DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2014/69

Engineering study between Total E&P and GEUS

November 2014

Niels H. Schovsbo

CONFIDENTIAL
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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

GEUS

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G E U S

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Introduction

This report collects the data interpretation and reporting made by GEUS to TOTAL E&P regarding an engineering study conducted to characterize the Silurian shales in Kattegat-Bornholm area. The work was made to Total E&P as part of a service contract. Raw data generated during the project are reported separately in the
GEUS report 2014/70. The data include hand-held XRF and XRD samples for the Terne-1, Lövestad A3-1 and Sommerodde-1 wells.

This report is structured according to the work plan agreed between Total E&P and GEUS.

Deliveries
1): Project status and budget control

2) Data inventory and review of stress-strain history

3) Chemostratigraphical analysis of the Silurian section in Terne-1 and Sommerodde-1 wells

4) Comparison of XRF measurements by GEUS with Geolog International

5) Geological analysis and samples from Fjerritslev Fm in Northern Jytland

6) Presentations at project meetings

1. Project status and Budget

Status meeting of Engineering study between Total E&P and GEUS

Presentation by Niels Schovsbo

1th October 2014

GEUS

- **Item 1: Select samples from the Sommerodde-1 core for testing by FracTech.**
- Two samples, rock type A2 and B2, will be identified in the Sommerodde-1 and send to FrachTech, Woking UK, for analysis
-
- Milestone:
- Samples selected and send to FrachTech before the 15/8-2014.

Completed – loan agreement made

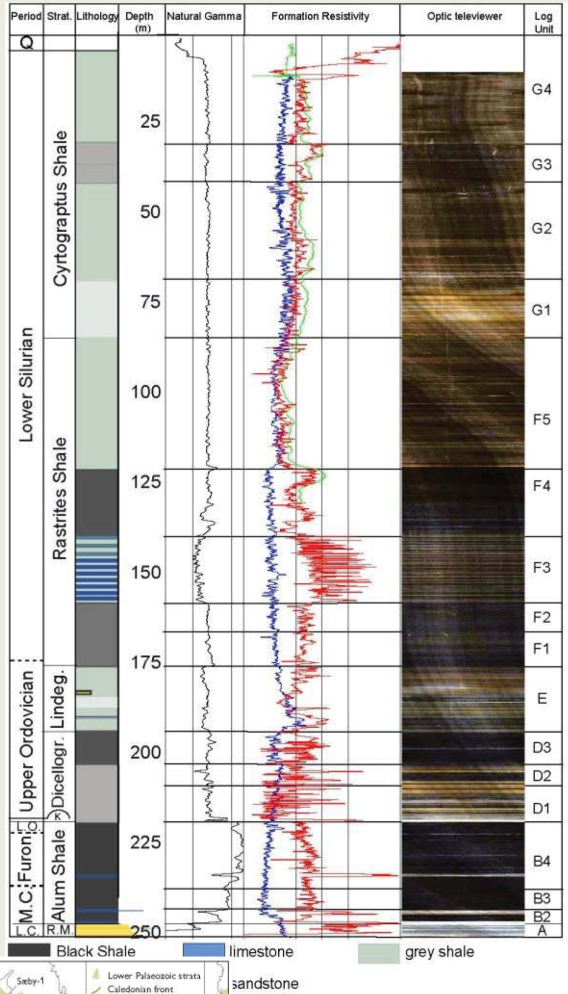
- **Item 2: Develop a stress / strain history to understand the natural fractures occurrence and current stress anisotropy.**
-
- The GEUS input on the stress-strain history will be a supplement to 3 key scientific papers summarizing the development Emphasis will be of the Lower Palaeozoic.
-
- This work could be supported by the fracture description report made in Billegrav-2.
-
- Milestone:
- Late September: Data inventory and scope of future work
- (the following PowerPoint)
- Late October: Progress report
- Early December: Final report
-
- *Delivery: PowerPoints and excel spreadsheets: Data inventory report. Progress reports, Final stress-strain history.*

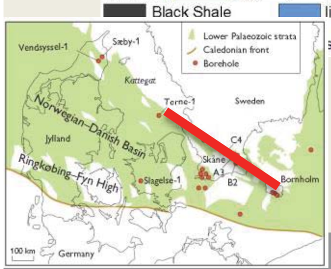
GEUS

- **Item 3: Determining key elements to focus on, when doing onsite drilling real time Xrf / Xrd analysis.**
-
- Item 3a
- A chemostratigraphical analysis will be performed on the Silurian section in the Sommerodde-1 well by preforming high resolution XRF profiles. The XRF data will be collected by a hand-held XRF devise at the GEUS core laboratory.
-
- The Silurian in the Sommerodde is 180 m thick and comprises the Rastrites (base) and Cyrtograptus shale (top). Of these the Cyrtograptus and uppermost Rastrites has highest interest. In this 90 m thick interval approximant 6 XRF analysis samples pr. m. (15 cm apart representing a log-scale of investigation) will be made and thus approximately 600 samples xrf analysis will be made.

