

Amplitude of Pair Correlation Function to Understand Heterogeneity from Well-Log and Seismic Data*

Ramya Ravindranathan¹ and Evgeny Chesnokov²

Search and Discovery Article #42157 (2017)**

Posted November 27, 2017

*Adapted from oral presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017

**Datapages © 2017 Serial rights given by author. For all other rights contact author directly.

¹Earth and Atmospheric Sciences, University of Houston, Pasadena, Texas, United States (rravindranathan@uh.edu)

²Earth and Atmospheric Sciences, University of Houston, Pasadena, Texas, United States

Abstract

The elastic properties of the medium are scale-dependent and therefore it would be ideal to make the best possible use of the seismic data by integrating it with the available well-log data. Effective medium theory (EMT) uses homogeneous physical properties to calculate the effective properties of a heterogeneous medium thereby bridging the gap between the macro- and micro- physical properties. Depending upon the complexity of the medium, different effective medium theories are used. Pair Correlation Function (PCF) approximation method that takes into account the effect of scattering is a very effective tool in understanding the heterogeneity of the medium. It considers the interactions between any two points of a heterogeneous medium. The maximum heterogeneity is recorded when there are fluid filled inclusions in the matrix. The study has previously been successfully carried out mostly on well-log data to distinguish the productive zones from the non- productive zones. The correlation function has two parts: amplitude and correlation radius. This work deals mainly with the amplitude part of the PCF that tends to be higher if the properties of the medium are drastically different in composition from its surroundings. The amplitudes of PCF are calculated for elastic stiffness tensors, density, and porosity. The seismic and well-log data are from the northern part of South Marsh Island in the Gulf of Mexico. The Tertiary sediments of interest are generally interbedded sands and shales. Apart from distinguishing the productive layer, an interesting correlation between the gamma ray-log and the amplitude of PCF has been observed through this study. This could help in quantifying the net to gross sands in a reservoir. We are also extending its application to the downscaled velocities to understand the measure of heterogeneity from 3D seismic data.

References Cited

Backus, G., 1962, Long-Wave Elastic Anisotropy Reduced by Horizontal Layering: Journal of Geophysical Research, v. 67, p. 4427-4440.

Bayuk, I.O., A.A. Vikhorev, J.M. Hooper, V.V. Tertychnyi, Y.A. Kukharensky, and E.M. Chesnokov, 2003, Frequency Dependent Effects in Porous Rocks: International Conference and Exhibition, EAEG, Extended Abstracts, PS10.

Chesnokov, E.M., A.K. Yuri, and I.O. Bayuk, 2001, Mathematical Modeling the Frequency Dependence of Velocities in Random Media Based on Well Log and Seismic Data: United Institute of Physics of the Earth Russian Academy of Sciences, Laboratory of Geophysics of Ordered Media Rock Physics and Reservoir Structure Monitoring Project, Norman, Ponca City, Moscow, 155 p.

Chesnokov, E.M., Y.A. Kukharenko, and P.A. Kukharenko, 1995, Method of Diagram Technique for Calculation of Effective Physical Parameters of Microinhomogeneous Media: SPIE – International Society of Optical Engineers, Mathematical Methods in Geophysical Imaging III, p. 2-12.

Gassiyev, A., F. Huang, and E.M. Chesnokov, 2016, Using the Pair-Correlation Function as a Tool to Identify the Location for Shale Gas/Oil Reservoir Based on Well-Log Data: Geophysics, v. 81/2, p. D91–D109.

Lifshitz, I.M., and L.N. Rosenzweig, 1947, On the Construction of the Green Tensor for the Basic Equation of the Theory of Elasticity of an Anisotropic Medium: Zh. Eksper. Teor. Fiz., v. 17, p. 783-791, (in Russian).

Shermergor, T.D., 1977, Theory of Elasticity of Microinhomogeneous Media: Moscow, Nauka, (in Russian).

Tiwary, D.K., I.O. Bayuk, A.A. Vikhorev, and E.M. Chesnokov, 2009, Comparison of Seismic Upscaling Methods: From Sonic To Seismic: Geophysics, v. 74/2, p. WA3–WA14.

Amplitude of Pair Correlation Function to Understand Heterogeneity from Well-log and Seismic data

UNIVERSITY of
HOUSTON
EARTH and
ATMOSPHERIC
SCIENCES

Ramya Ravindranathan and Dr. Evgeny Chesnokov



UNIVERSITY of
HOUSTON

Outline

Motivation

Objective

Pair Correlation Function

Results

Conclusions

References

Motivation

- Better and effective integration of the seismic and well-log data to understand the subsurface
- On the look out for a methodology that can help map the producing zones as well as enable to understand the heterogeneity of the reservoir
- Net sand thickness estimation and understanding of depositional element or environment ???

Objective

- To understand heterogeneity using correlations of fluctuations of various measured and calculated parameters like velocity, density, porosity and stiffness tensors

Pair Correlation Function (PCF) Approximation method

- Introduced by Lifshitz and Rosenzweig in 1947 and modified by Shermergor, 1977
- Modified and applied by Chesnokov et al., 1995
- An averaging and upscaling technique
- Identify the productive from the non – productive zones

Pair Correlation Function Approximation method

The effective stiffness tensor and density using the pair correlation function method is given by :

$$C_{ijkl}^* (\omega, \mathbf{k}) = \langle C_{ijkl} \rangle + \int \boxed{B_{pqkl}^{ijmn}(\mathbf{r})} G_{mp,nq}^0 (\omega, \mathbf{r}) e^{-i\mathbf{k}\mathbf{r}} d\mathbf{r}$$

$$\rho^* (\omega, \mathbf{k}) = \langle \rho(\mathbf{r}) \rangle - \omega^2 \int \cos(\mathbf{k}, \mathbf{r}) G_{ii}^0 (\omega, \mathbf{r}) \overset{\rho\rho}{B}(\mathbf{r}) d\mathbf{r}$$

Where,

ω = cyclic frequency

\mathbf{k} = wave vector,

B = correlation function,

C_{ijkl} , ($i, j, k, l = 1, 2, 3$) = 4th rank effective elasticity tensor, and

G^0 = dynamic Green's function which depends on medium properties and frequency.

Pair Correlation Function

$B_{ijkl}^{pqmn}(\mathbf{r})$ is the pair correlation function

$${}^{cc\ pqmn}B_{ijkl}(\mathbf{r}) = \langle C'_{ijkl}(\mathbf{x}) C'_{pqmn}(\mathbf{x} + \mathbf{r}) \rangle$$

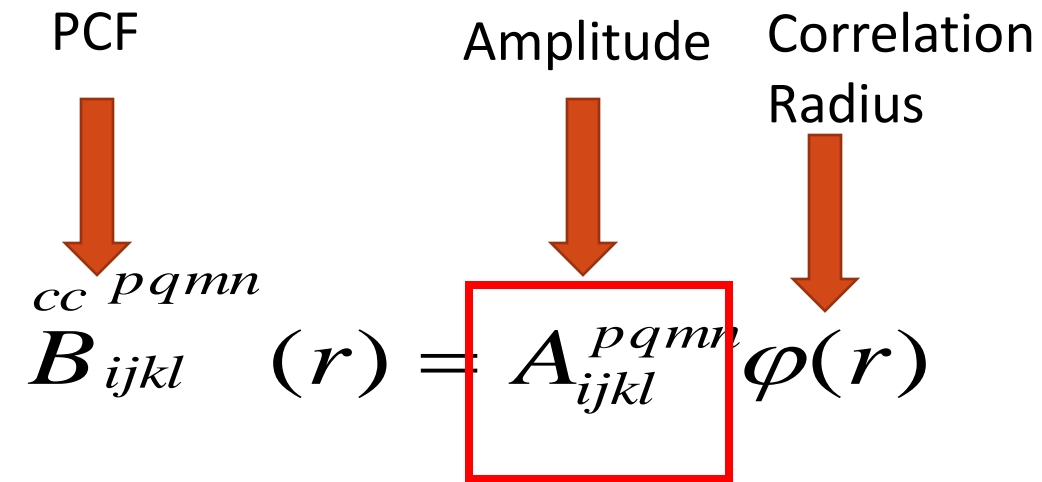
$${}^{\rho}B(\mathbf{r}) = \langle \rho'(\mathbf{x}) \rho'(\mathbf{x} + \mathbf{r}) \rangle$$

where, $C'_{ijkl}(\mathbf{x}) = C_{ijkl}(\mathbf{x}) - \langle C_{ijkl}(\mathbf{x}) \rangle$ the fluctuation of stiffness tensor

$\rho'(\mathbf{x}) = \rho(\mathbf{x}) - \langle \rho(\mathbf{x}) \rangle$ the fluctuation of density tensor

Fluctuation is the deviation of the function from its averaged value

Components of Pair Correlation function



The diagram illustrates the decomposition of the Pair Correlation Function (PCF) into its amplitude and correlation radius components. Three orange arrows point downwards from the labels 'PCF', 'Amplitude', and 'Correlation Radius' to their respective terms in the equation. The term A_{ijkl}^{pqmn} is highlighted with a red rectangular box.

$${}^{cc\ pqmn}B_{ijkl}(r) = A_{ijkl}^{pqmn} \varphi(r)$$

$\Phi(r)$ - Function describing co-ordinate dependency of the correlation function

$${}^{cc\ pqmn}A_{ijkl}(\mathbf{r}) = \langle C'_{ijkl}(\mathbf{x}) C'_{pqmn}(\mathbf{x}) \rangle \Big|_{window}$$

Averaging window

- Medium within the window is statistically homogeneous.
- The logging step is one feet
- Window length = wavelength (calculated from velocity and frequency)

