PS Integration of XRF and Shades of Grey Profiles for In-Depth Characterization of Shale Properties*

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Abstract

Integration of XRF and of shades of grey profiles has been tested on cores and on several hundreds of drill cuttings samples pertaining to several Duvernay vertical and horizontal wells. Very high-resolution images have been used to extract a shade of grey profile for complete Duvernay and Montney cored intervals. These profiles have helped define detailed sequence stratigraphy as minima and maxima clearly showed trends that could be associated to basin related changes occurring in neighboring wells at the same stratigraphic levels. The study also looked at differences in output and usefulness of shades of grey profiles between various core photography set-ups, i.e. between high-resolution (200 microns per pixel) traditional lab photo equipment and very high-resolution photos (35 microns per pixel) taken on a rolling bench. The results integrated with work on other images from various laboratories on the same cores have delivered a series of criteria and patterns useful to recognize lighting issues that would minimize the usefulness of shades of grey profiles. For a test study, shades of grey have also been extracted using a line scanner at a resolution of 200 microns per pixel on several extensive series of drill cuttings. Ten successive XRF measurements for each cutting vial allowed for statistical analysis of 26 elements and gave a solid data set to evaluate the shade of grey approach. These ten XRF measurements per vial were compared to single XRF value from a handheld XRF device to outline similarities and differences linked to the tools. Prediction of total organic carbon was then tested using the two sets of XRF mentioned and Leco TOC done on many of the samples. Additionally, the study generated a series of workflows that successfully tested frac placement prediction using XRF data (elements, ratios and multilinear regression). It is important point to strengthen the analysis by analyzing frac stages that would have limited facies changes as evidenced by XRF; thus, stages that would saddle two very different lithologies should not be incorporated in the initial learning data set. Both XRF and shades of grey can be extremely useful to geologists and engineers to better understand what will make a good hydraulic frac, but calibration and quality control are essential.

Integration of XRF and shades of grey profiles for in-depth characterization of shale properties

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Very high resolution images have been used to extract a shade of grey profile for complete Duvernay and Montney cored intervals. These profiles have helped define detailed sequence stratigraphy as minima and maxima clearly showed trends that could be associated to basin related changes occurring in neighboring wells at the same stratigraphic levels.

The study also looked at differences in output and usefulness of shades of grey profiles between various core photography set-ups, i.e. between high resolution (200 microns per pixel) traditional lab photo equipment and very high resolution photos (35 microns per pixel) taken on a rolling bench. The results integrated with work on other images from various laboratories on the same cores have delivered a series of criteria and patterns useful to recognize lighting issues that would minimize the usefulness of shades of grey profiles.

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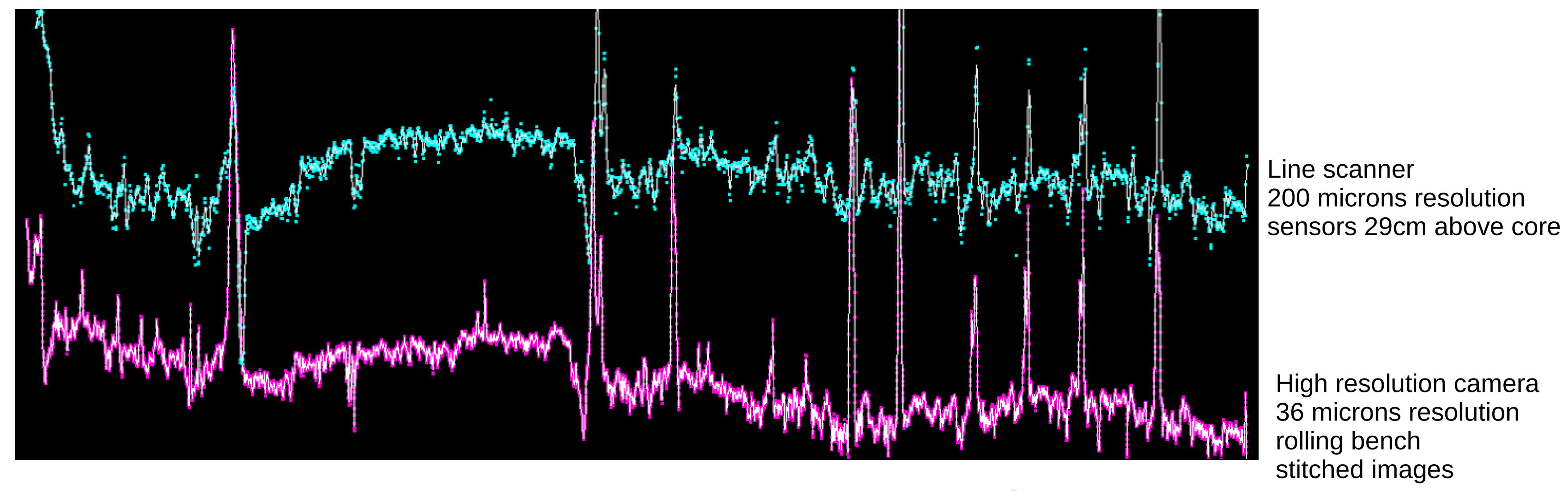
Importance of lighting set-up for shades of Grey profile