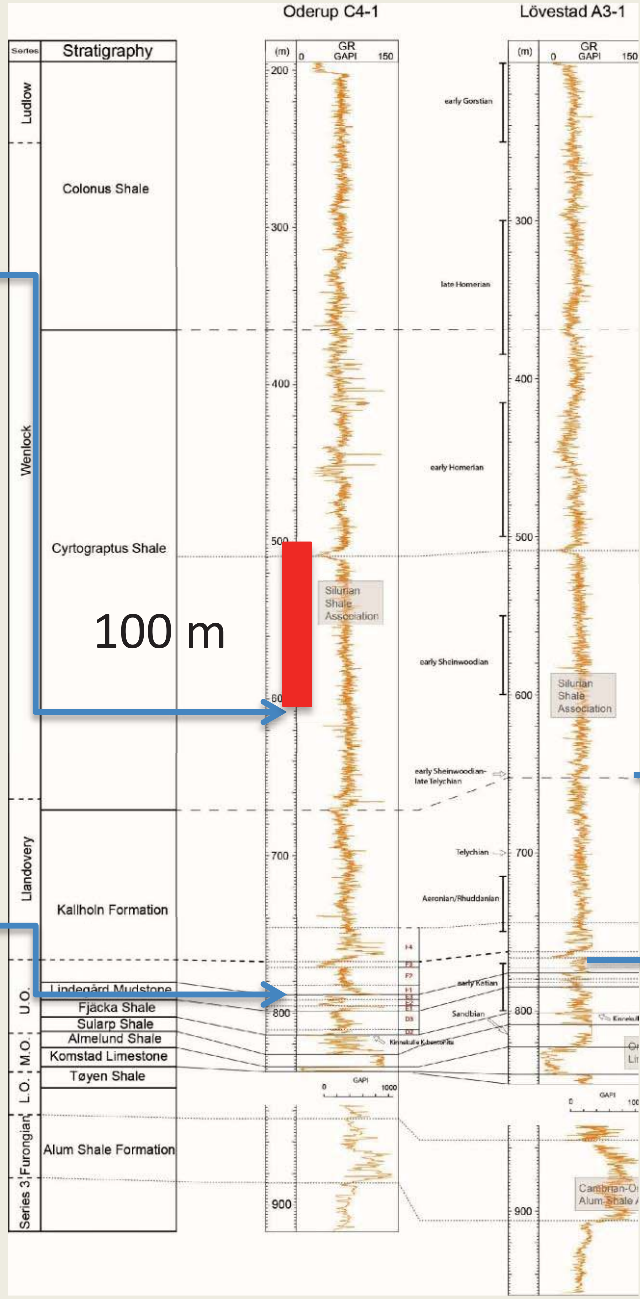
- Milestones Item 3a
- End October: XRF profiles of the upper 90 m in the Sommerodde-1 well completed and about 600 samples points measured.
- (Progress XRF completed to date 55 m –on time)
- End October: PCA and PLS predictions made
- End November: Recommendation for selecting key important elements to analysis during drilling operation and for determine the casing point for the 9-5/8 based on Mudlogging data.

