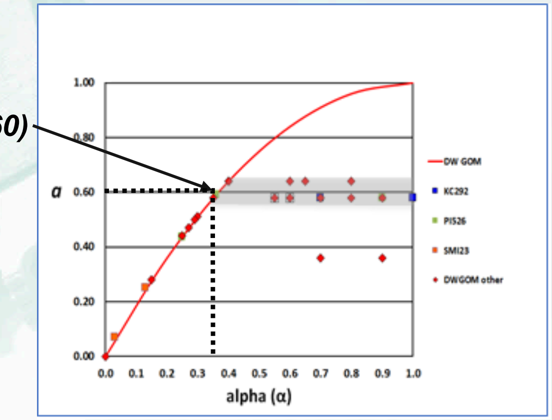
$$V = V_0 + A(\rho - \rho_o)^B$$

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



(0.37,0.60)

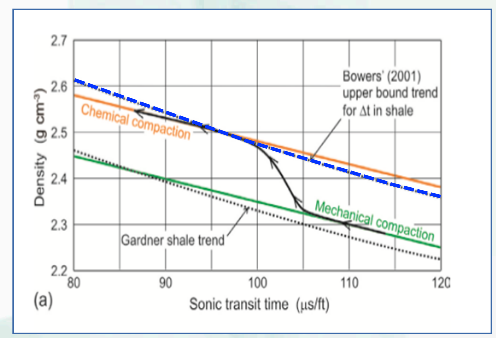


$$a = 2\alpha - \alpha^2$$

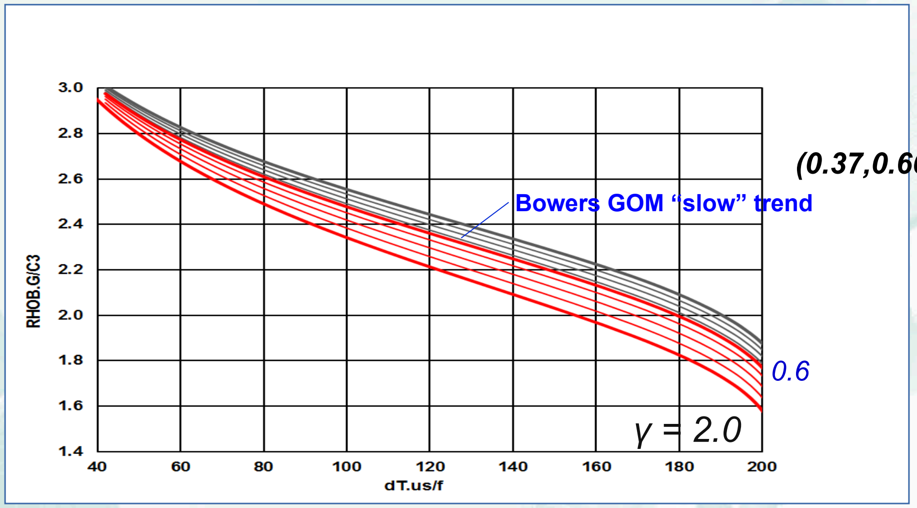
V-Rho equation (Bowers, OTC 2001) :

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

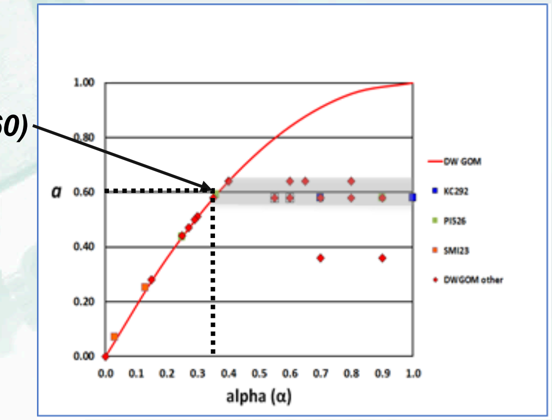
BOWERS GOM “Slow” Trend		RhoVE-Ɛ	RhoVE-S
Vo:	4790	4800	4900
A:	2953	2000	4500
B:	3.57	4.2	3
ρ_o:	1.3	1.3	1.3



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



(0.37,0.60)



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

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

OVERVIEW

INTRODUCTORY DEMO

PREVIOUS WORK - THEORY

- Mechanical vs Chemical Compaction
- Smectite – Illite Conversion

RHOVE METHOD

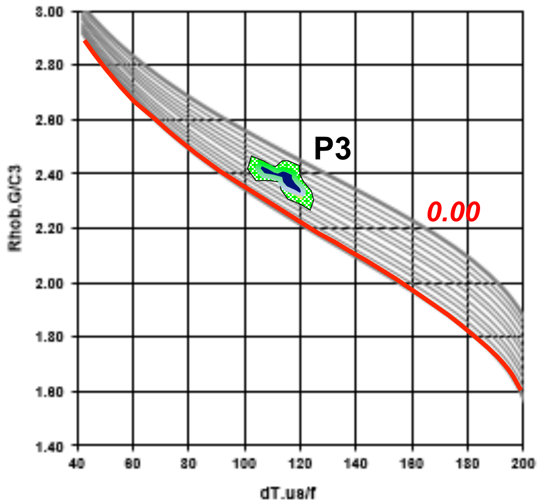
- Summary
- Virtual Model
- Alpha – A-Term
- Shale Discrimination

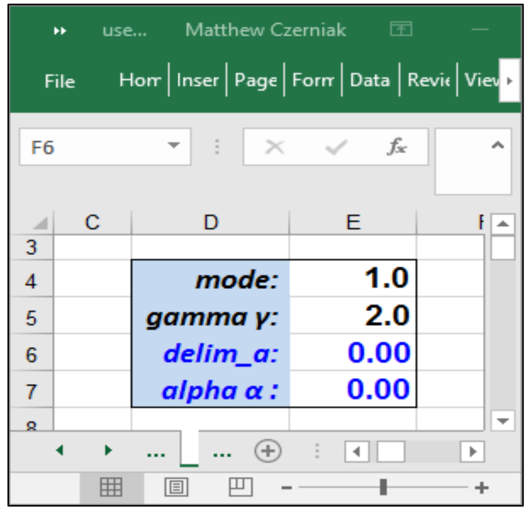
SUMMARY DEMOS

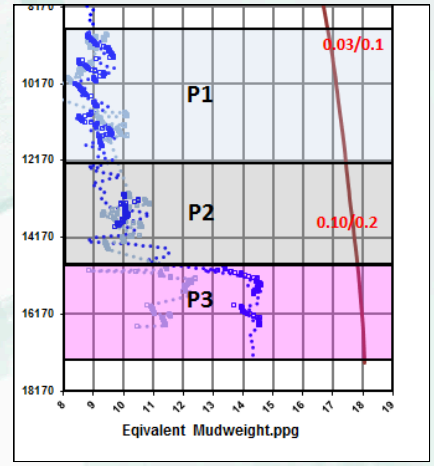
- Untethered Mode
- Tethered Mode

WELL EXAMPLES using RHOVE METHOD

ADVANTAGES of RHOVE Method

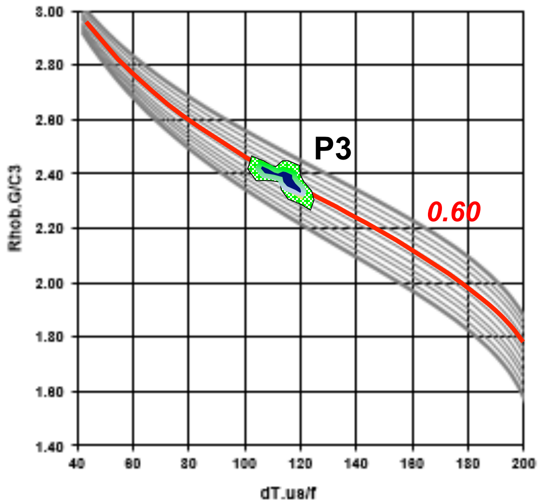


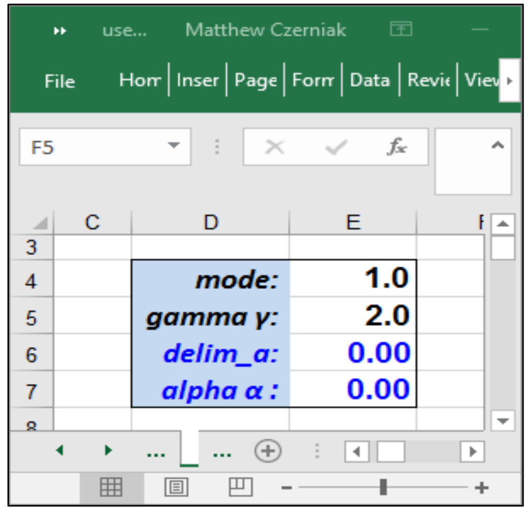


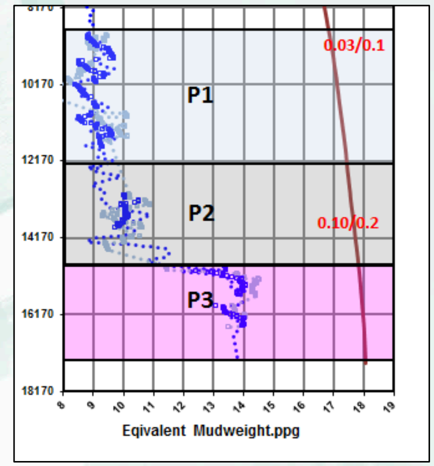


0.0

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

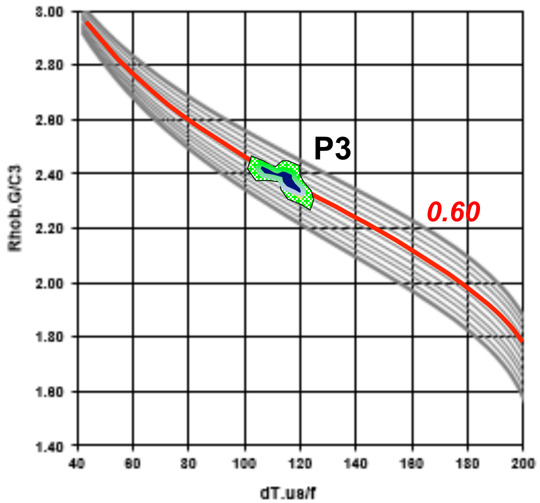


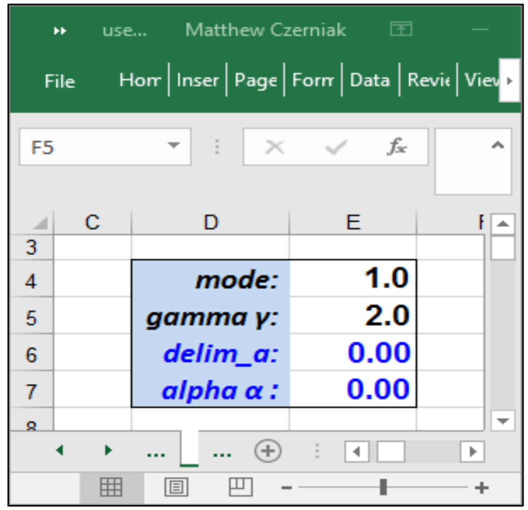


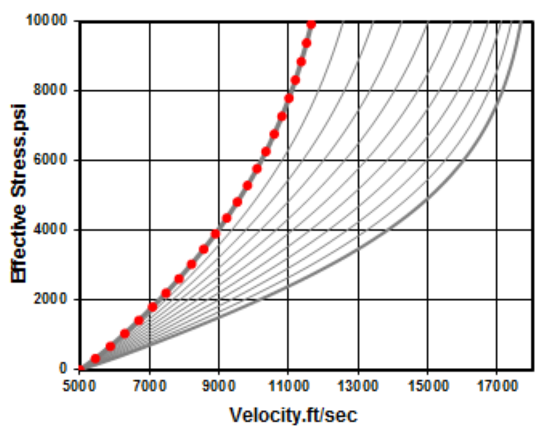


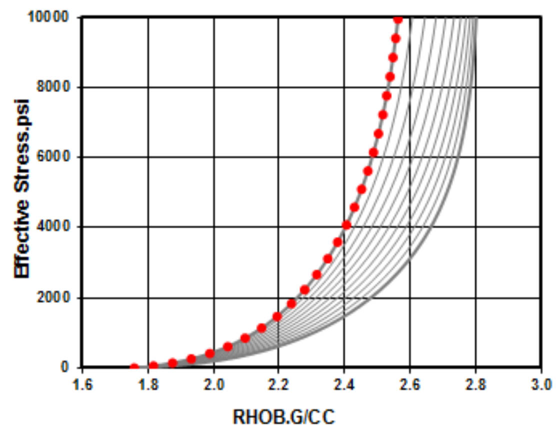
0.0

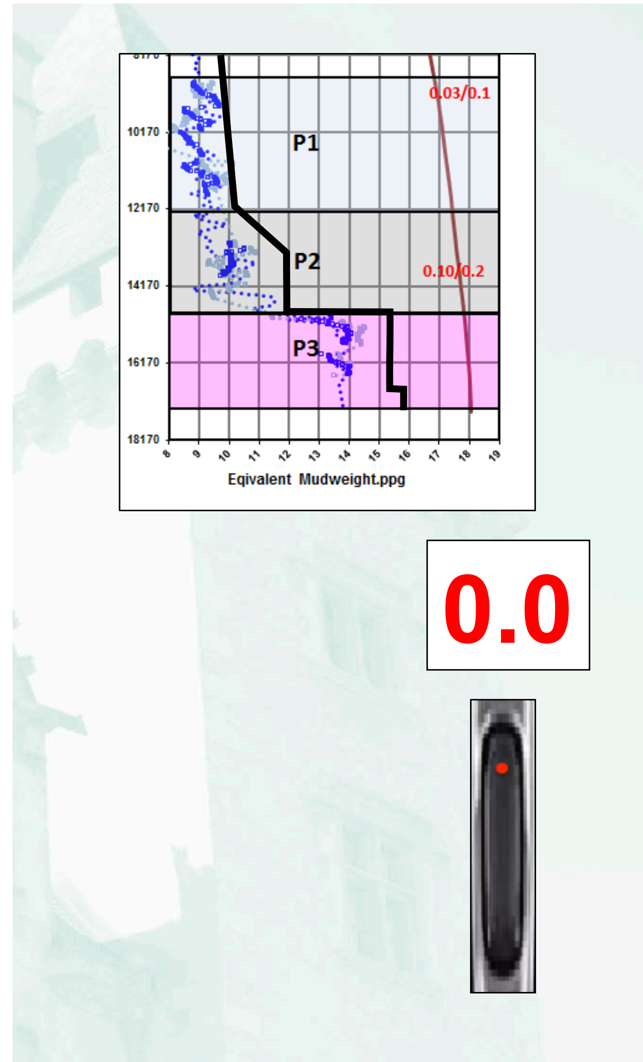
RhoVe interm: α * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S

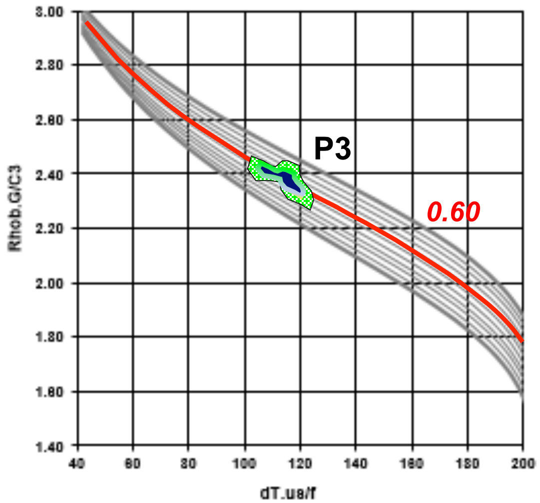

P3
0.60
Rhob.G/C3
dT.us/f

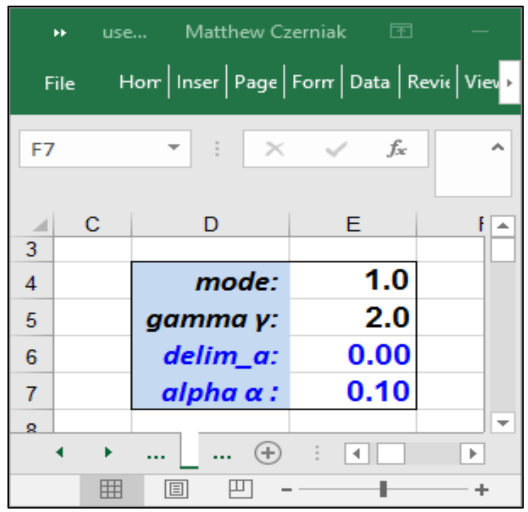

Matthew Czerniak
File
F5
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.00

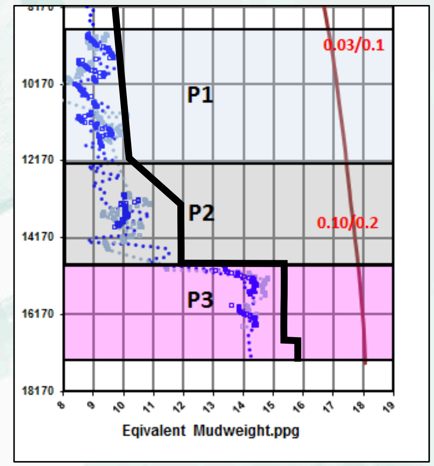

Effective Stress.psi
Velocity.ft/sec


Effective Stress.psi
RHOB.G/CC

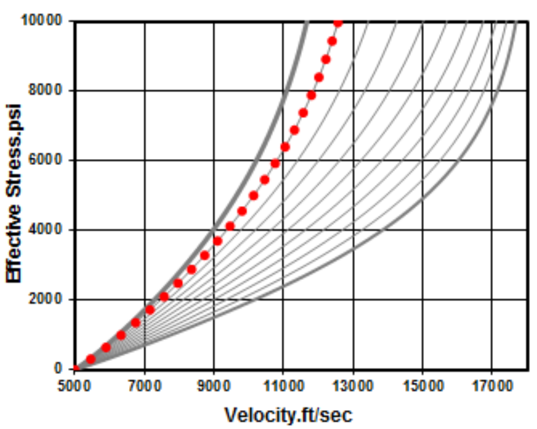

P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg
0.0

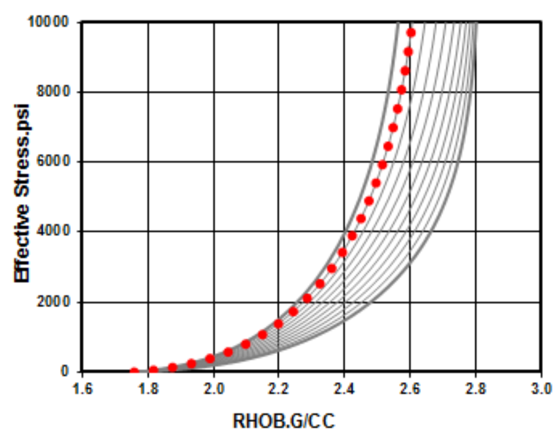

P3
0.60
Rhob.G/C3
dT.us/f

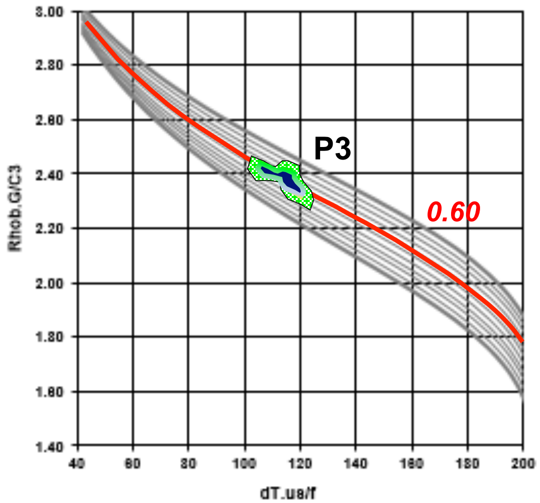

use... Matthew Czerniak
File Hom Inser Page Forr Data Revie View
F7
C D E
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.10

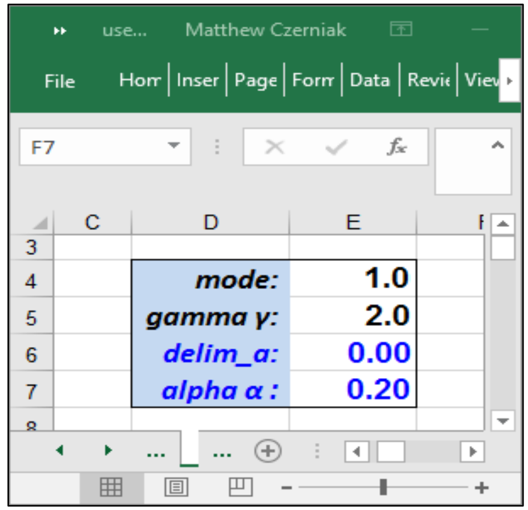

0.03/0.1
P1
P2
0.10/0.2
P3
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

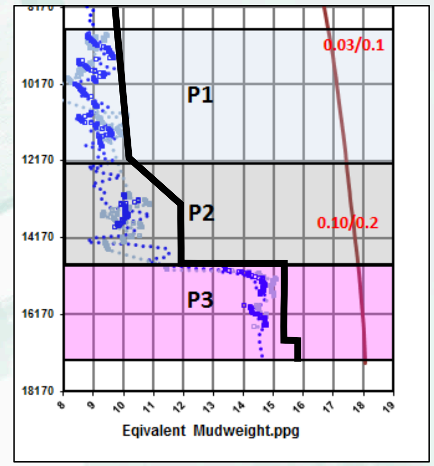
0.1


Effective Stress.psi
Velocity.ft/sec

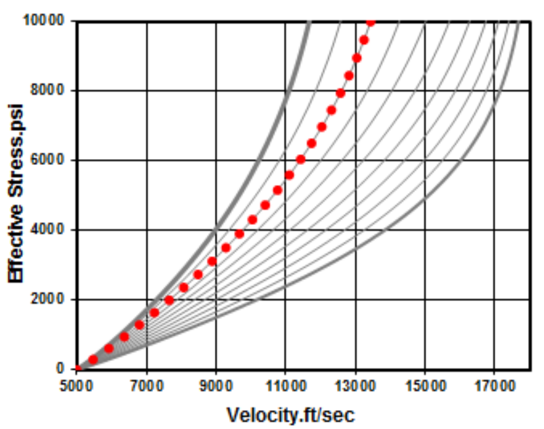

Effective Stress.psi
RHOB.G/CC

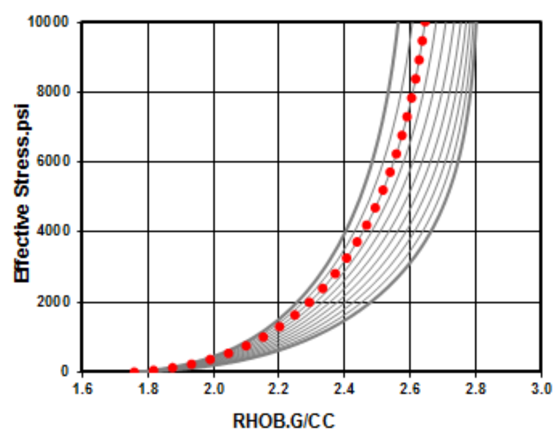

P3
0.60
Rhob.G/C3
dT.us/f

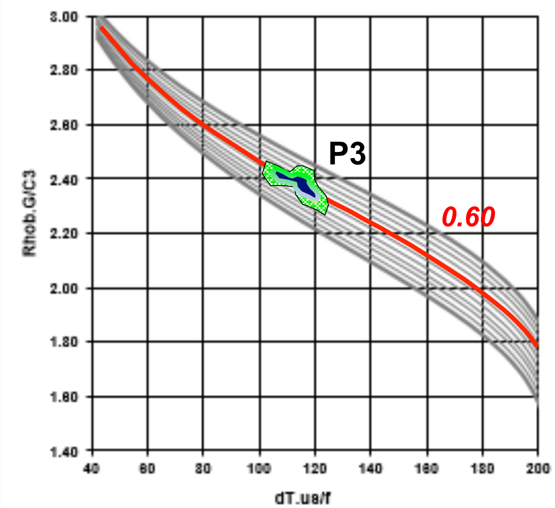

use...
Matthew Czerniak
File
Hom
Inser
Page
Forr
Data
Revie
View
F7
C
D
E
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.20

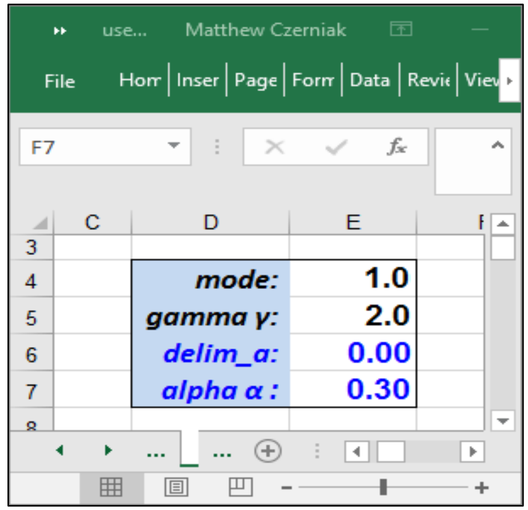

10170
12170
14170
16170
18170
P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

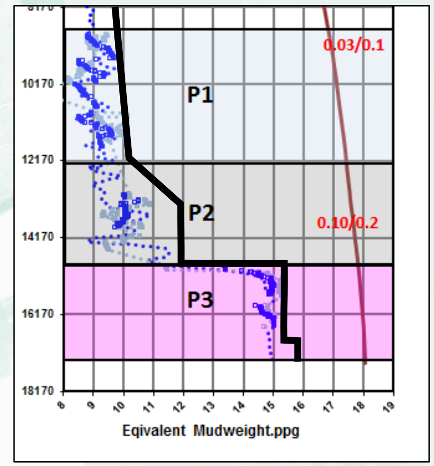
0.2


Effective Stress.psi
Velocity.ft/sec

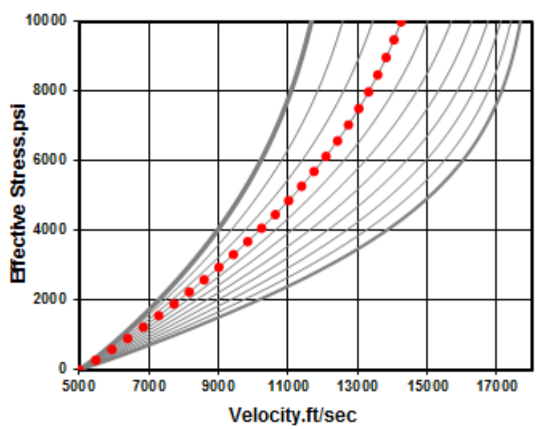

Effective Stress.psi
RHOB.G/CC

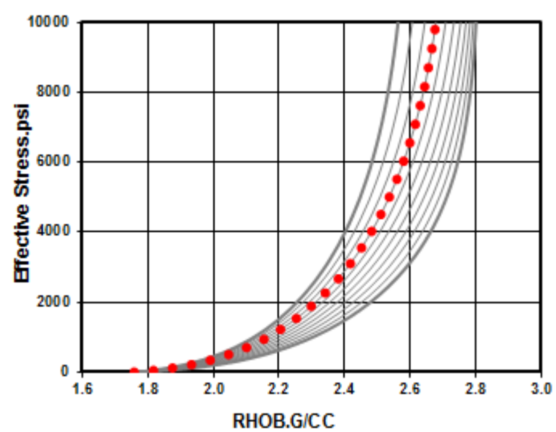

P3
0.60
Rhob.G/C3
dT.us/f

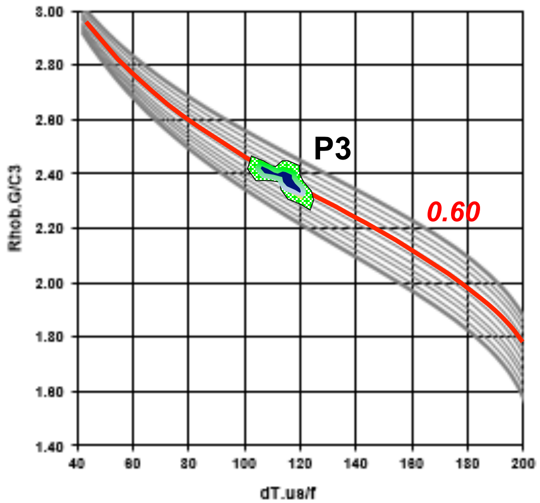

use... Matthew Czerniak
File Hom Inser Page Form Data Revie View
F7
C D E
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.30

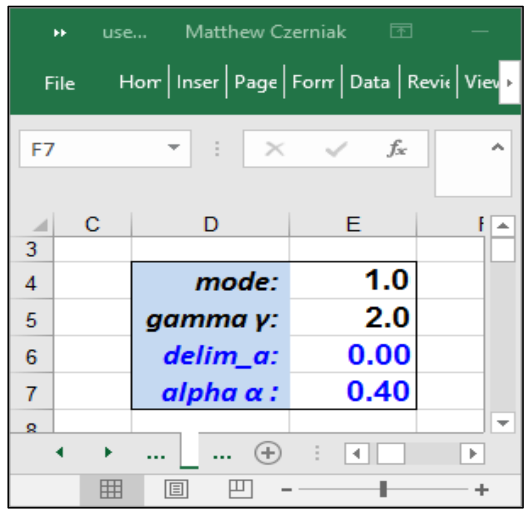

0.03/0.1
P1
P2
0.10/0.2
P3
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

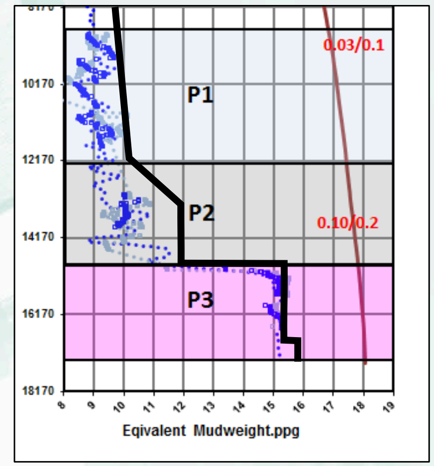
0.3


Effective Stress.psi
Velocity.ft/sec

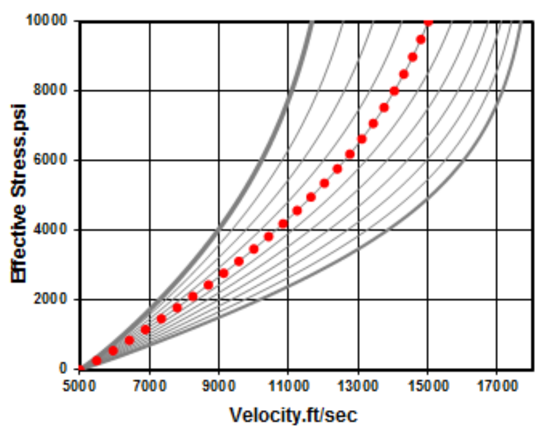

Effective Stress.psi
RHOB.G/CC

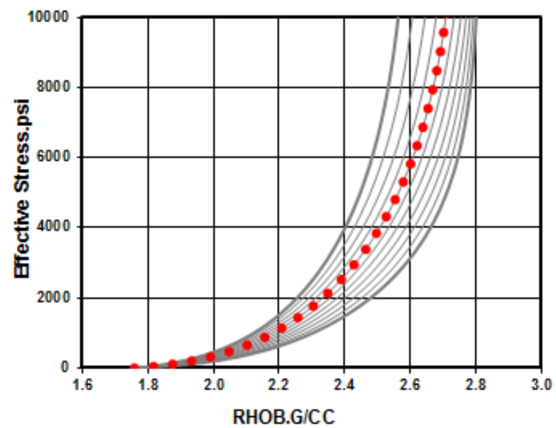

Rhob.G/C3
dT.us/f
P3
0.60

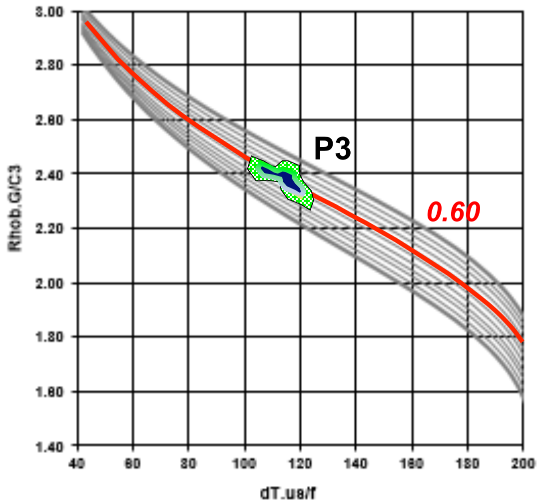

use... Matthew Czerniak
File Hom Inser Page Form Data Revie View
F7
C D E
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.40