Match between two different image acquisition set-ups

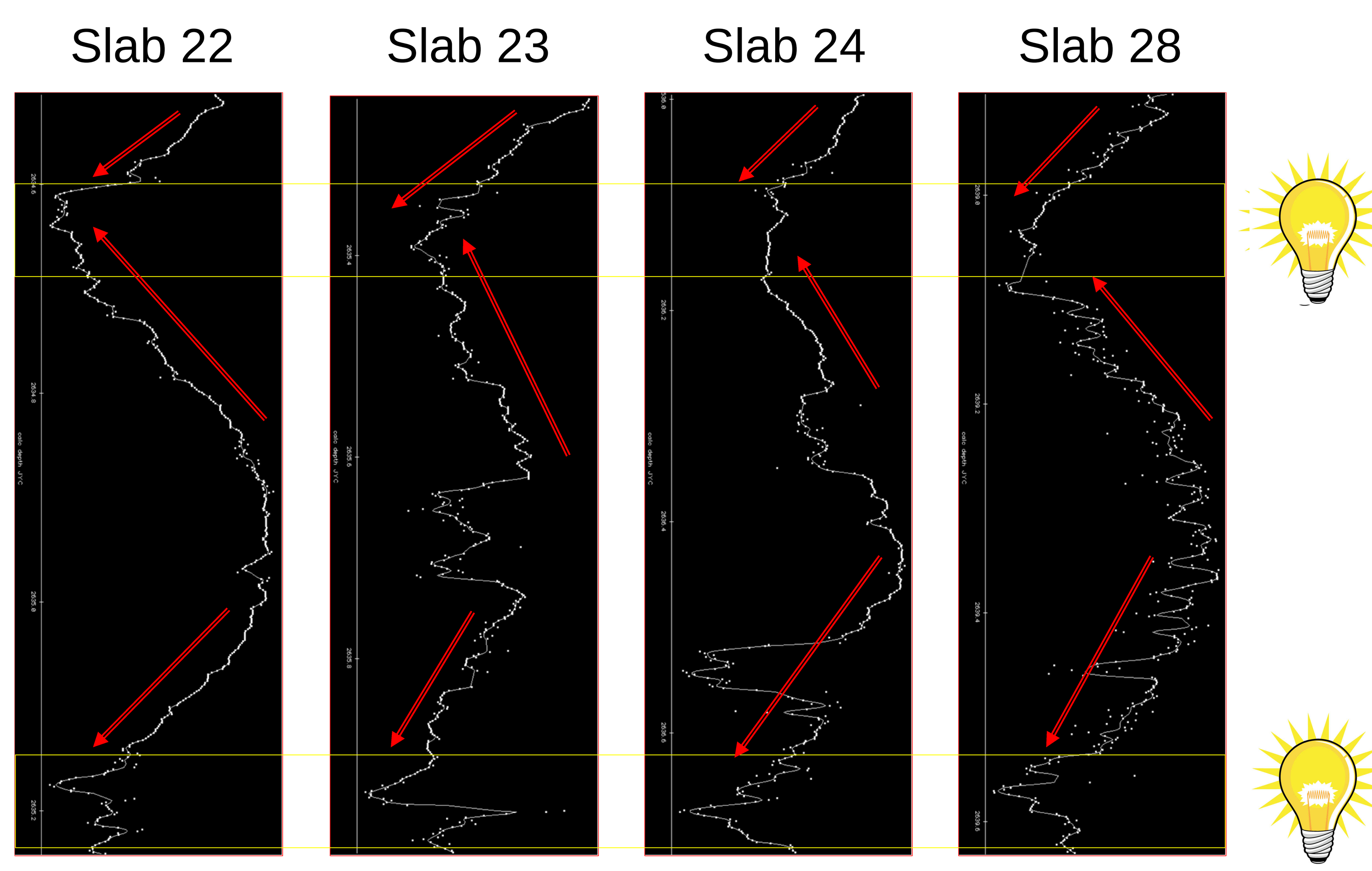


Outstanding match between shades of grey by two laboratories and two completely different technologies

core length shown = 45.7m

blue profile (Lab 1) from image taken using a Line scanner every 200 microns (Itrax from INRS)

pink profile (Lab 2) from stitched images with a 35.7 micron resolution



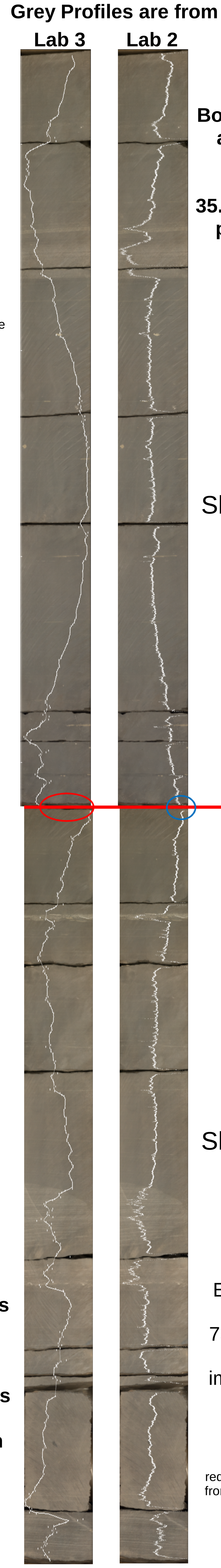
Parasite lighting may alter the image to the point of creating very nice but meaningless grey profile trends.

The red arrows indicate brightening associated to the background lighting; these trends are not linked to changes in rock composition; shades of grey profiles from these images cannot be used.

The images with lighting issues are not shown in order to not criticize any laboratory in particular.

The two images to the right are identical but the grey profiles are from different laboratories. The images are the results of stitching 8 images (each of 28 megapixels) taken with a shutterless camera moving along the core; the corresponding grey profile is on the right while the grey profile with lighting issues (Lab 3) is on the core photo on the left but the photos are from Lab 2.

The split between slabs 22 and 23 is negligeable on the right example but very strong on the left grey profile.