$$\langle C_{33} \rangle = \frac{1}{L_w} \sum_{r=1}^{L_w} C_{33}(r)$$

$$C_{33}(r) = V_p^2(r) \rho(r)$$

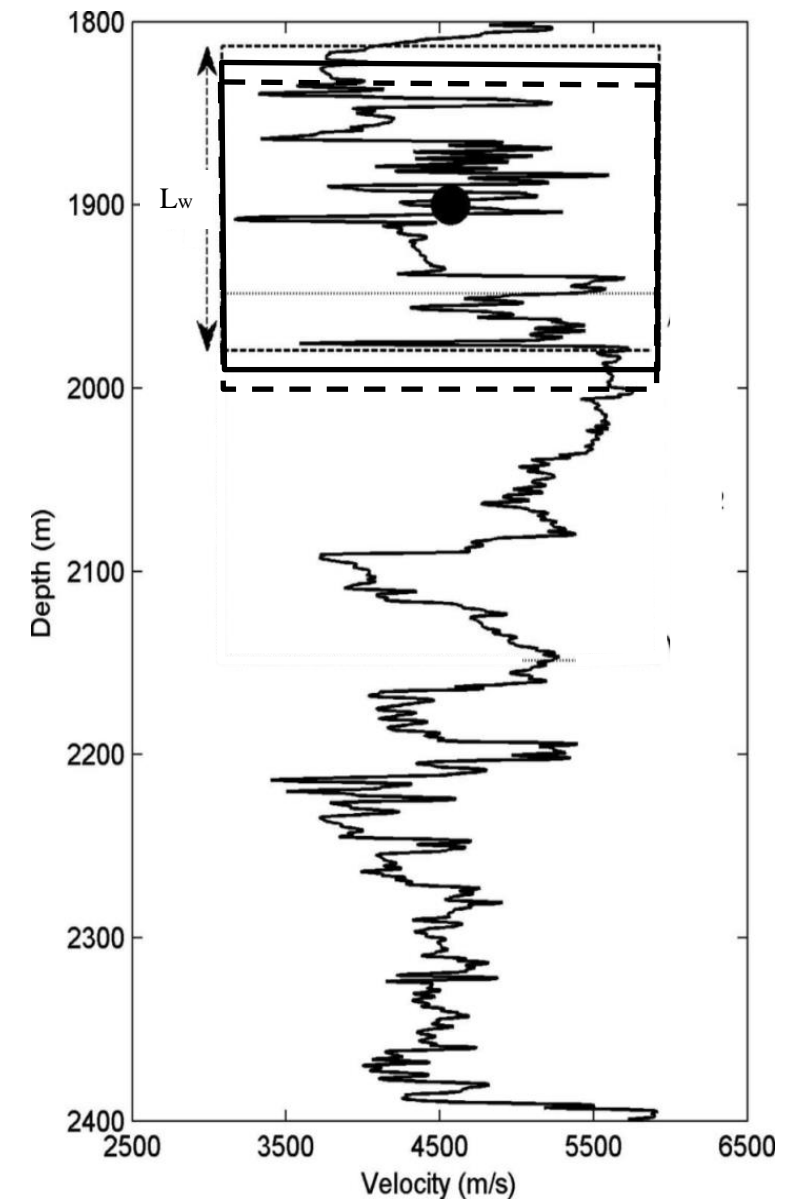
Where,

C_{33} = Stiffness Tensor

L_w = Window length

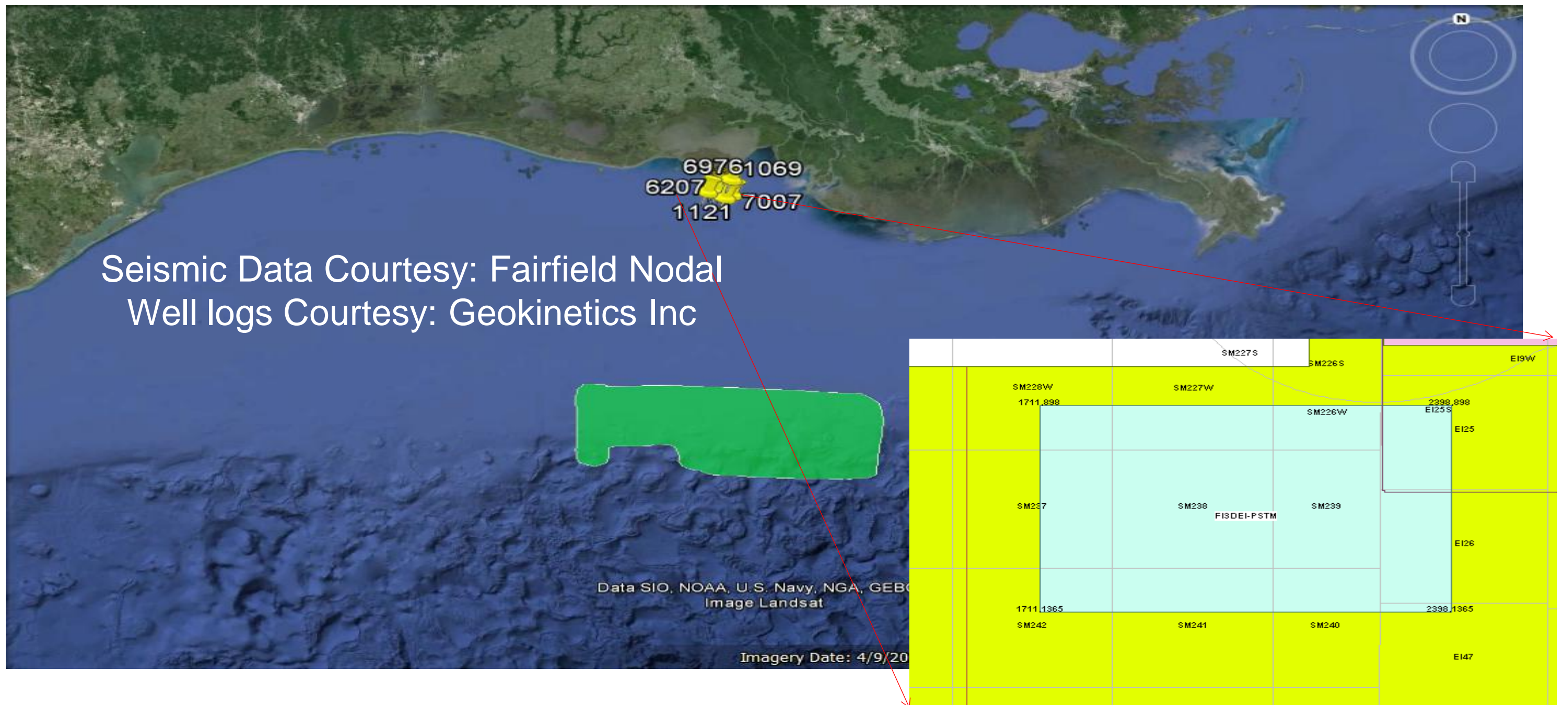
V_p = P-wave Velocity

ρ = Bulk Density



*Modified from Tiwary et. al, 2009
Backus, 1952*

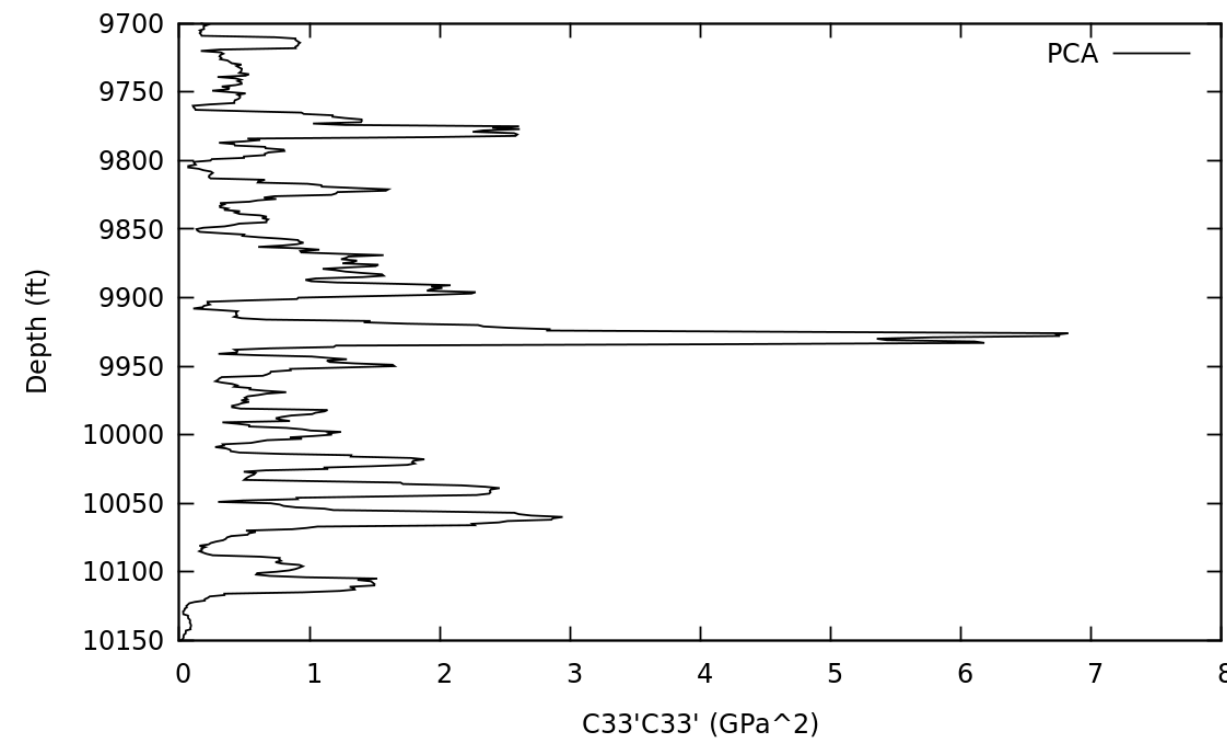
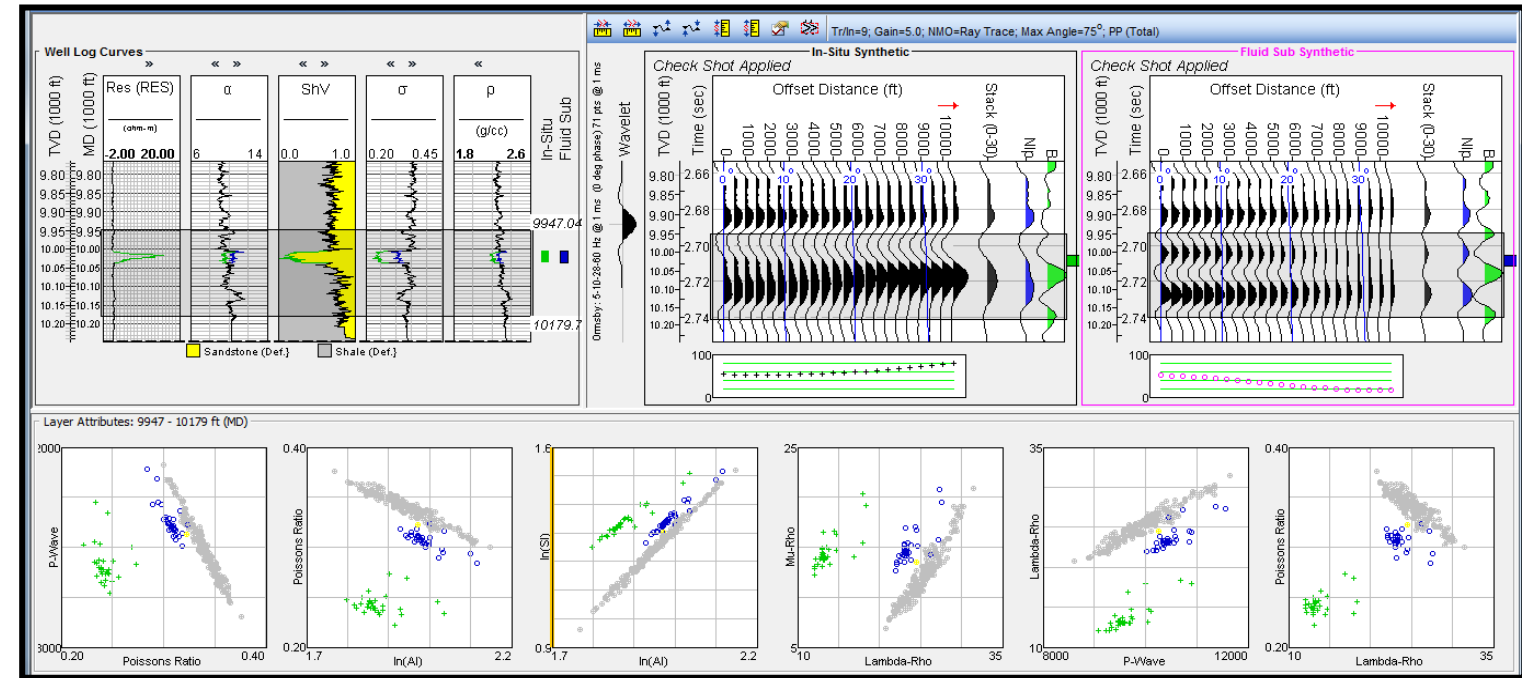
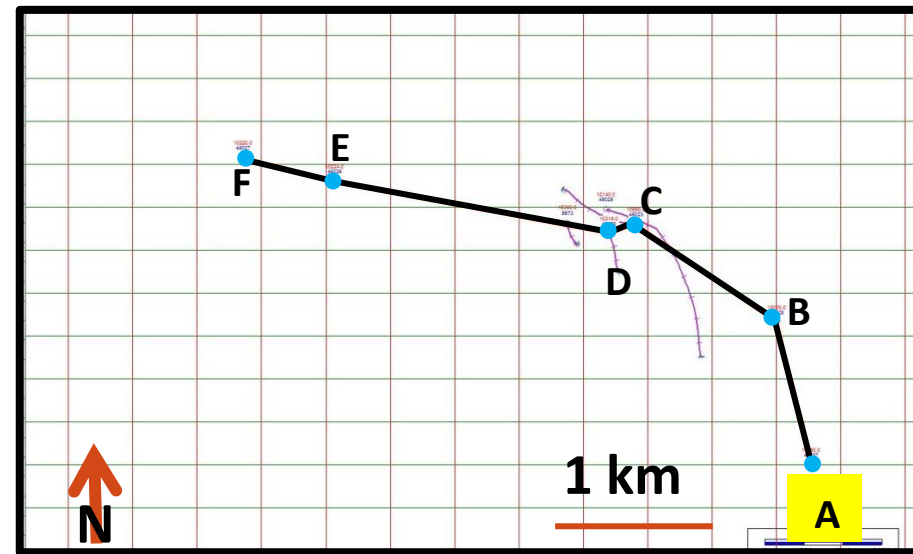
South Marsh Island