P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

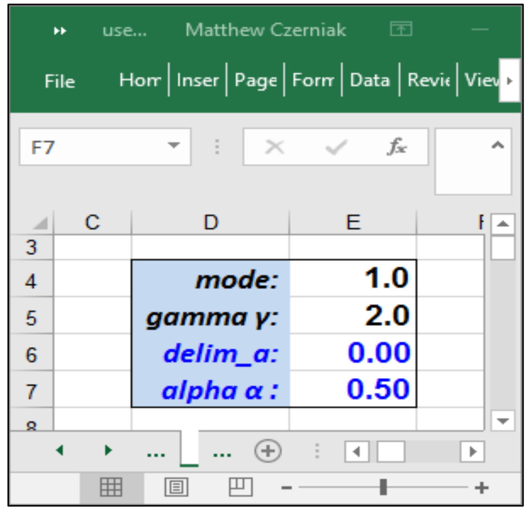
0.4


Effective Stress.psi
Velocity.ft/sec

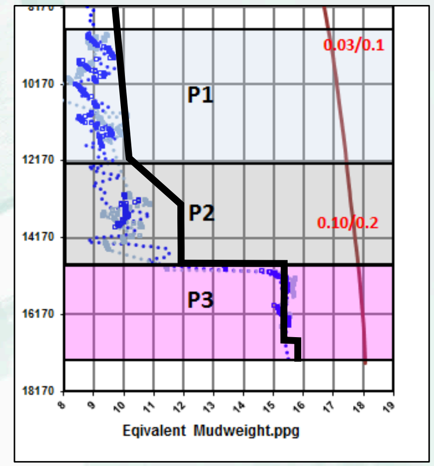

Effective Stress.psi
RHOB.G/CC



P3
0.60
Rhob.G/C3
dT.us/f

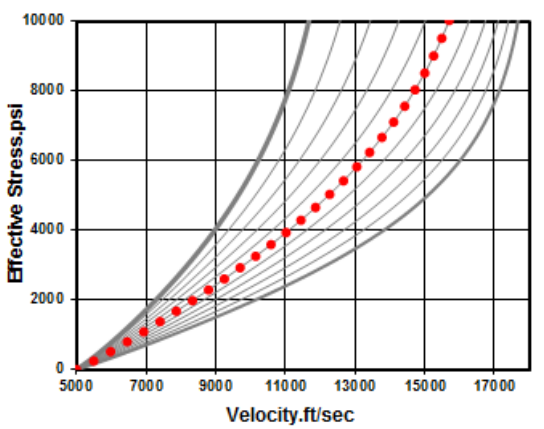


Matthew Czerniak
File
F7
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.50

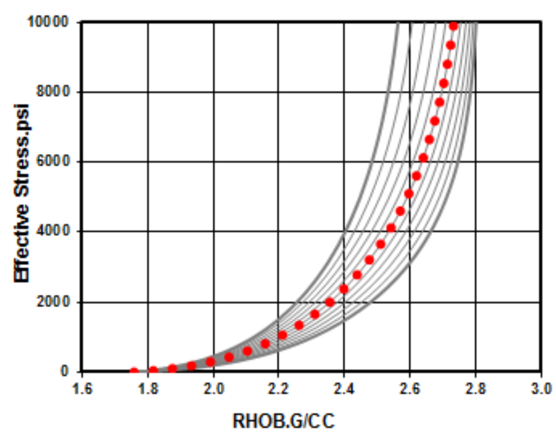


P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

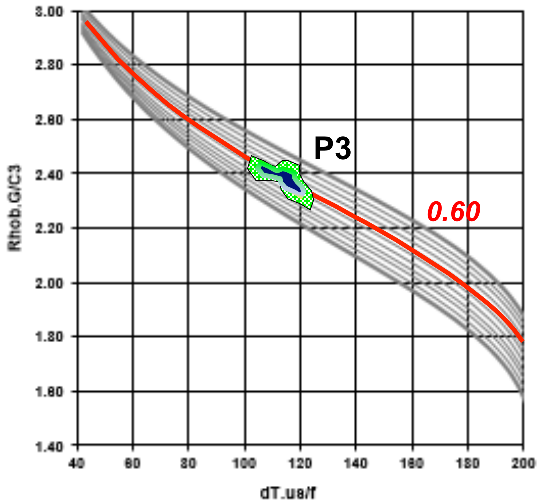
0.5

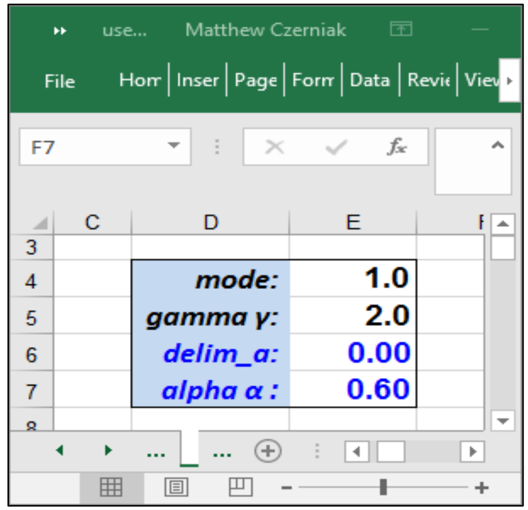


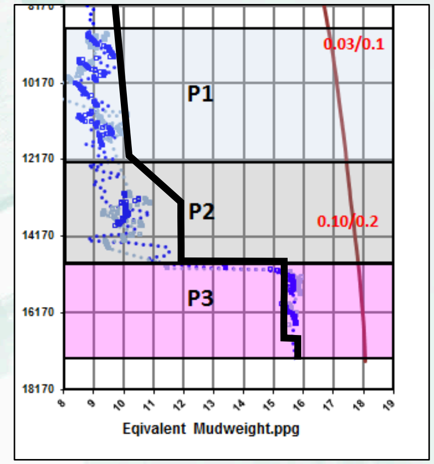
Effective Stress.psi
Velocity.ft/sec



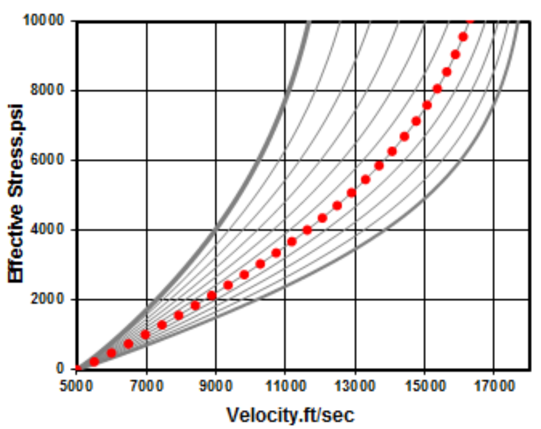
Effective Stress.psi
RHOB.G/CC

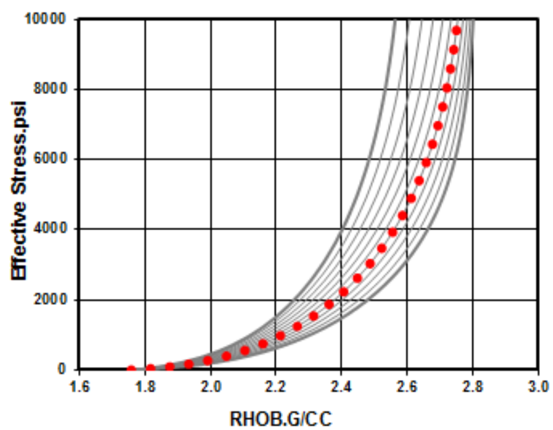

P3
0.60
Rhob.G/C3
dT.us/f

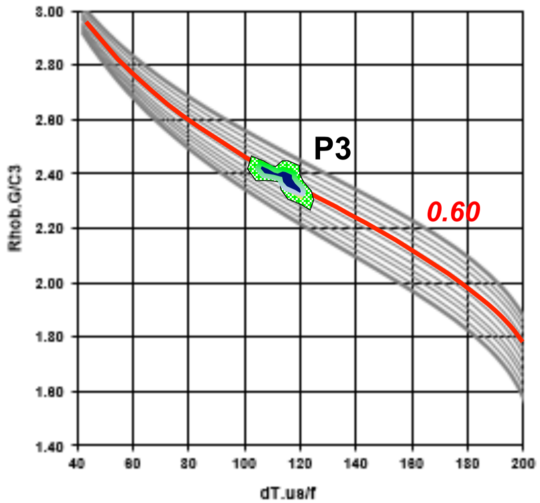

Matthew Czerniak
File
F7
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.60

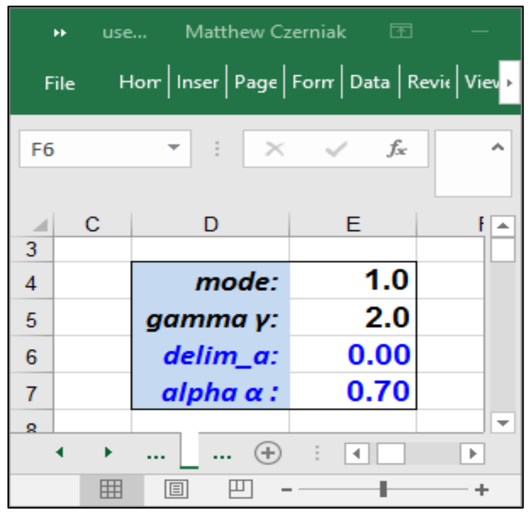

P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

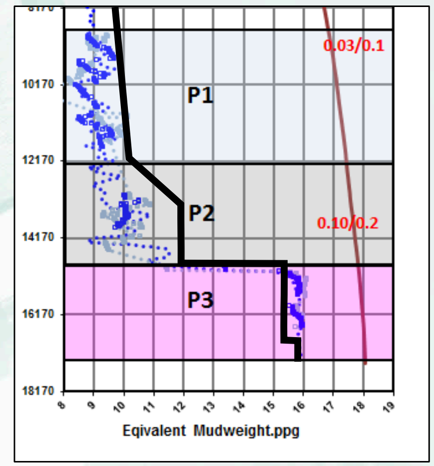
0.6


Effective Stress.psi
Velocity.ft/sec

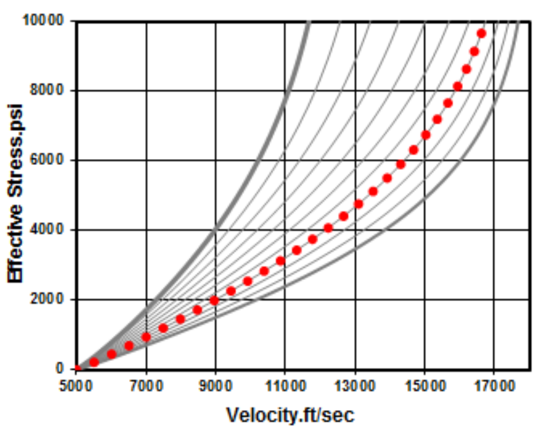

Effective Stress.psi
RHOB.G/CC

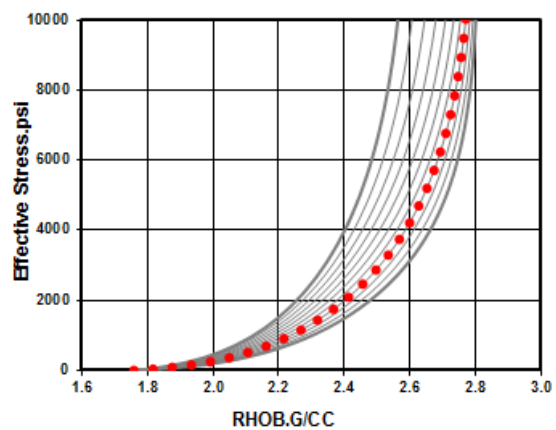

P3
0.60
Rhob.G/C3
dT.us/f

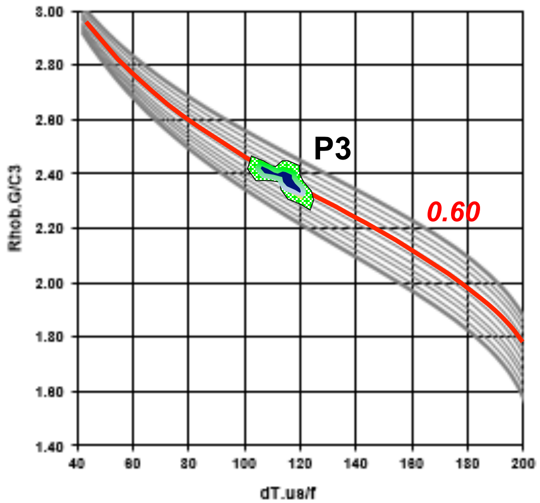

use... Matthew Czerniak
File Horr Inser Page Forr Data Revi Viev
F6
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.70


P1
P2
P3
0.03/0.1
0.10/0.2
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

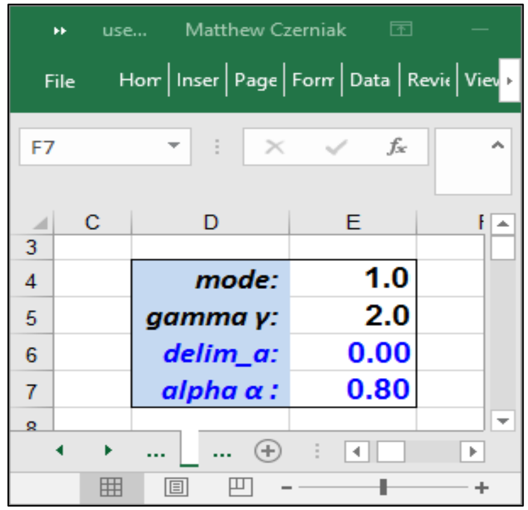
0.7


Effective Stress.psi
Velocity.ft/sec

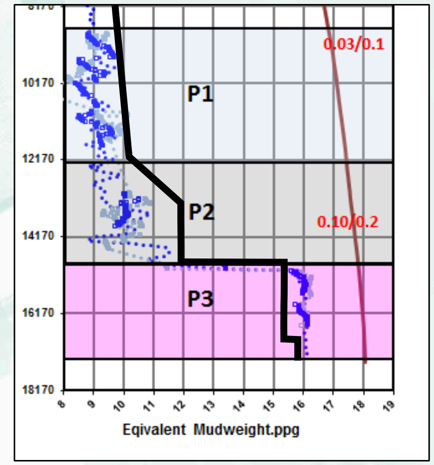

Effective Stress.psi
RHOB.G/CC



Rhob.G/C3
dT.us/f
P3
0.60

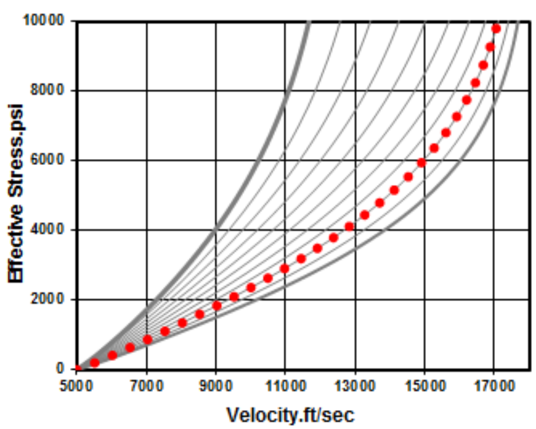


use...
Matthew Czerniak
File
F7
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.80

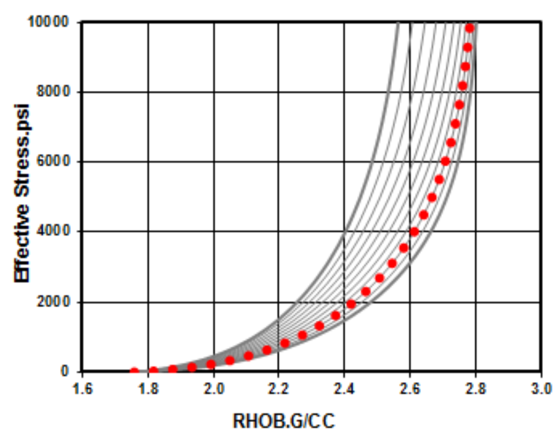


P1
P2
P3
0.03/0.1
0.10/0.2
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

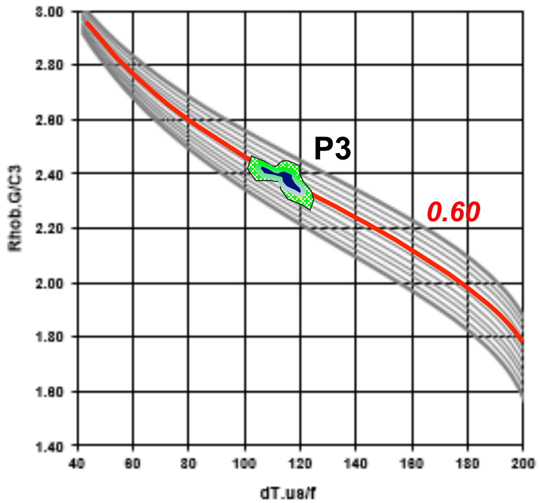
0.8

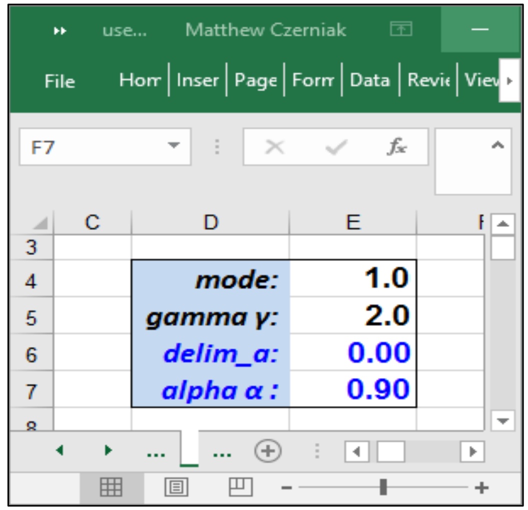


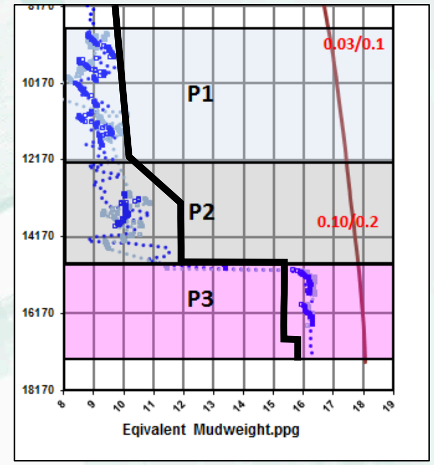
Effective Stress.psi
Velocity.ft/sec



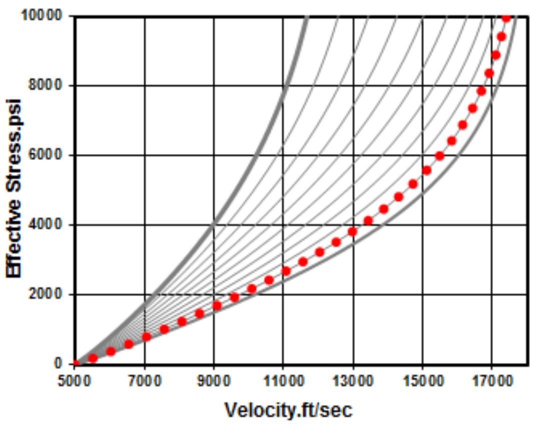
Effective Stress.psi
RHOB.G/CC

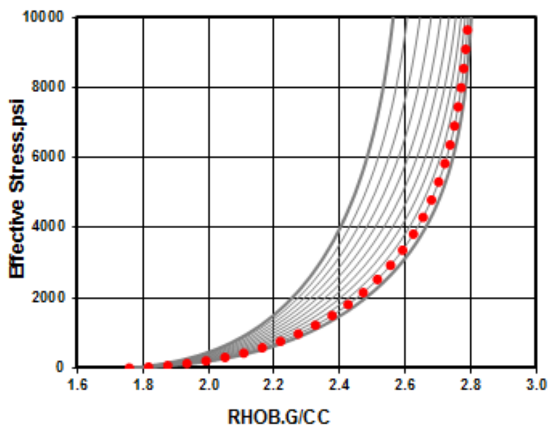

P3
0.60
Rhob.G/C3
dT.us/f

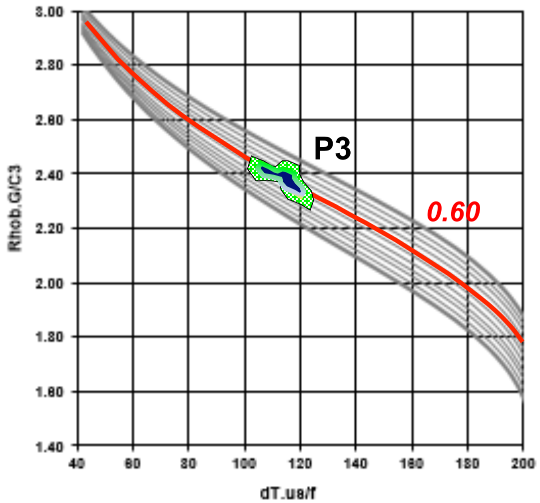

use...
Matthew Czerniak
File
F7
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.90

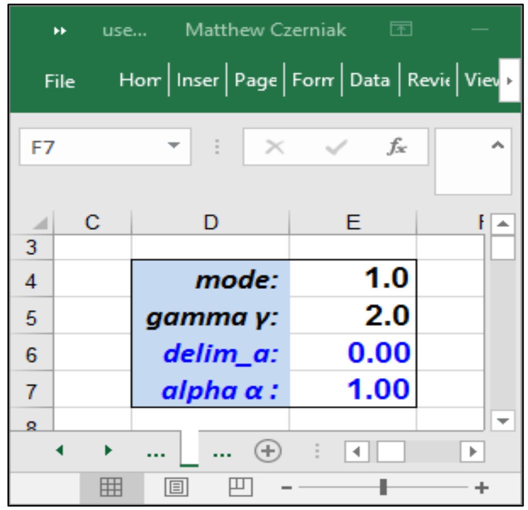

P1
P2
P3
0.03/0.1
0.10/0.2
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

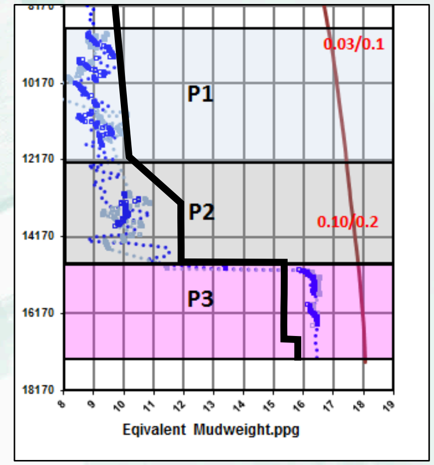
0.9


Effective Stress.psi
Velocity.ft/sec

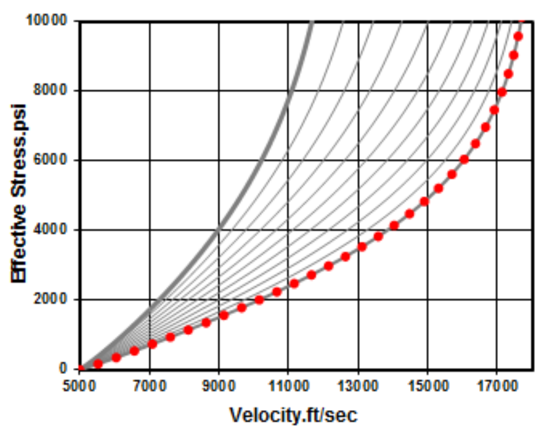

Effective Stress.psi
RHOB.G/CC

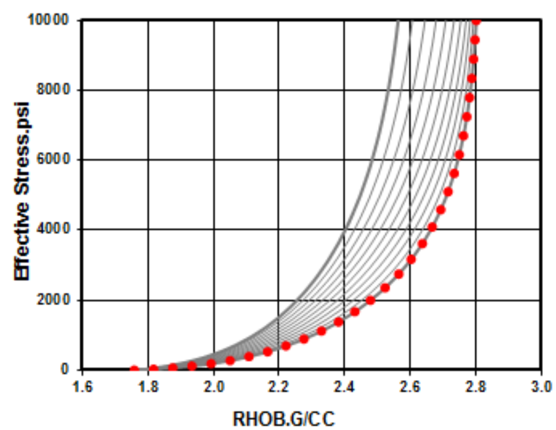

Rhob.G/C3
dT.us/f
P3
0.60

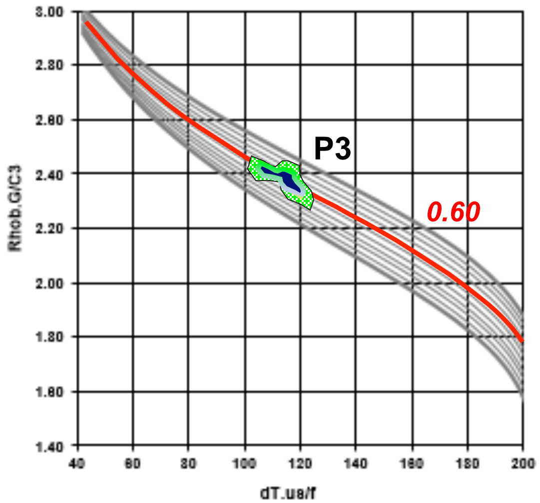

use...
Matthew Czerniak
File
Horr
Inser
Page
Forr
Data
Revie
Viev
F7
C
D
E
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 1.00


P1
P2
P3
0.03/0.1
0.10/0.2
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

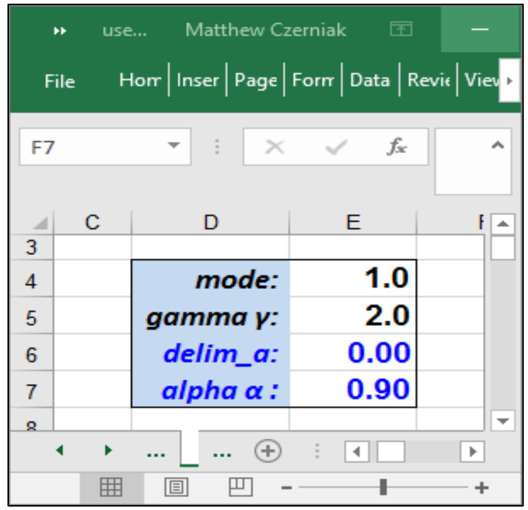
1.0


Effective Stress.psi
Velocity.ft/sec

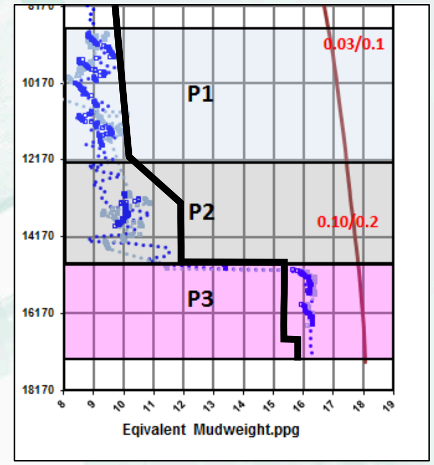

Effective Stress.psi
RHOB.G/CC



Rhob.G/C3
dT.us/f
P3
0.60

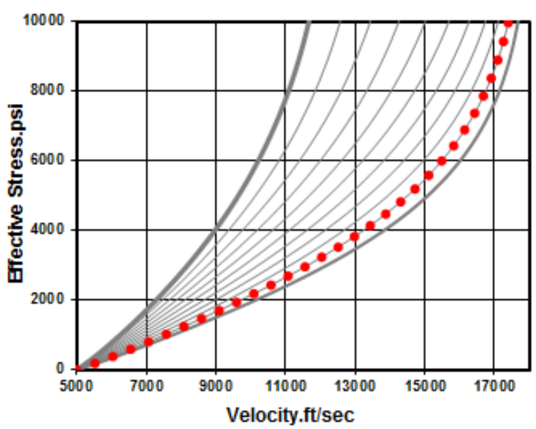


use...
Matthew Czerniak
File
F7
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.90

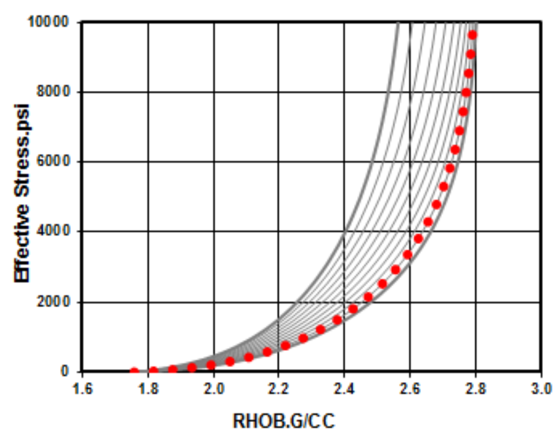


P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

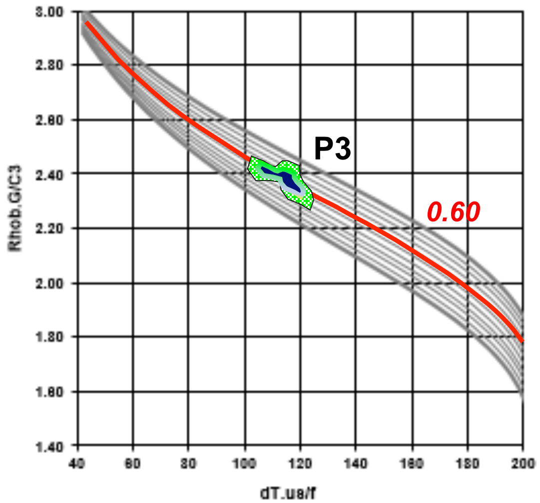
0.9

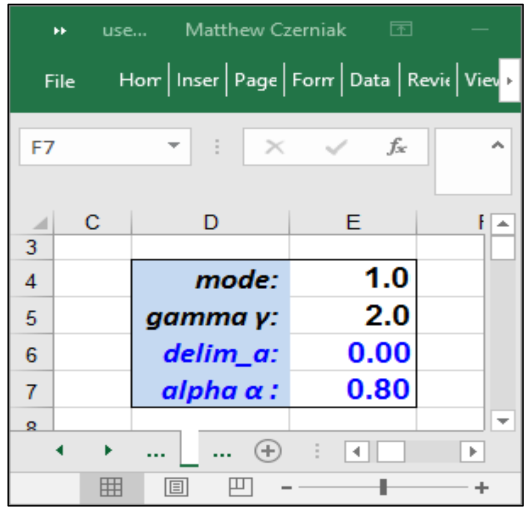


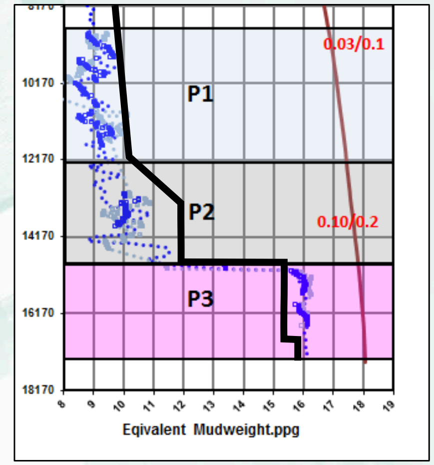
Effective Stress.psi
Velocity.ft/sec



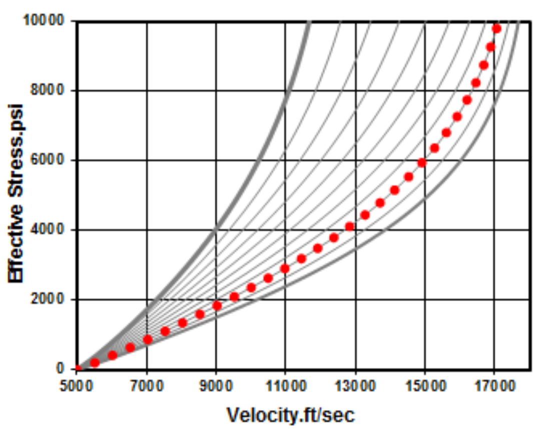
Effective Stress.psi
RHOB.G/CC

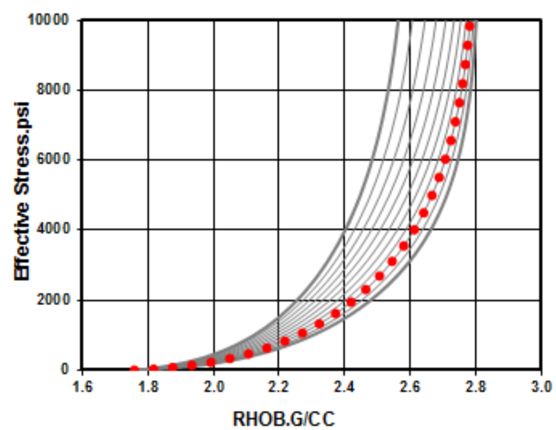

Rhob.G/C3
dT.us/f
P3
0.60

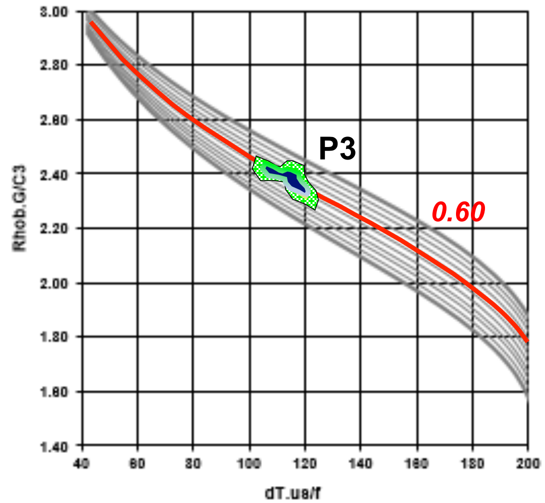

Matthew Czerniak
File
F7
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.80