Both images are from Lab 2 at 35.7 microns per pixel

Both images are from Lab 2 at 35.7 microns per pixel to focus on the grey profile

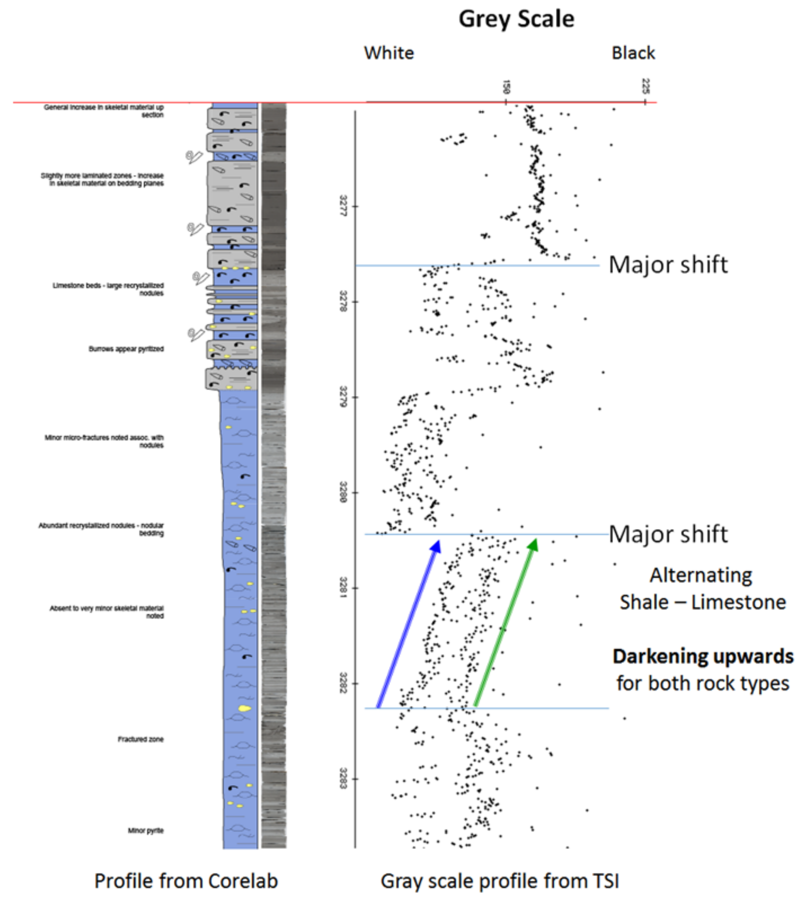
Each core slab is 75 cm long

images are from

100 times reduced resolution from original photo

Shades of grey from low resolution photos

7.1 microns/pixel = 7,120 microns/pixel



Low resolution photo from the Web

6482 grey average values

The images used are not the original high resolution photos by Corelab.

However the lighting was fine and low resolution images still deliver meaningful observations:

Darkening upward trends for both the shale and the carbonates are prominent below the Middle Duvernay indicating a deepening upward tendency

Shades of grey from very high resolution photos

35.7 microns/pixel = 200 times higher resolution than previous slide

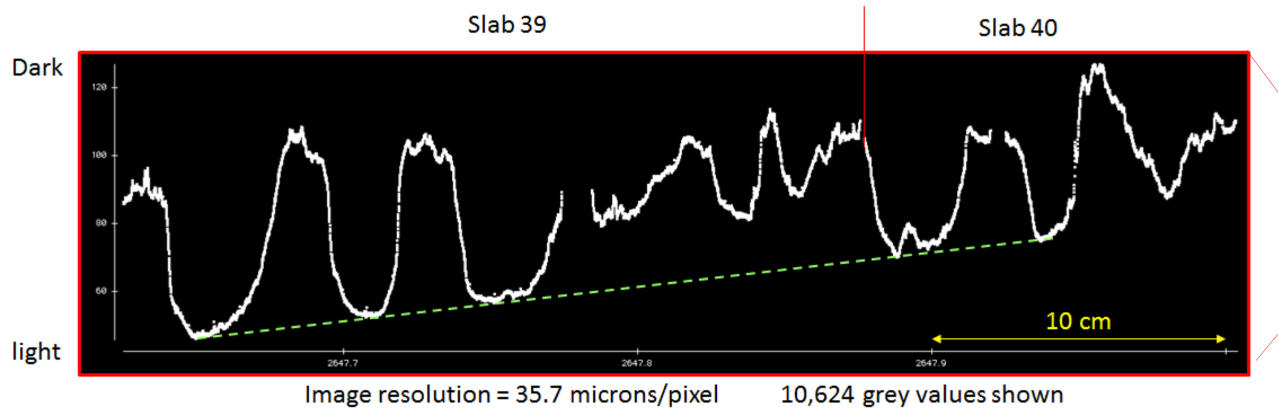
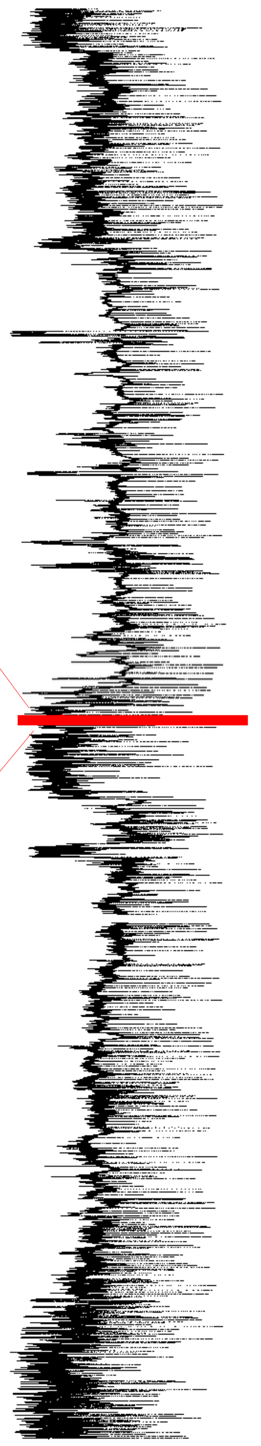


Image resolution = 35.7 microns/pixel 10,624 grey values shown

Outstanding trend showing lightening upward carbonate on an interval 3metre thick