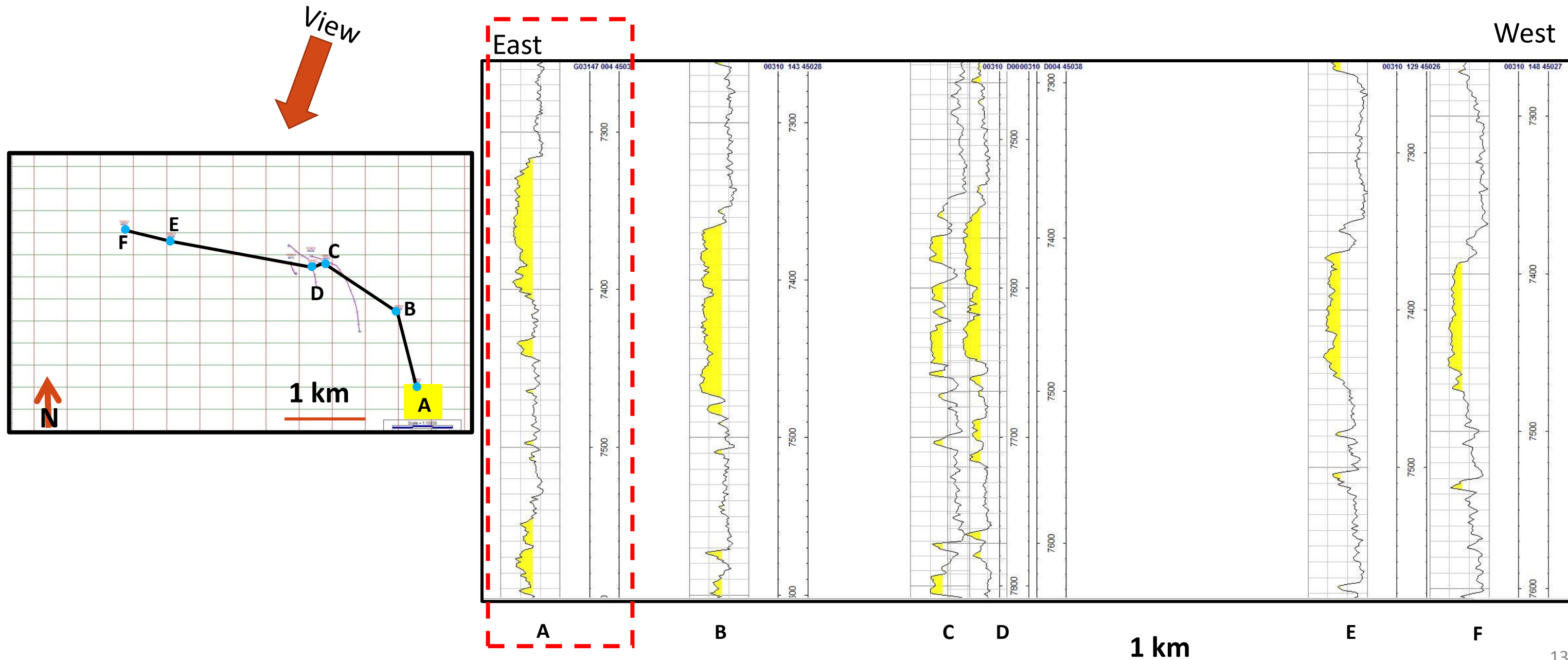
South Marsh Island

- Terrigenous sediments deposited by the shifting Mississippi depocenter from the Oligo-Miocene to the present.
- Sediments are dominated by shale with inter bedded sands deposited by fluvial and deltaic systems.
- Dominated by listric normal faults that sole into evacuated salt sheets, or welds.

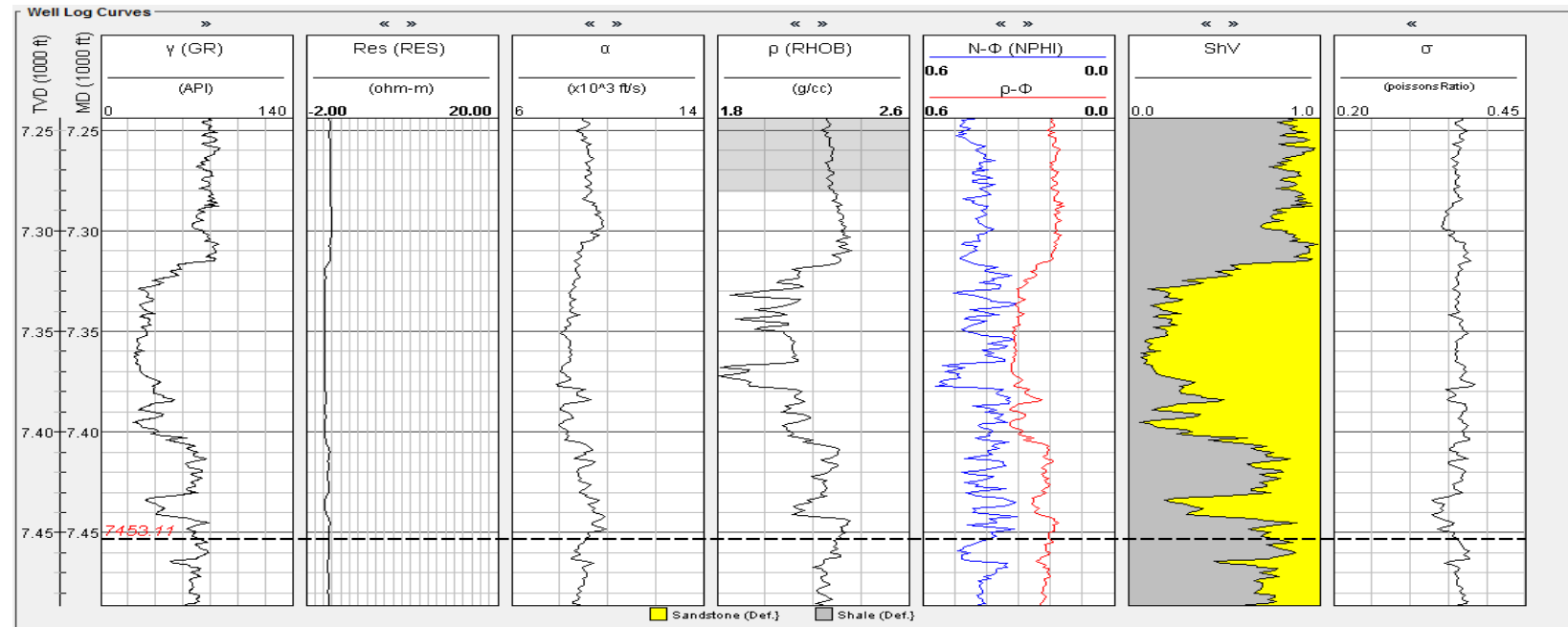
Well A - Amplitude of fluctuations of C33 – Productive zone (10000-10030 ft MD/ 9922- 9952 ft TVDSS)