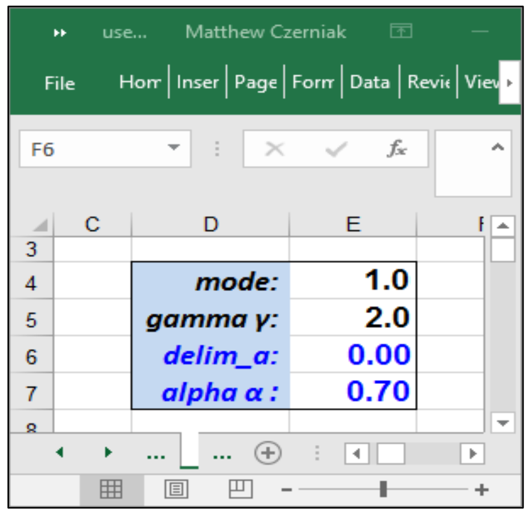

P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

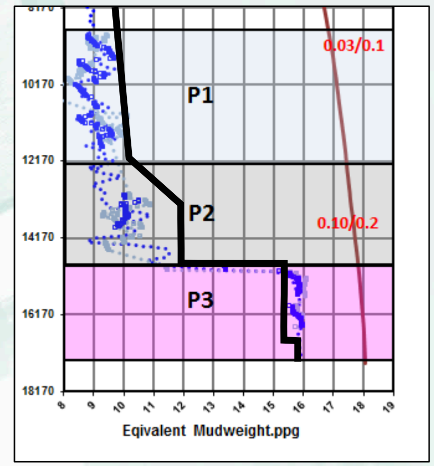
0.8


Effective Stress.psi
Velocity.ft/sec

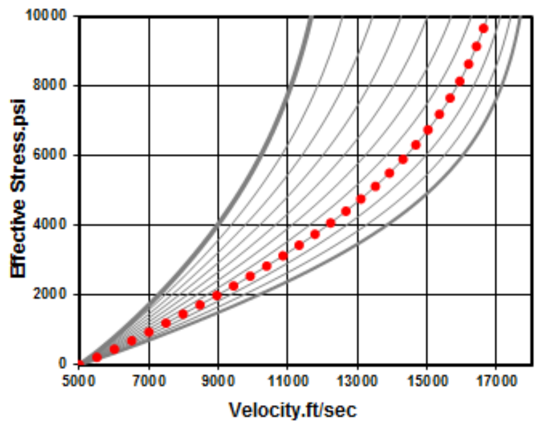

Effective Stress.psi
RHOB.G/CC

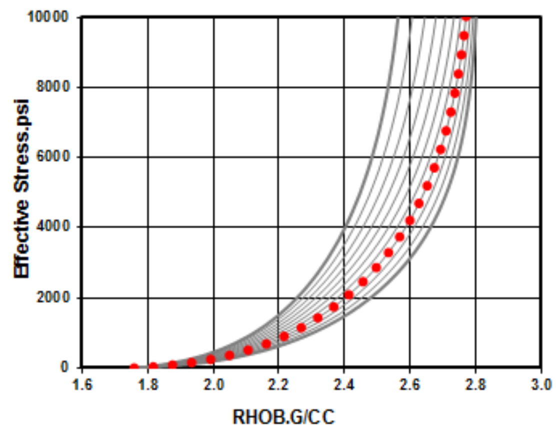

Rhob.G/C3
dT.us/f
P3
0.60

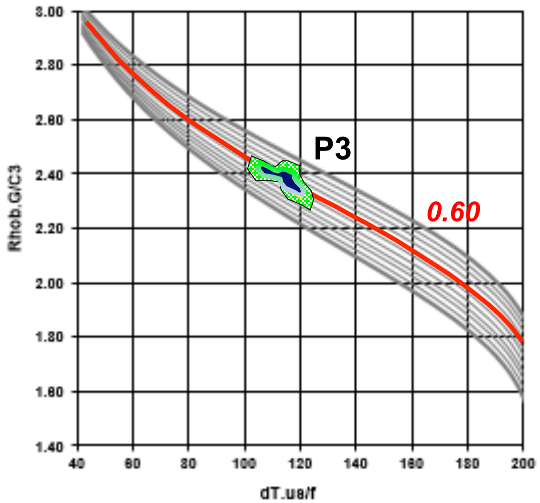

use... Matthew Czerniak
File Hom Inser Page Forr Data Revie View
F6
C D E
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.70

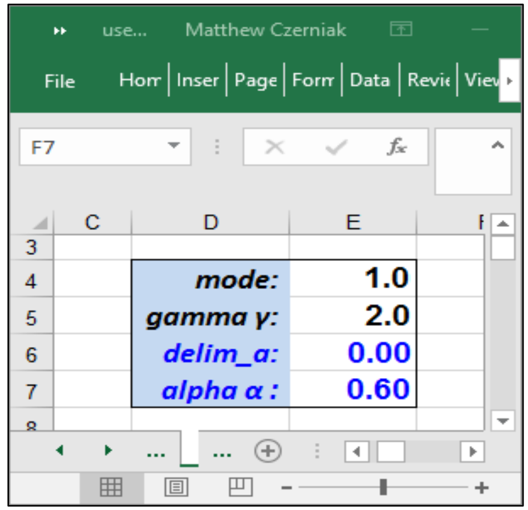

P1
P2
P3
0.03/0.1
0.10/0.2
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

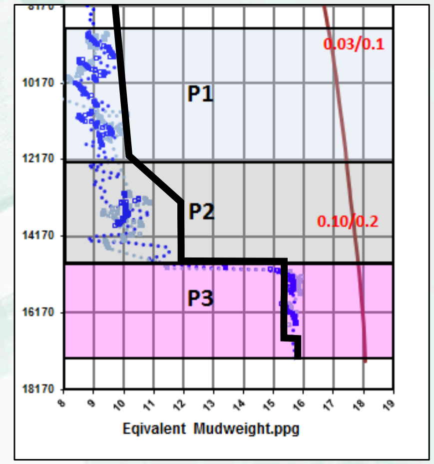
0.7


Effective Stress.psi
Velocity.ft/sec

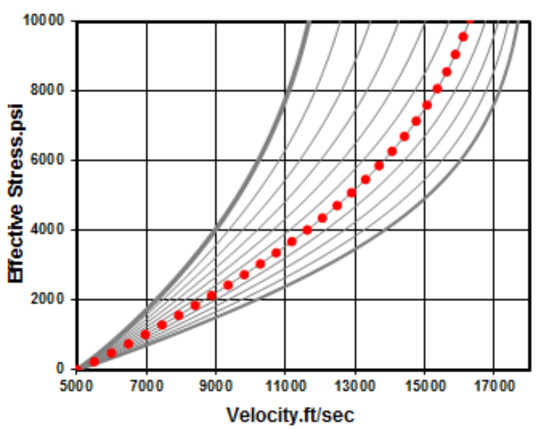

Effective Stress.psi
RHOB.G/CC

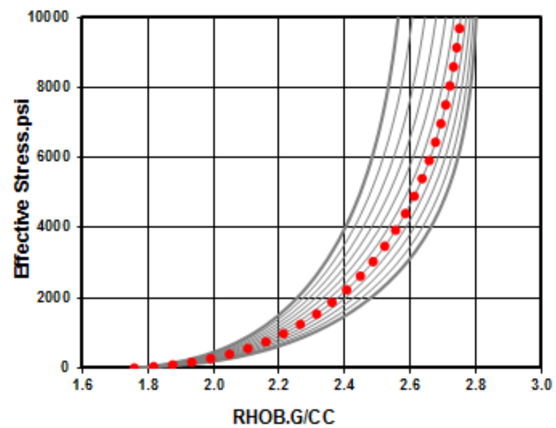

P3
0.60
Rhob.G/C3
dT.us/f

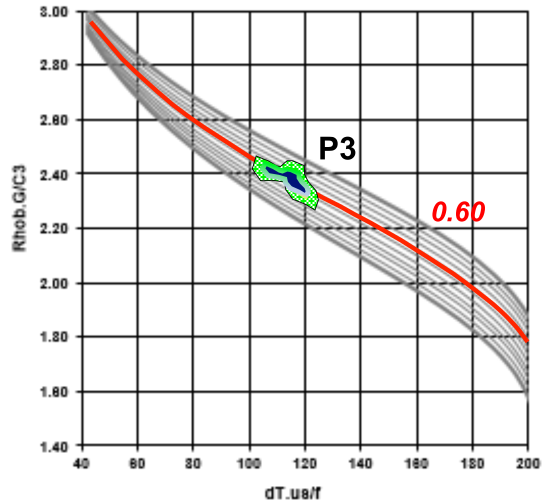

Matthew Czerniak
File
F7
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.60

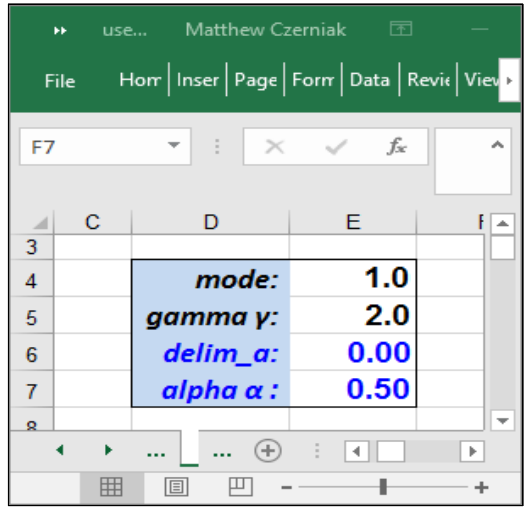

0.03/0.1
P1
P2
0.10/0.2
P3
Eqivalent Mudweight.ppg

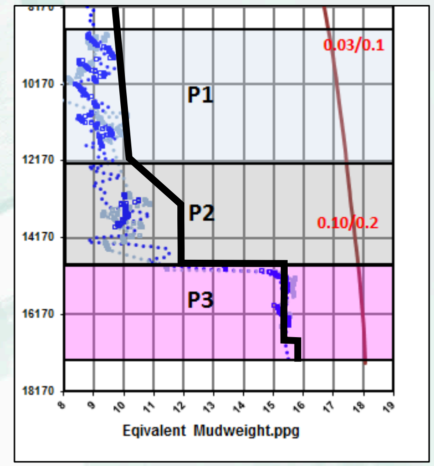
0.6


Effective Stress.psi
Velocity.ft/sec

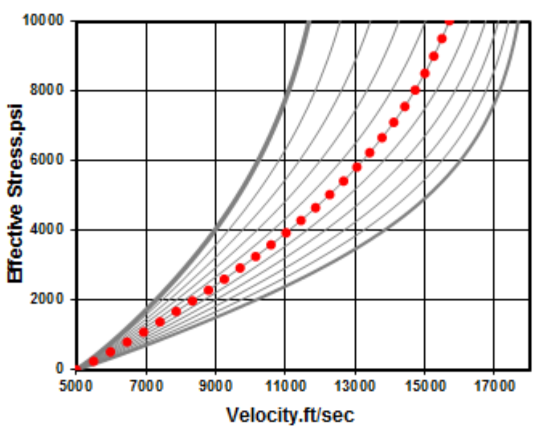

Effective Stress.psi
RHOB.G/CC

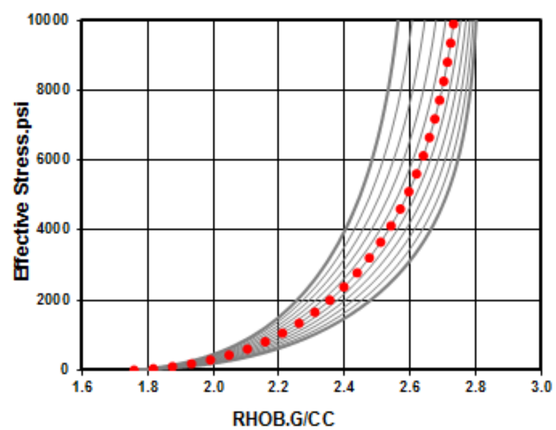

P3
0.60
Rhob.G/C3
dT.us/f

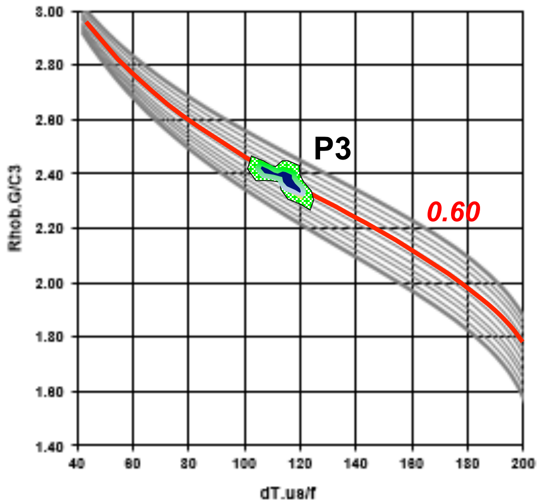

Matthew Czerniak
File
F7
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.50

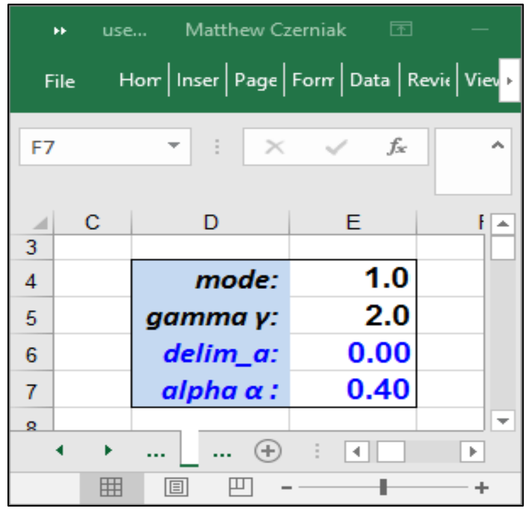

P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

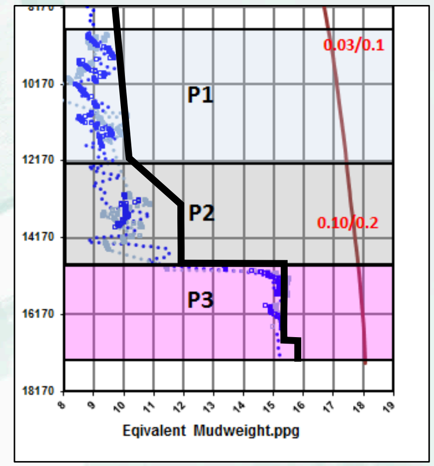
0.5


Effective Stress.psi
Velocity.ft/sec

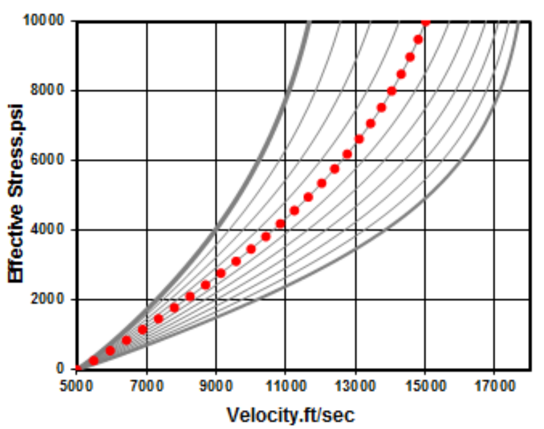

Effective Stress.psi
RHOB.G/CC

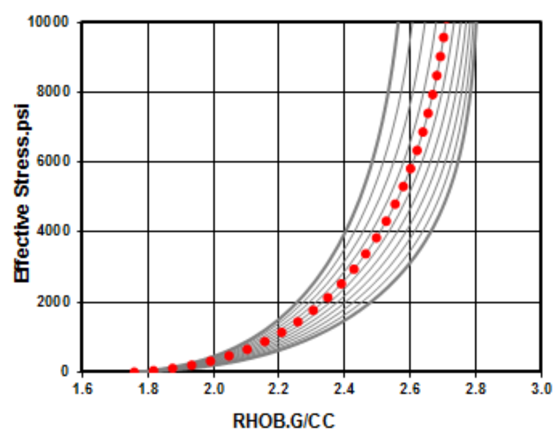

P3
0.60
Rhob.G/C3
dT.us/f
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
40
60
80
100
120
140
160
180
200

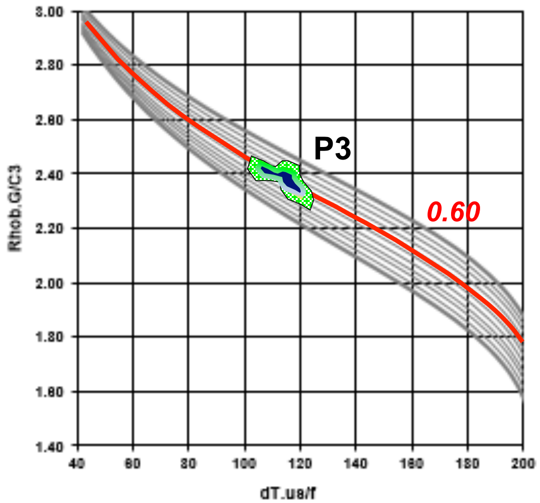

use...
Matthew Czerniak
File
Hom
Inser
Page
Forn
Data
Revie
View
F7
C
D
E
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.40

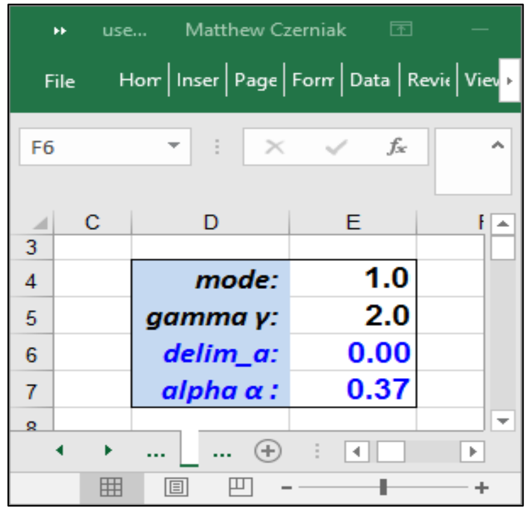

10170
12170
14170
16170
18170
P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

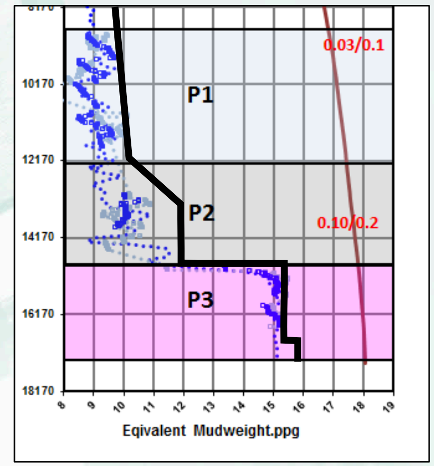
0.4


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

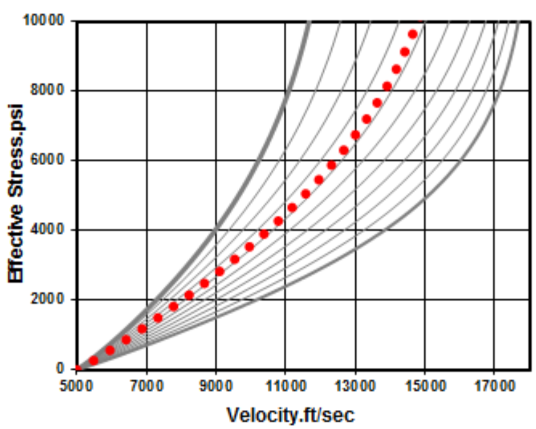

Effective Stress.psi
RHOB.G/CC
0
2000
4000
6000
8000
10000
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0

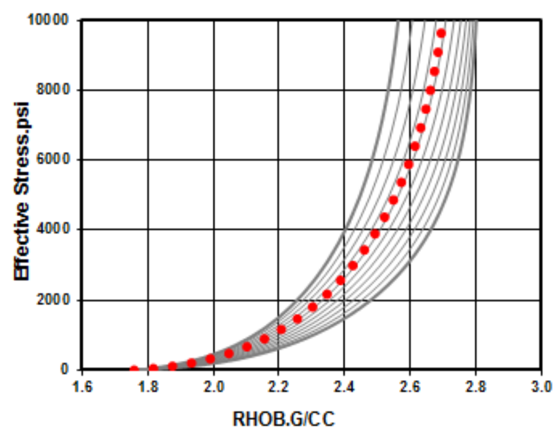

P3
0.60
Rhob.G/C3
dT.us/f


use...
Matthew Czerniak
File
F6
mode: 1.0
gamma γ: 2.0
delim_a: 0.00
alpha α : 0.37


P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

0.37


Effective Stress.psi
Velocity.ft/sec


Effective Stress.psi
RHOB.G/CC

OVERVIEW

INTRODUCTORY DEMO

PREVIOUS WORK - THEORY

- Mechanical vs Chemical Compaction
- Smectite – Illite Conversion

RHOVE METHOD

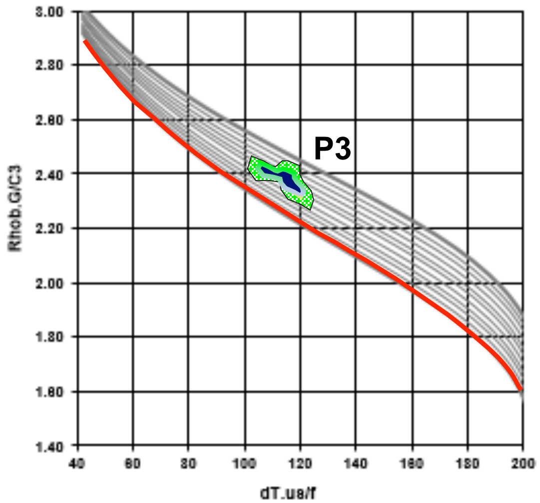
- Summary
- Virtual Model
- Alpha – A-Term
- Shale Discrimination

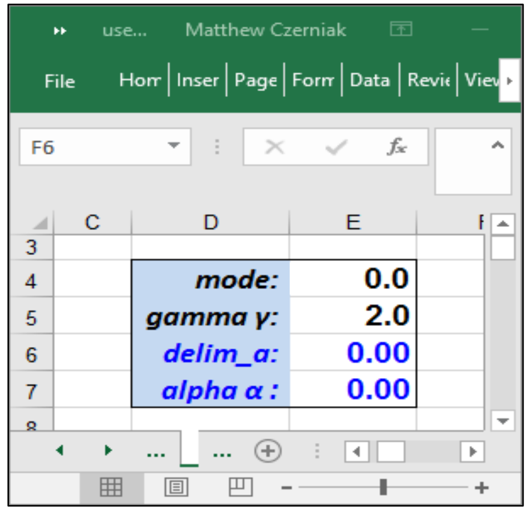
SUMMARY DEMOS

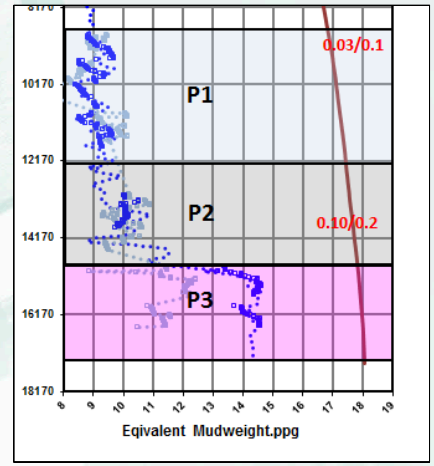
- Untethered Mode
- Tethered Mode

WELL EXAMPLES using RHOVE METHOD

ADVANTAGES of RHOVE Method

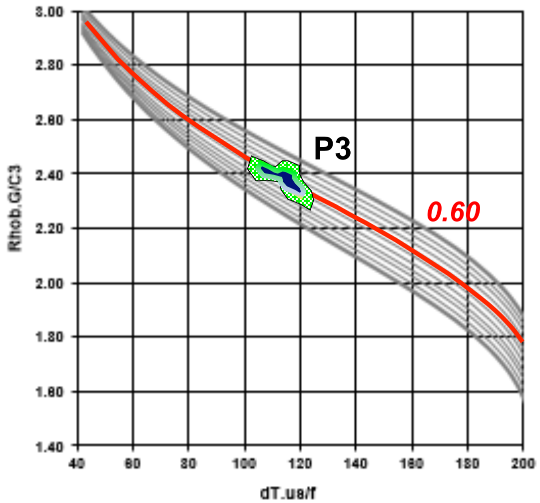


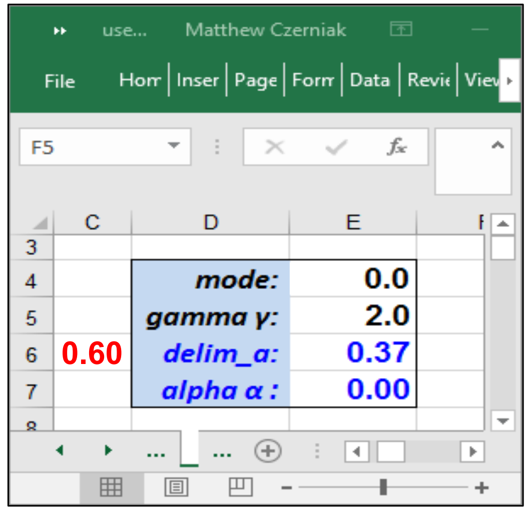


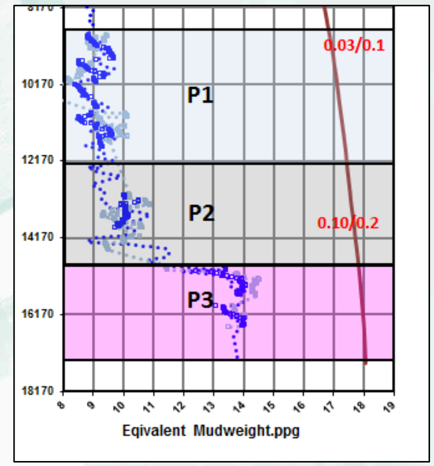


0.0

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

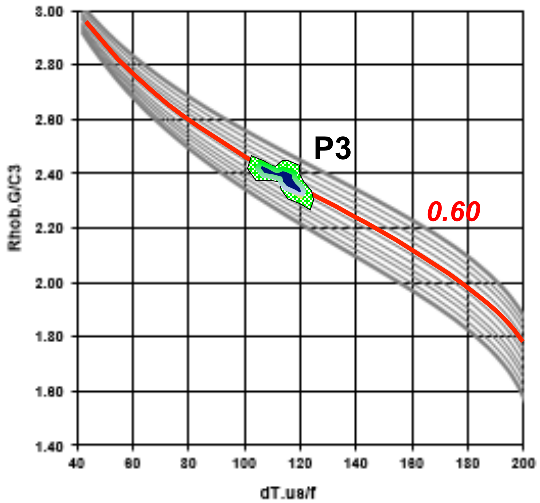


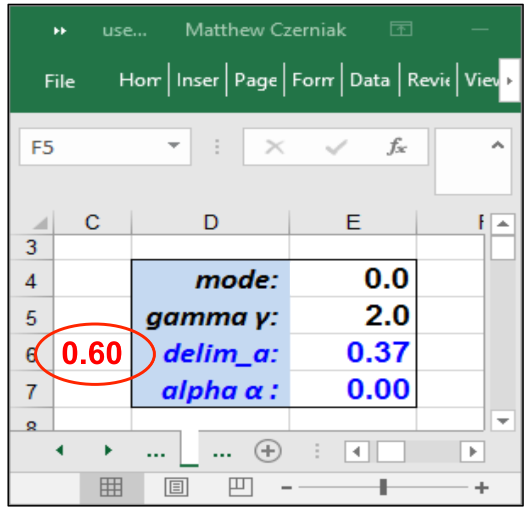


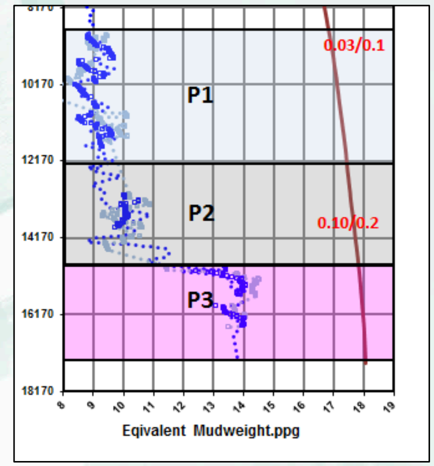


0.0

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

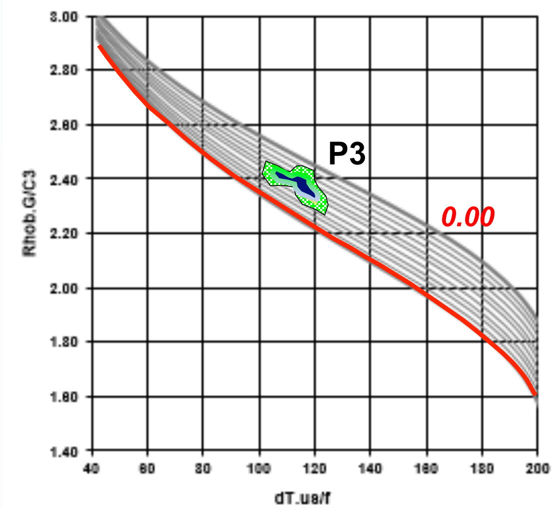


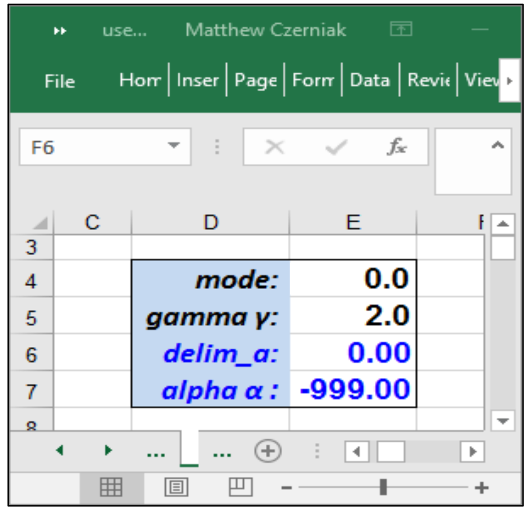




0.0

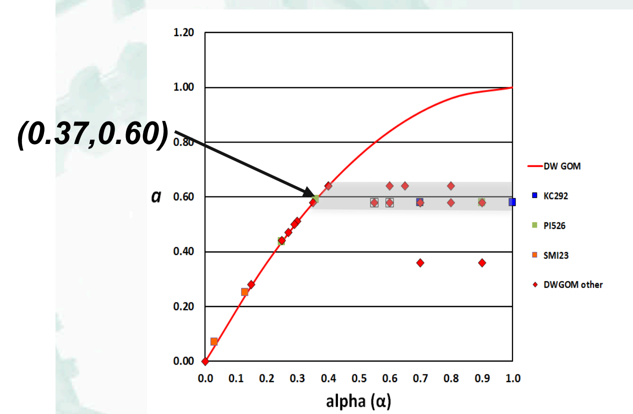
RhoVe interm: *f(α)* * (RhoVE-Ɛ– RhoVE-S) + RhoVE-S

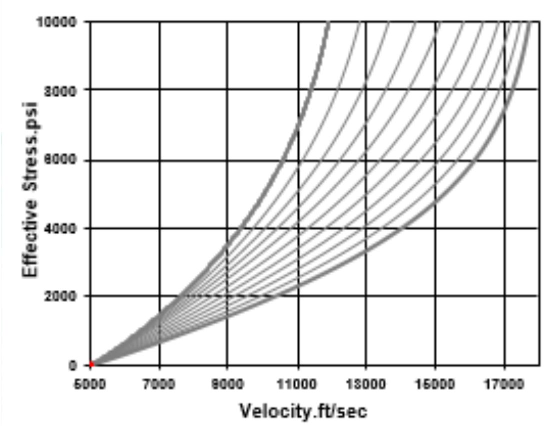


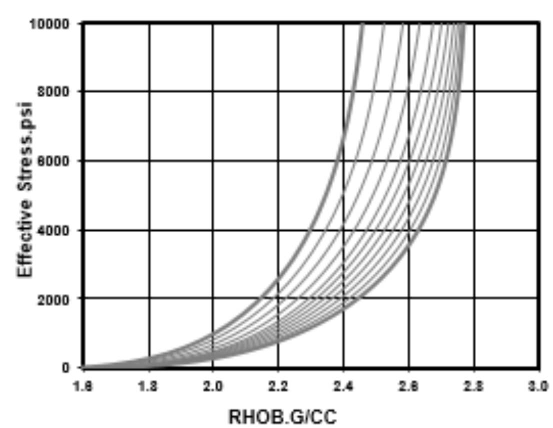


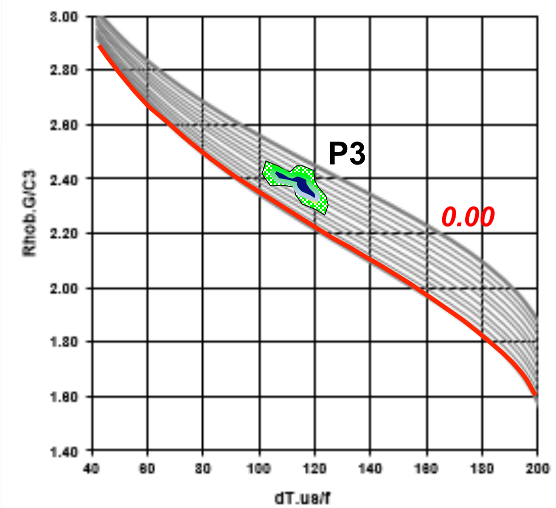
RhoVE interm: $f(\alpha)$ * (RhoVE-ε – RhoVE-S) + RhoVE-S