Note the perfect transition in shades of grey between Slab 39 and slab 40

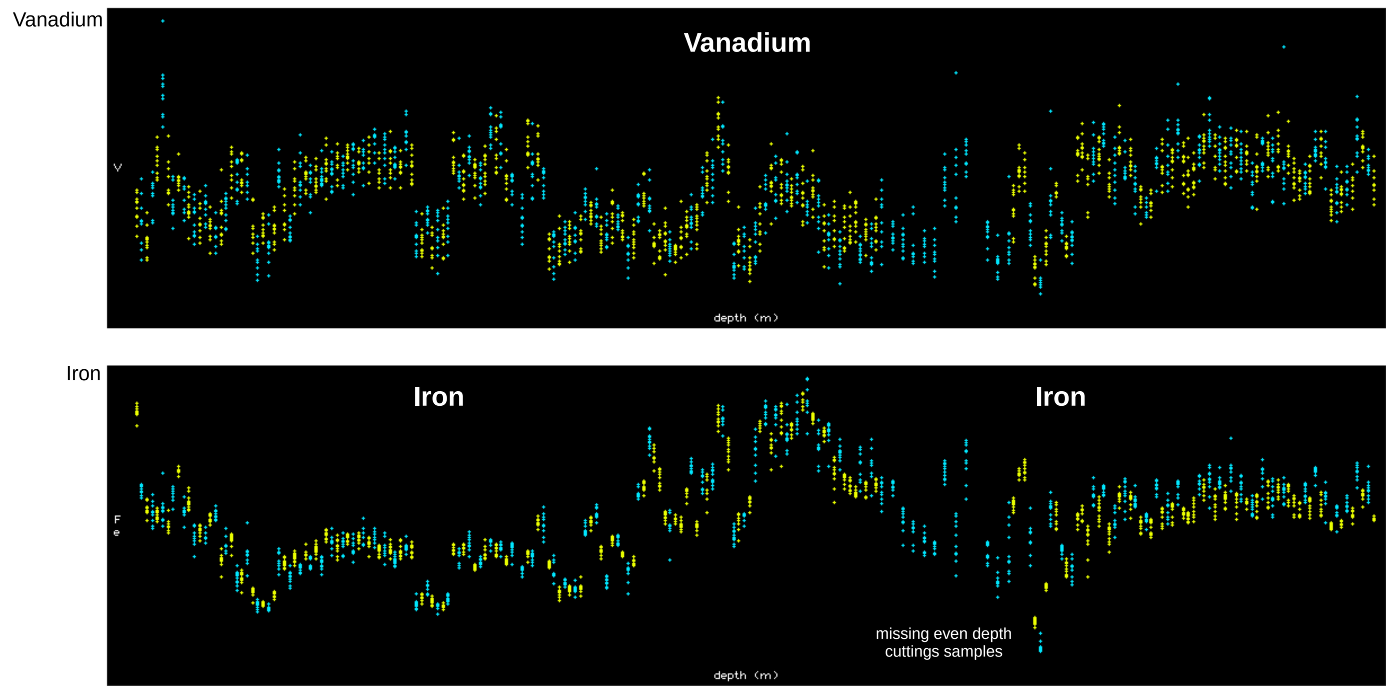


1.6 million grey average values for a 54.7 m Duvernay core

Duvernay XRF data from cuttings

Sample prepared by different labs but analyzed by one lab (INRS)

Blue = odd depths only Yellow = even depths only



Four sets of cuttings have been analyzed with the ITRAX XRF device; samples every 5 m (same color 10 m)

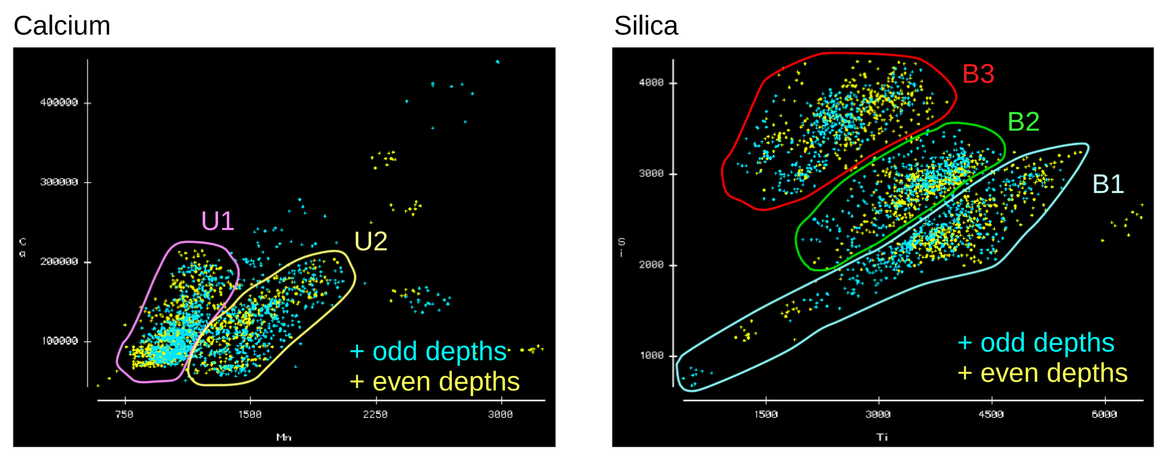
Each available cuttings vial has been analyzed by INRS using the ITRAX continuous XRF scanner,

The samples in yellow have been prepared by a commercial laboratory and have been analyzed by that lab and by INRS (only INRS shown)