Basemap showing the well locations and correlation of gamma ray logs

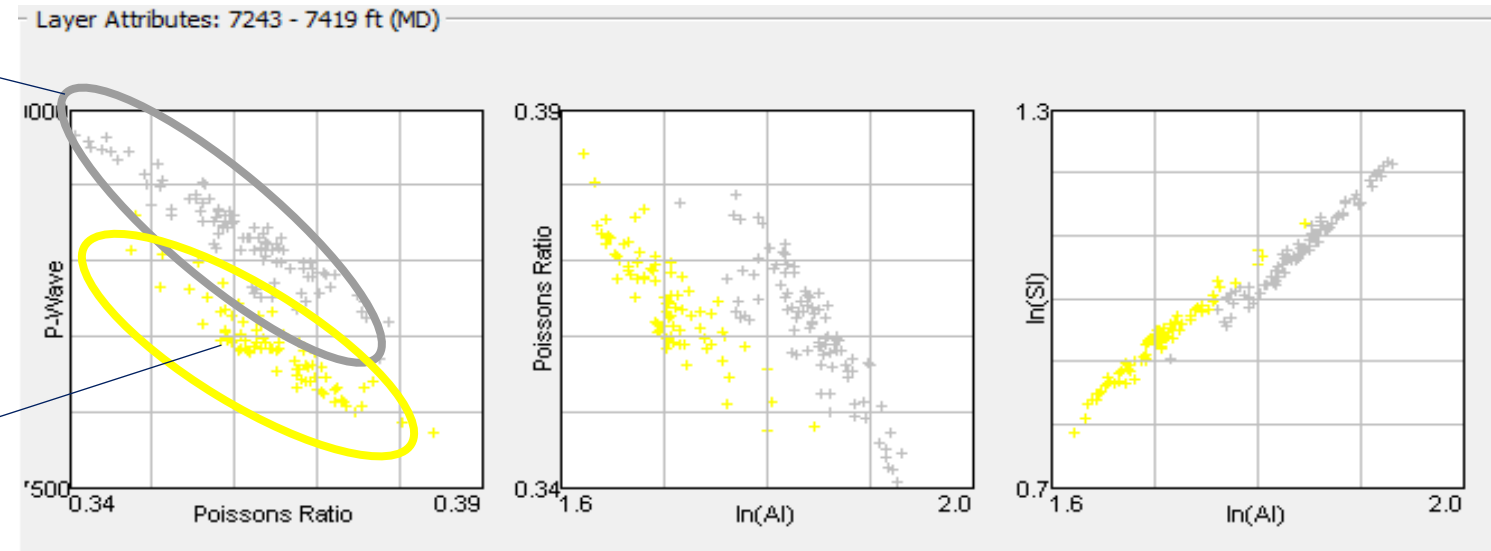


Well A – Layer Attributes

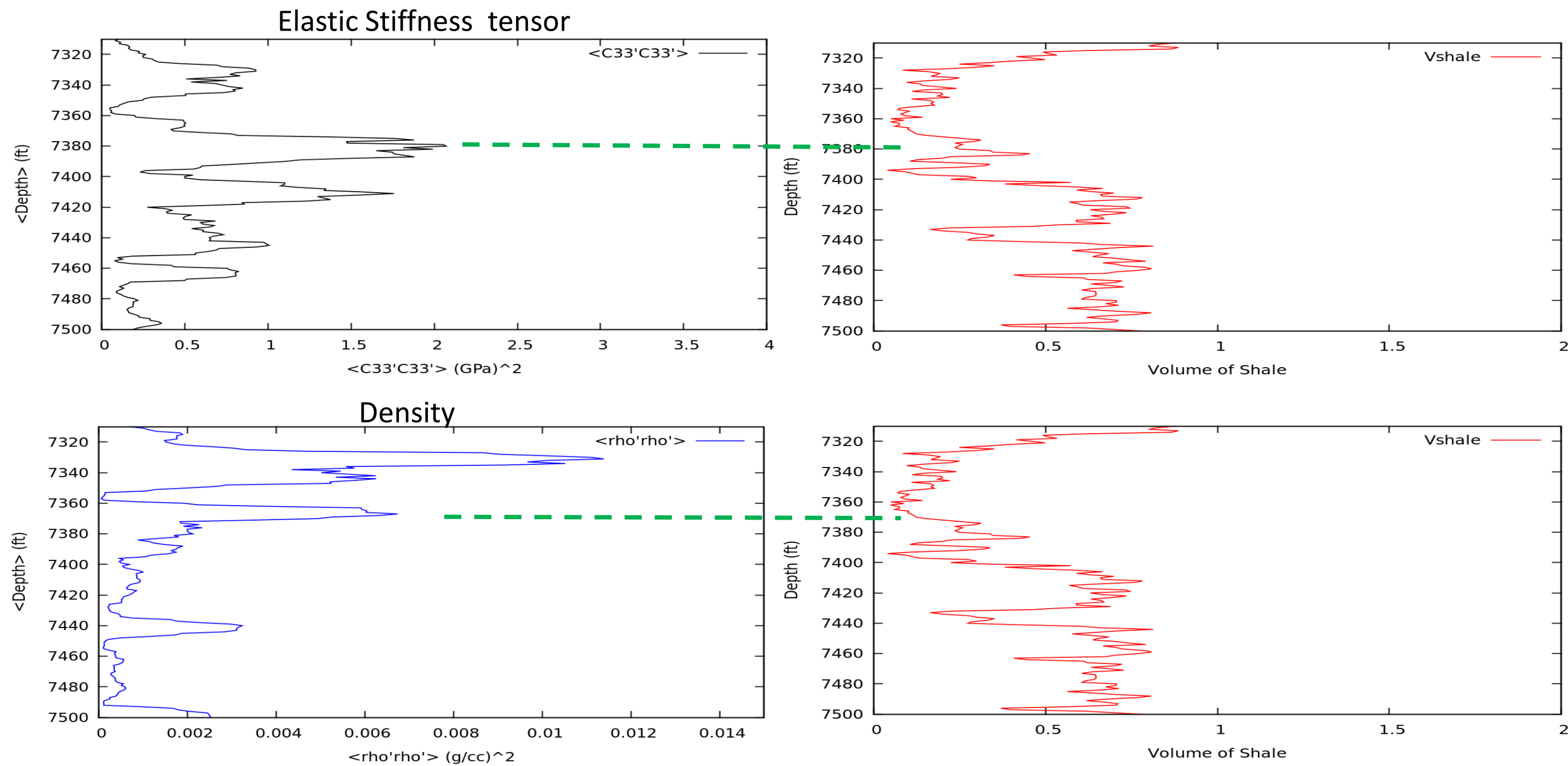


Shale

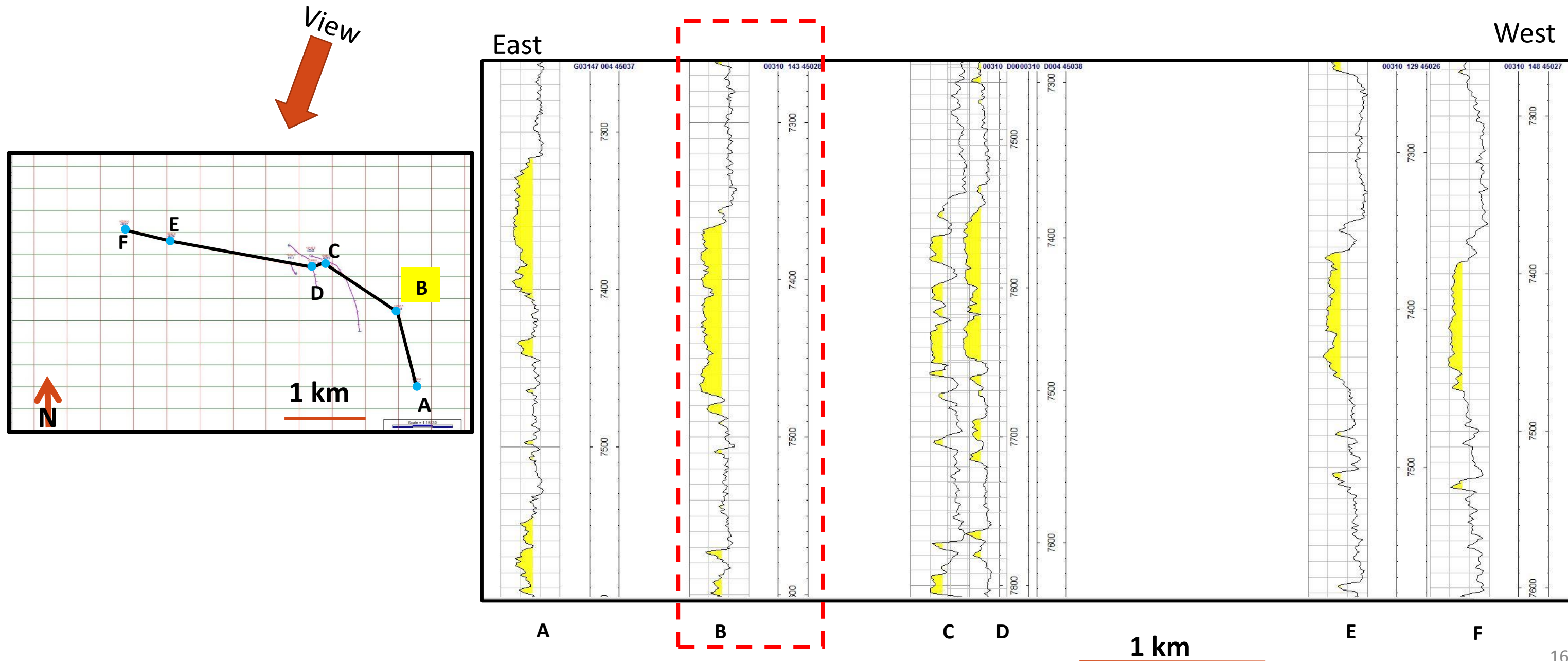
Sand



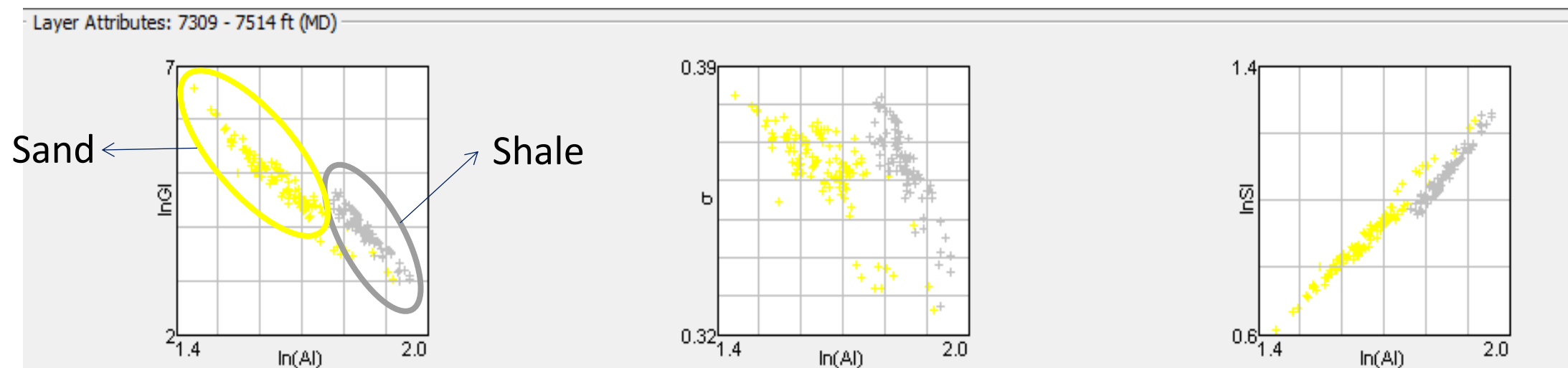
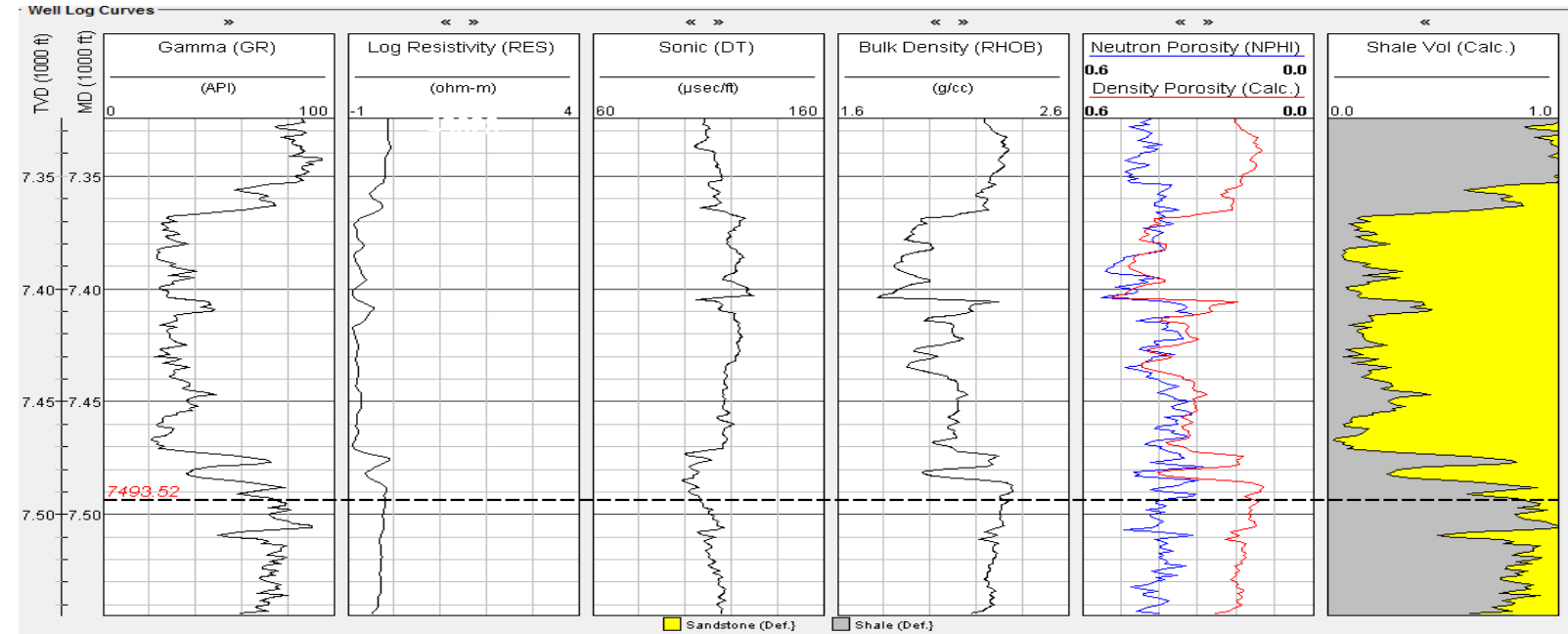
Well A - Amplitude of fluctuations of C33 and Density