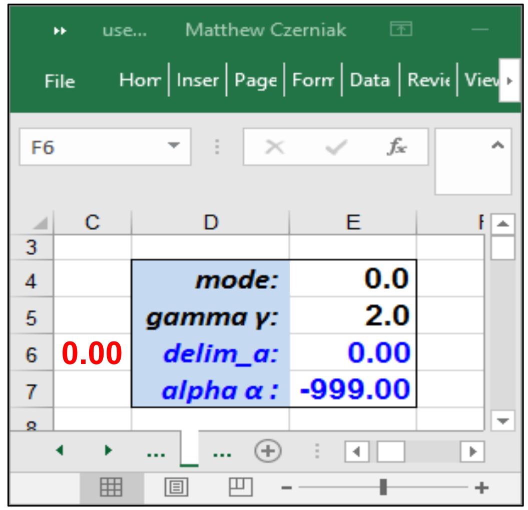
$$a = 2\alpha - \alpha^2$$





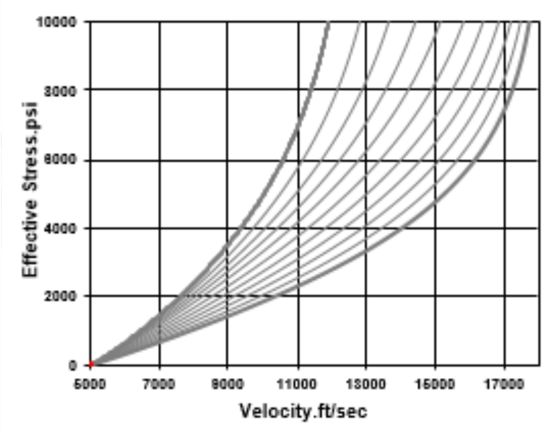


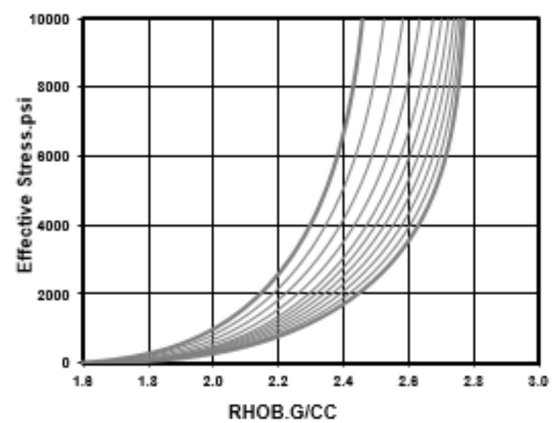




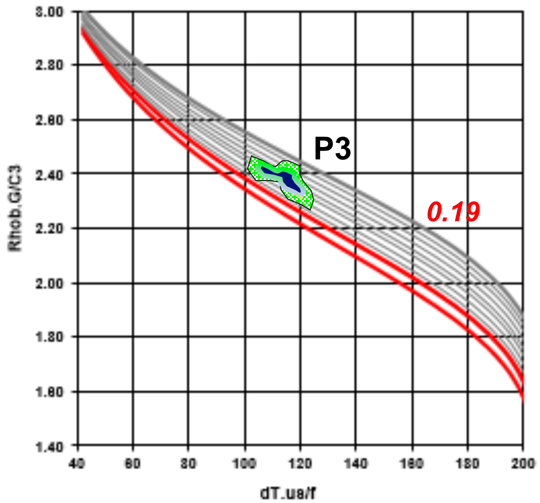
RhoVE interm: ***f*(α)** * (RhoVE-ε – RhoVE-S) + RhoVE-S

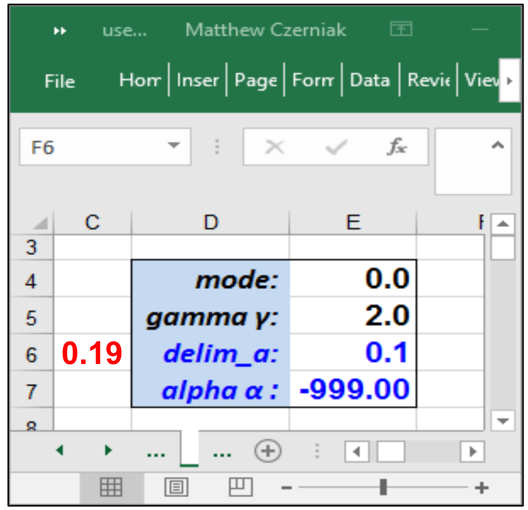
$$a = 2\alpha - \alpha^2$$





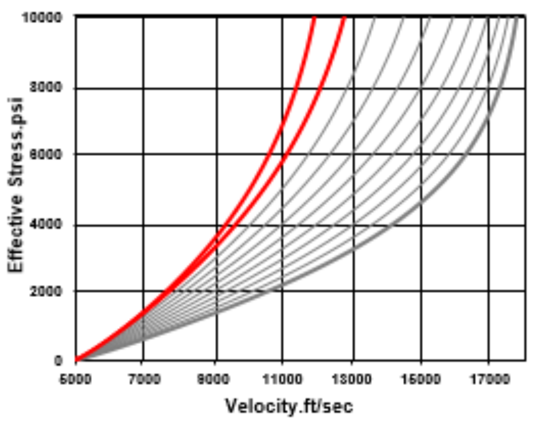
0.0

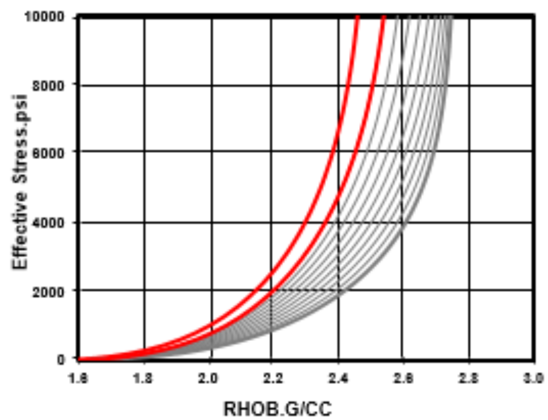




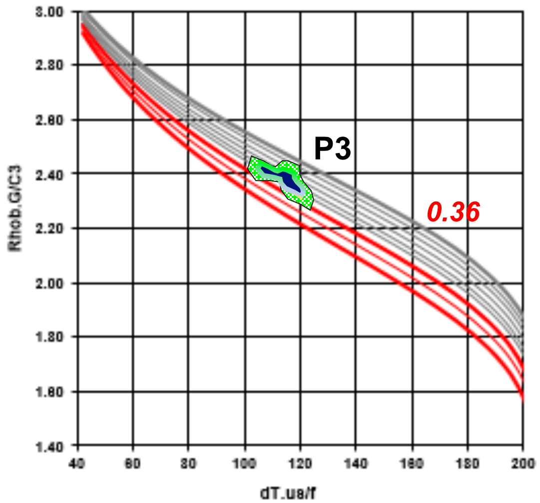
RhoVE interm: *f*(α) * (RhoVE-ε – RhoVE-S) + RhoVE-S

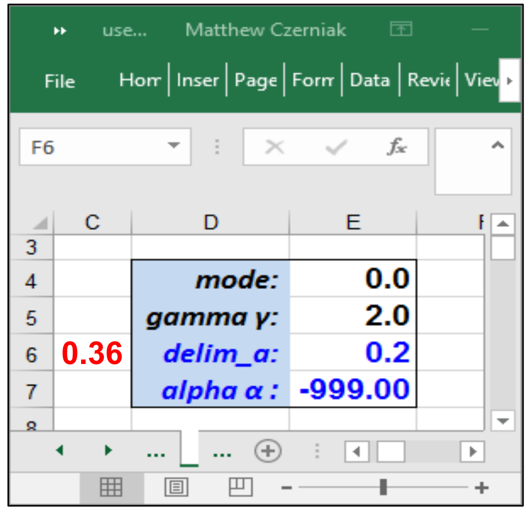
$$a = 2\alpha - \alpha^2$$





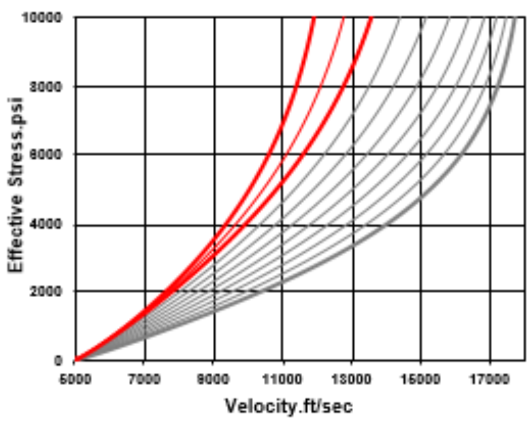
0.0

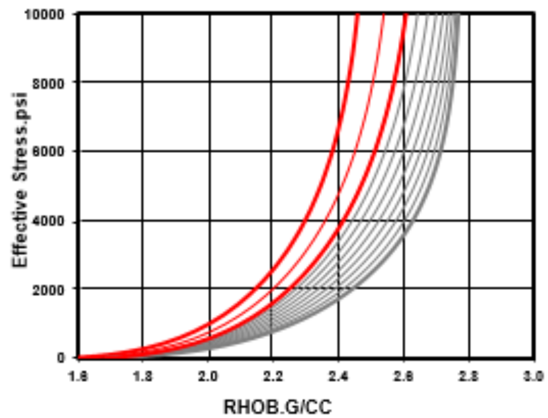




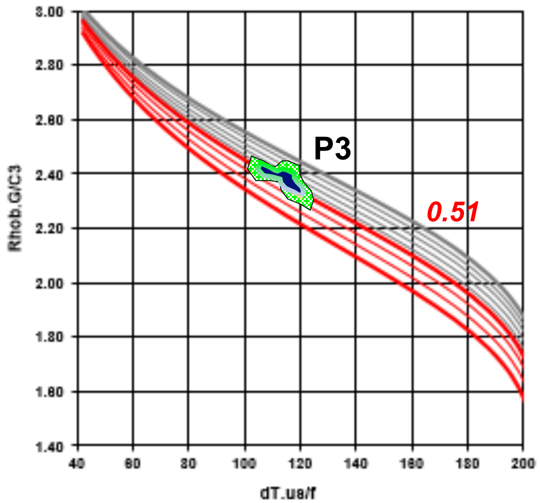
RhoVE interm: *f*(α) * (RhoVE-ε – RhoVE-S) + RhoVE-S

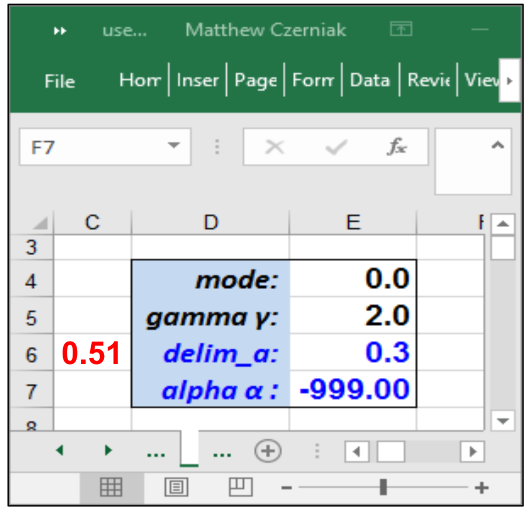
$$a = 2\alpha - \alpha^2$$





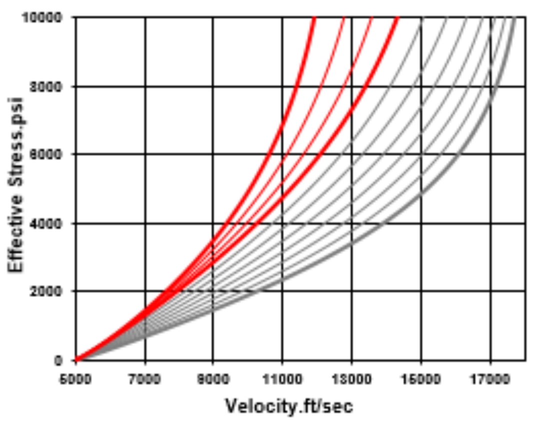
0.0

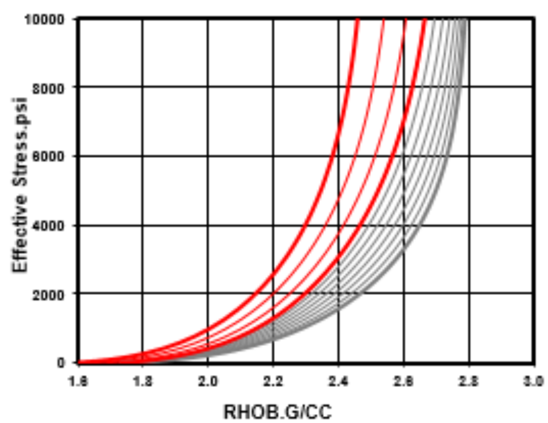




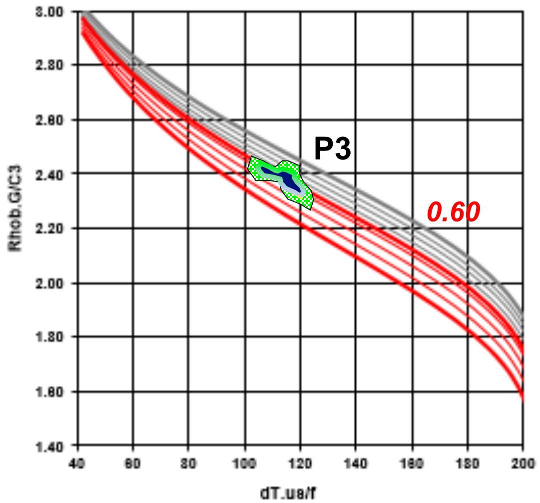
RhoVE interm: ***f*(α)** * (RhoVE-ε – RhoVE-S) + RhoVE-S

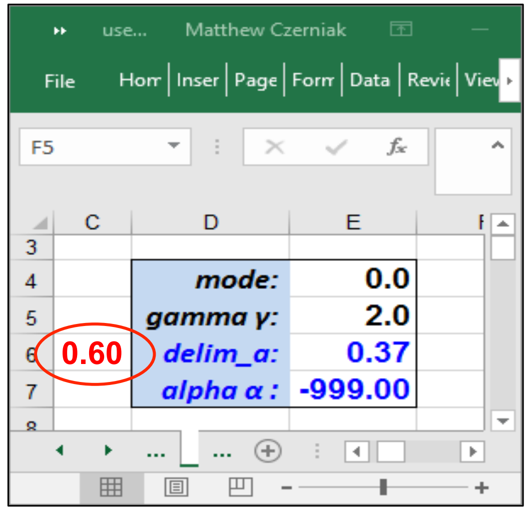
$$a = 2\alpha - \alpha^2$$





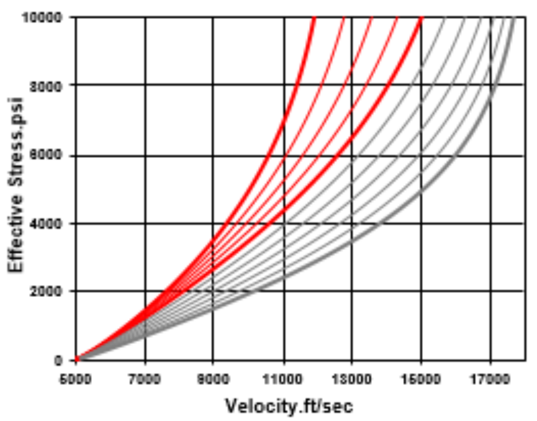
0.0

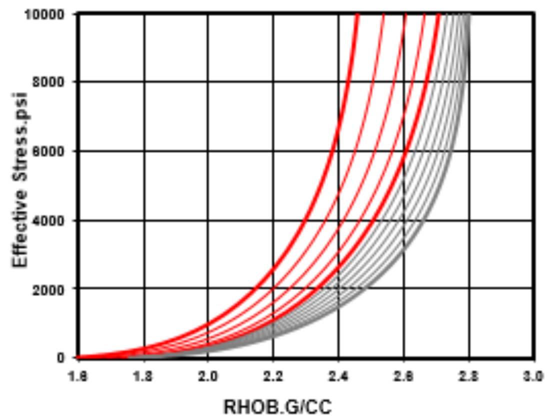




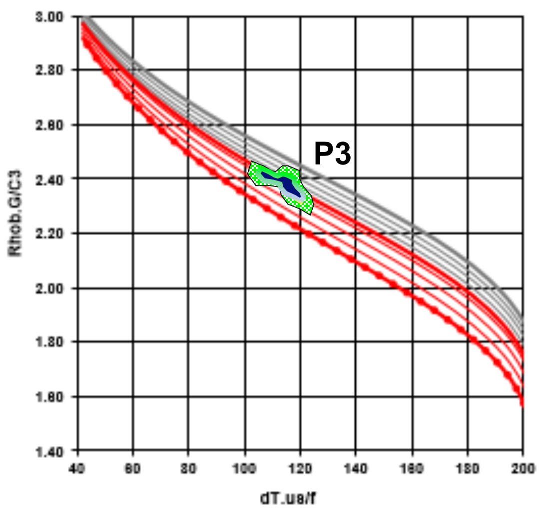
RhoVE interm: ***f*(α)** * (RhoVE-ε – RhoVE-S) + RhoVE-S

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

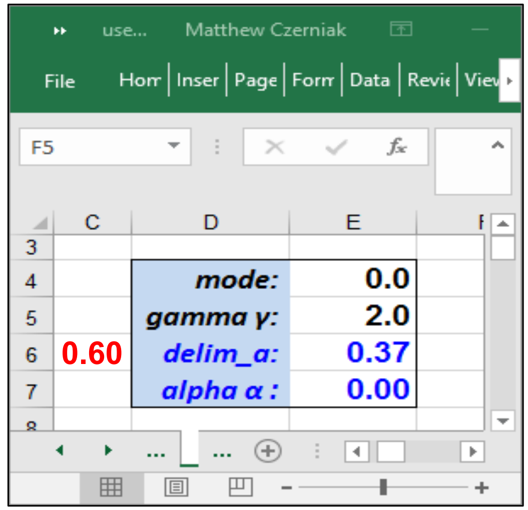




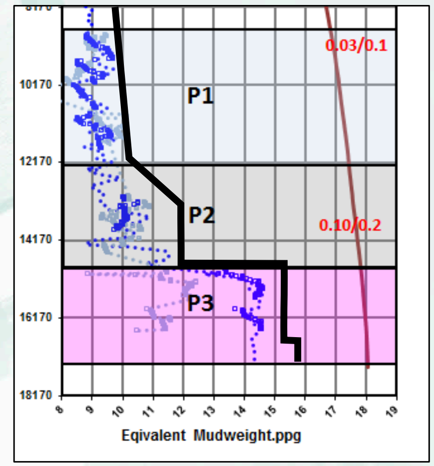
0.0



P3
Rhob.G/C3
dT.us/f

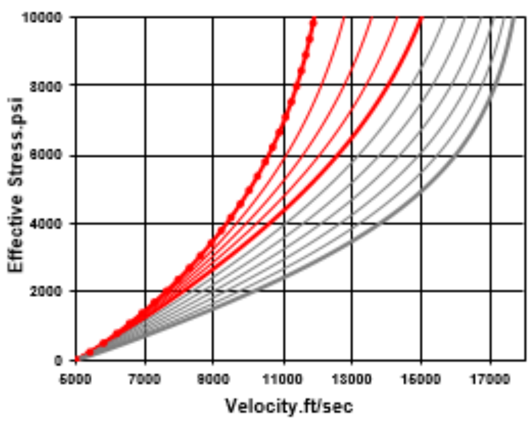


use... Matthew Czerniak
File Hom Inser Page Form Data Revie View
F5
C D E
mode: 0.0
gamma γ: 2.0
0.60 delim_a: 0.37
alpha α : 0.00

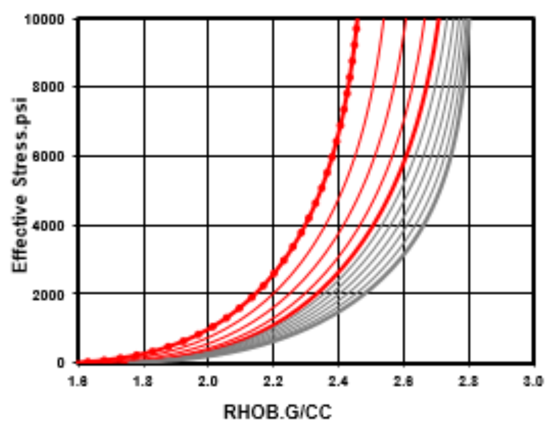


P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

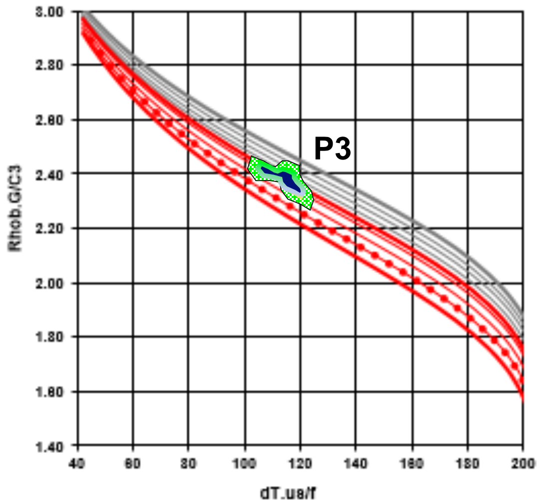
0.0

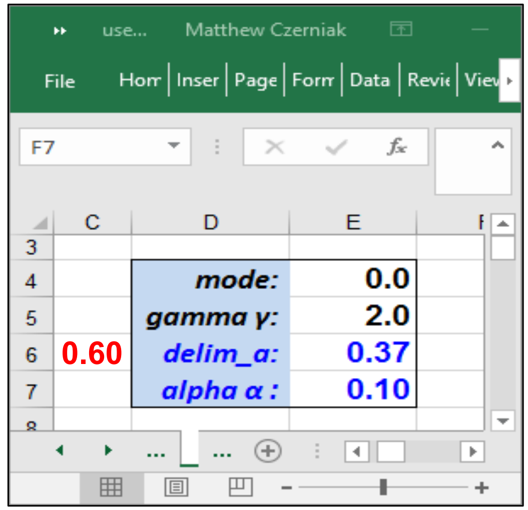


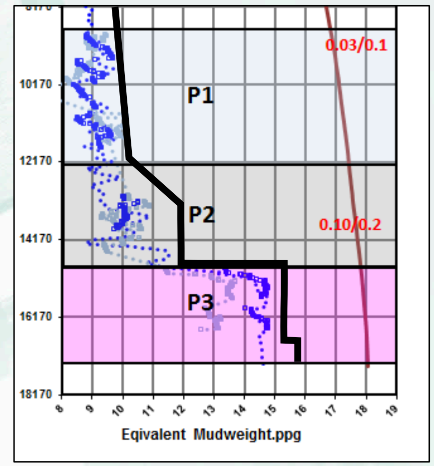
Effective Stress.psi
Velocity.ft/sec

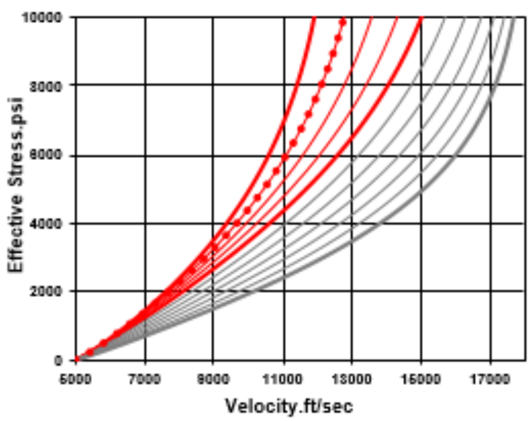


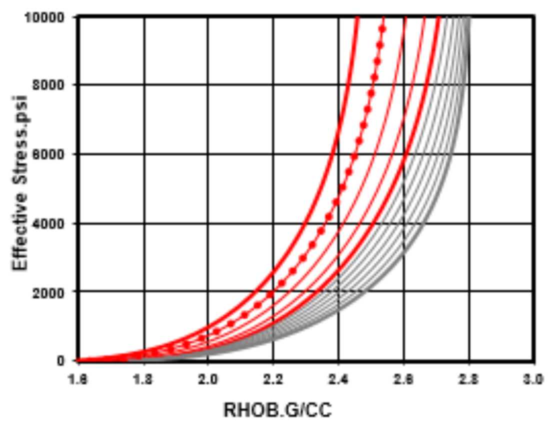
Effective Stress.psi
RHOB.G/CC


P3
Rhob.G/C3
dT.us/f

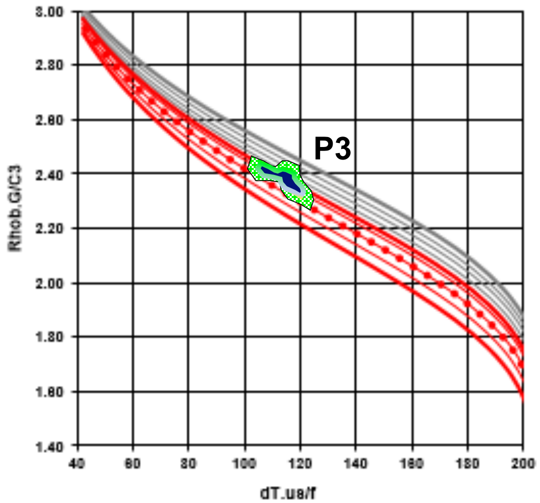

use...
Matthew Czerniak
File
Hom
Inser
Page
Form
Data
Revie
View
F7
C
D
E
mode: 0.0
gamma γ: 2.0
0.60
delim_a: 0.37
alpha α : 0.10

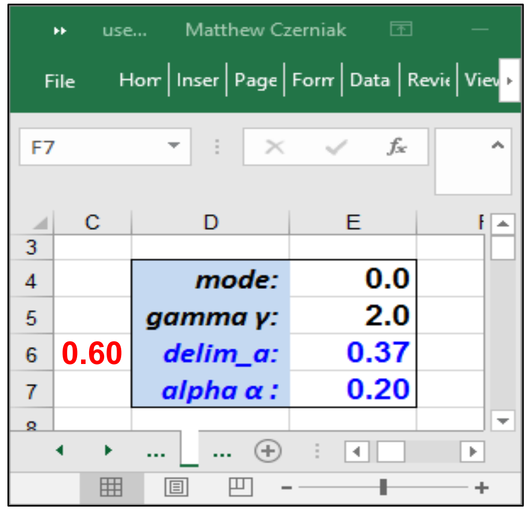

0.03/0.1
P1
P2
0.10/0.2
P3
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

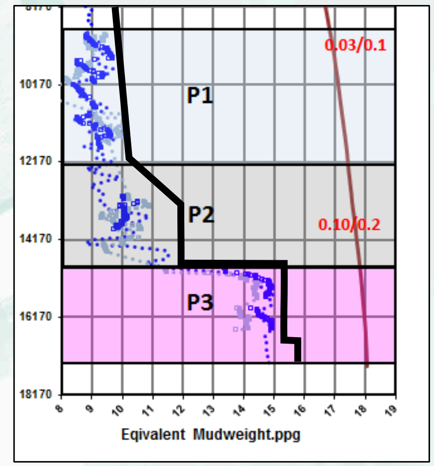

Effective Stress.psi
Velocity.ft/sec


Effective Stress.psi
RHOB.G/CC

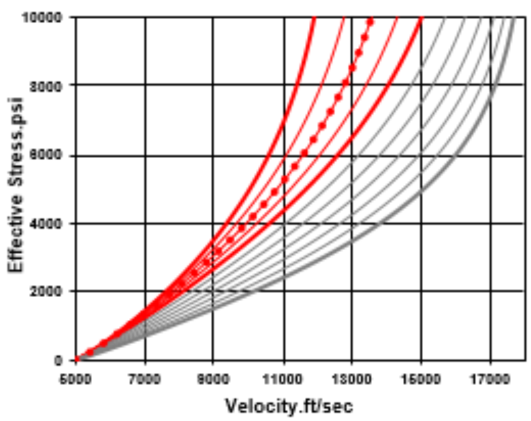
0.1

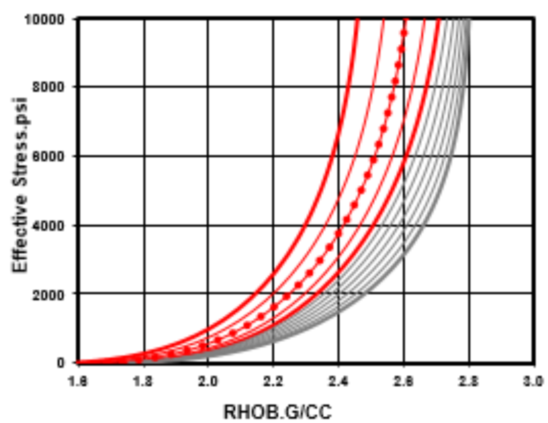

P3
Rhob.G/C3
dT.us/f

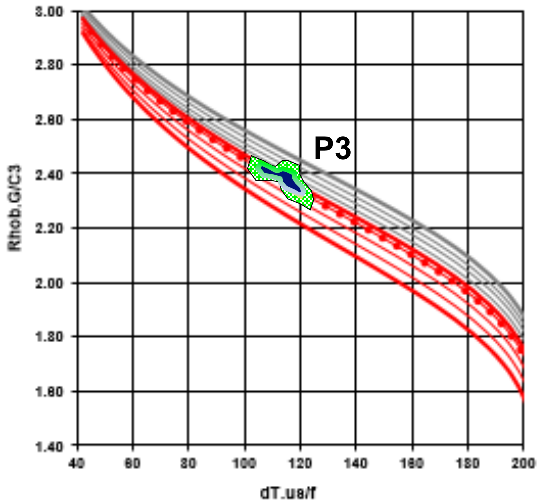

use... Matthew Czerniak
File Hom Inser Page Forr Data Revie View
F7
mode: 0.0
gamma γ: 2.0
0.60 delim_a: 0.37
alpha α : 0.20

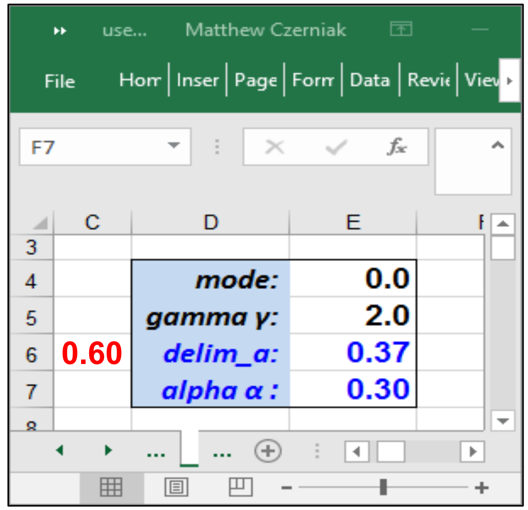

P1
P2
P3
0.03/0.1
0.10/0.2
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

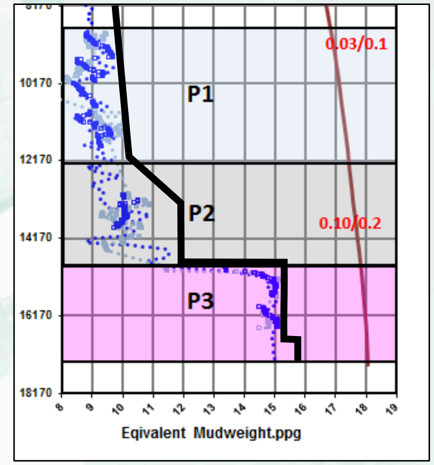
0.2


Effective Stress.psi
Velocity.ft/sec

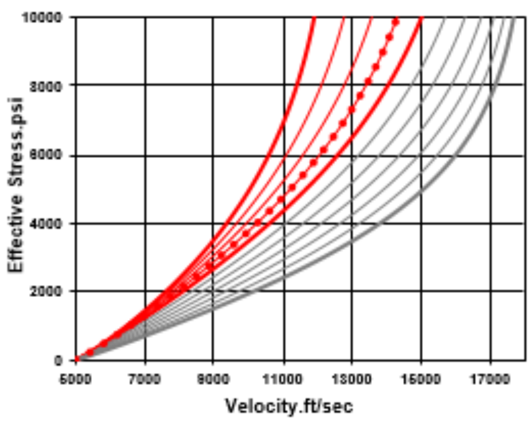

Effective Stress.psi
RHOB.G/CC

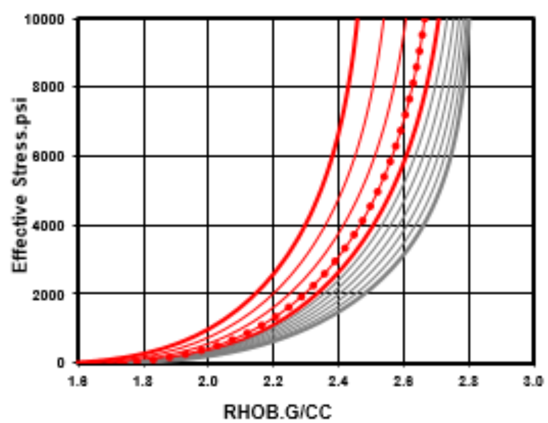

P3
Rhob.G/C3
dT.us/f

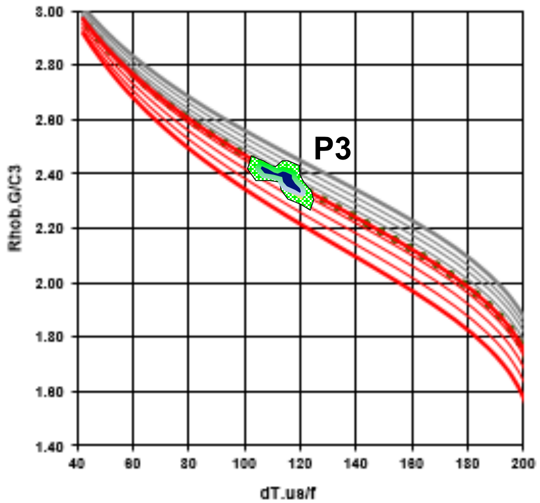

use...
Matthew Czerniak
File
Hom
Inser
Page
Form
Data
Revie
View
F7
C
D
E
mode: 0.0
gamma γ: 2.0
0.60
delim_a: 0.37
alpha α : 0.30