Sommerodde-1



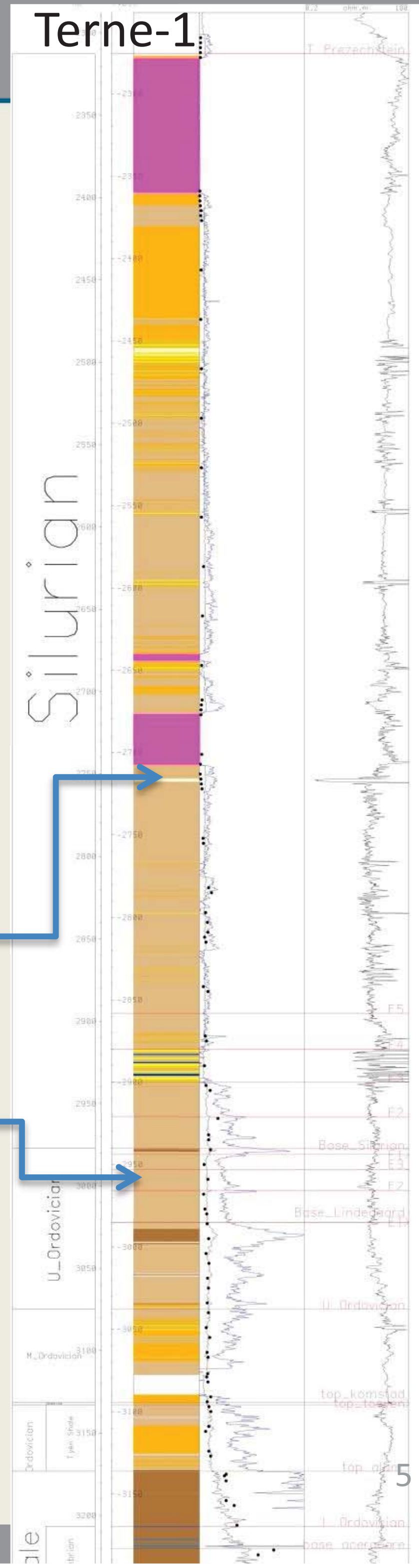


Scania, Shell e&p wells



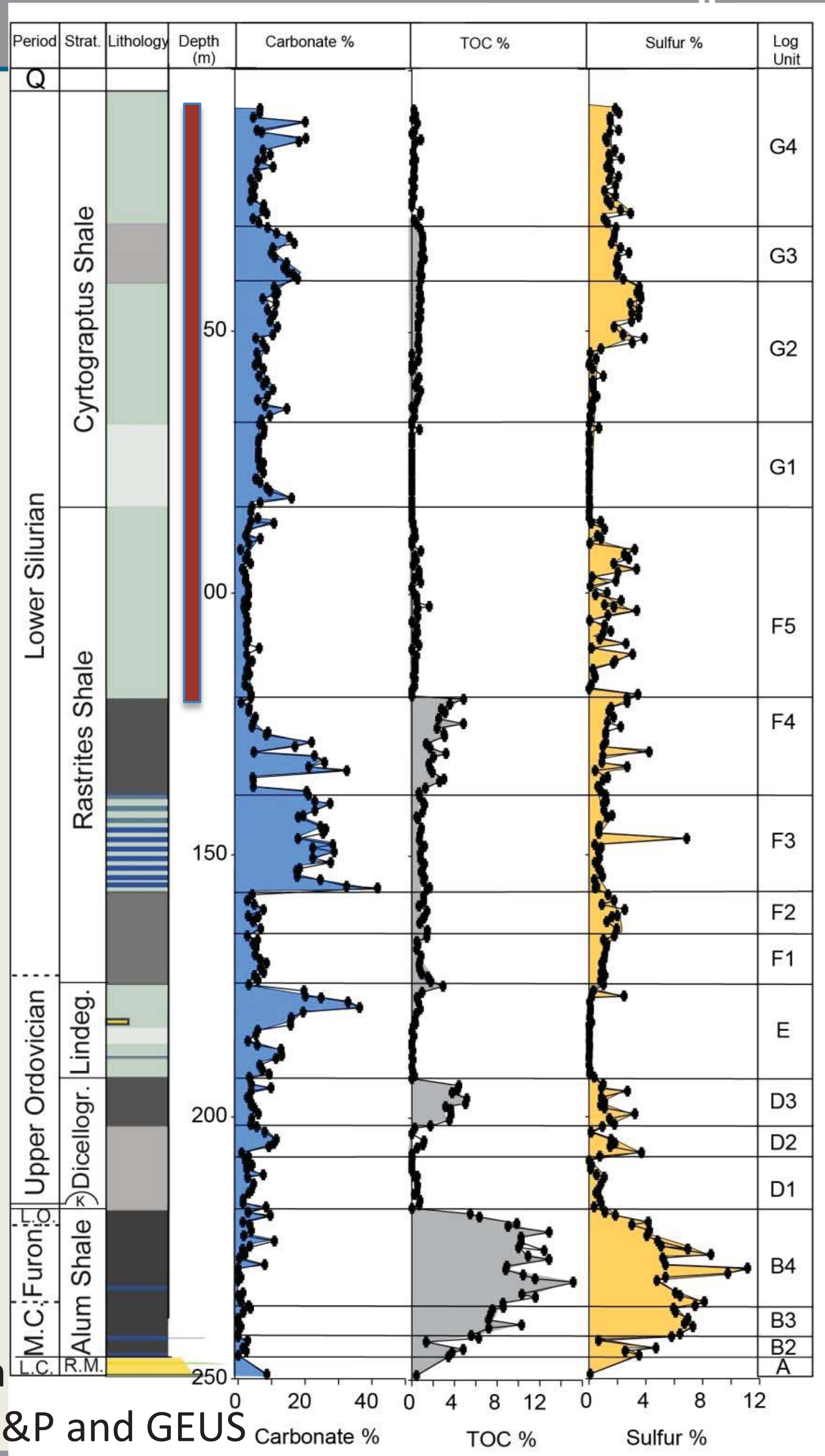
Eriksson, 2012

Terne-1



Geochemical profiles in Sommerodde-1

- 600 XRF scanning are made in the upper part to the F4 unit (i.e. 10-120 m) to detail the top Rastrites shale.
- The G1 zone is the likely casing point for the 9-5/8 casing
- We expect it to be defined on the combined Ca, Fe, S systematics