Basemap showing the well locations and correlation of gamma ray logs

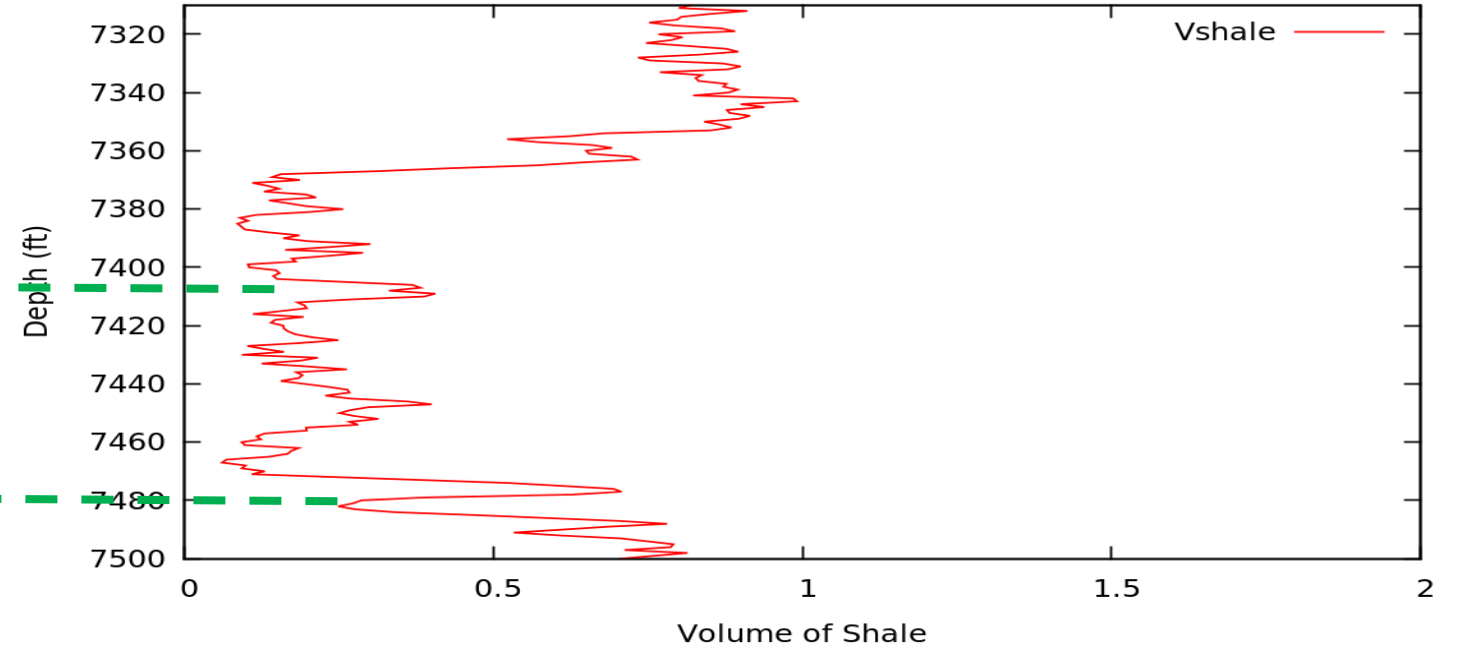
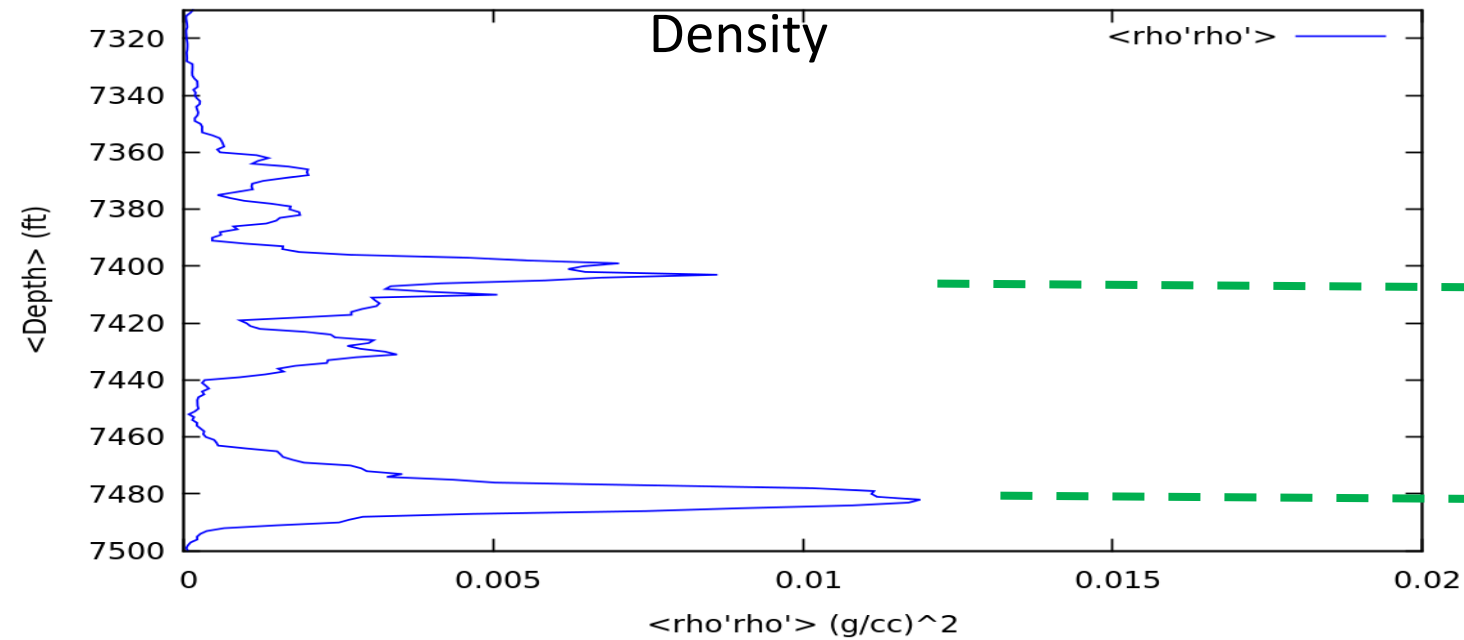
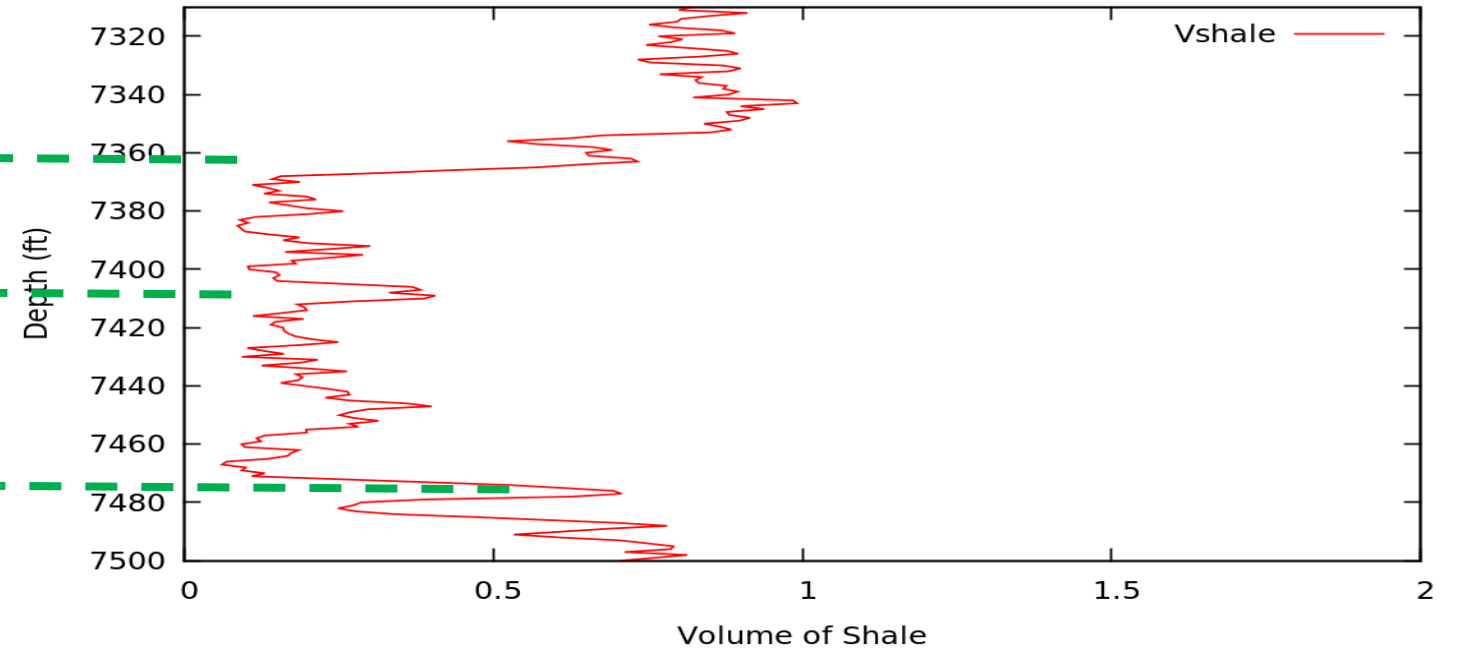
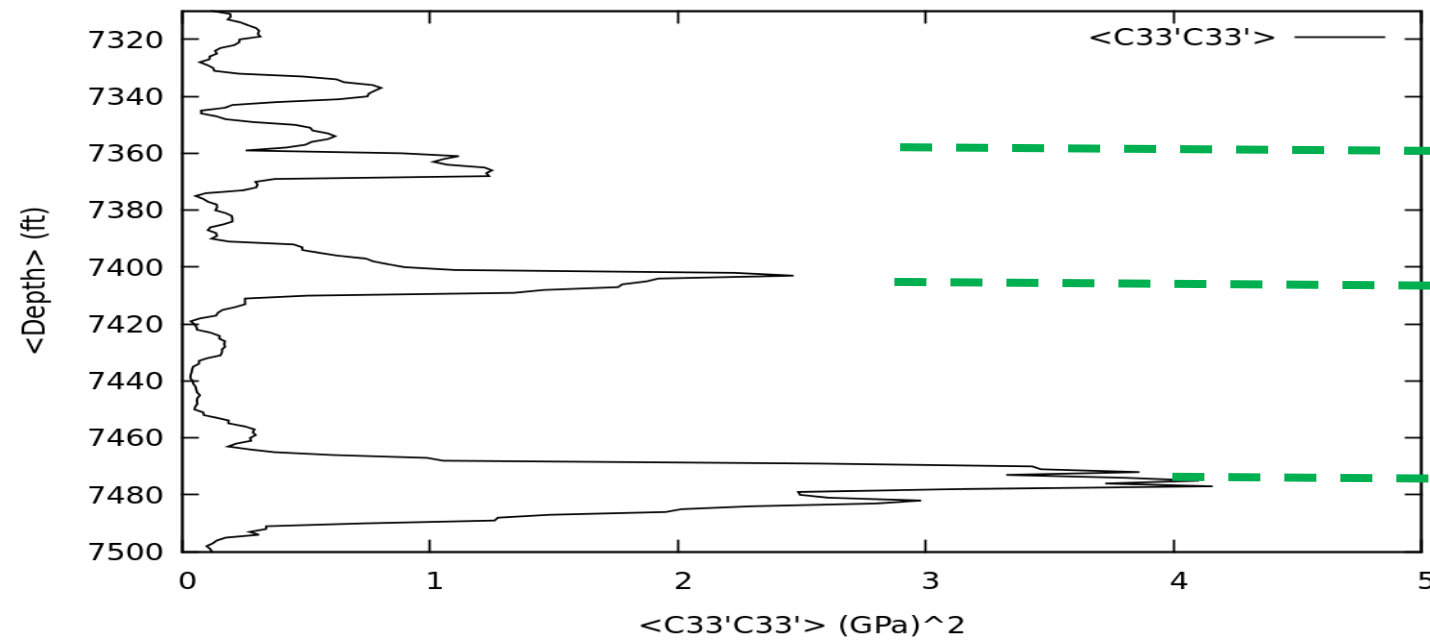