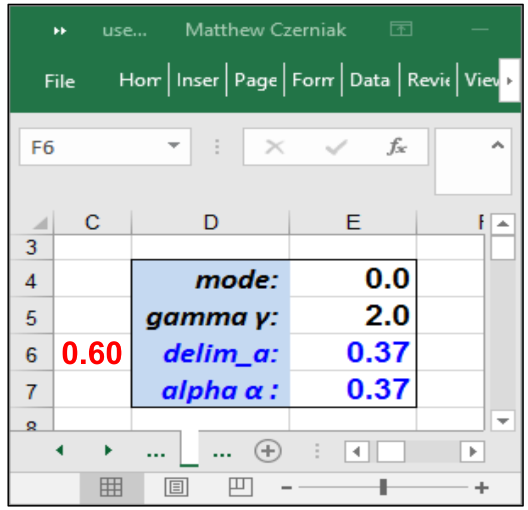

0.03/0.1
P1
P2
0.10/0.2
P3
Eqivalent Mudweight.ppg

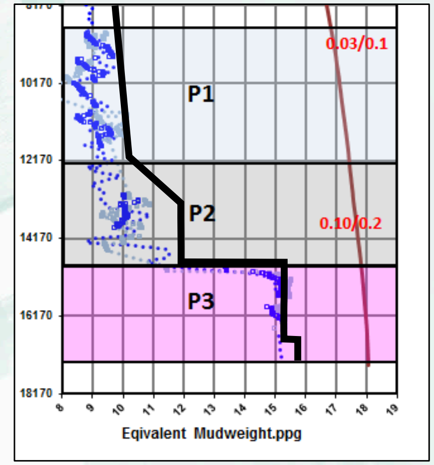
0.3


Effective Stress.psi
Velocity.ft/sec

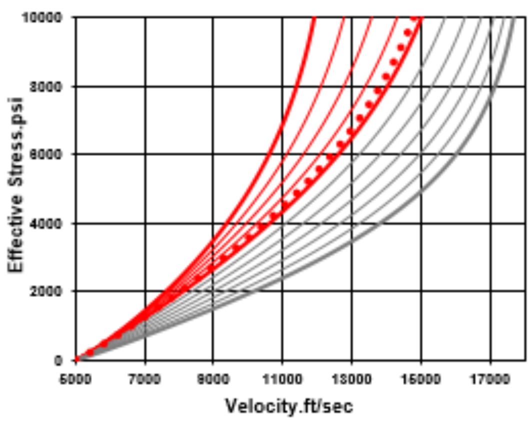

Effective Stress.psi
RHOB.G/CC

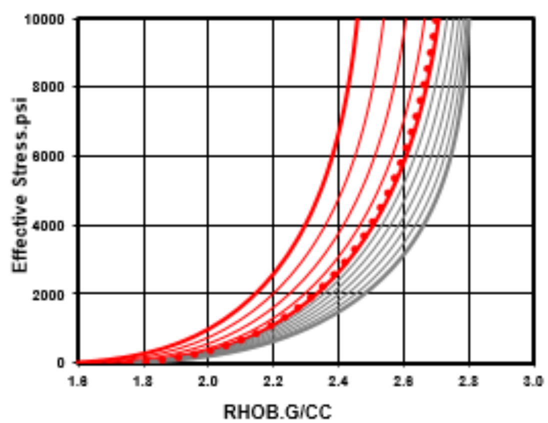

P3
Rhob.G/C3
dT.us/f

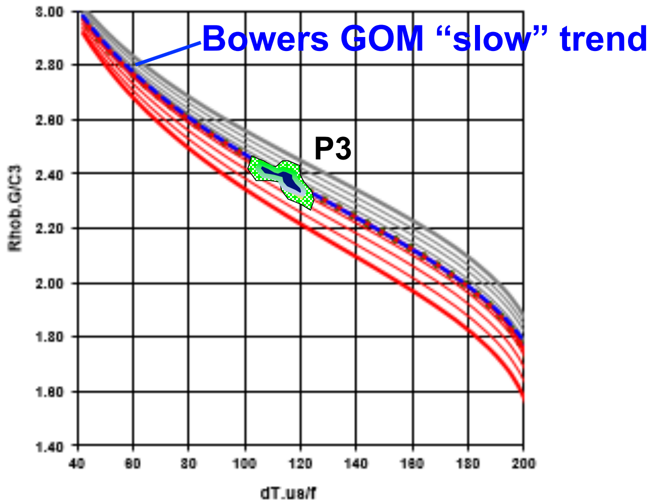

use...
Matthew Czerniak
File
Hom
Inser
Page
Form
Data
Revie
View
F6
C
D
E
mode: 0.0
gamma γ: 2.0
0.60
delim_a: 0.37
alpha α : 0.37

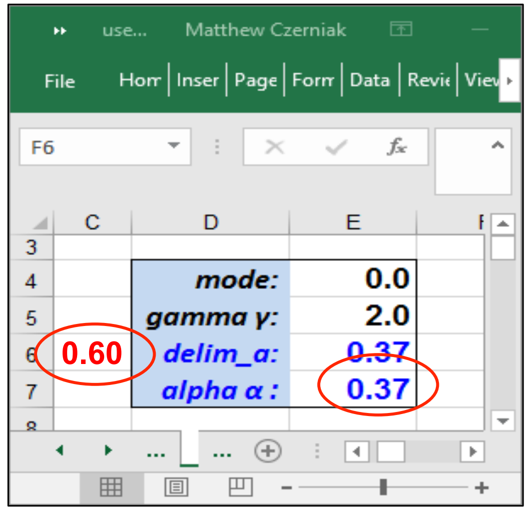

0.03/0.1
P1
P2
0.10/0.2
P3
10170
12170
14170
16170
18170
Eqivalent Mudweight.ppg

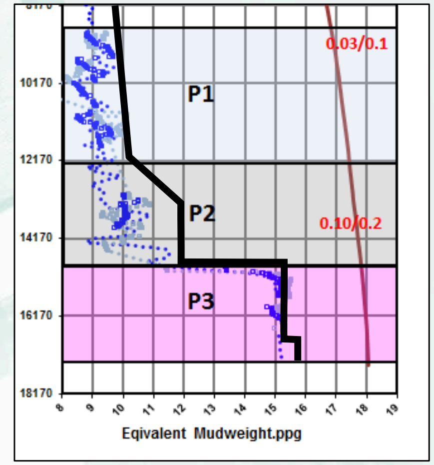
0.37


Effective Stress.psi
Velocity.ft/sec

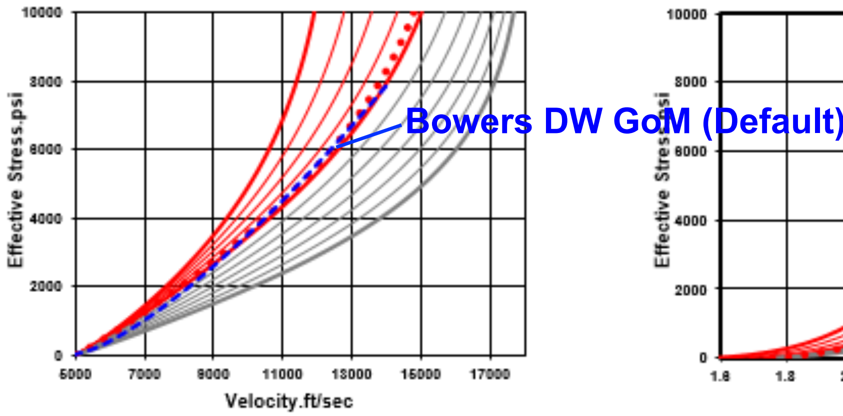

Effective Stress.psi
RHOB.G/CC

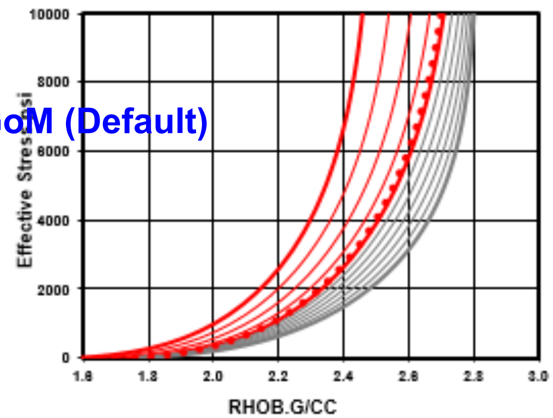

Bowers GOM "slow" trend
P3
Rhob.G/C3
dT.us/f


use...
Matthew Czerniak
File
F6
mode: 0.0
gamma γ: 2.0
0.60
delim_α: 0.37
alpha α : 0.37


P1
P2
P3
0.03/0.1
0.10/0.2
Eqivalent Mudweight.ppg

0.37


Bowers DW GoM (Default)
Effective Stress.psi
Velocity.ft/sec


RHOB.G/CC

OVERVIEW

INTRODUCTORY DEMO

PREVIOUS WORK - THEORY

- Mechanical vs Chemical Compaction
- Smectite – Illite Conversion

RHOVE METHOD

- Summary
- Virtual Model
- Alpha – A-Term
- Shale Discrimination

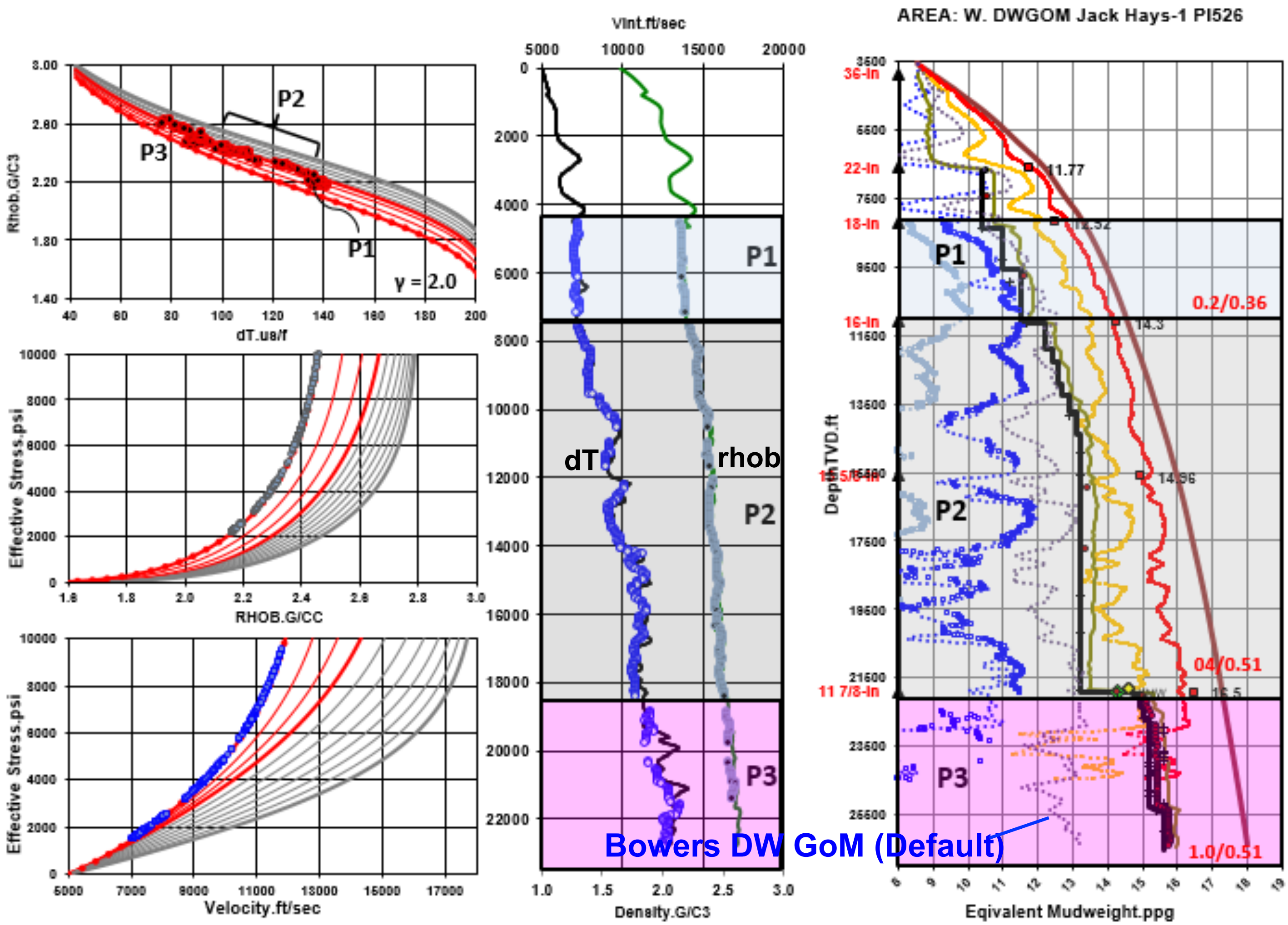
SUMMARY DEMOS

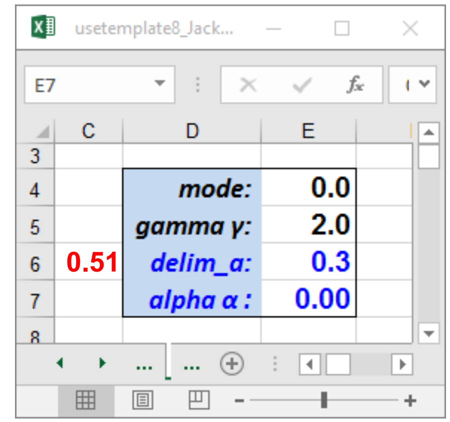
- Untethered Mode
- Tethered Mode

WELL EXAMPLES using RHOVE METHOD

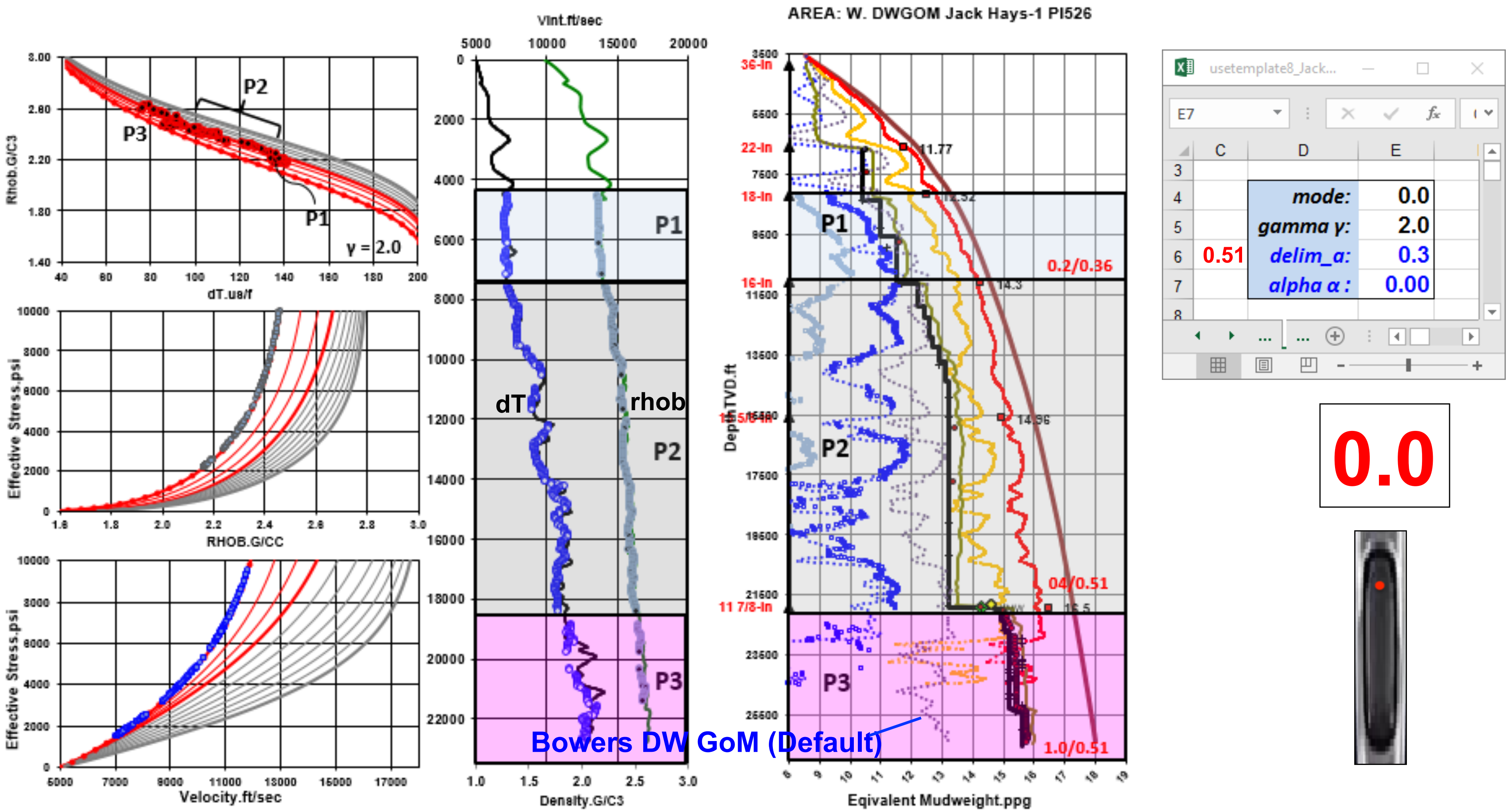
ADVANTAGES of RHOVE Method

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

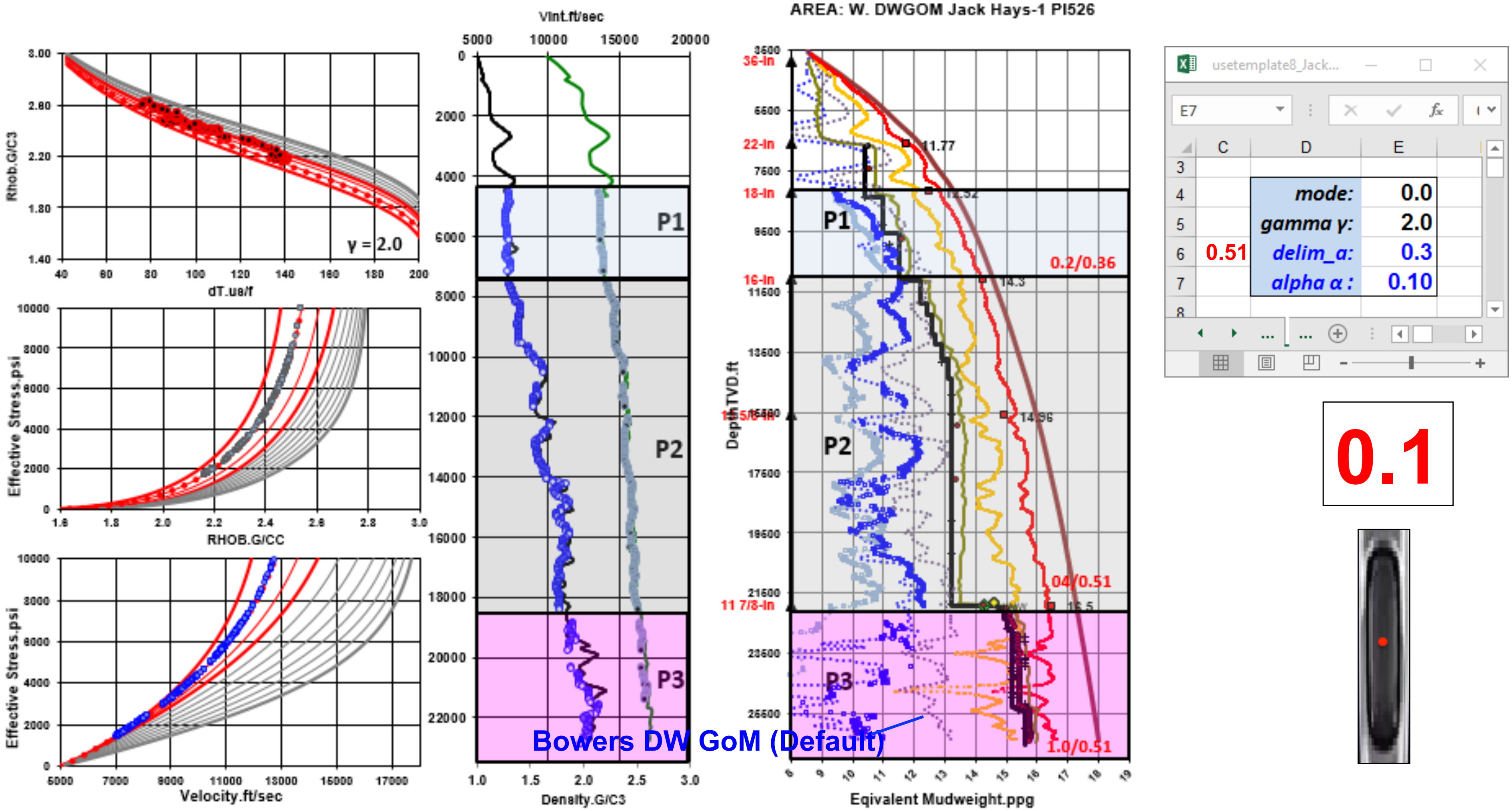

AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
P1
P2
P3
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
dT
rhob
Bowers DW GoM (Default)
DepthTVD.ft
36-In
22-In
18-In
16-In
11 7/8-In
11.77
14.3
14.96
15.5
0.2/0.36
04/0.51
1.0/0.51
Eqivalent Mudweight.ppg


usetemplate8_Jack...
E7
C
D
E
mode:
0.0
gamma γ:
2.0
0.51
delim_a:
0.3
alpha α :
0.00

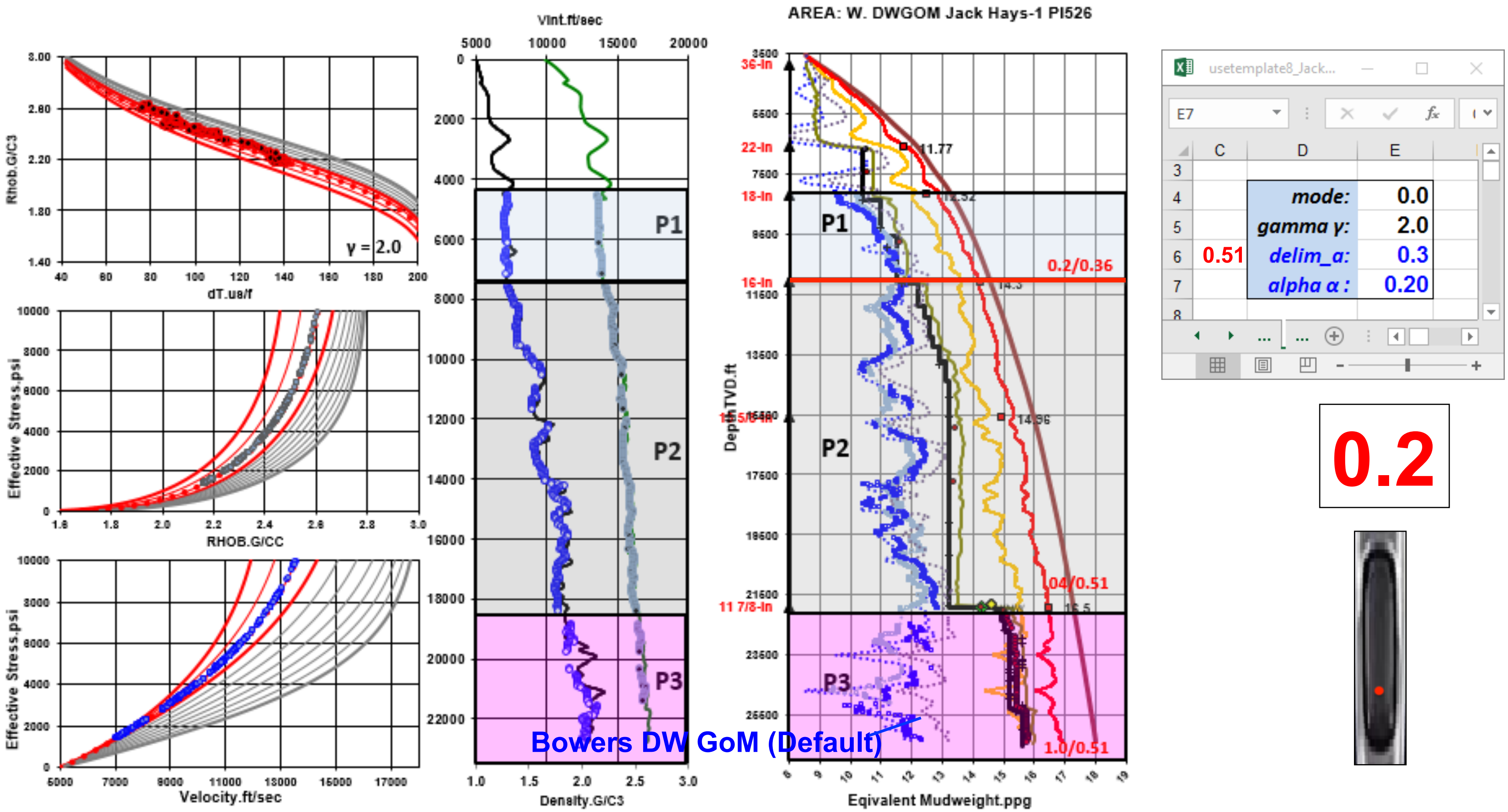
0.0



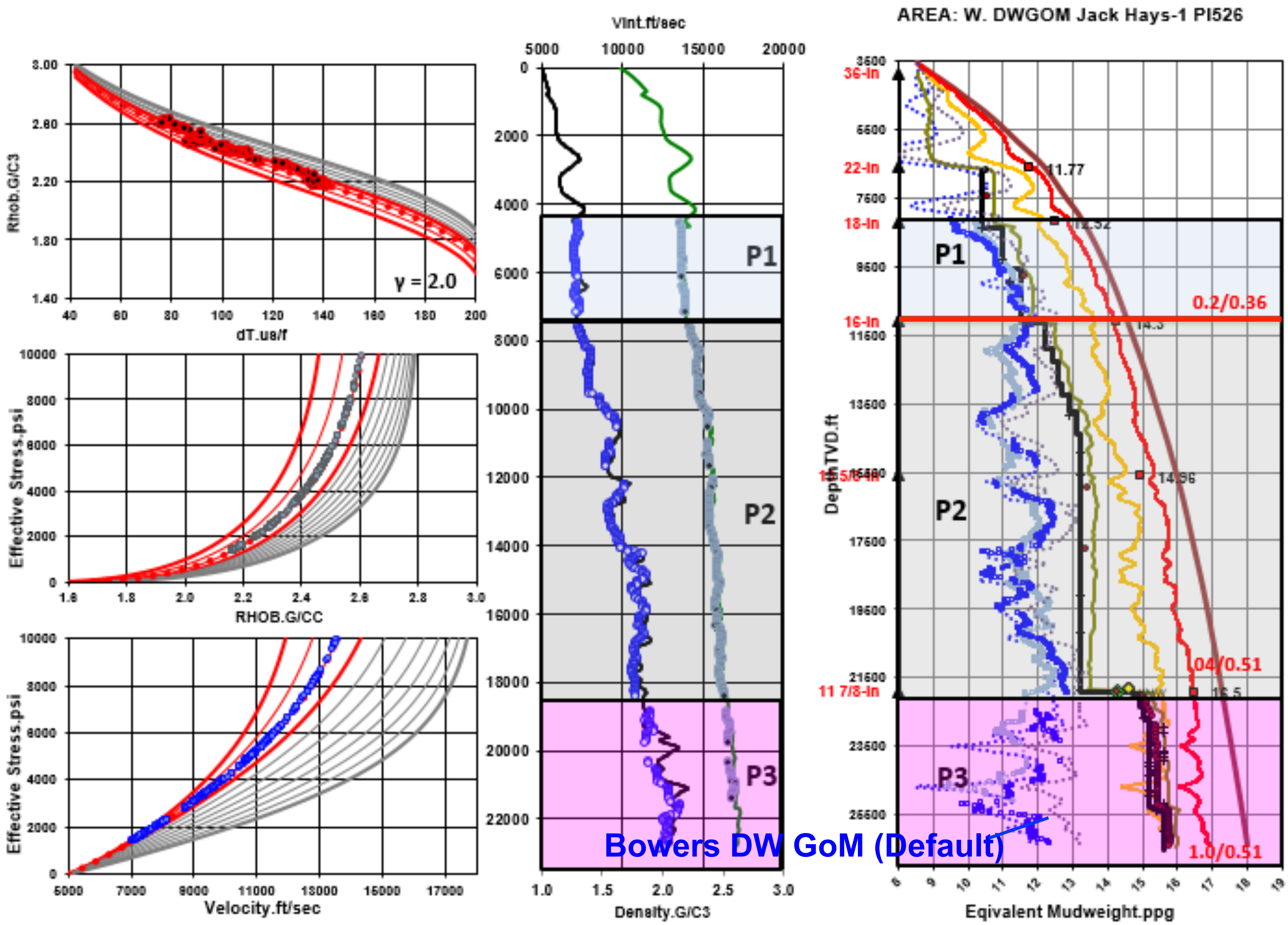
AREA: W. DWGOM Jack Hays-1 PI526
Vint.ft/sec
Rhob.G/C3
dT.us/f
P1
P2
P3
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
dT
rhob
Density.G/C3
DepthTVD.ft
Eqivalent Mudweight.ppg
36-In
22-In
18-In
16-In
11 7/8-In
0.2/0.36
04/0.51
1.0/0.51
Bowers DW GoM (Default)
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
delim_a: 0.3
alpha α : 0.00
0.51
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
36-In
22-In
18-In
16-In
11 7/8-In
Depth TVD.ft
11.77
14.3
14.96
15.5
0.2/0.36
04/0.51
1.0/0.51
Bowers DW GoM (Default)
Eqivalent Mudweight.ppg
usetemplate8_Jack...
E7
mode:
0.0
gamma γ:
2.0
0.51
delim_a:
0.3
alpha α :
0.10

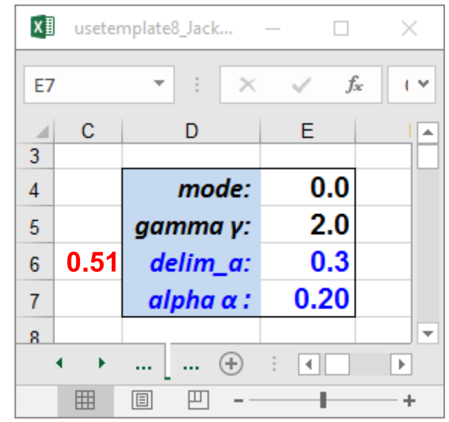
0.1



AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
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
0.2/0.36
14.96
04/0.51
1.0/0.51
usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.20
0.2

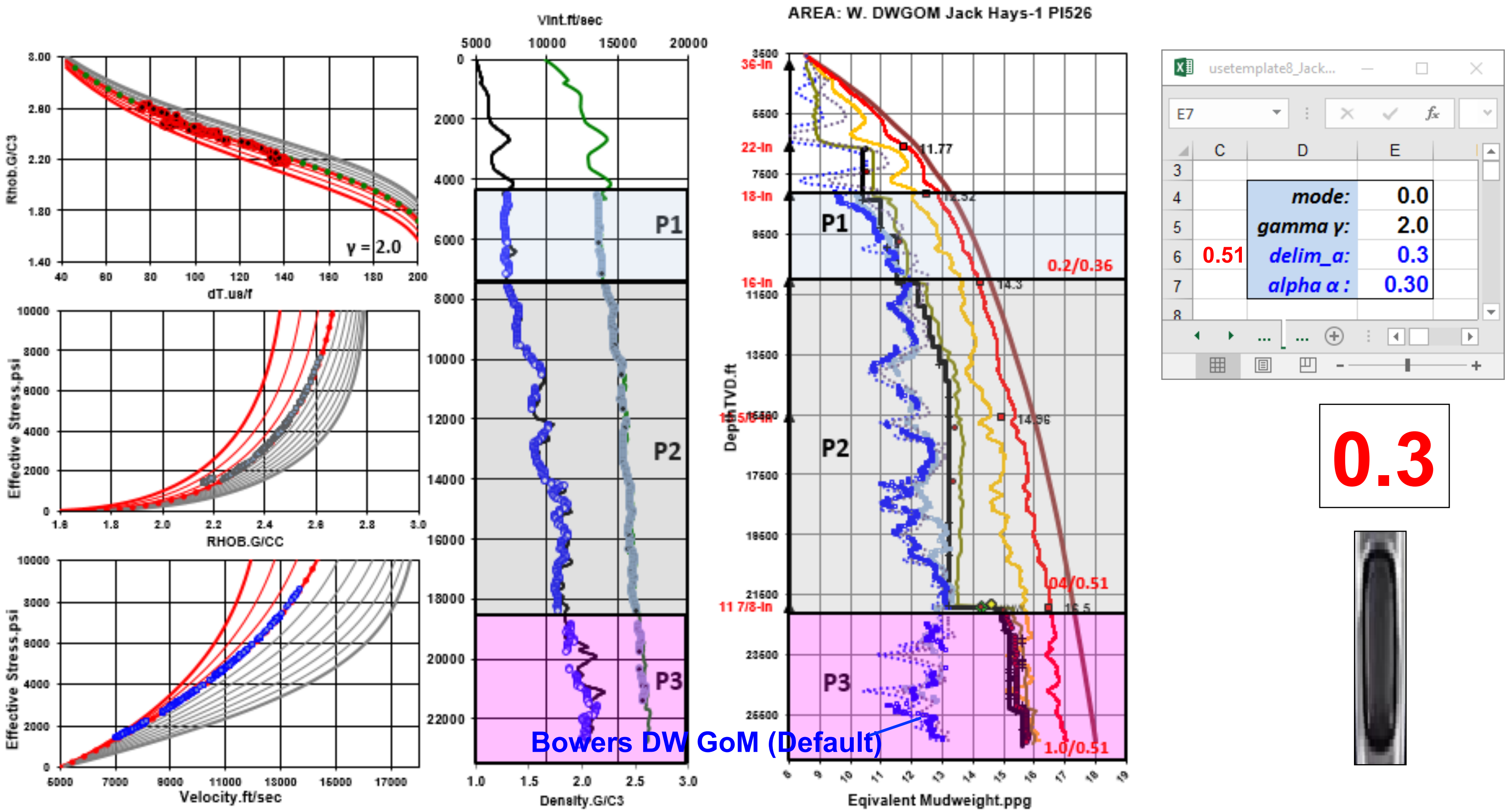


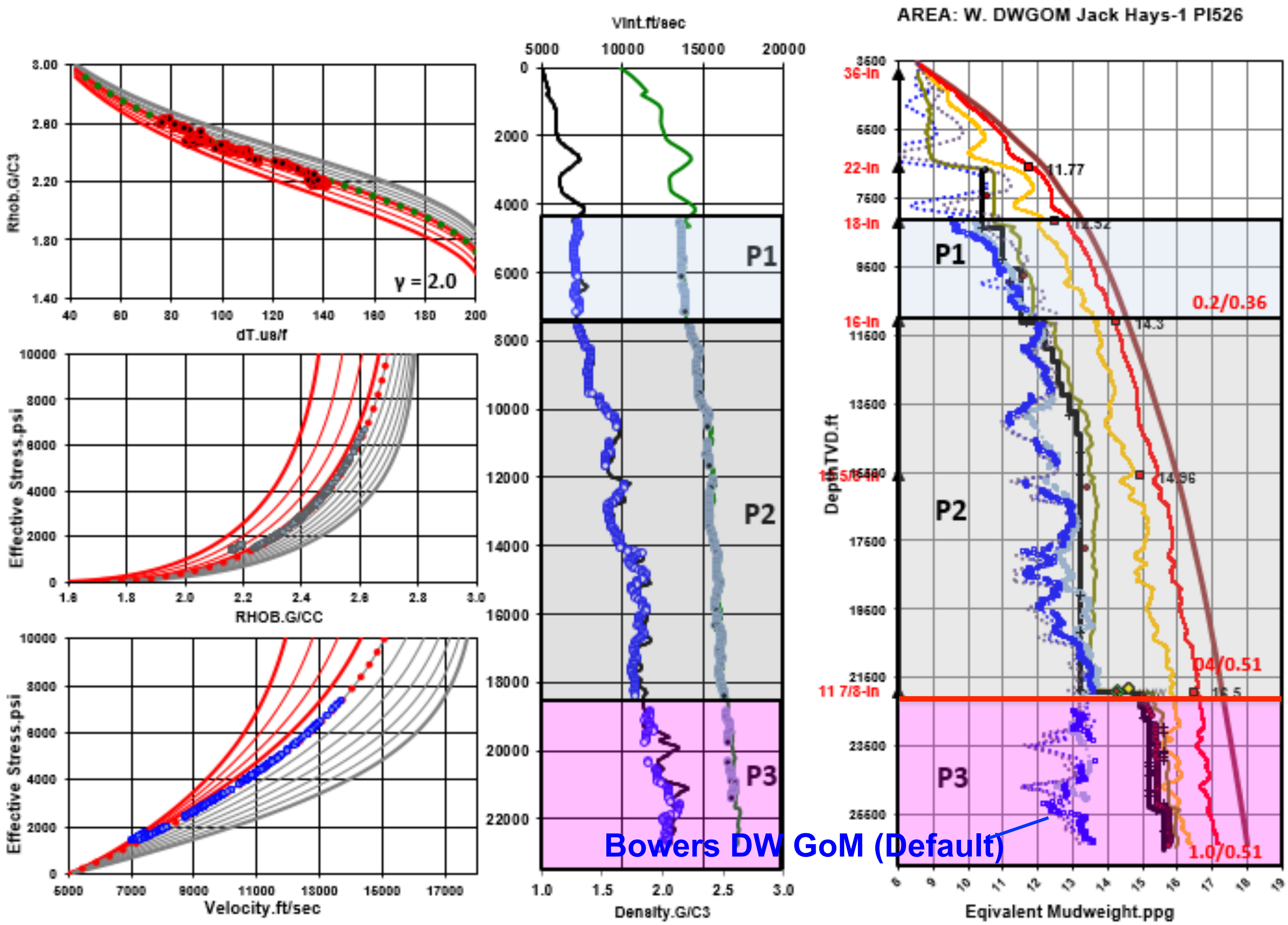
AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
DepthTVD.ft
36-In
22-In
18-In
16-In
11 7/8-In
11.77
14.96
0.2/0.36
04/0.51
1.0/0.51
Eqivalent Mudweight.ppg
Bowers DW GoM (Default)