The samples in blue have been prepared and studied only by INRS

Note the overall good match between the blue and yellow elemental values

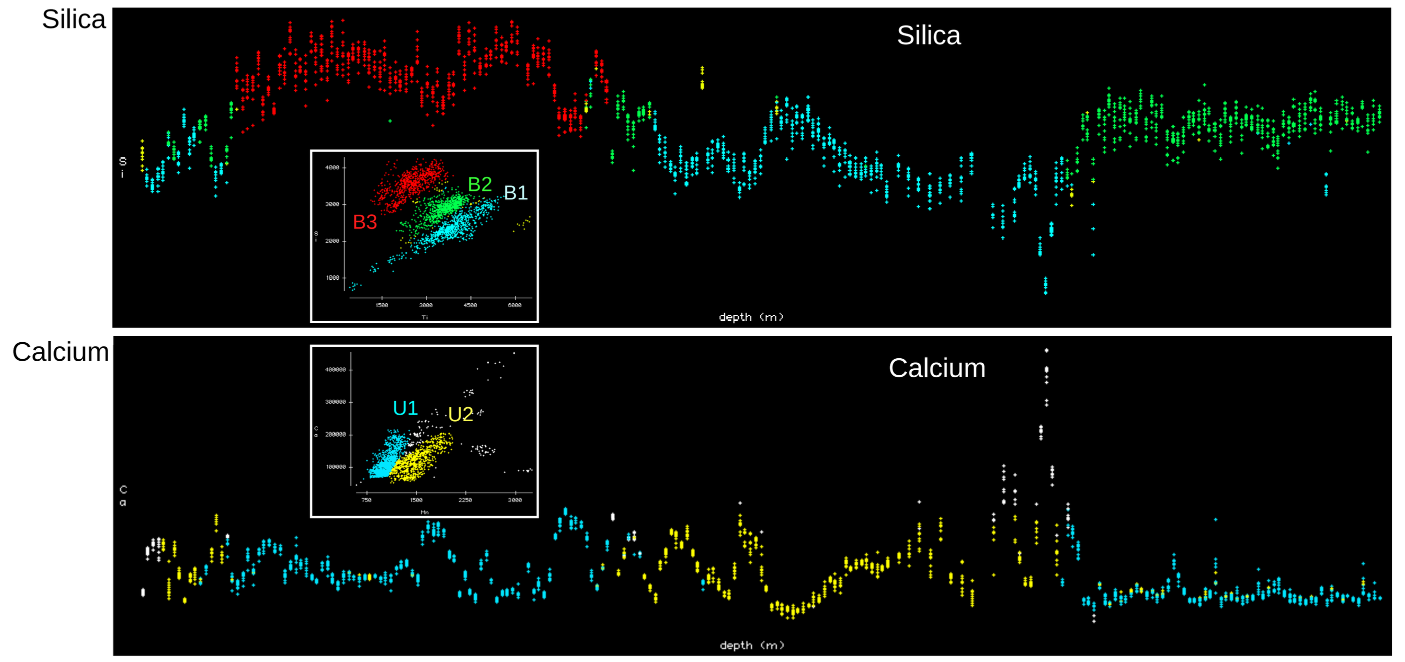
Stratigraphy and diagenesis using XRF



Two separate populations indicating different stratigraphic units (U1 & U2)

Three distinct well-defined populations indicating varying biogenic silica content (B1, B2 & B3)

Two sets of displays offer a break down of the stratigraphy along the horizontal borehole: the first one based on calcium manganese ratio should distinguish between different units; the second one based on silicon versus titanium is interpreted as a proxy to the amount of diagenetic silica present.



The depth profiles of two major elements (Si and Ca) have been colored to outline the groups that have been identified using the Ca/Mn relationship as well as the Si/Ti relationship.

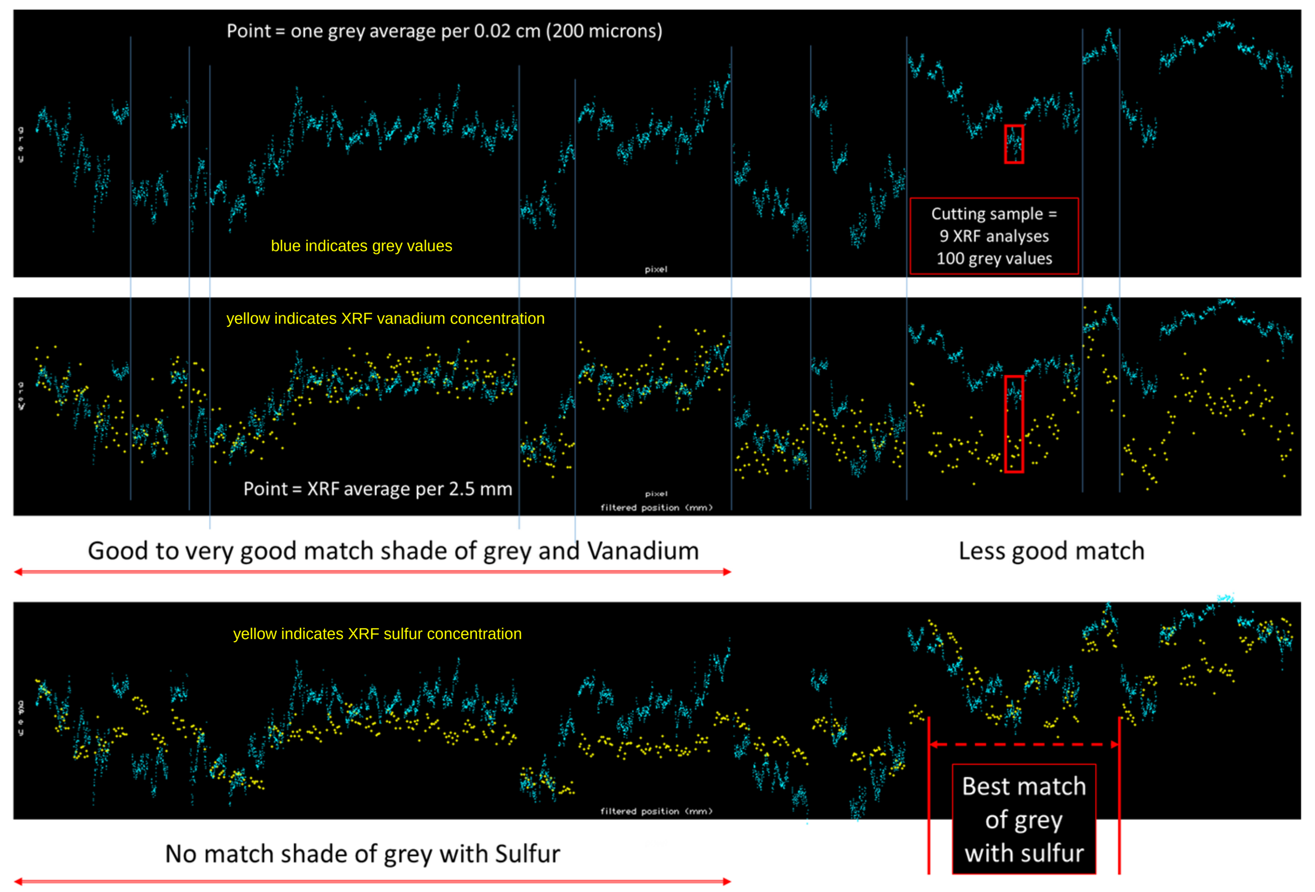
Very strong coherence of the results clearly validate the approach taken and the usefulness of the proposed units.