Well B - Layer Attributes

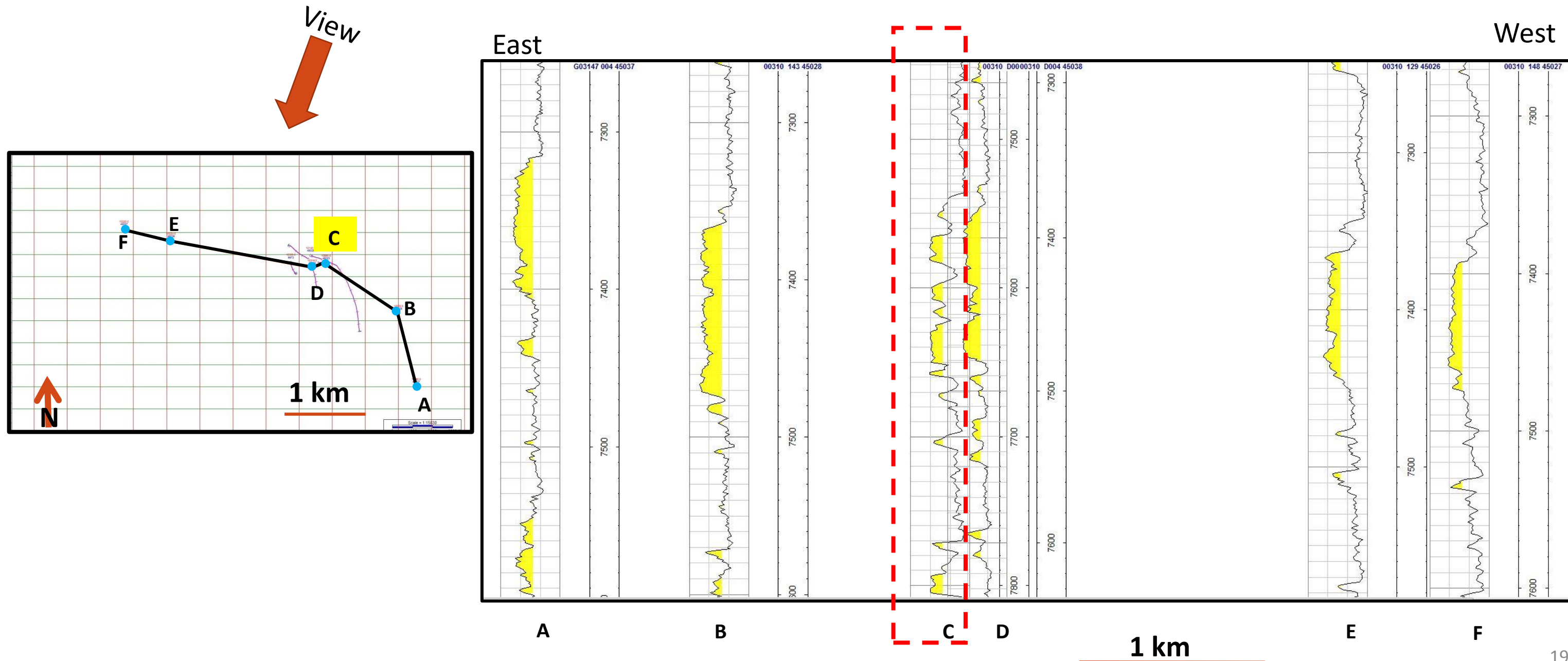


Well B - Amplitude of fluctuations of C33 and Density

Elastic Stiffness tensor

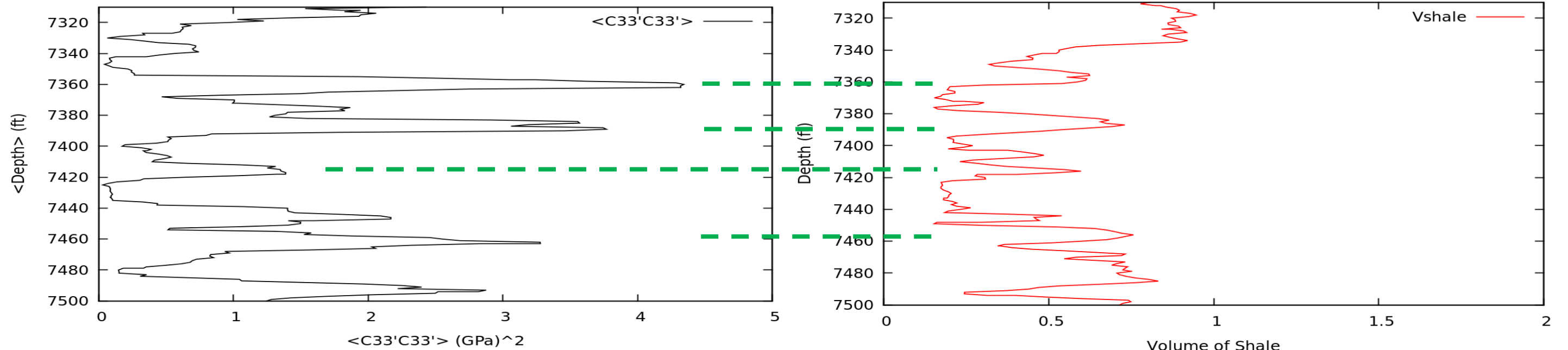


Basemap showing the well locations and correlation of gamma ray logs

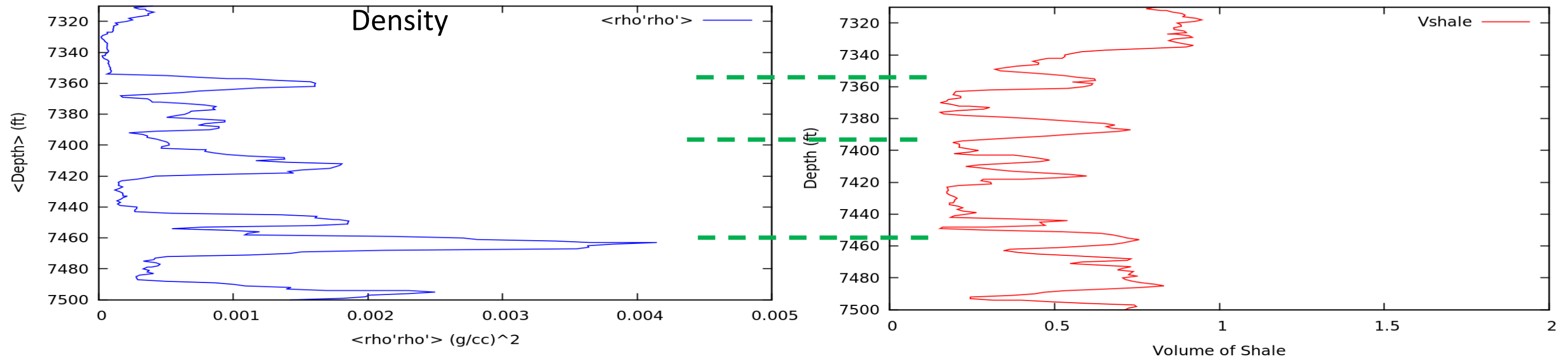


Well C- Amplitude of fluctuations of C33 and Density

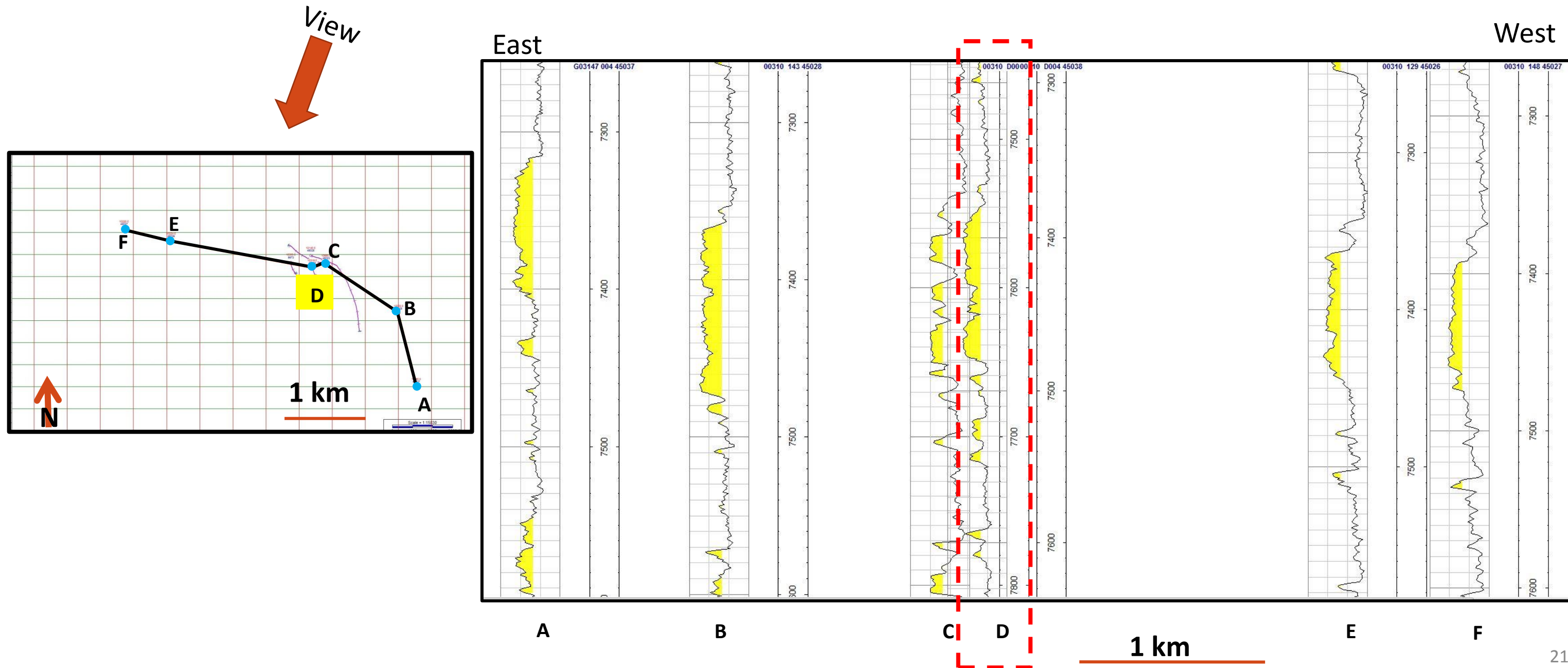
Elastic Stiffness tensor



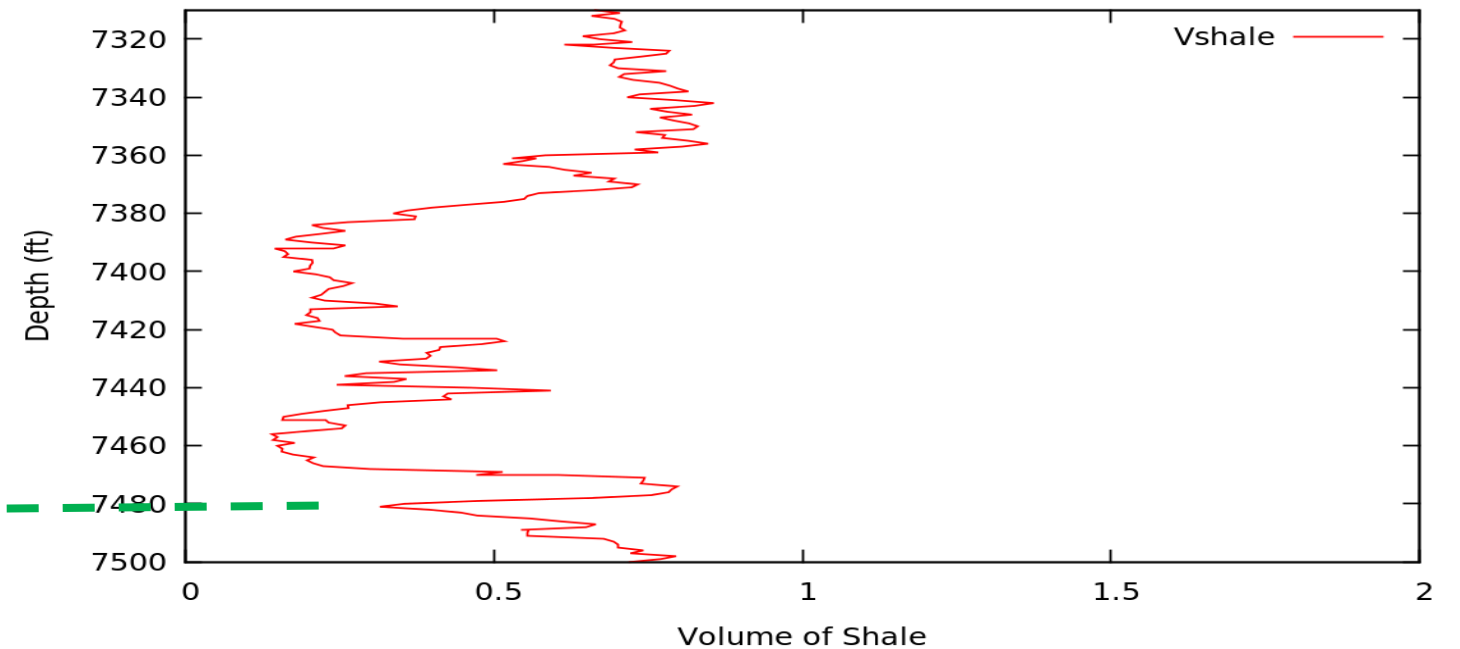
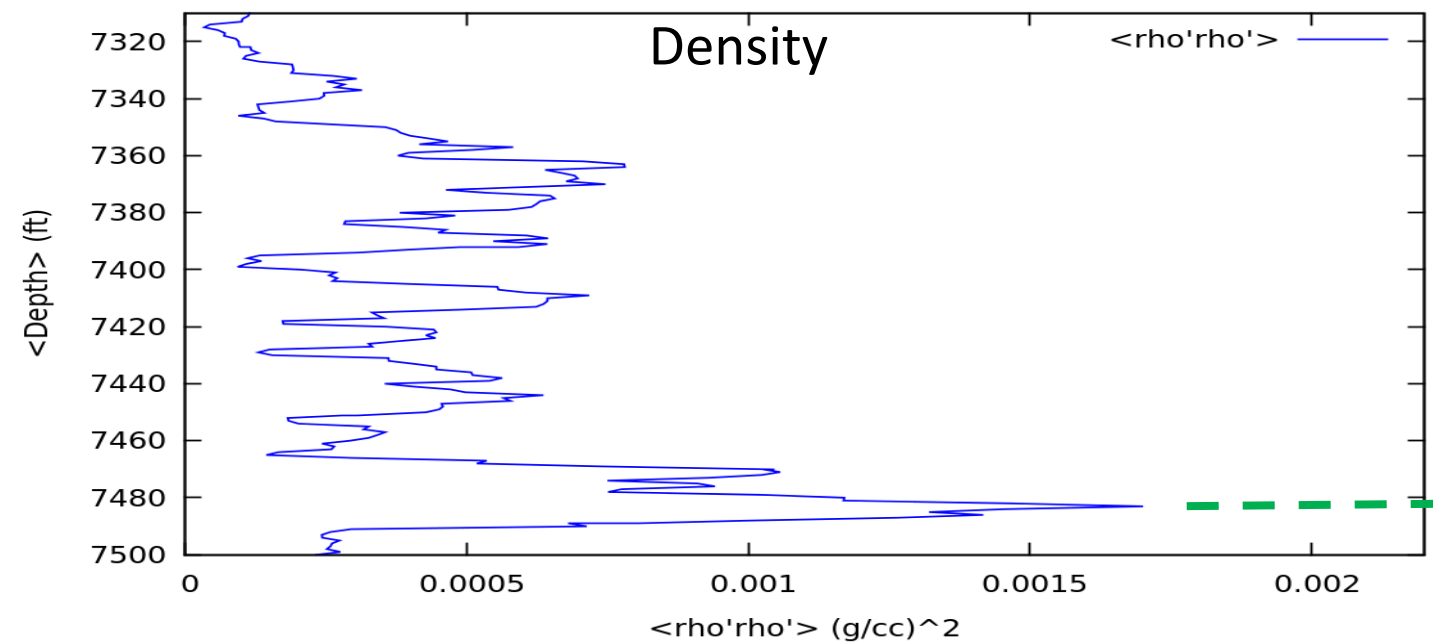
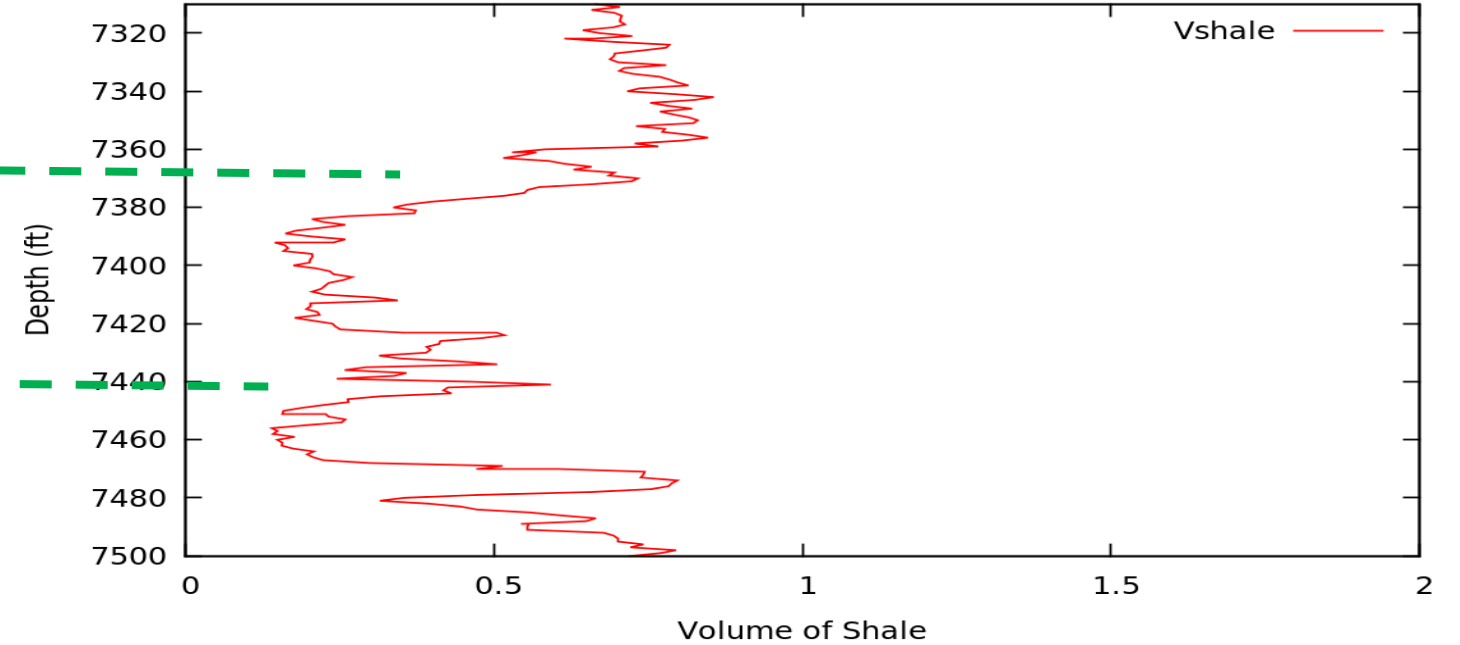
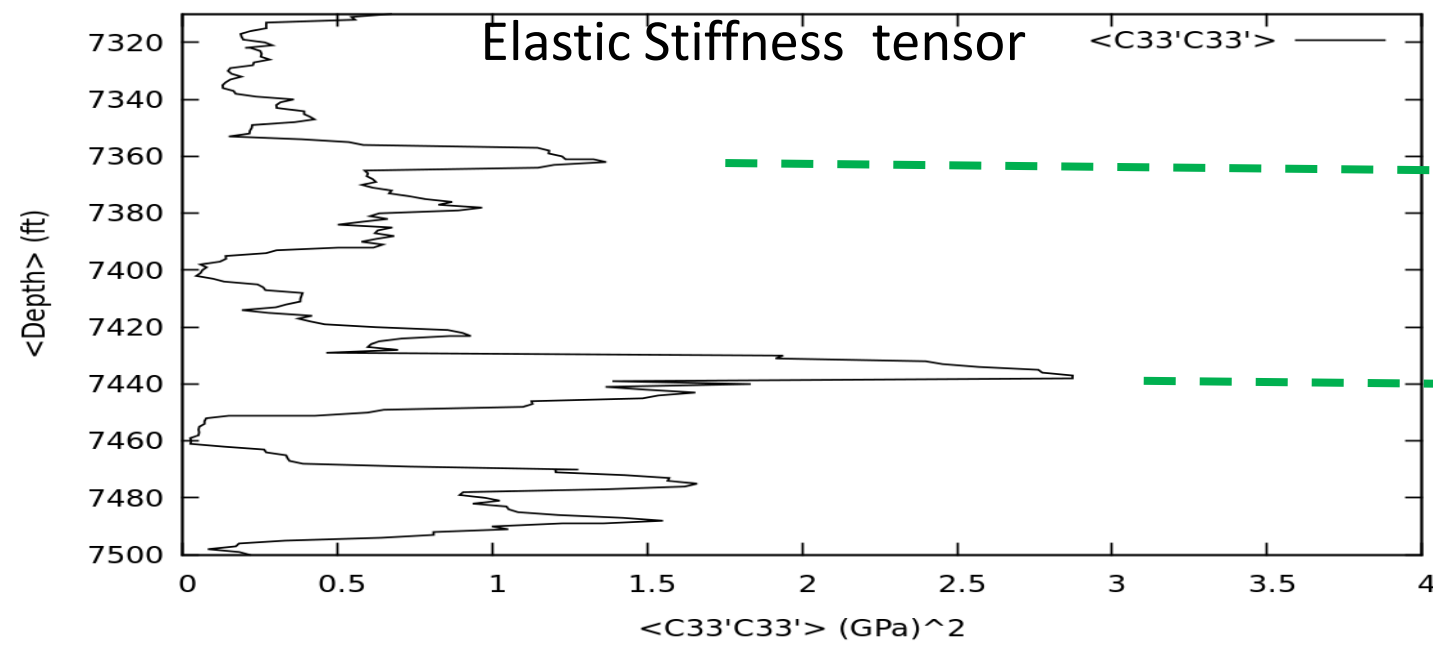
Density