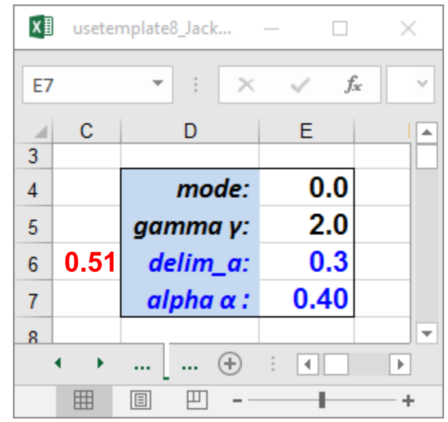


usetemplate8_Jack...
E7
C
D
E
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.20

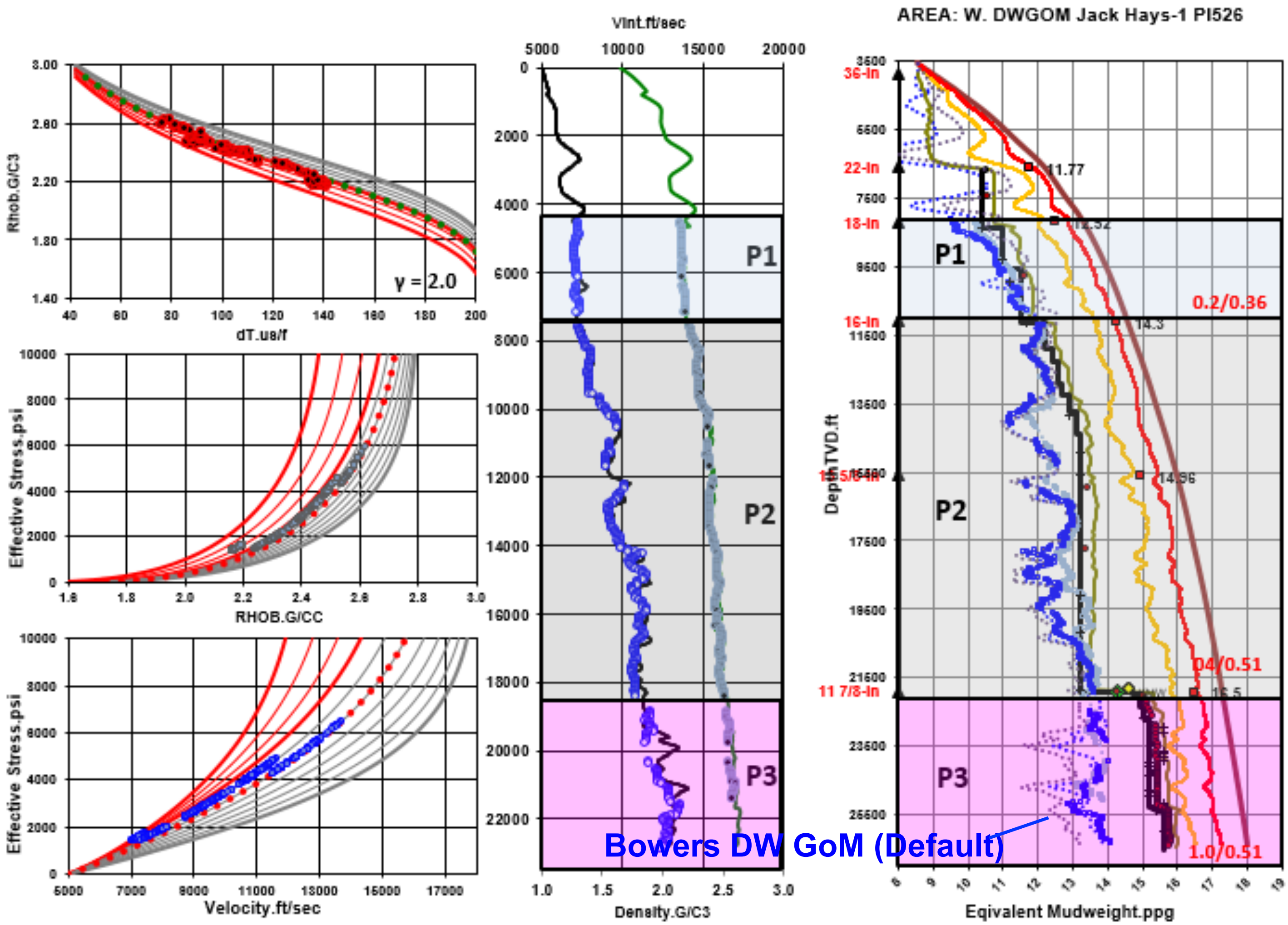
0.2

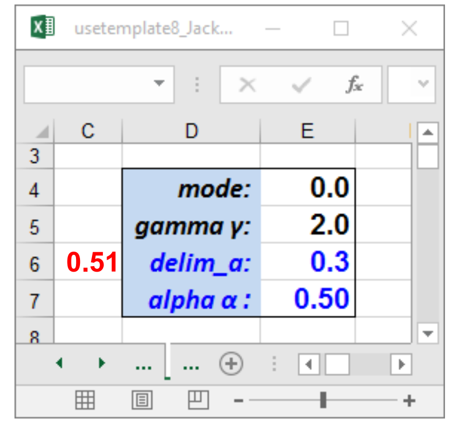

AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Depth TVD.ft
36-In
22-In
18-In
16-In
11 7/8-In
11.77
14.3
14.96
16.5
0.2/0.36
04/0.51
1.0/0.51
Bowers DW GoM (Default)
Eqivalent Mudweight.ppg
usetemplate8_Jack...
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
Eqivalent Mudweight.ppg
36-In
22-In
18-In
16-In
11 7/8-In
11.77
14.3
14.96
16.5
0.2/0.36
.04/0.51
1.0/0.51

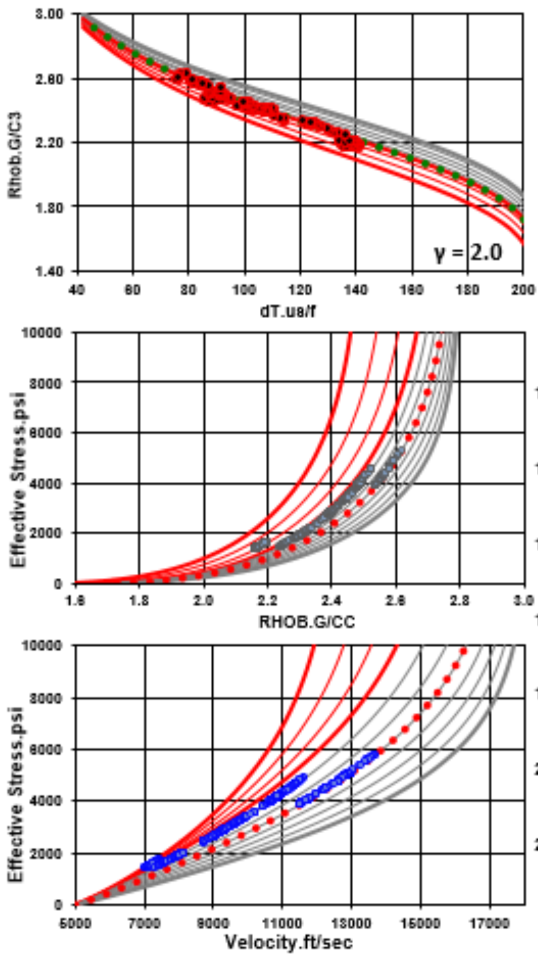

usetemplate8_Jack...
E7
C
D
E
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.40

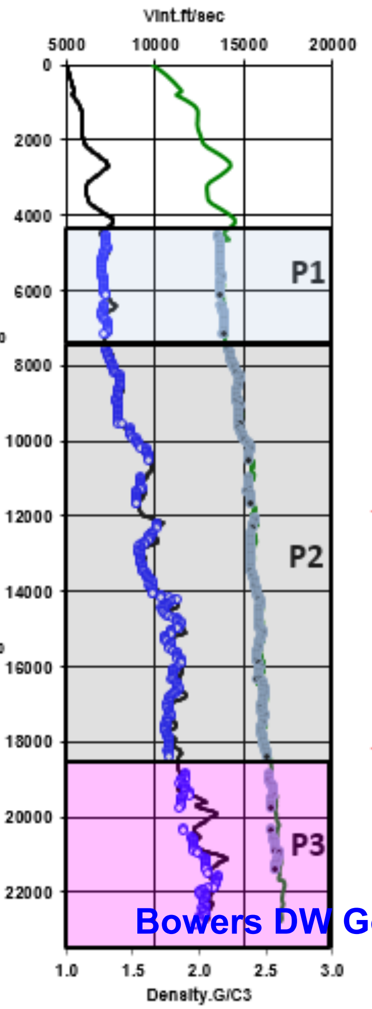
0.4

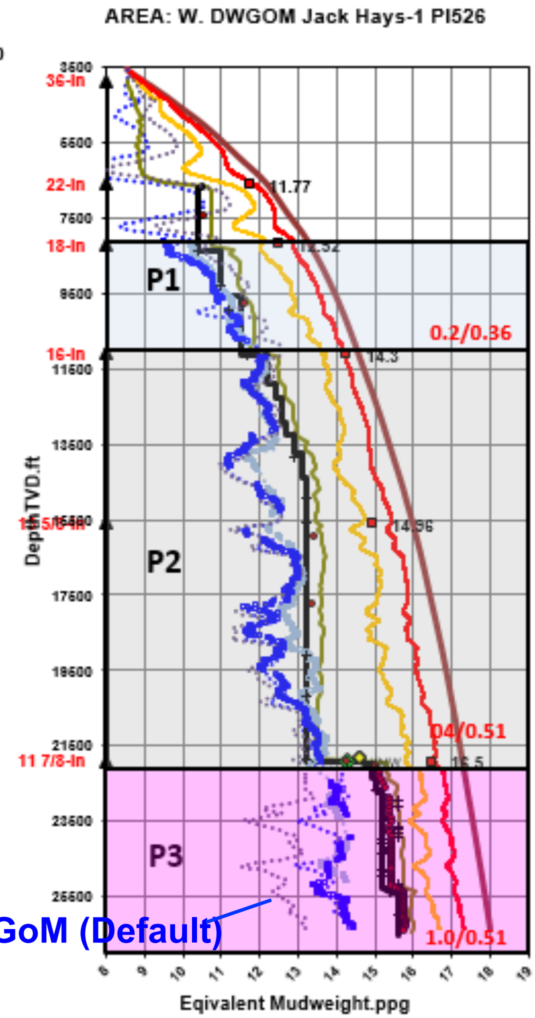

AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Effective Stress.psi
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Bowers DW GoM (Default)
36-In
22-In
18-In
16-In
11 7/8-In
Depth TVD.ft
11.77
14.3
14.96
16.5
0.2/0.36
04/0.51
1.0/0.51
Eqivalent Mudweight.ppg

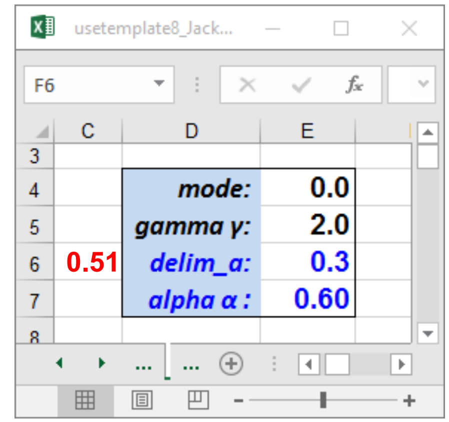

usetemplate8_Jack...
C
D
E
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.50

0.5

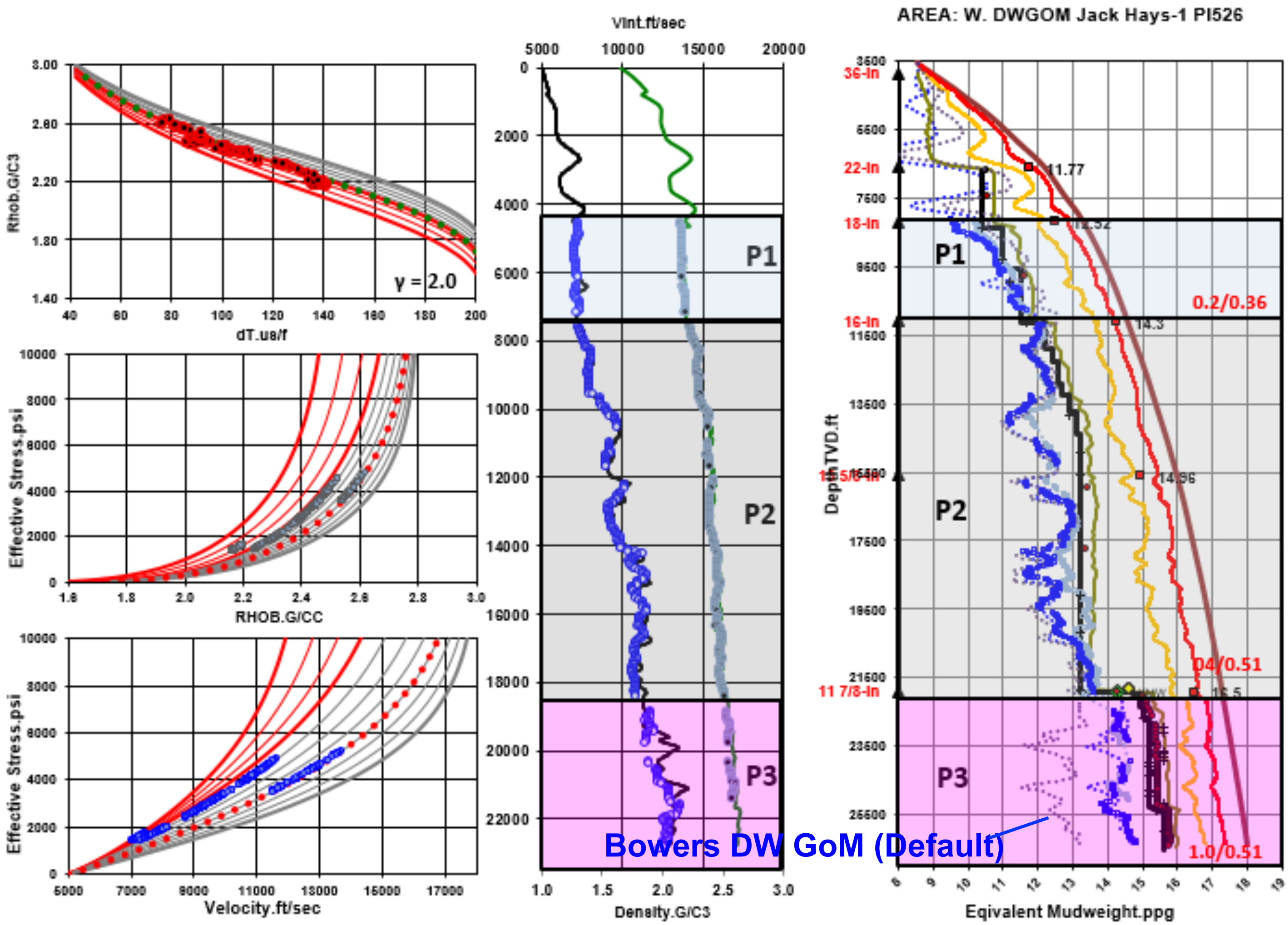

Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Effective Stress.psi
Velocity.ft/sec

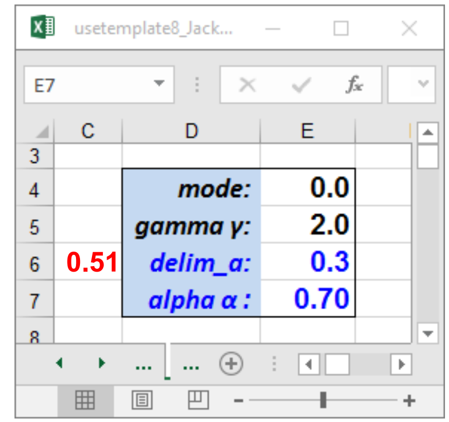

Vint.ft/sec
P1
P2
P3
Density.G/C3


AREA: W. DWGOM Jack Hays-1 PI526
36-In
22-In
18-In
16-In
11 7/8-In
11.77
14.3
14.96
16.5
0.2/0.36
04/0.51
1.0/0.51
P1
P2
P3
DepthTVD.ft
Eqivalent Mudweight.ppg
Bowers DW GoM (Default)

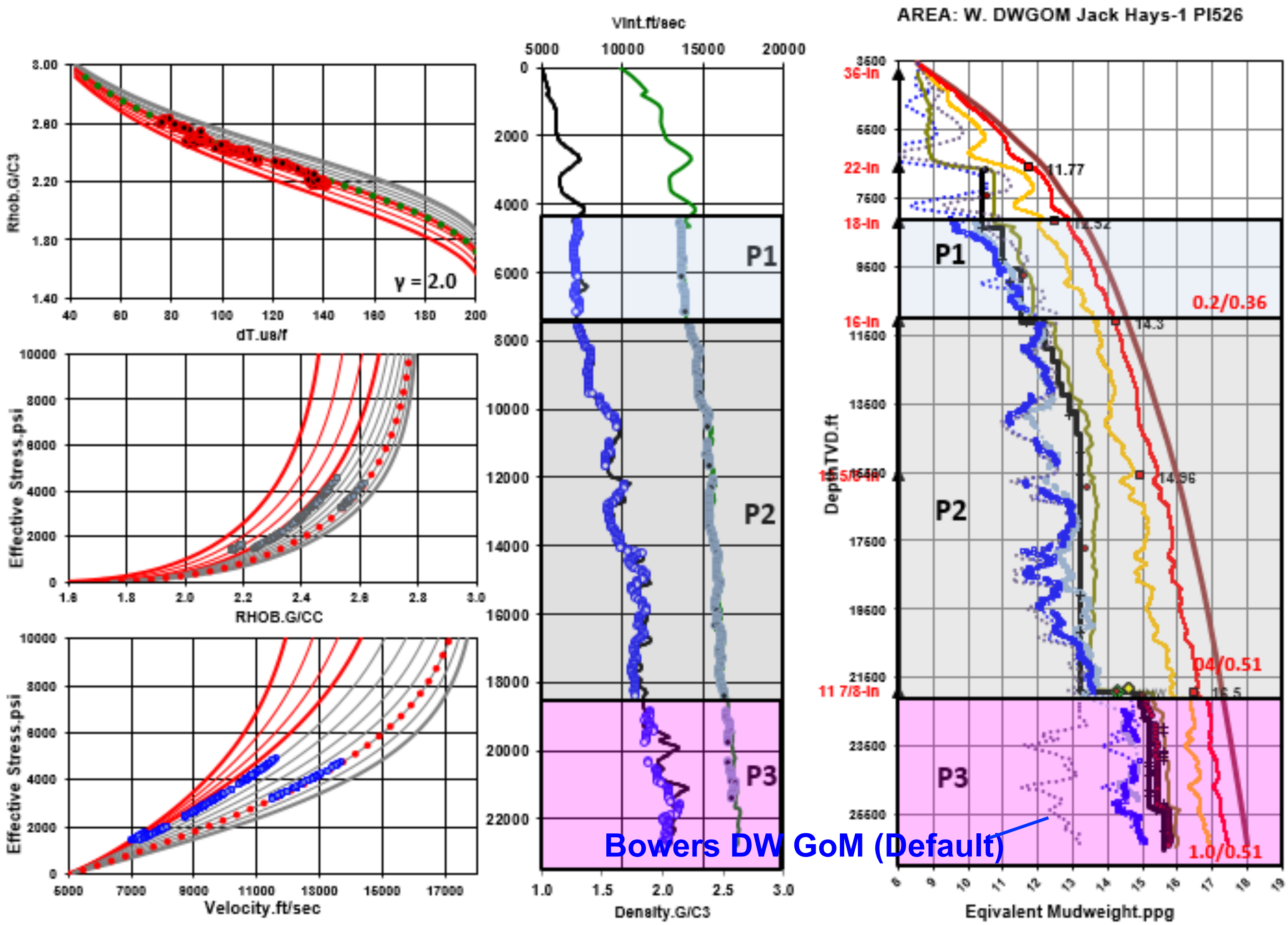

usetemplate8_Jack...
F6
C
D
E
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.60

0.6

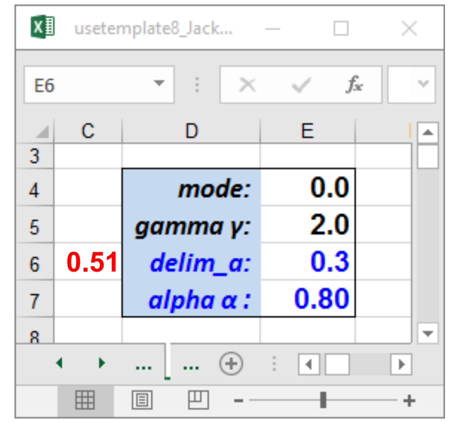

AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Bowers DW GoM (Default)
DepthTVD.ft
Eqivalent Mudweight.ppg
36-In
22-In
18-In
16-In
11 7/8-In
0.2/0.36
04/0.51
1.0/0.51


usetemplate8_Jack...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.70

0.7

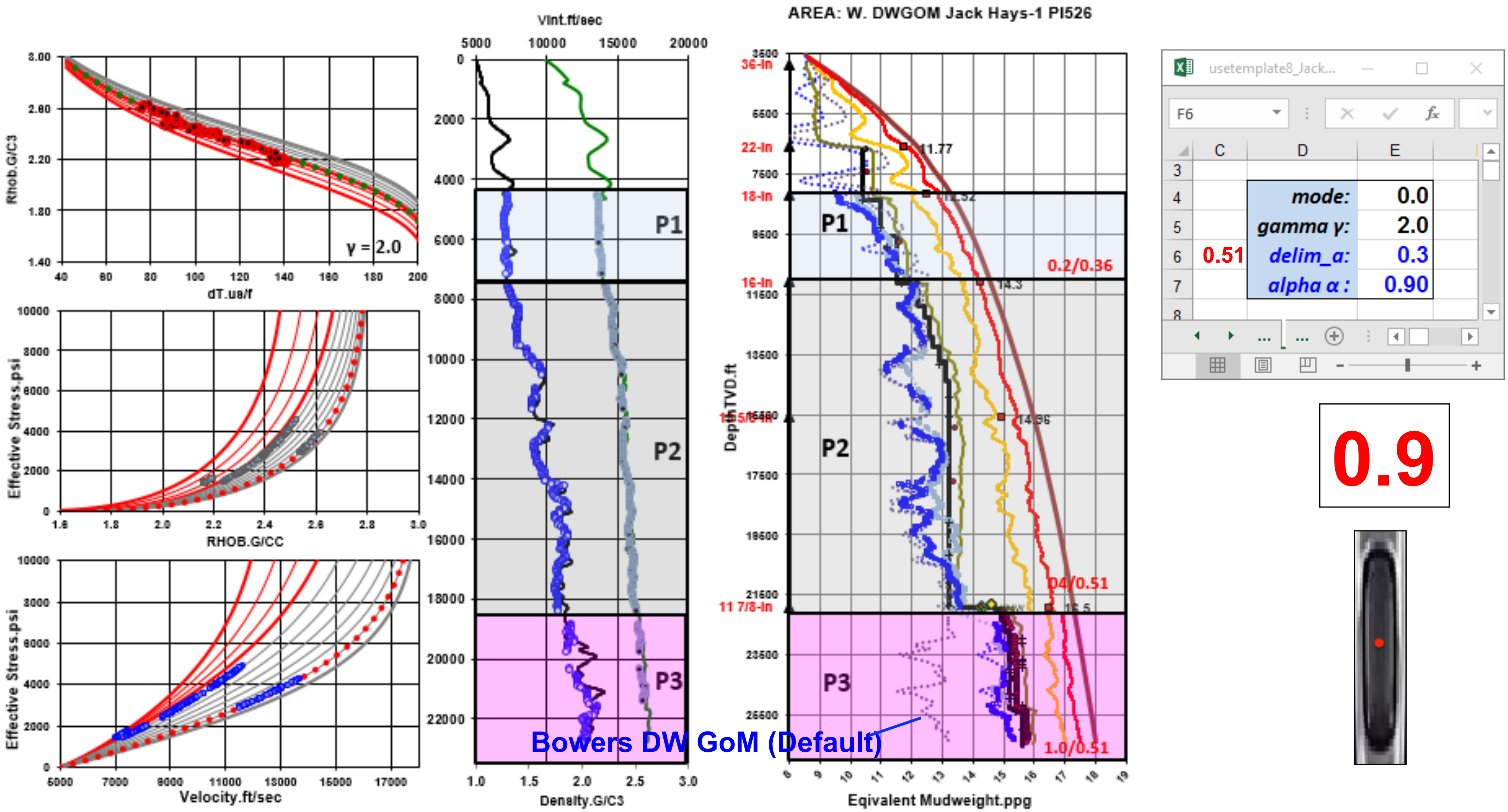


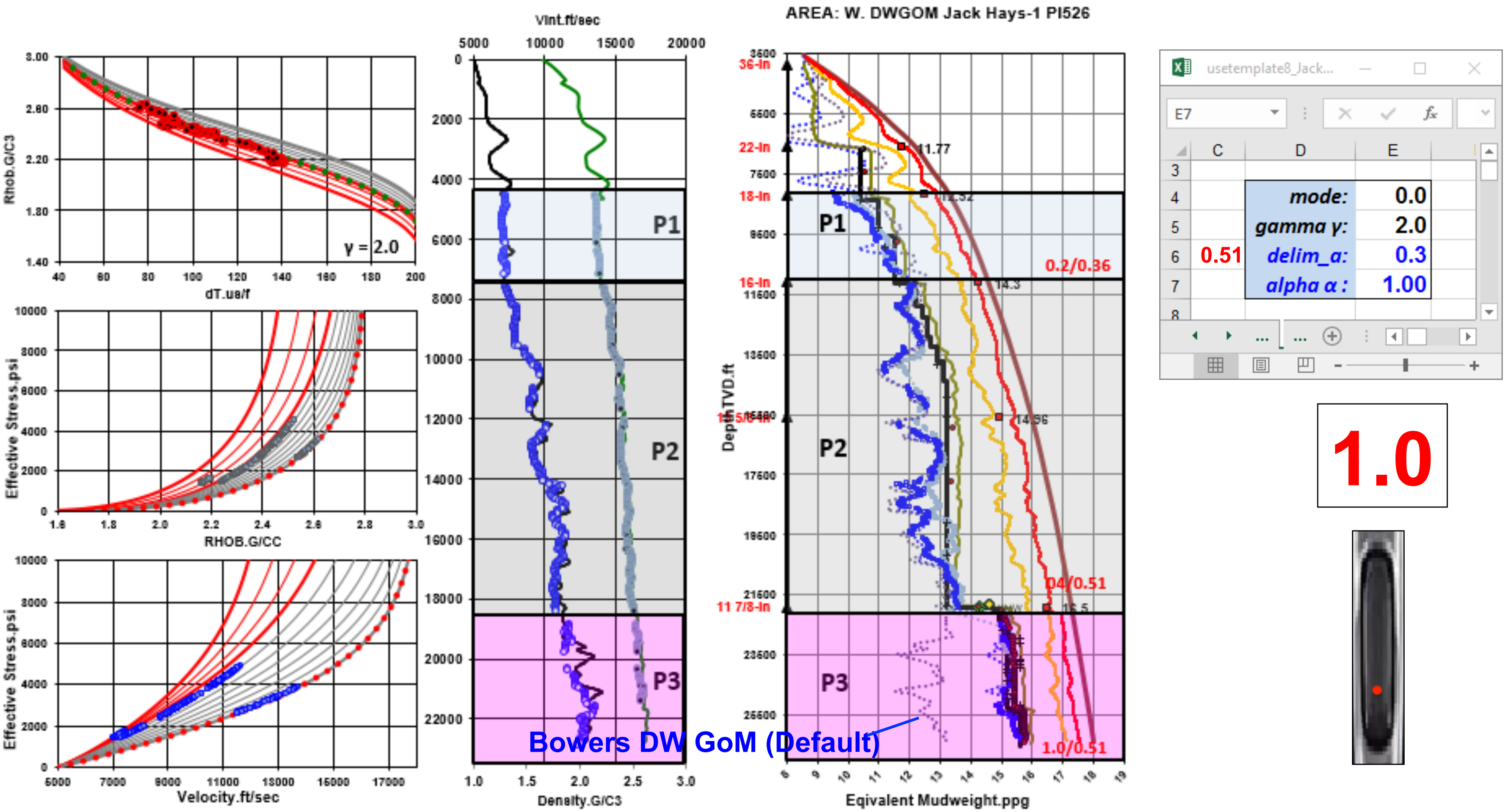
AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Effective Stress.psi
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Bowers DW GoM (Default)
DepthTVD.ft
36-In
22-In
18-In
16-In
11 7/8-In
11.77
14.3
14.96
0.2/0.36
04/0.51
1.0/0.51
Eqivalent Mudweight.ppg