Continuous XRF analysis of cuttings delivers cheap and reliable results to recognize stratigraphical units and diagenetic alteration allowing for optimal frac design

TOC prediction controlled by organic facies

Pyritic and non-pyritic Duvernay facies

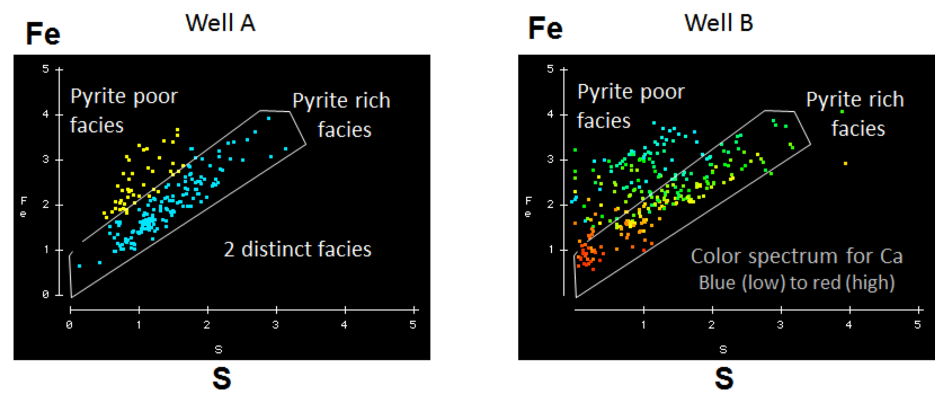
Example of a few odd numbers "blue" cuttings samples for XRF and grey values; photo using a line scanner – depths increasing towards the left



Shades of grey every 200 microns have been compared to some XF elements in order to identify different types of organic matter (TOC).

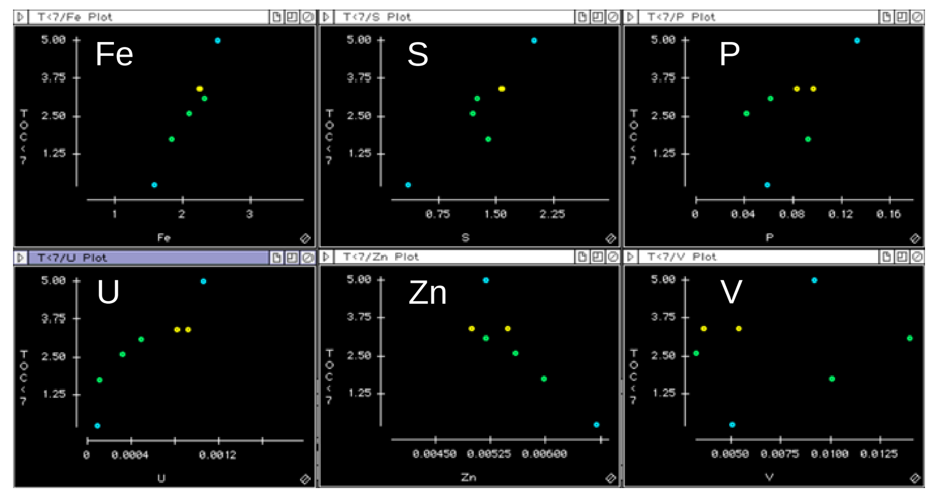
The two lower displays show that part of the horizontal borehole has the shade of grey values mimicking either the vanadium or the sulfur content. This indicates that at least two organic facies can be recognized, the one linked to sulfur is interpreted as pyrite rich because iron is also matching the shade of grey values.

Organic facies distinction in two cored wells (West Duvernay Basin)



At least two organic facies have been recognized within the Duvernay Shale. These have been identified by the link between XRF values of some elements and the shades of grey of these samples.

Organic facies distinction in one cored well (East Duvernay Basin)



The colors indicate three different laboratories that measured the TOC content from core material. The well is located in the East Duvernay Basin. Note the near perfect relationship of TOC with Iron.

Two cross-plots of iron versus sulfur for two cored wells of the West Duvernay Basin show a distinction of two facies, pyrite rich and pyrite poor.

The group of six cross-plots in the lower diagram shows the relationship between TOC measured in core and some selected XRF elements for the pyrite rich facies.