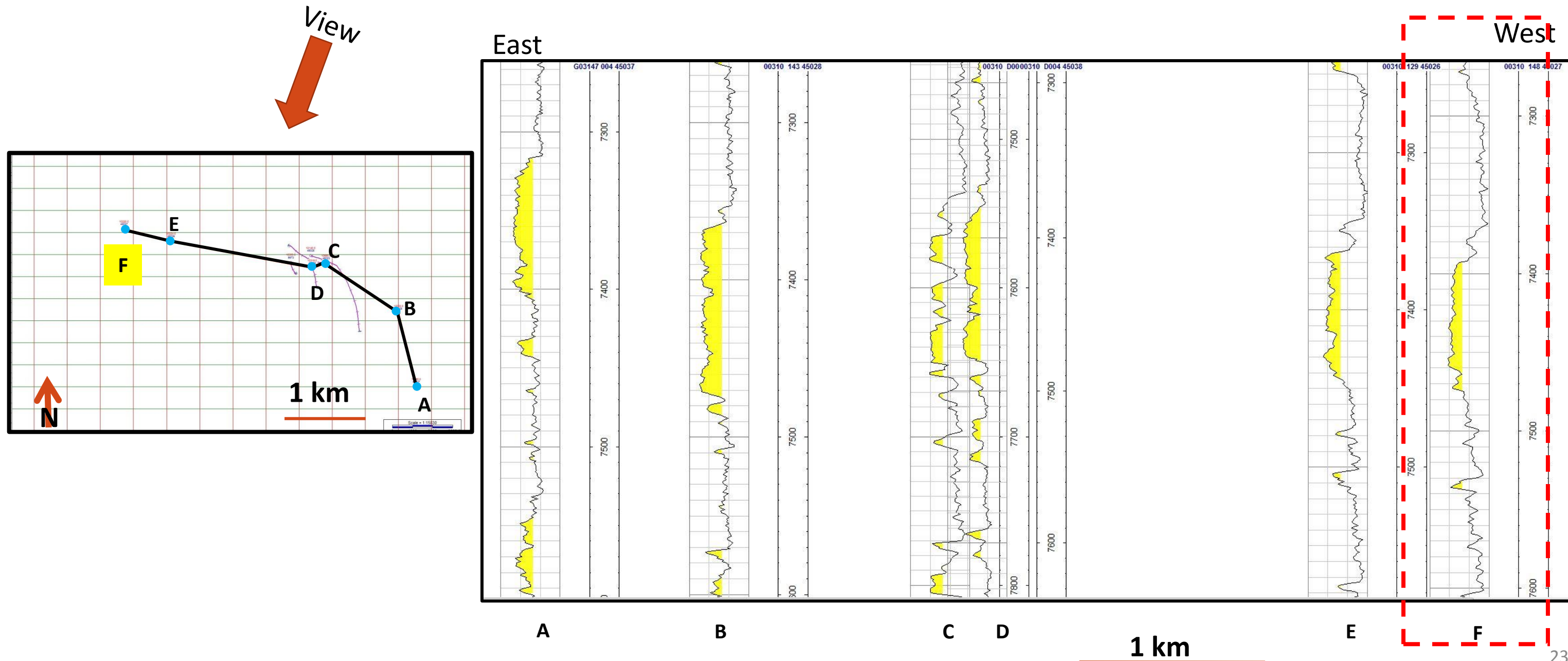
Basemap showing the well locations and correlation of gamma ray logs



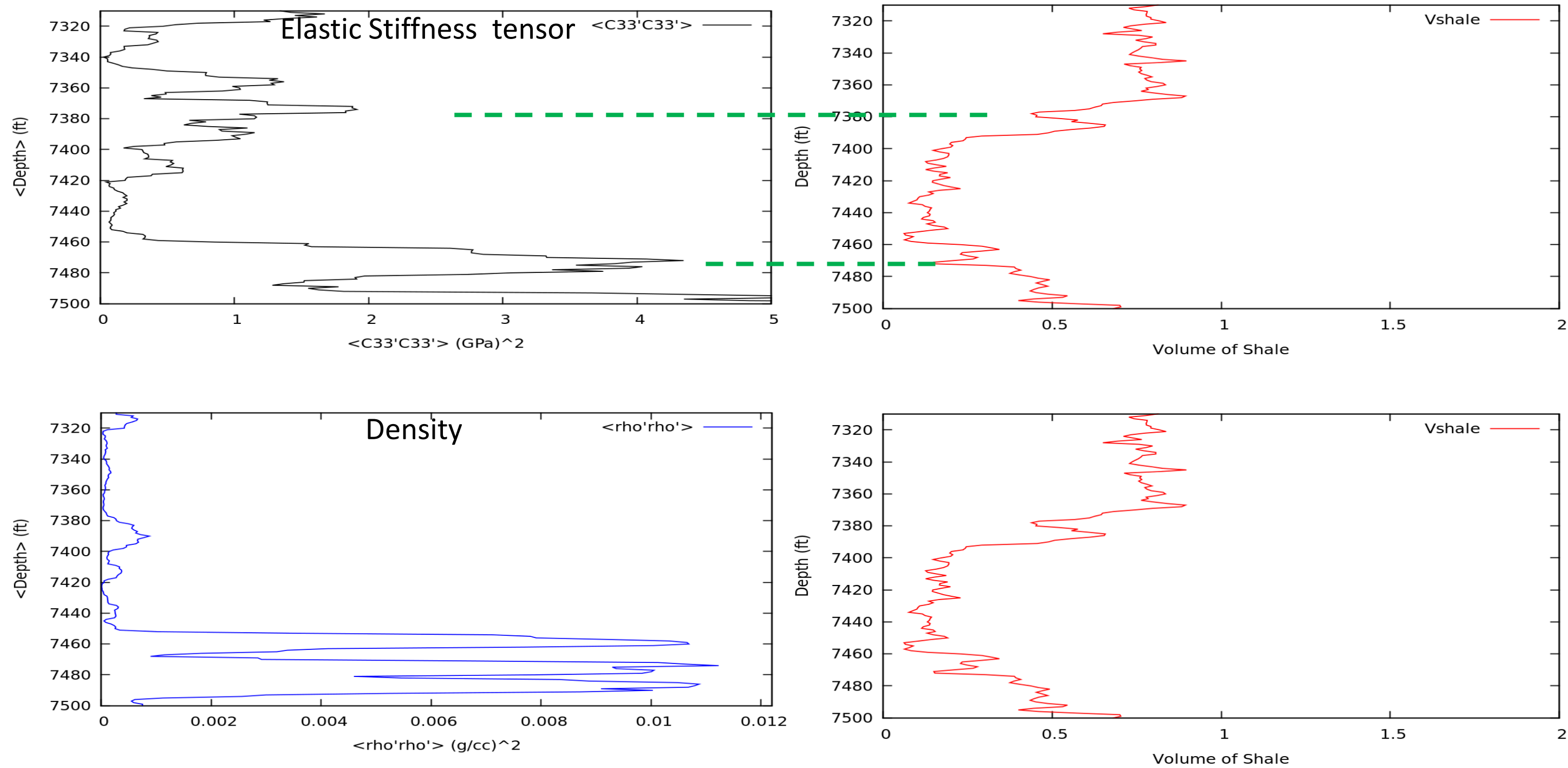
Well D- Amplitude of fluctuations of C33 and Density