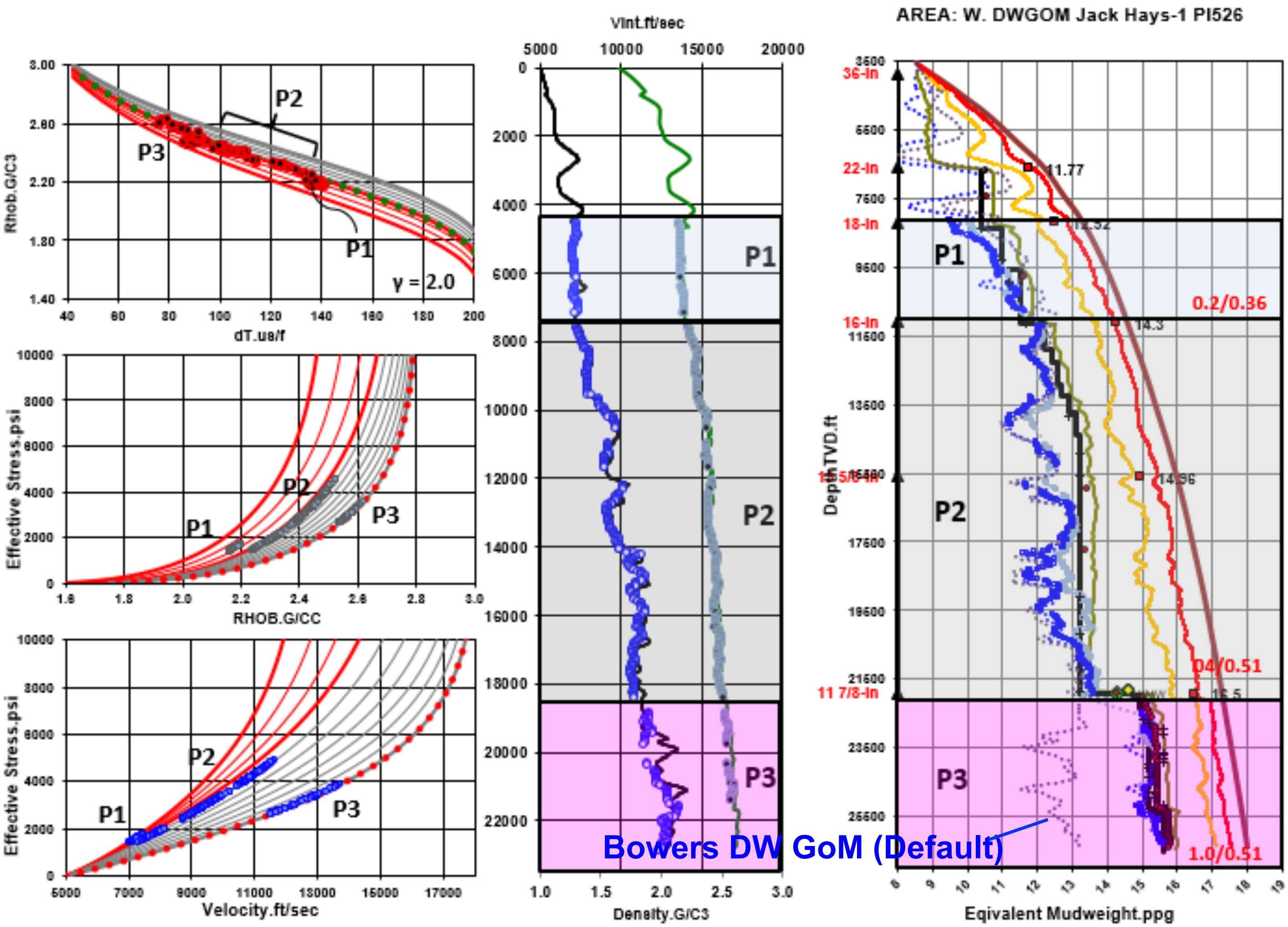


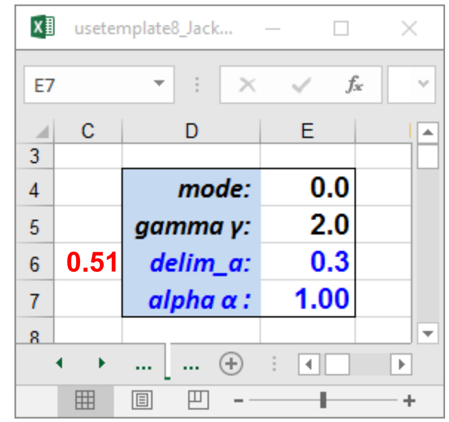
usetemplate8_Jack...
E6
C
D
E
mode: 0.0
gamma γ: 2.0
0.51 delim_a: 0.3
alpha α : 0.80

0.8

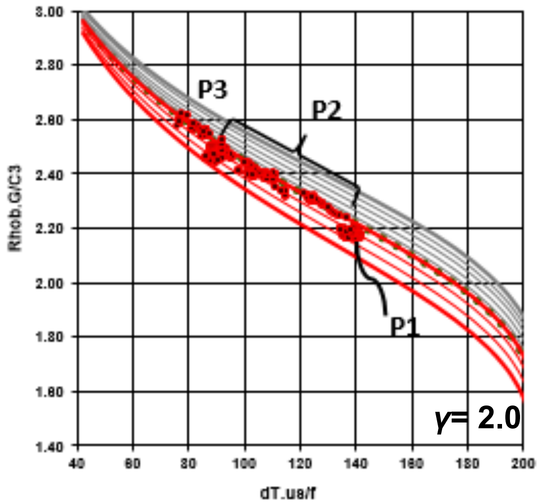

AREA: W. DWGOM Jack Hays-1 PI526
Vint.ft/sec
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Density.G/C3
DepthTVD.ft
Eqivalent Mudweight.ppg
36-In
22-In
18-In
16-In
11 7/8-In
P1
P2
P3
11.77
14.3
14.96
16.5
0.2/0.36
04/0.51
1.0/0.51
Bowers DW GoM (Default)
usetemplate8_Jack...
F6
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.90
0.9

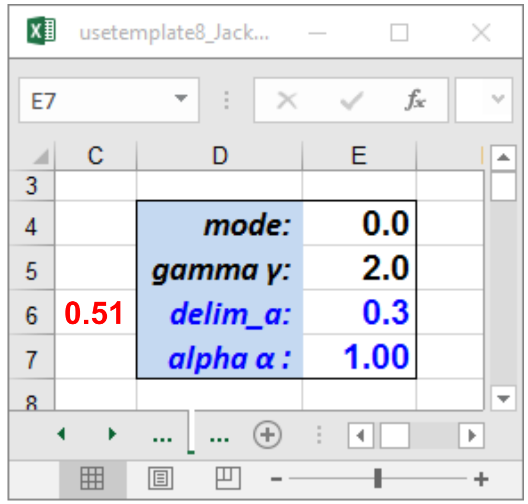

AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
P3
Bowers DW GoM (Default)
DepthTVD.ft
Eqivalent Mudweight.ppg
36-In
22-In
18-In
16-In
11 7/8-In
11.77
14.3
14.96
0.2/0.36
04/0.51
1.0/0.51
usetemplate8_Jack...
E7
mode:
0.0
gamma γ:
2.0
0.51
delim_a:
0.3
alpha α :
1.00
1.0

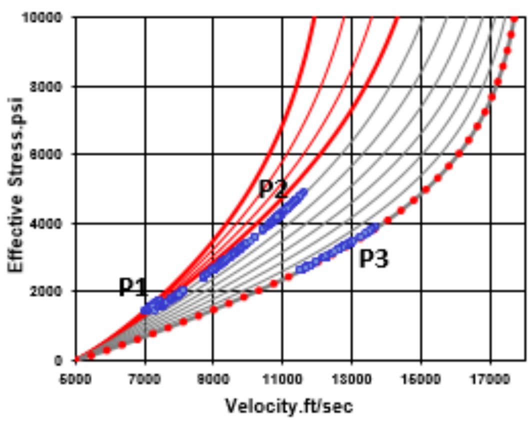

AREA: W. DWGOM Jack Hays-1 PI526
Rhob.G/C3
dT.us/f
P1
P2
P3
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
Eqivalent Mudweight.ppg
DepthTVD.ft
36-In
22-In
18-In
16-In
11 7/8-In
11.77
14.3
14.96
16.5
0.2/0.36
04/0.51
1.0/0.51
Bowers DW GoM (Default)

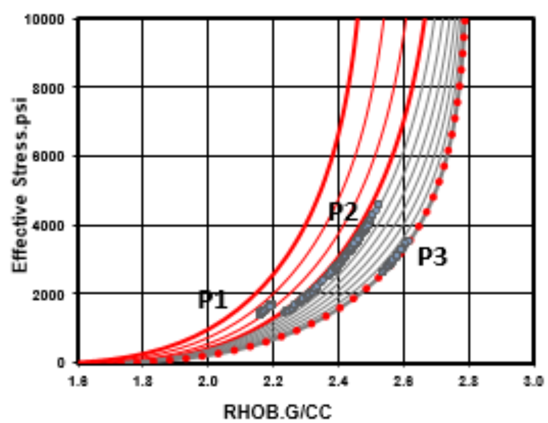

usetemplate8_Jack...
E7
C
D
E
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 1.00

1.0

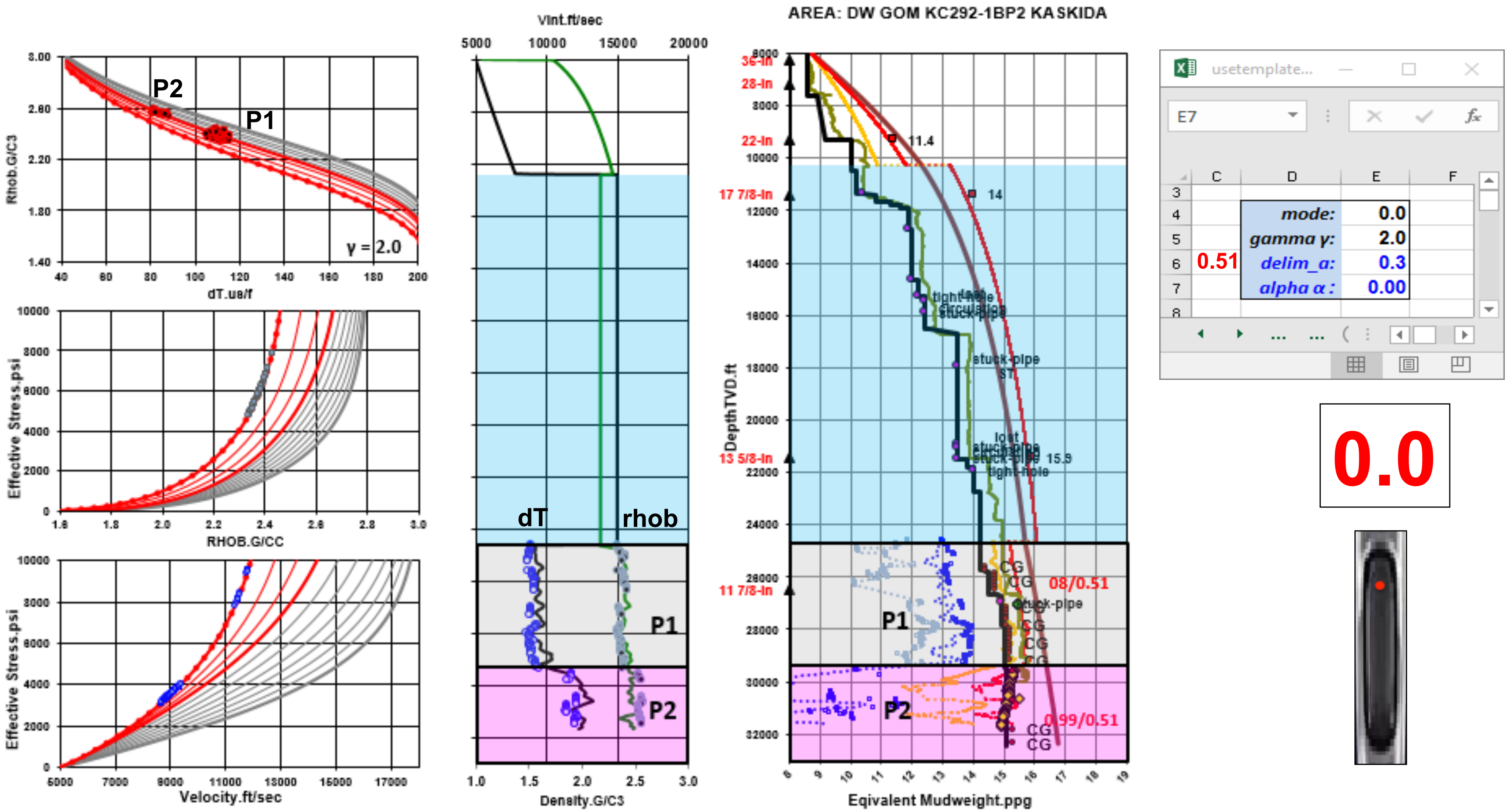

P3
P2
P1
γ= 2.0
Rhob.G/C3
dT.us/f


usetemplate8_Jack...
E7
C
D
E
mode: 0.0
gamma γ: 2.0
0.51
delim_α: 0.3
alpha α : 1.00

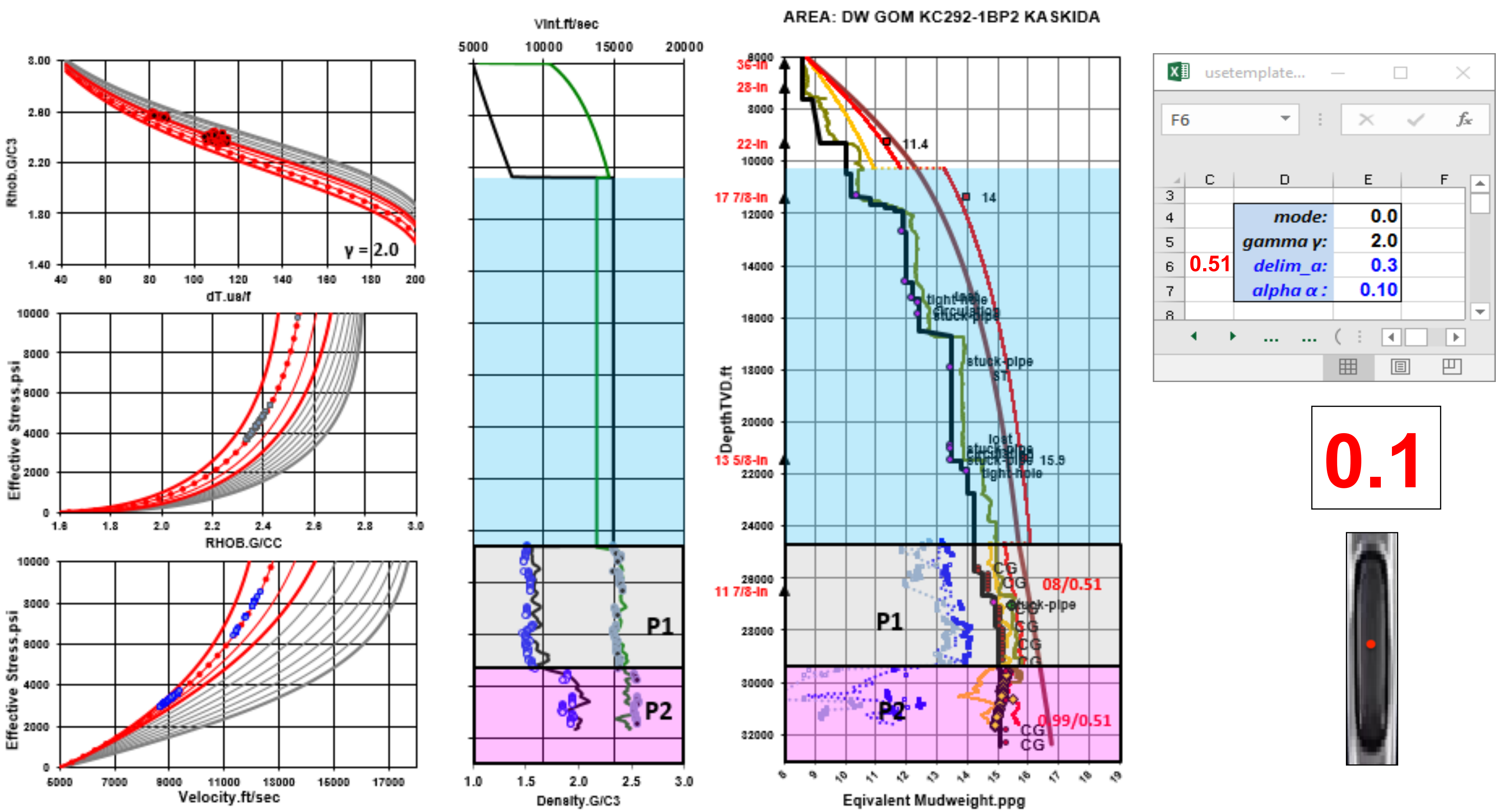

P2
P1
P3
Effective Stress.psi
Velocity.ft/sec


P2
P1
P3
Effective Stress.psi
RHOB.G/CC

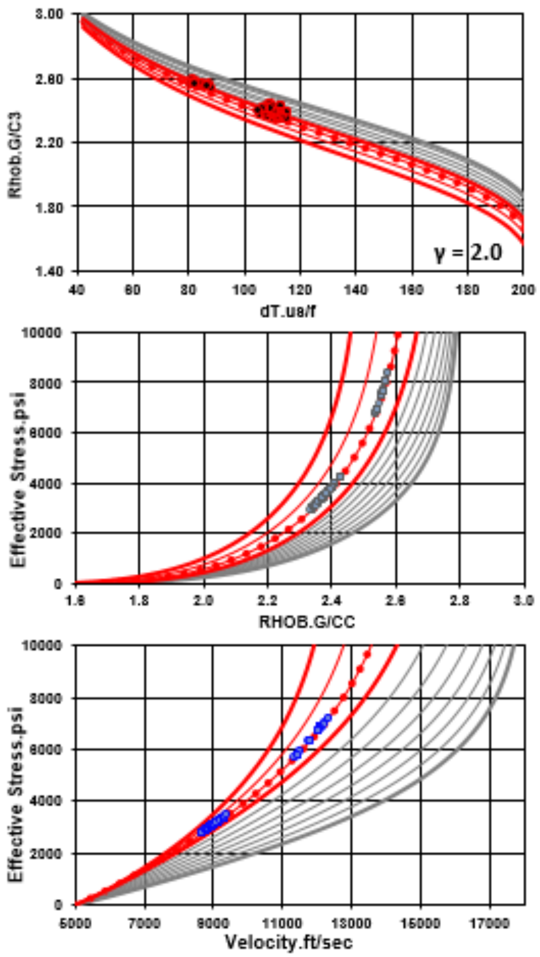
KC292-1BP2 Kaskida
DW Gulf of Mexico
U.S.A.

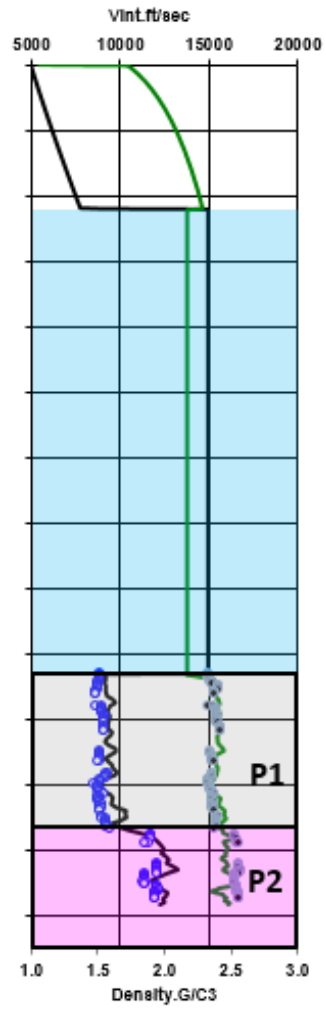


AREA: DW GOM KC292-1BP2 KASKIDA
P2
P1
γ = 2.0
dT.us/f
Rhob.G/C3
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
dT
rhob
Density.G/C3
DepthTVD.ft
36-in
28-in
22-in
17 7/8-in
13 5/8-in
11 7/8-in
11.4
14
15.9
tight hole
lost circulation
stuck-pipe
ST
tight-hole
CG
08/0.51
0.99/0.51
Eqivalent Mudweight.ppg
usetemplate...
E7
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 0.00
0.0

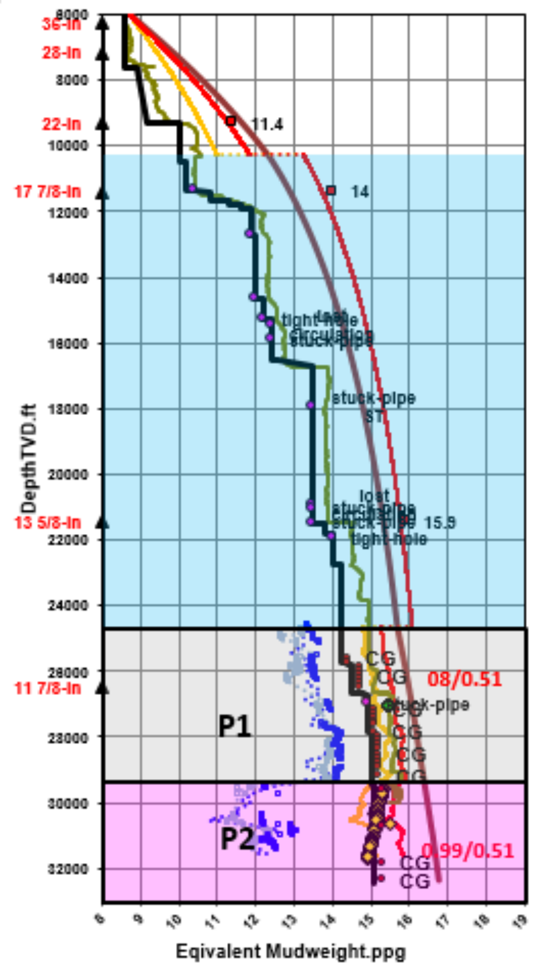


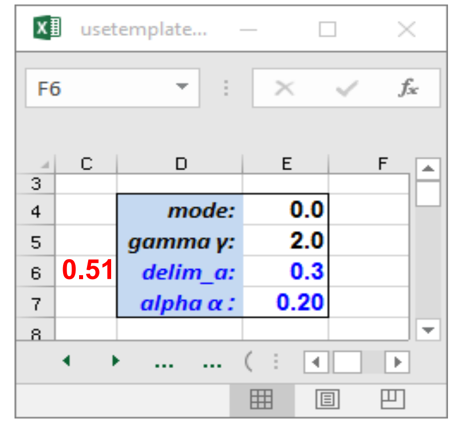
AREA: DW GOM KC292-1BP2 KASKIDA
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
Depth TVD.ft
Eqivalent Mudweight.ppg
36-In
28-In
22-In
17 7/8-In
13 5/8-In
11 7/8-In
11.4
14
15.9
tight hole
lost circulation
stuck-pipe
ST
08/0.51
0.99/0.51
CG
usetemplate...
F6
mode: 0.0
gamma γ: 2.0
0.51
delim_α: 0.3
alpha α : 0.10
0.1