Best predictions of Total Organic Carbon in the Duvernay have been systematically achieved when distinguishing between two organic facies based on pyrite abundance

Some cuttings for XRF of well 11-3

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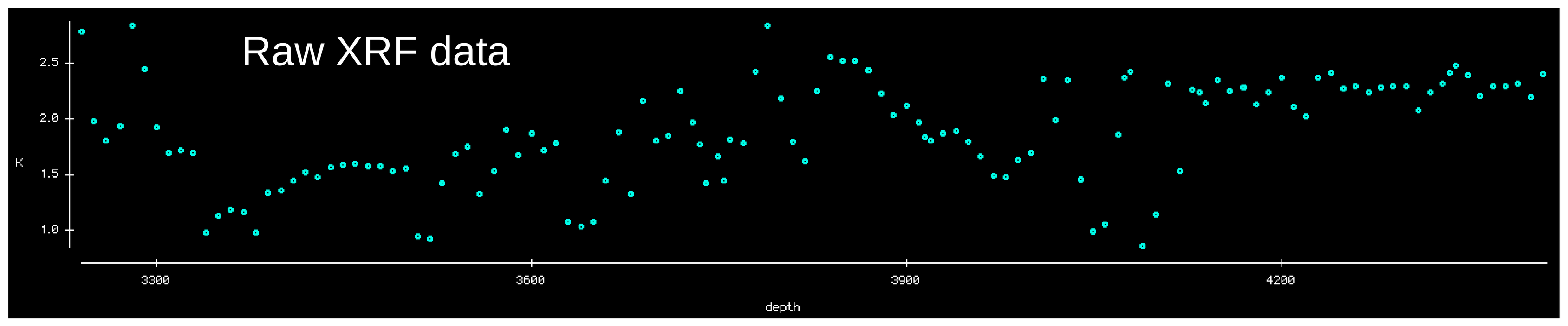
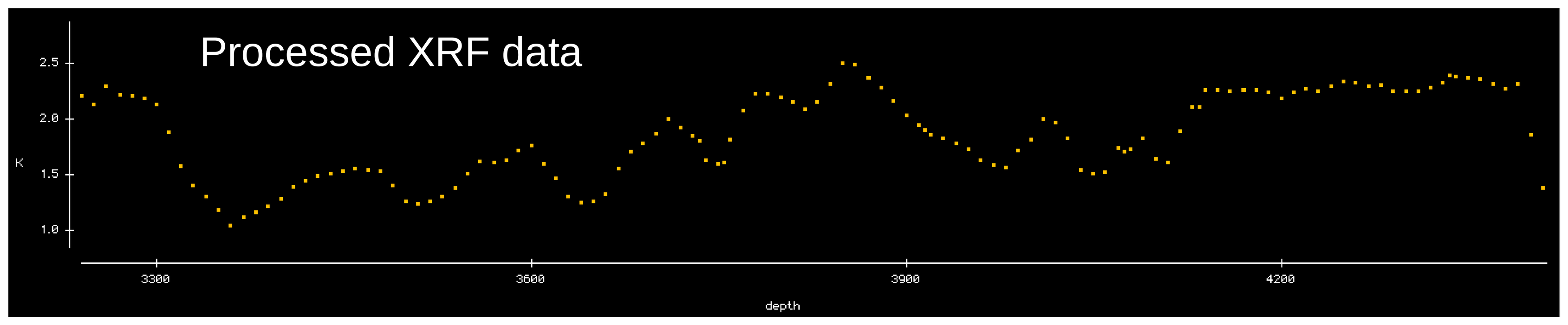
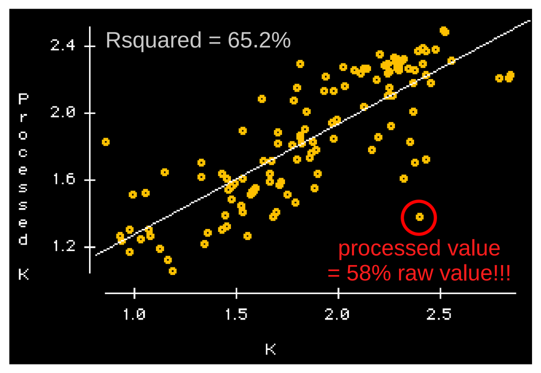






Processing the data should not be made to improve sales

The data is analyzed to get useful results, not nice trends

Smoothing the data may be OK on cores with a lot of data points

Smoothing applied to sparse cuttings data reduce significantly its usefulness and should not be done

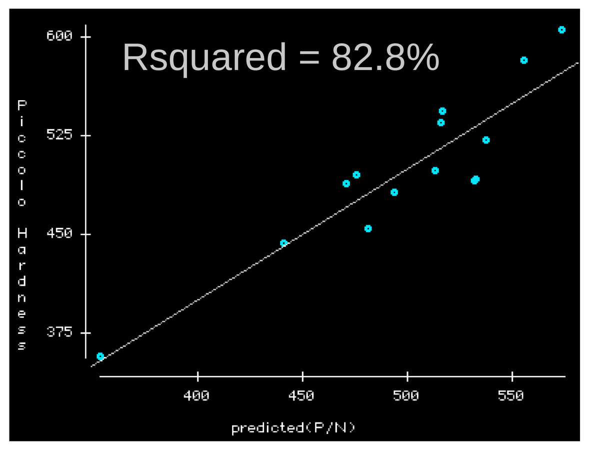
Raw versus processed data

Cuttings from Duvernay Hz well analyzed by Lab 4

The data shown is from cuttings collected in a horizontal well with spacing every 10 meters. For cuttings, the naturally occurring mixing brings uncertainty to the representativity of the collected samples. The representativity can be further reduced by processing the data as done by Lab 4 using a smoothing function; this brings additional unwanted uncertainty that alter the data set to the point of missing important lithological changes. That will strongly influence the results of any attempted prediction, e.g. TOC, brittleness, frac placement... and that would lead to unsatisfactory and costly frac designs.

In the shown example the correlation coefficient between the processed and raw XRF data for potassium is only 65.2% and one can see major alteration of concentration values that are absolutely unacceptable.