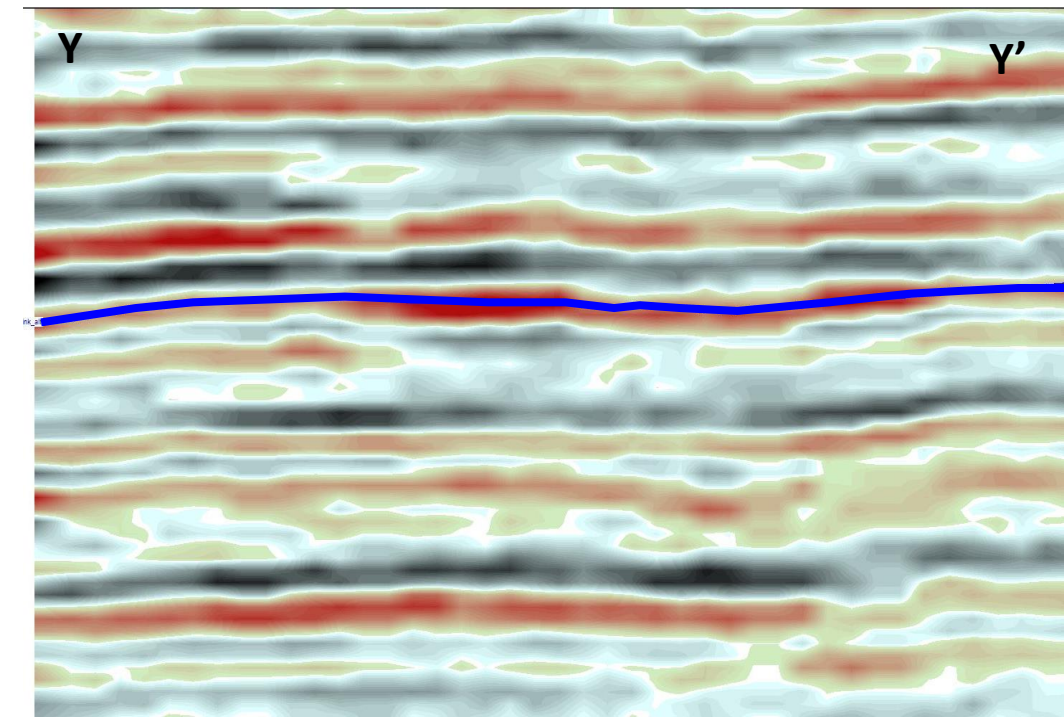
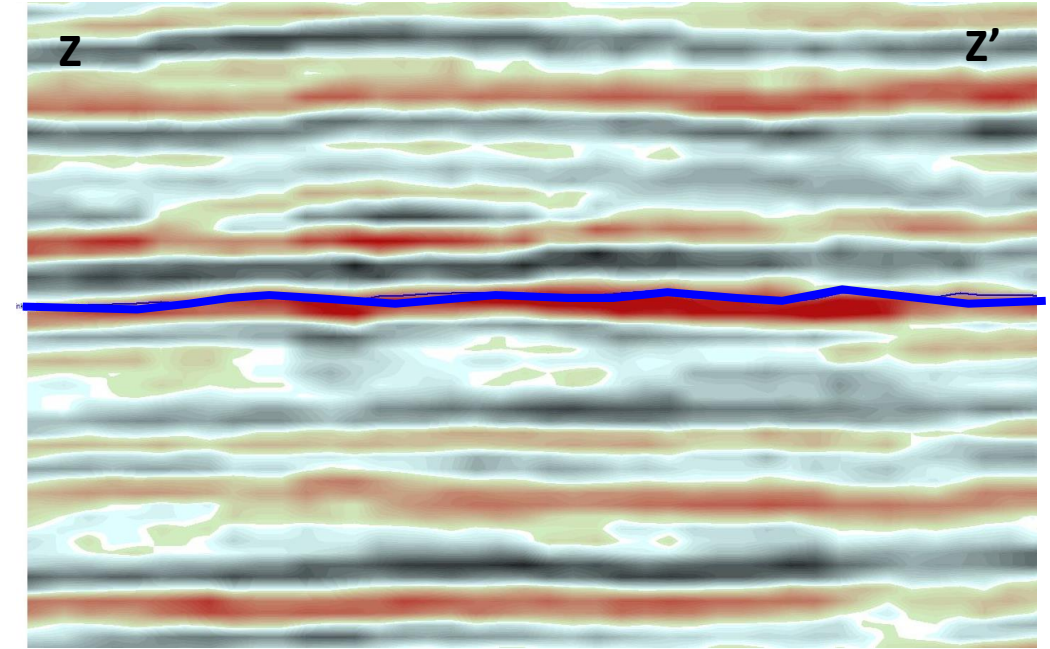
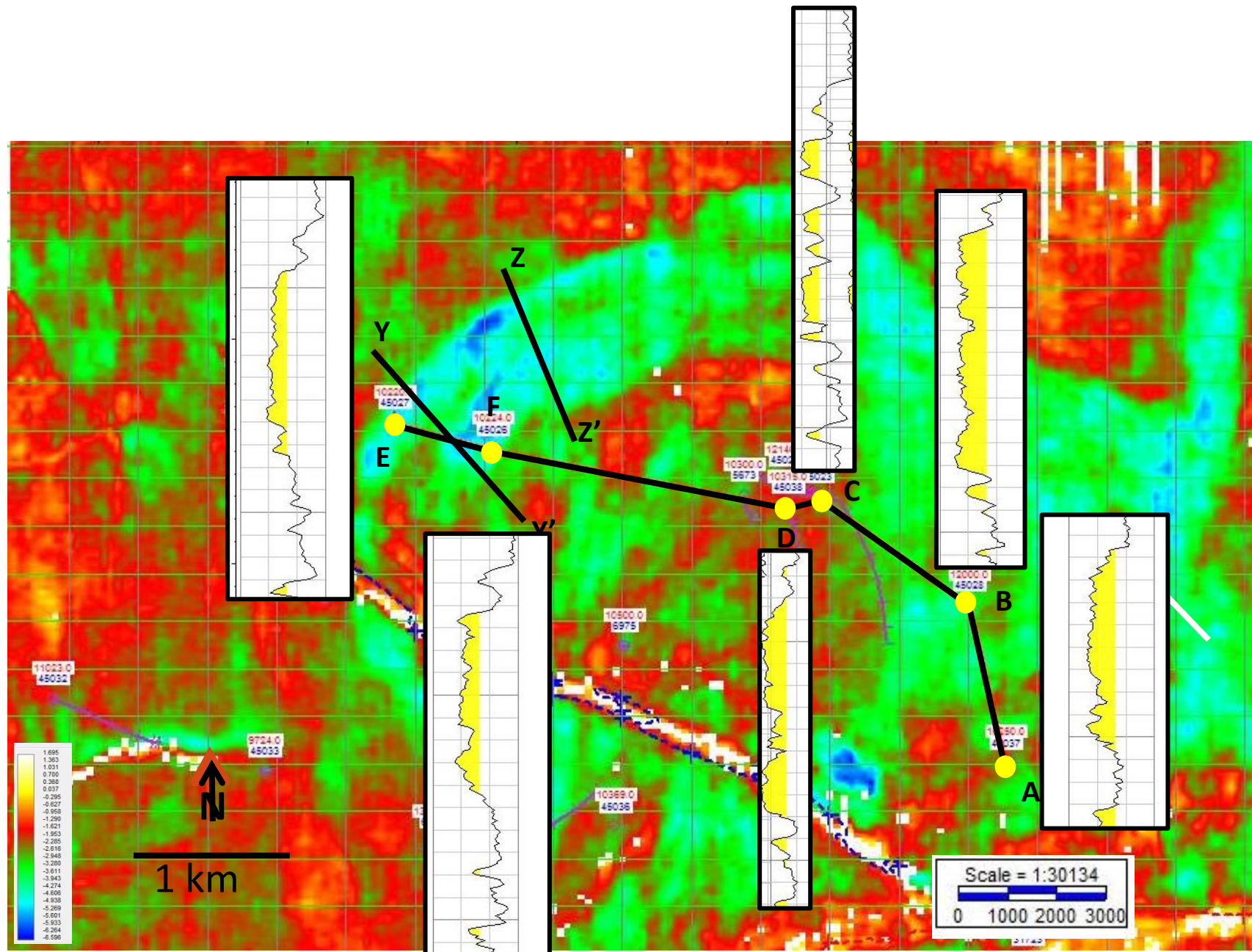
Basemap showing the well locations and correlation of gamma ray logs



Well F- Amplitude of fluctuations of C33 and Density



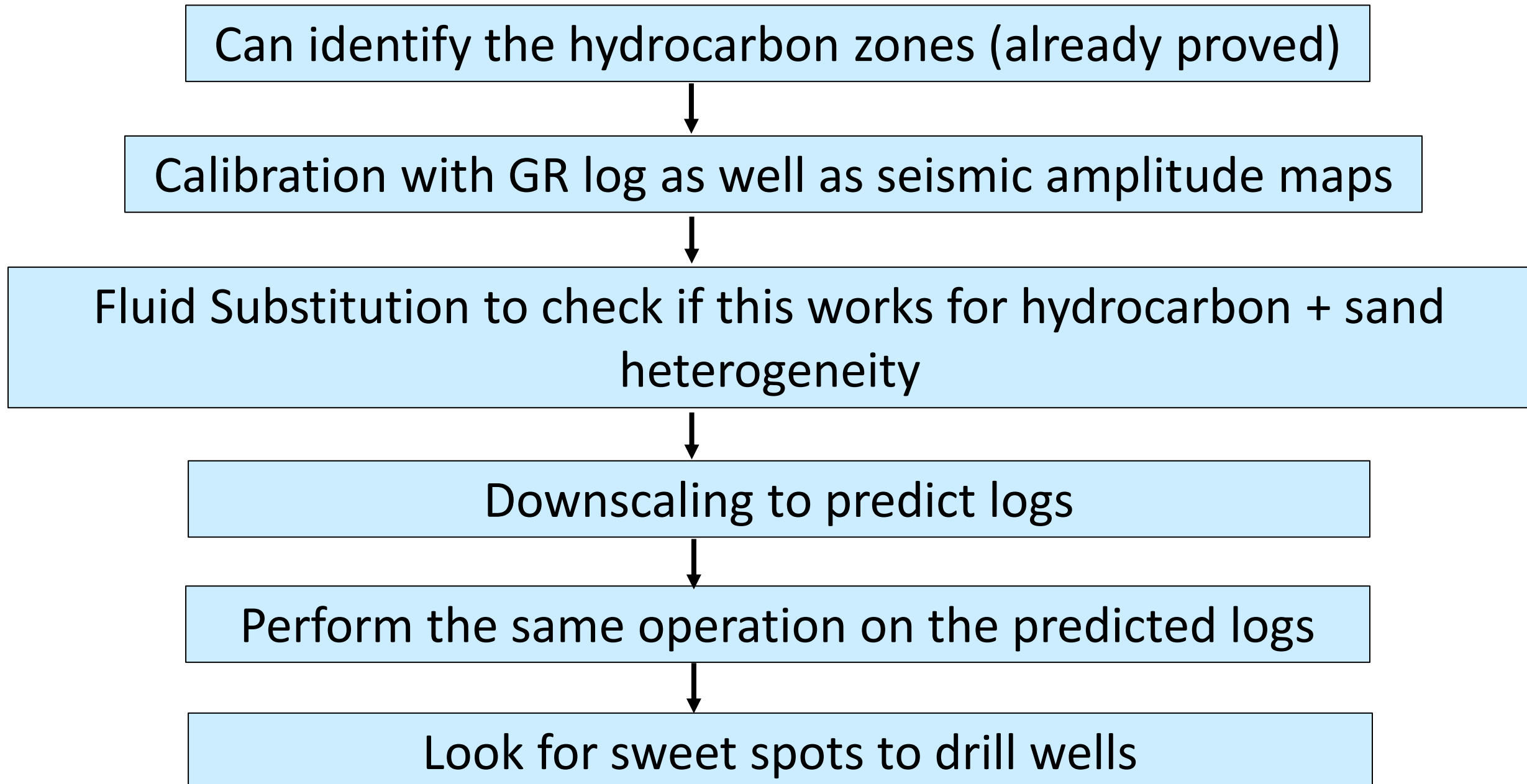
Amplitude map extracted along the blue horizon



Conclusions

- Can identify/detect the hydrocarbon zone
- Reflects the inhomogeneity of the sands, which is supported by the GR log or calculated volume of shale
- Understand the depositional element
- High confidence Time-Depth table very crucial for integrating this study with seismic

What next?



References

- Bayuk, I. O., A. A. Vikhorev, J. M. Hooper, V. V. Tertychnyi, Y. A. Kukharenko, and E.M. Chesnokov, 2003, Frequency dependent effects in porous rocks: International Conference and Exhibition, EAEG, Extended Abstracts, PS10.
- Chesnokov, E. M., A, K, Yuri, and I. O. Bayuk, 2001, Mathematical modeling the frequency dependence of velocities in random media based on well log and seismic data.: United institute of physics of the earth Russian academy of sciences, Laboratory of Geophysics of Ordered Media Rock Physics and Reservoir Structure Monitoring Project, Norman, Ponca City, Moscow, 155p
- Chesnokov, E. M., Y. A. Kukharenko, and P. A. Kukharenko, 1995, Method of diagram technique for calculation of effective physical parameters of microinhomogeneous media: SPIE—International Society of Optical Engineers, Mathematical Methods in Geophysical Imaging III, 2–12
- Gassiyev, A., F. Huang, and E. M. Chesnokov, 2016, Using the pair-correlation function as a tool to identify the location for shale gas/oil reservoir based on well-log data. *Geophysics* **81**, no.2, D91–D109.
- Tiwary, D. K. , I. O. Bayuk, A. A. Vikhorev, and E. M. Chesnokov, 2009, Comparison of seismic upscaling methods: From sonic to seismic: *GEOPHYSICS*, v. 74, no. 2, p.WA3–WA14.

Acknowledgements

- Geokinetics Inc. and Dr. Fred Hilterman
- Fairfield Nodal
- Dr. William Dupre
- Dr. Anne Cecile Lesage

Thank you