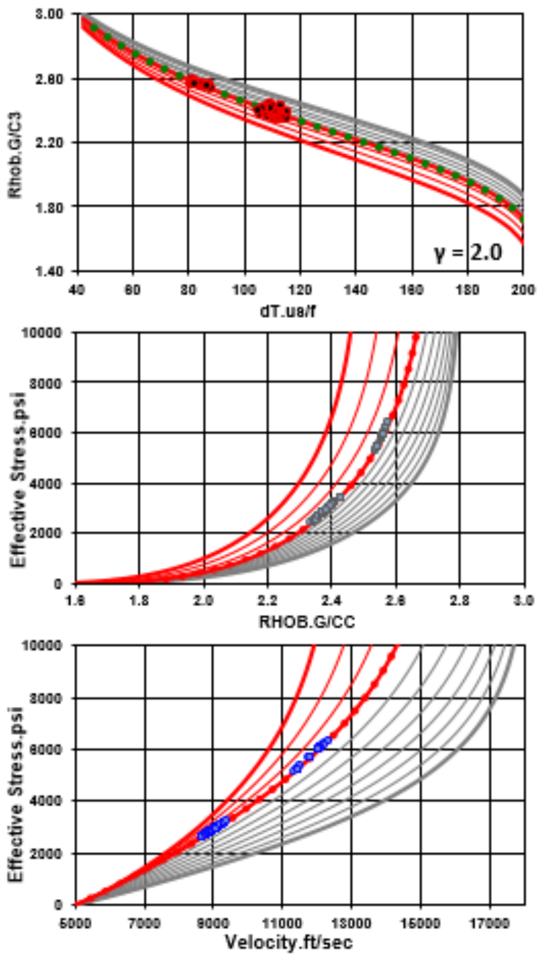


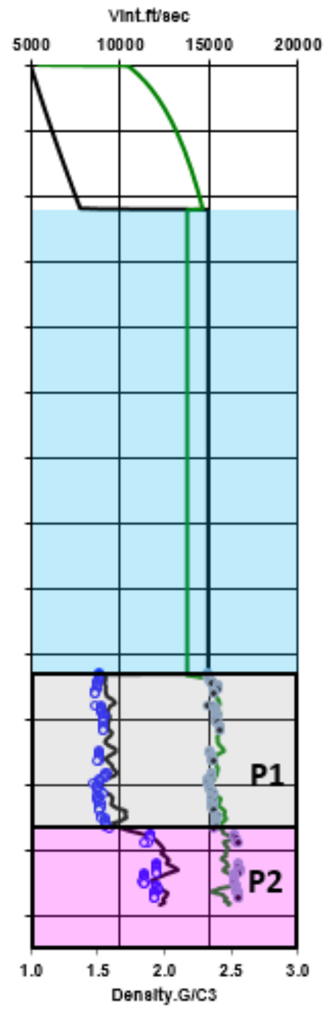
AREA: DW GOM KC292-1BP2 KASKIDA



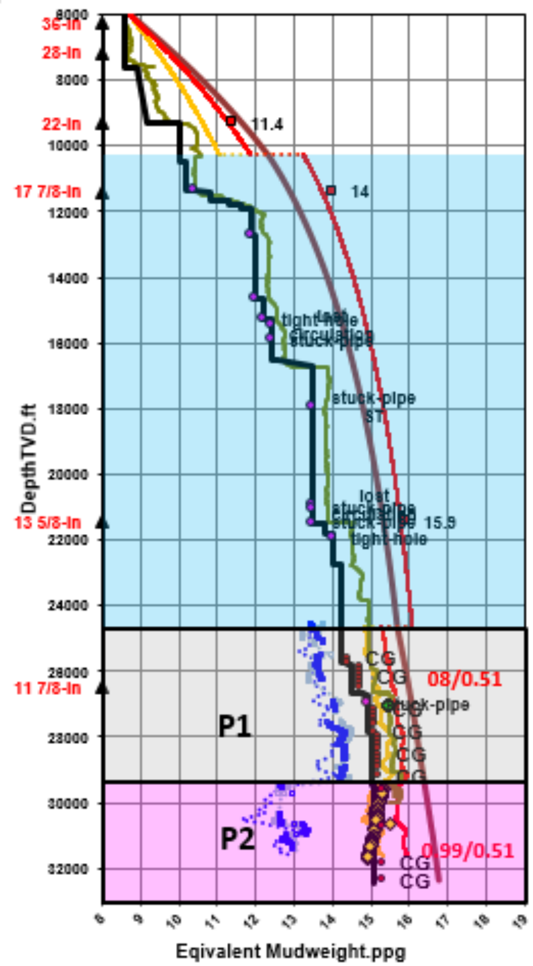


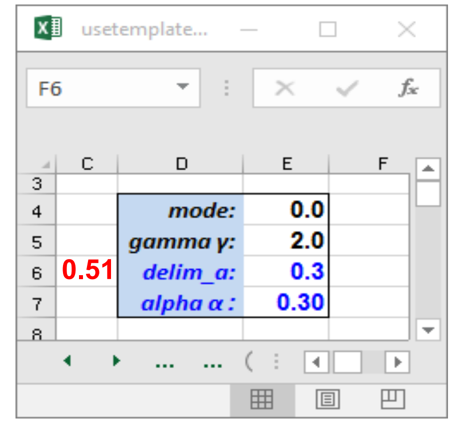
0.2



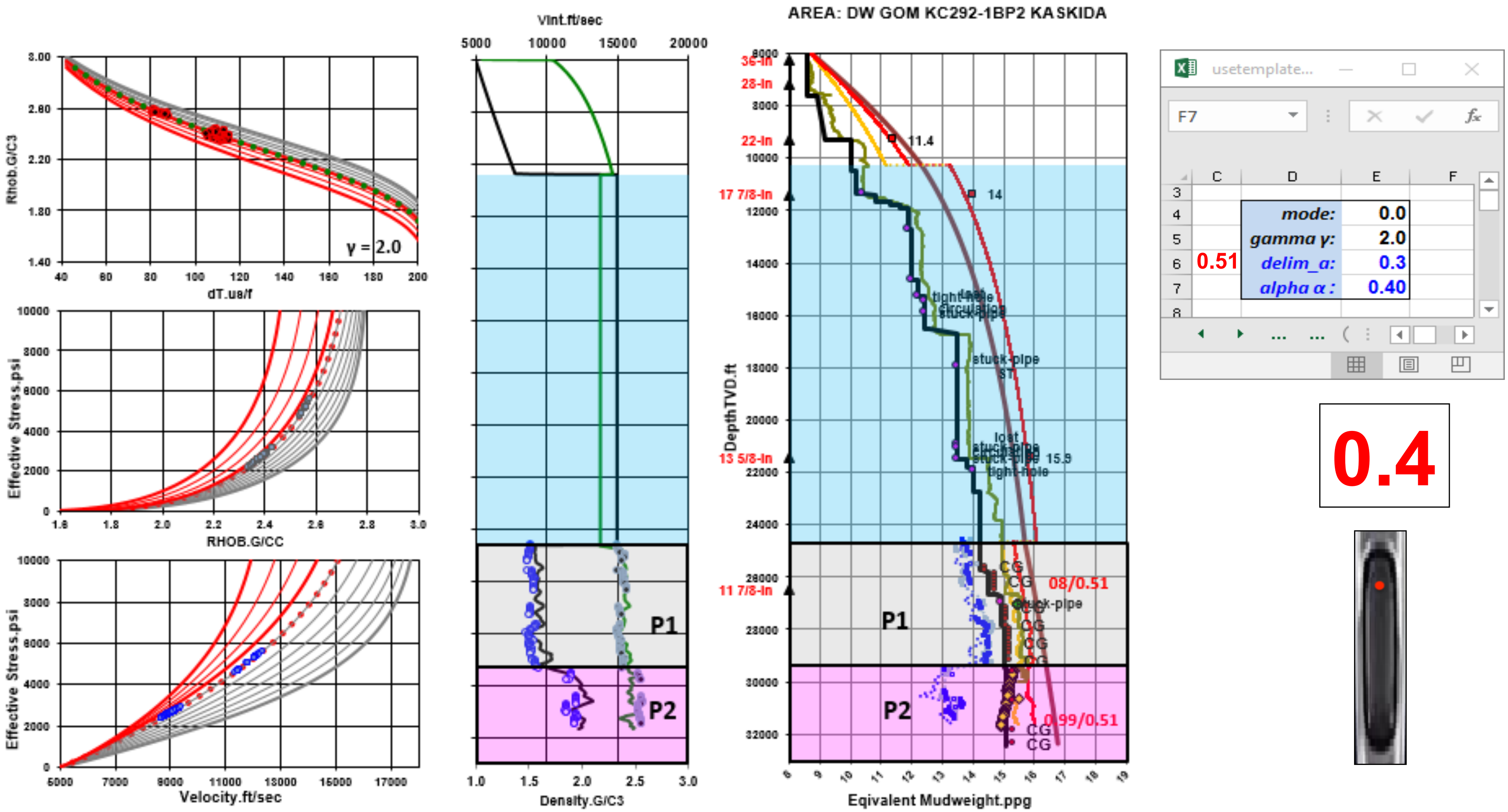


AREA: DW GOM KC292-1BP2 KASKIDA

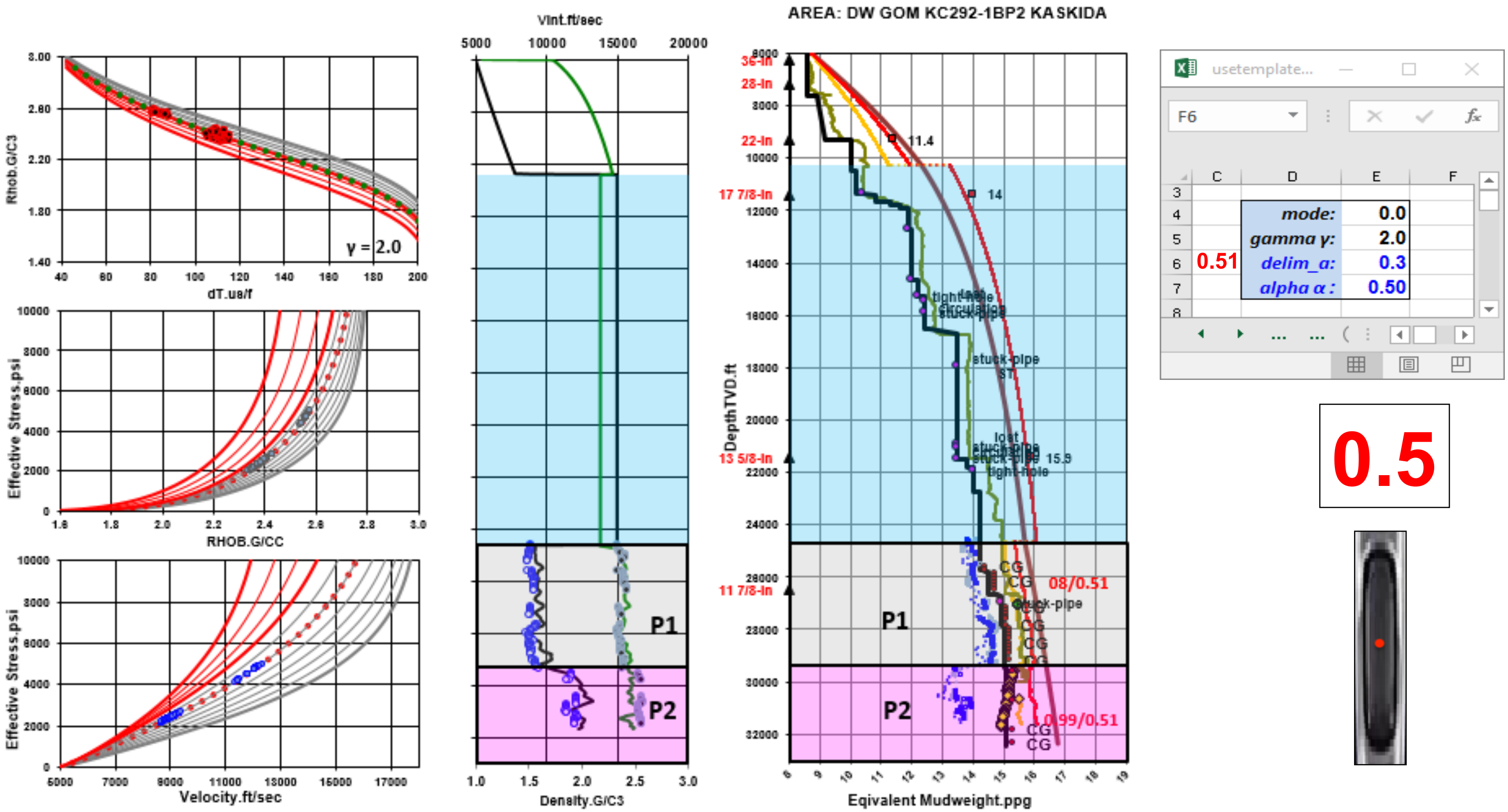


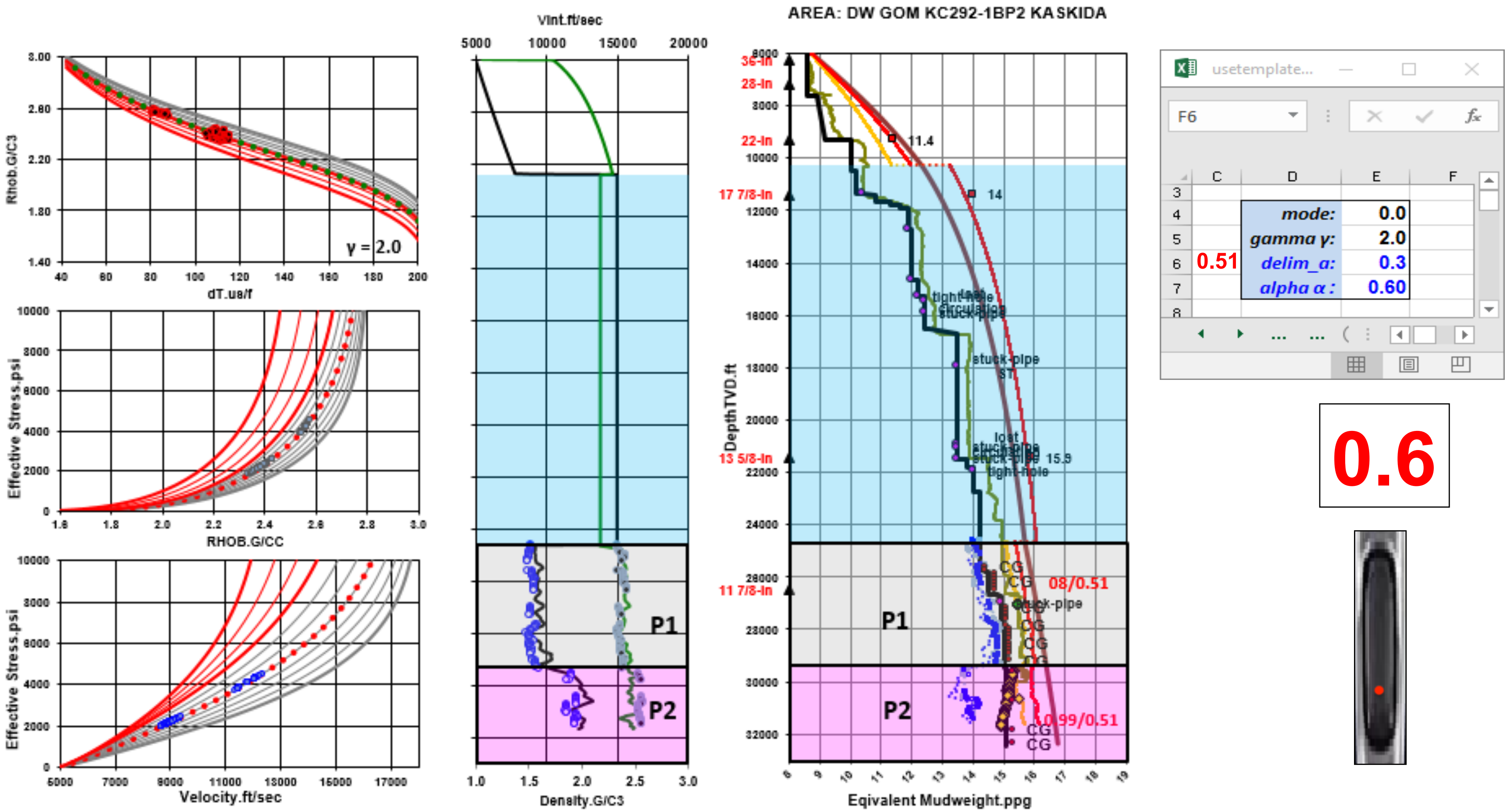


0.3



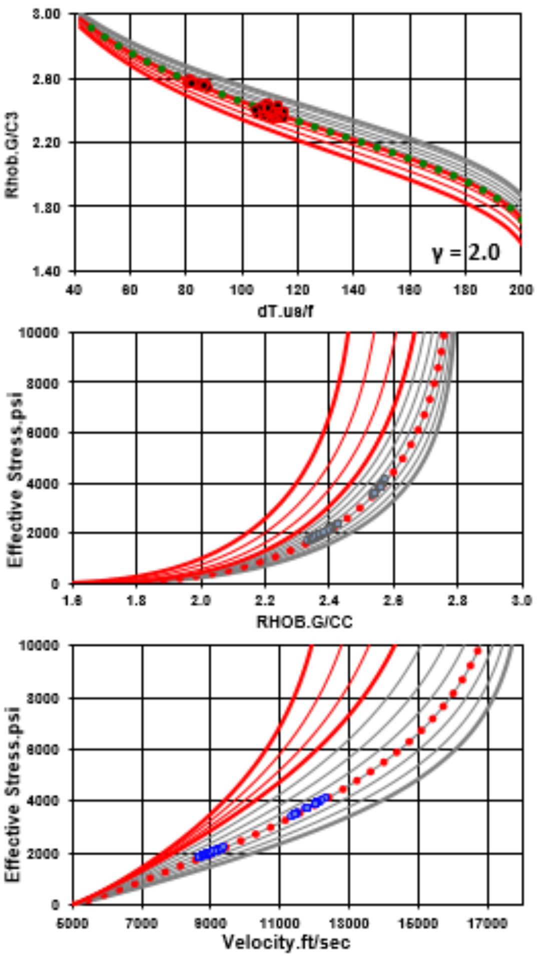
AREA: DW GOM KC292-1BP2 KASKIDA
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
DepthTVD.ft
Eqivalent Mudweight.ppg
36-in
28-in
22-in
17 7/8-in
13 5/8-in
11 7/8-in
11.4
14
15.9
tight-hole
lost circulation
stuck-pipe
ST
CG
08/0.51
0.99/0.51
usetemplate...
F7
mode: 0.0
gamma γ: 2.0
delim_α: 0.3
alpha α : 0.40
0.51
0.4

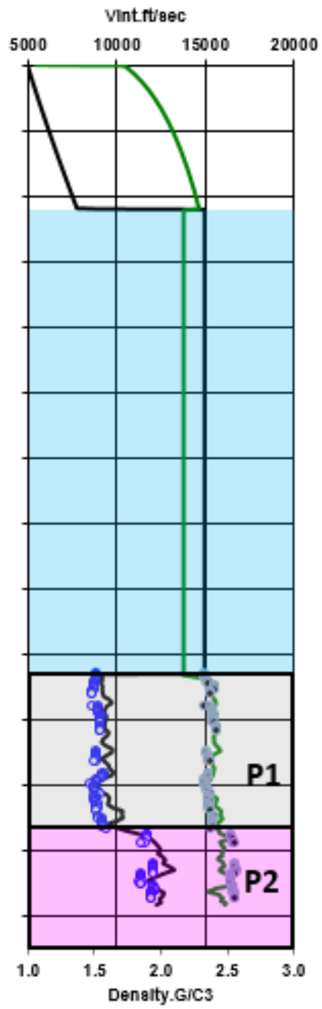

AREA: DW GOM KC292-1BP2 KASKIDA
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Effective Stress.psi
Velocity.ft/sec
Vint.ft/sec
5000
10000
15000
20000
Density.G/C3
P1
P2
DepthTVD.ft
36-in
28-in
22-in
17 7/8-in
13 5/8-in
11 7/8-in
11.4
14
15.9
tight hole
lost circulation
stuck-pipe
ST
tight hole
CG
08/0.51
0.99/0.51
Eqivalent Mudweight.ppg
usetemplate...
F6
mode: 0.0
gamma γ: 2.0
0.51
delim_α: 0.3
alpha α : 0.50
0.5

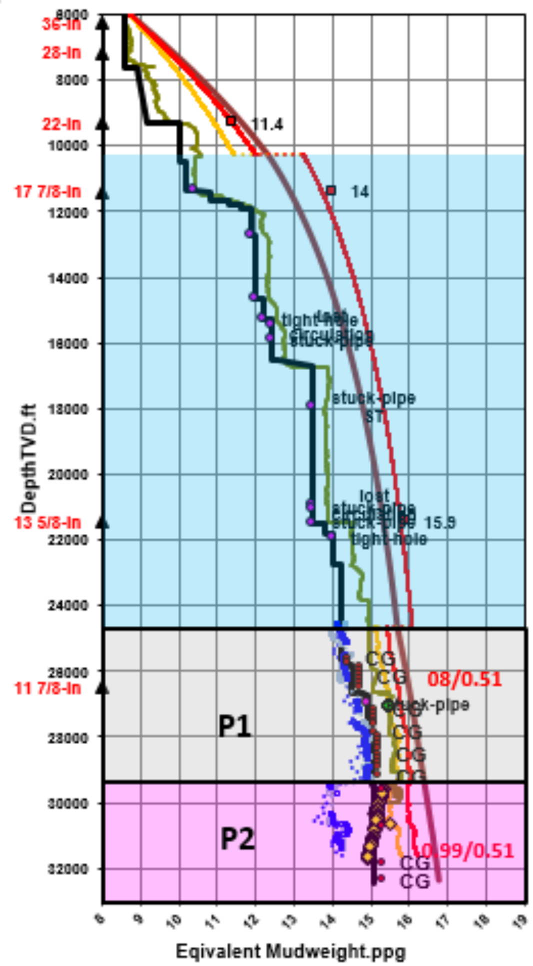


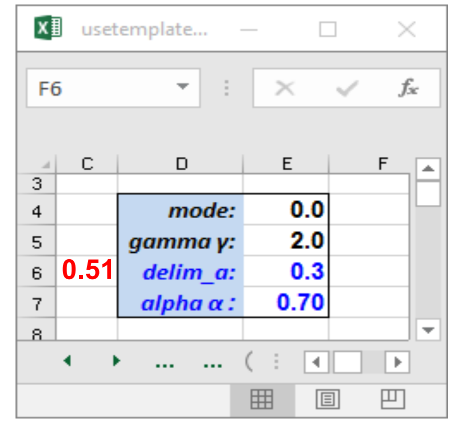
AREA: DW GOM KC292-1BP2 KASKIDA
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
DepthTVD.ft
Eqivalent Mudweight.ppg
36-in
28-in
22-in
17 7/8-in
13 5/8-in
11 7/8-in
11.4
14
15.9
tight-hole
lost circulation
stuck-pipe
ST
CG
08/0.51
0.99/0.51
usetemplate...
F6
mode: 0.0
gamma y: 2.0
0.51
delim_a: 0.3
alpha α : 0.60
0.6

AREA: DW GOM KC292-1BP2 KASKIDA

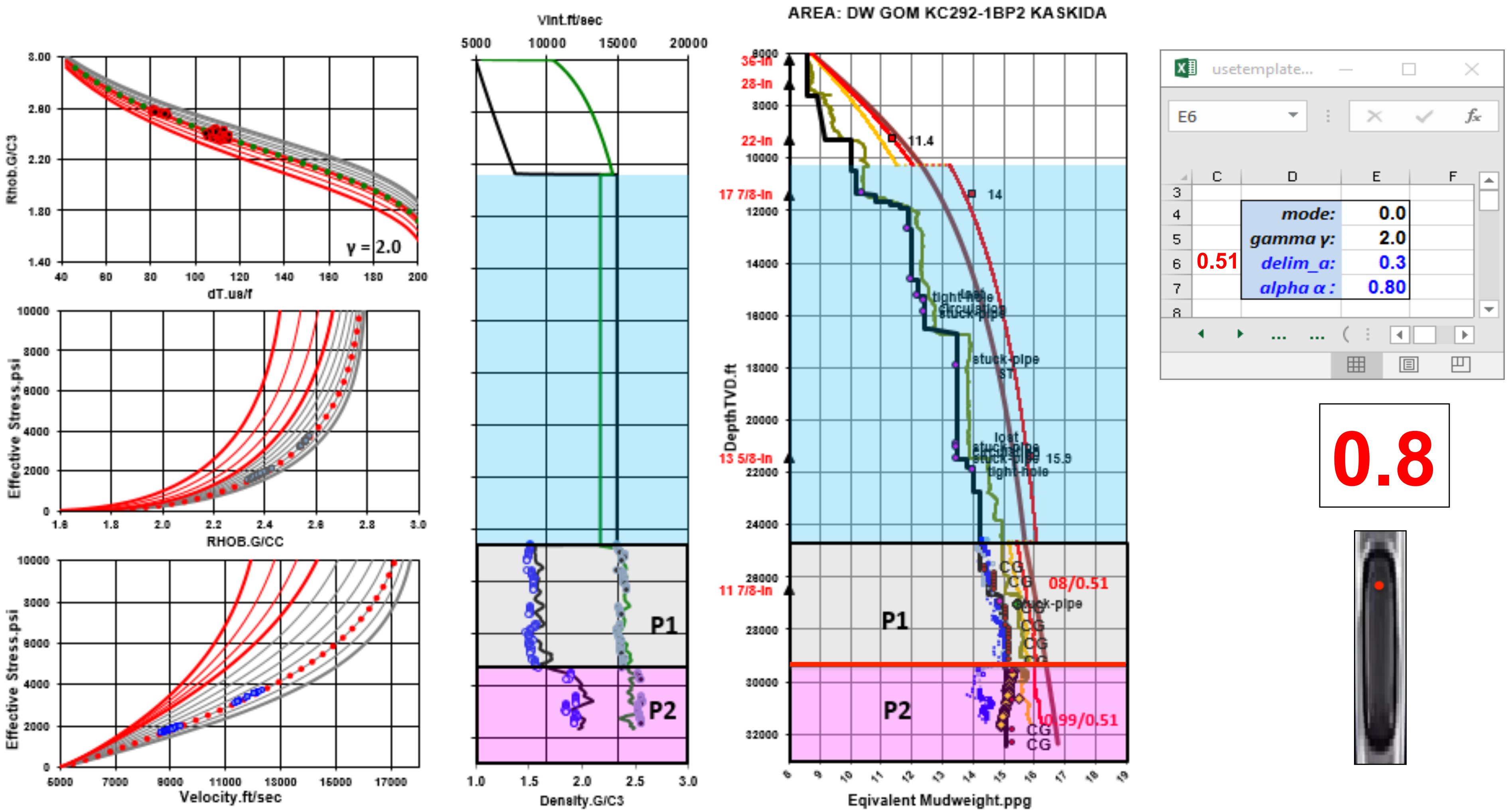


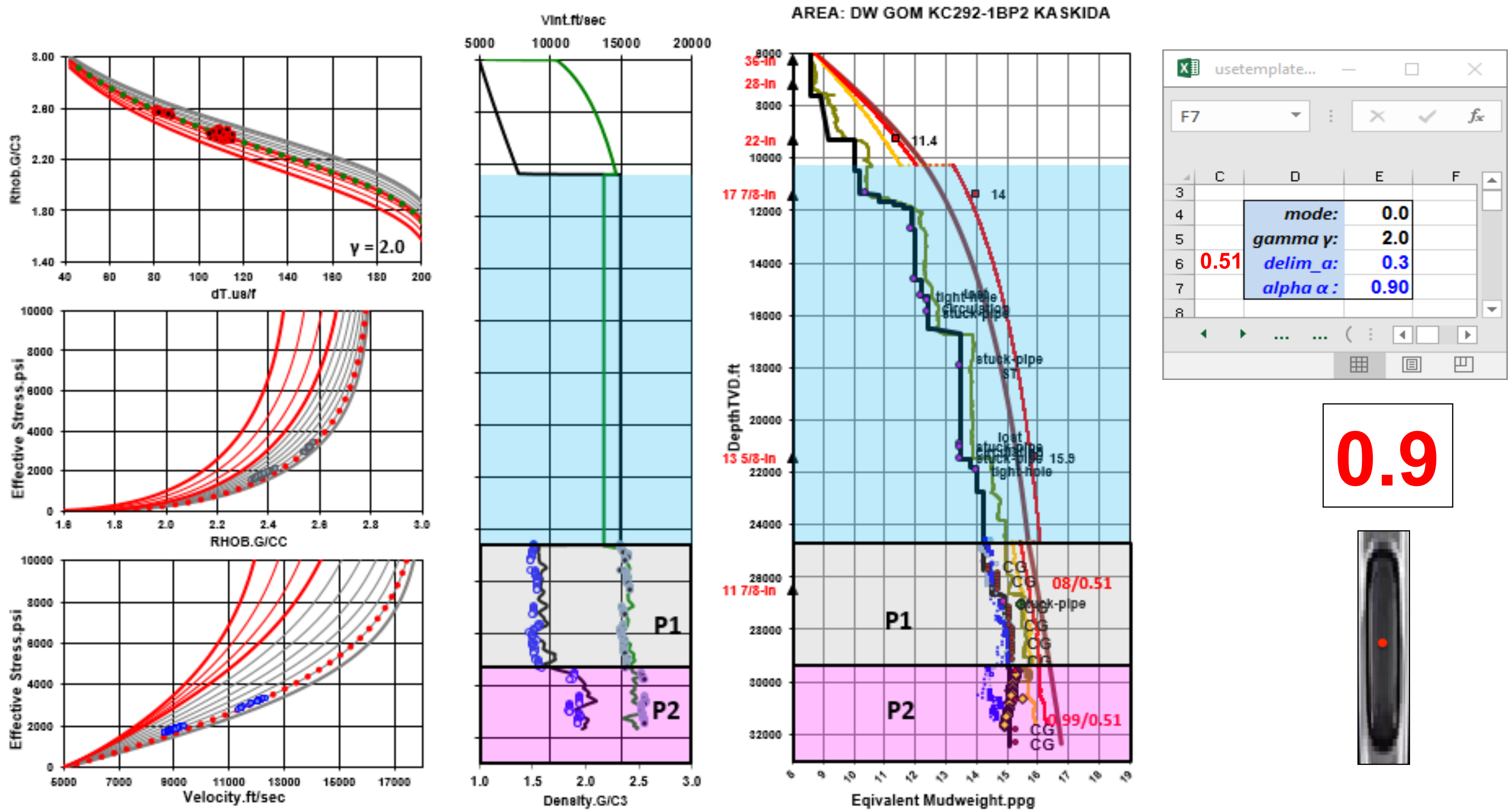




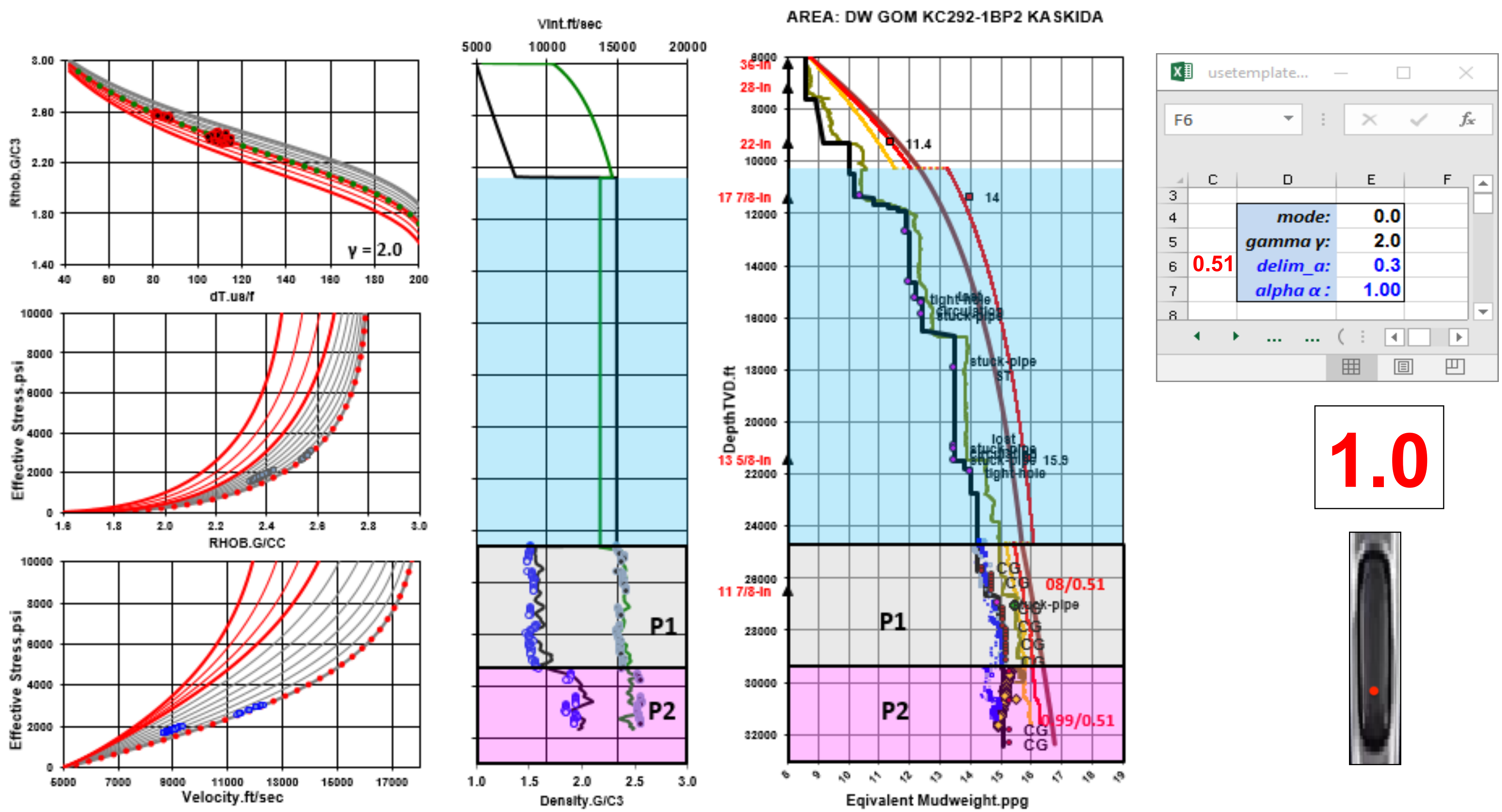


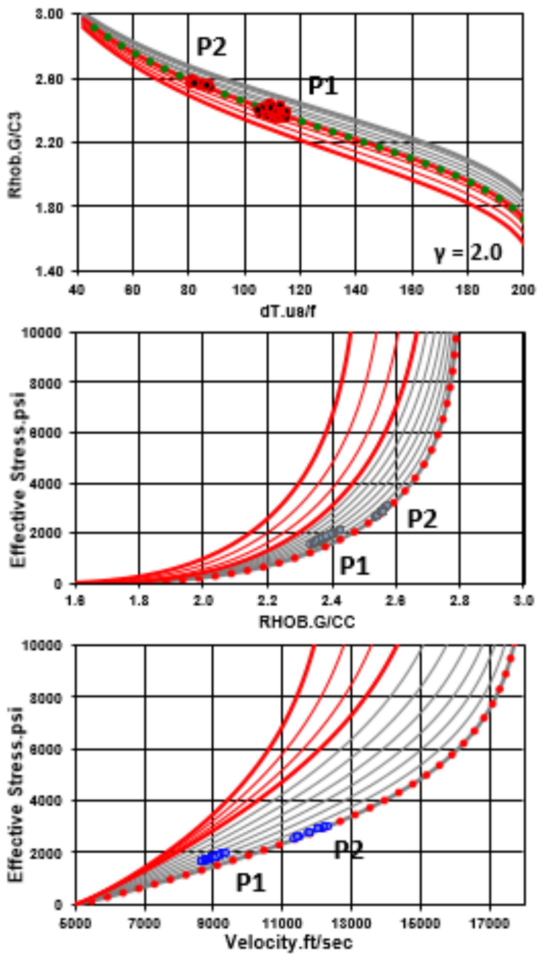
0.7

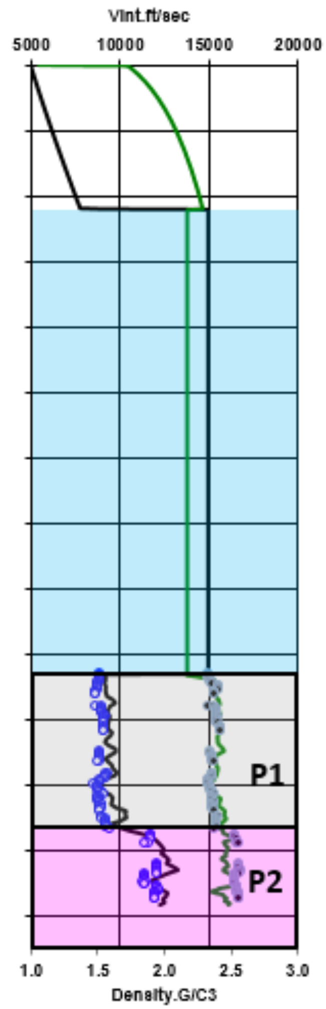

AREA: DW GOM KC292-1BP2 KASKIDA
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
DepthTVD.ft
Eqivalent Mudweight.ppg
36-in
28-in
22-in
17 7/8-in
13 5/8-in
11 7/8-in
11.4
14
15.9
08/0.51
0.99/0.51
usetemplate...
E6
mode:
0.0
gamma γ:
2.0
0.51
delim_α:
0.3
alpha α :
0.80
0.8



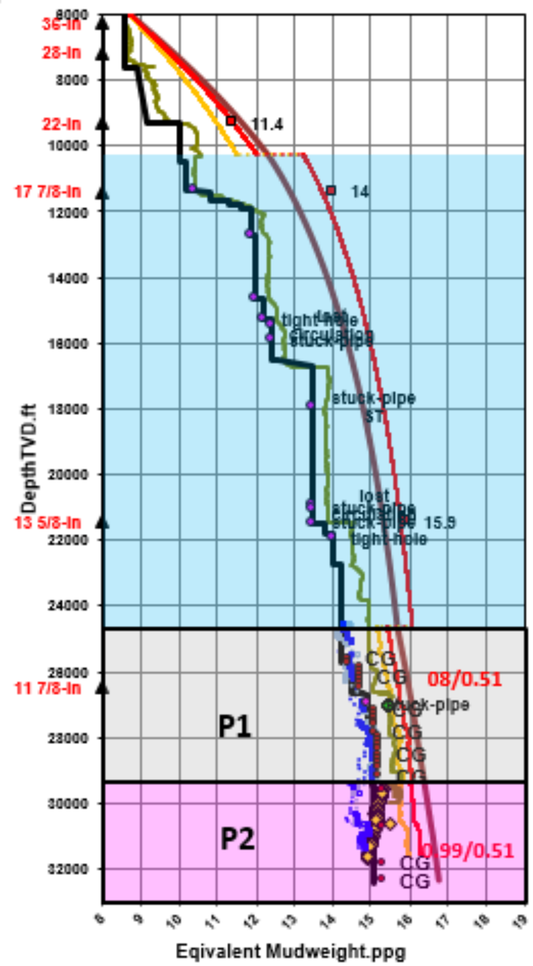
AREA: DW GOM KC292-1BP2 KASKIDA
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
DepthTVD.ft
Eqivalent Mudweight.ppg
36-in
28-in
22-in
17 7/8-in
13 5/8-in
11 7/8-in
11.4
14
15.9
tight-hole
stuck-pipe
ST
lost
CG
08/0.51
0.99/0.51
usetemplate...
F7
mode:
0.0
gamma γ:
2.0
delim_a:
0.3
alpha α :
0.90
0.51
0.9

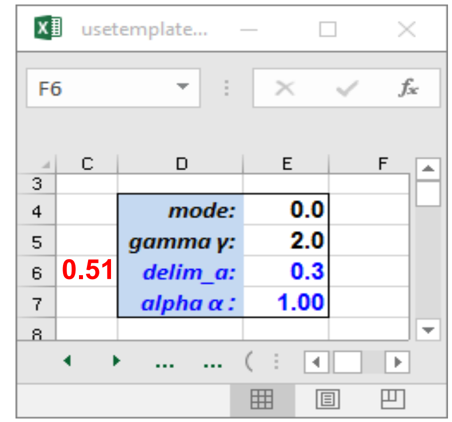

AREA: DW GOM KC292-1BP2 KASKIDA
Rhob.G/C3
dT.us/f
γ = 2.0
Effective Stress.psi
RHOB.G/CC
Velocity.ft/sec
Vint.ft/sec
Density.G/C3
P1
P2
DepthTVD.ft
36-In
28-In
22-In
17 7/8-In
13 5/8-In
11 7/8-In
11.4
14
15.9
stuck-pipe
tight-hole
CG
08/0.51
0.99/0.51
Eqivalent Mudweight.ppg
usetemplate...
F6
mode: 0.0
gamma γ: 2.0
0.51
delim_a: 0.3
alpha α : 1.00
1.0



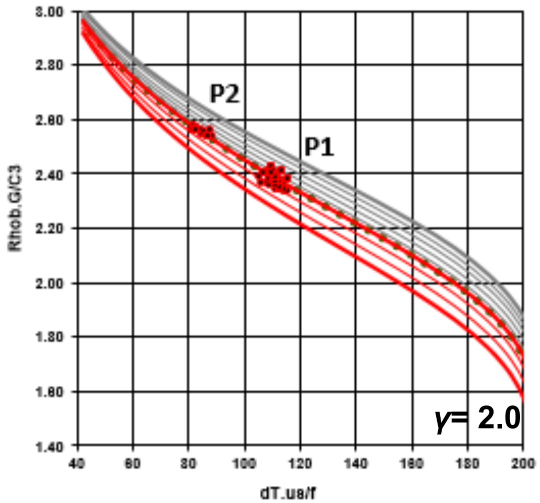


AREA: DW GOM KC292-1BP2 KASKIDA

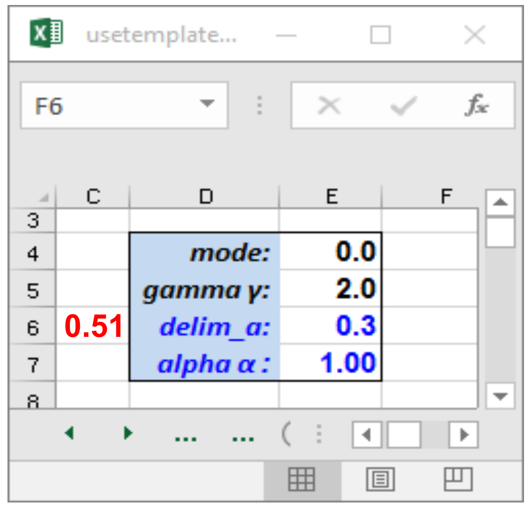




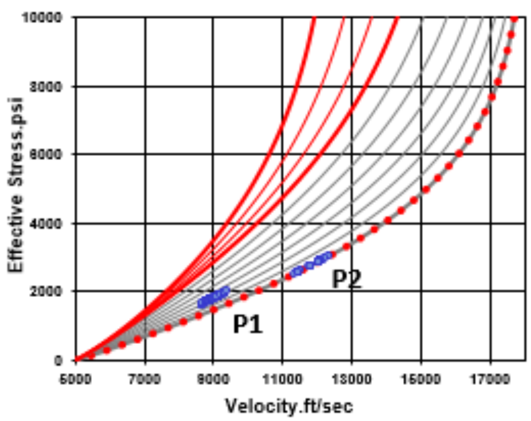
1.0



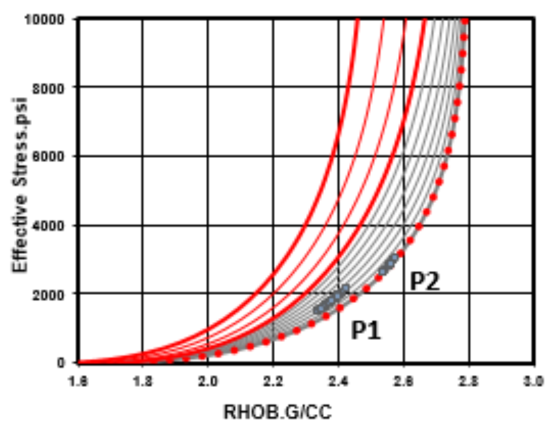
Rhob.G/C3
dT.us/f
P2
P1
γ= 2.0



usetemplate...
F6
mode: 0.0
gamma γ: 2.0
0.51 delim_a: 0.3
alpha α : 1.00



Effective Stress.psi
Velocity.ft/sec
P1
P2



Effective Stress.psi
RHOB.G/CC
P1
P2

OVERVIEW

INTRODUCTORY DEMO

PREVIOUS WORK - THEORY

- Mechanical vs Chemical Compaction
- Smectite – Illite Conversion

RHOVE METHOD

- Summary
- Virtual Model
- Alpha – A-Term
- Shale Discrimination

SUMMARY DEMOS

- Untethered Mode
- Tethered Mode

WELL EXAMPLES using RHOVE METHOD

ADVANTAGES of RHOVE Method

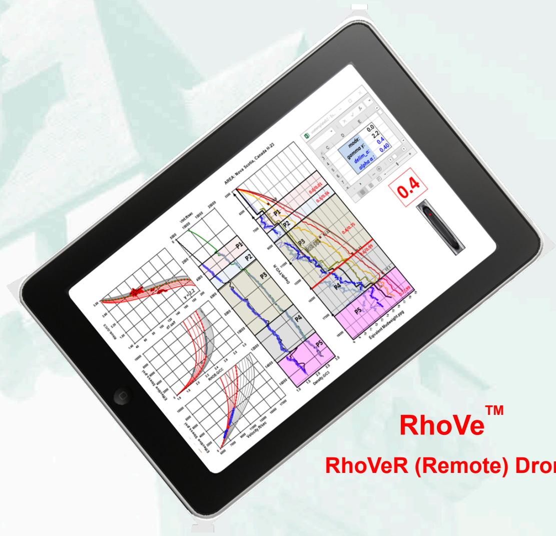
Advantages

- Efficiency through simplicity –

- RhoVe method has universal application -

- RhoVe method provides interactive solutions for:
    - Prospect Exploration
    - Prospect Maturation
    - Operations

- Rhob density transformed to effective stress and pore pressure,
- Rationale for subdivision of major flow units,
- Potential to automate pore pressure solutions related to compositional changes.



RhoVe™
RhoVeR (Remote) Drone

GCS Solutions, Inc.

geopressure consulting
services & solutions

Thank You!

Additional References

- 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.