Processing data delivers nice gradual changes that can fool clients; these processed values are commonly considered to be “true” and “reliable” but in fact, they should not be used, at least in cuttings.



Elements	Rsquared all	valence
Zr	66.7	negative
Th	59.5	negative
Rb	55.8	negative
Ti	54.7	negative
Si	50	negative
Nb	49.6	negative
Al	49.5	negative
K	45.8	negative
Ca	35.8	positive
Cr	34.9	negative
Co	19.6	negative

Multilinear regression for Leeb Hardness

Dependent variable is: Piccolo Hardness
No Selector
65 total cases of which 51 are missing
R squared = 82.8% R squared (adjusted) = 68.0%
s = 34.39 with 14 - 7 = 7 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	39779.8	6	6629.96	5.61
Residual	8277.07	7	1182.44	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	720.853	92.38	7.8	0.0001
Zr	-33230.7	27.86e3	-1.19	0.2718
Ti	437.357	1327	0.33	0.7513
Th	-507034	314.6e3	-1.61	0.1511
Si	-3.29922	15.64	-0.211	0.8389
K	244.538	126.7	1.93	0.0949
Al	-76.4742	50.3	-1.52	0.1722

The correlation coefficient improves to 100% after splitting facies based on a carbonate cut-off to distinguish carbonate rich and carbonate poor lithofacies (40% cut-off).
The elements used for the predictions are then different for carbonate rich and carbonate poor facies

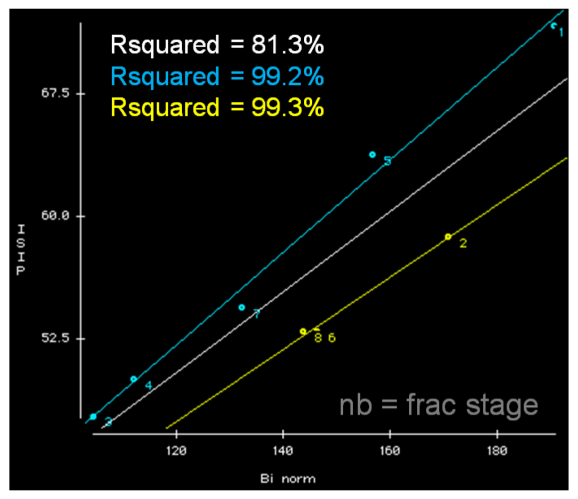
Brittleness based on core data

There is a very strong correlation between the Leeb hardness measured on the cores and some elemental compositions as indicated in the table to the left. Most strong relationships between single element composition and hardness are negative in the studied data set; only calcium had a positive relationship.

A multilinear regression has been chosen after combining various elements together. The best results using 6 elements delivered a 82% Rsquared. Note that two elements that have a negative relationship with hardness as stand alone element have a positive relationship when combined with other elements (see Ti and K in the table).

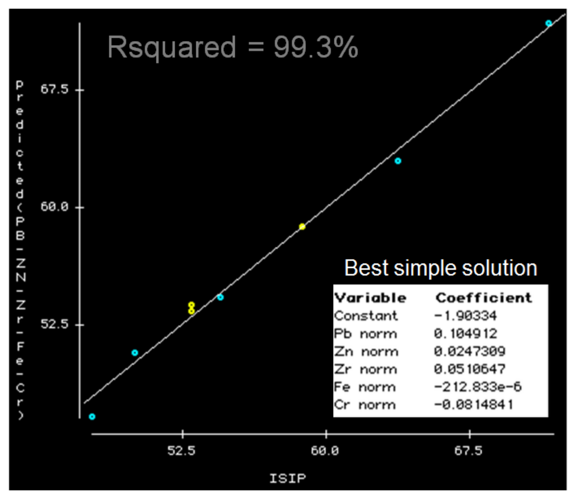
Rsquared of 100% is achieved for multilinear regressions when splitting the data set based on a carbonate cut-off of 40%.

ISIP



XRF Bismuth concentration
Use of one single element

ISIP predicted



ISIP (Frac Initial Shut-in Pressure)
Use of multilinear regressions

Rank	element	Rsquared %	Positive/negative relation to ISIP
1	Bi	81.3	positive
2	Pb	73.1	positive
3	Cd	66.9	negative
4	Cs	65.6	negative
5	Rb	62.7	positive
6	Cu	60.6	positive
7	Pd	60.4	negative
8	Ca	60.0	negative
9	Y	54.2	positive
10	Sr	52.1	negative
11	Al	51.8	positive
12	Ti	44.2	positive
13	Zn	43.2	positive
14	U	42.2	positive
15	K	41.4	positive
16	Fe	38.6	positive
17	Mn	31.4	negative
18	Ni	26.6	positive
19	V	24.5	positive

Best single elements to predict ISIP (initial shut-in pressure)

Two populations can be distinguished on the basis of Bismuth and are colored in blue and yellow. White lines are regression lines with no bismuth distinction

Frac placement vs XRF

As a function of continuous XRF elemental composition on cuttings

Parameters extracted from each of 8 hydraulic frac stage have been analyzed against the elemental composition of the collected cuttings. Between 70 and 120 XRF measurements have been averaged for each of the 8 frac stages; these correspond to 10 continuous XRF measurements for 7 to 10 cutting vials. Among the obtained results the link between XRF and frac placement has been illustrated using the frac initial shut-in pressure (ISIP). Six stand-alone XRF elements has Rsquared greater than 60%; these are noted in the table to the left.

Bismuth is the best stand-alone element with a Rsquared of 81.3%; lead is the next best predictor of frac placement; both elements are characteristic of SEDEX mineralization, i.e. hydrothermal fluid affecting the marine sediments.

Note that the best linear regression extracted from the data does not make use of bismuth; results are best when combining some elements to lead instead.

Avoid use of processed data when attempting to predict reservoir properties in horizontal wells.

For frac design, core calibrated brittleness should be complemented by continuous XRF on cuttings