Screening data for every 1 m
data shared between Total E&P and GEUS

- Item 3b
- Handheld XRF analysis of 40 cutting samples from the Lovestad A-3 well, Scania. The sample represent an 800 m thick section of Silurian (mostly) to upper Ordovician. PCA comparison of data with Sommerodde-1 will be made

- Milestones:
- Item 3b data completed before time including TOC profile and selected RE

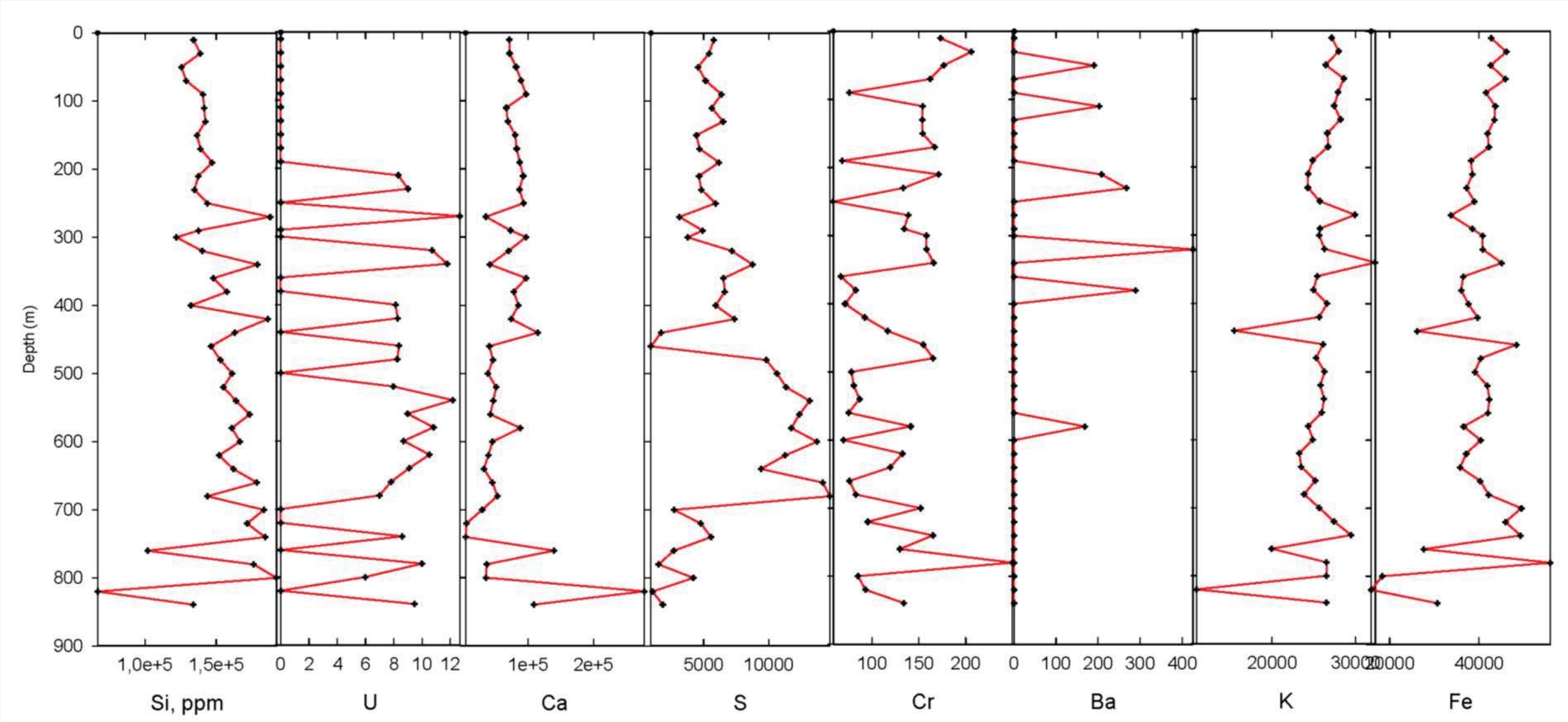
- Item 3c
- Ha-xrf measurements of the Silurian section in Terne-1 well. The section is approximately 600 m thick (2400-2950 m, md) and about 200 cutting samples exist in the interval. Characterization of the Cyrtograptus to topmost Rastrites by 100 analysis of cuttings.

- Milestones:
- Item 3c
- Preparation of samples done.
- Analysis expected to be completed by early October

- *Deliveries: Reports as PowerPoints, Excel sheets with XRF data and calculations.*

GEUS

Item 3b Lövestad A-3



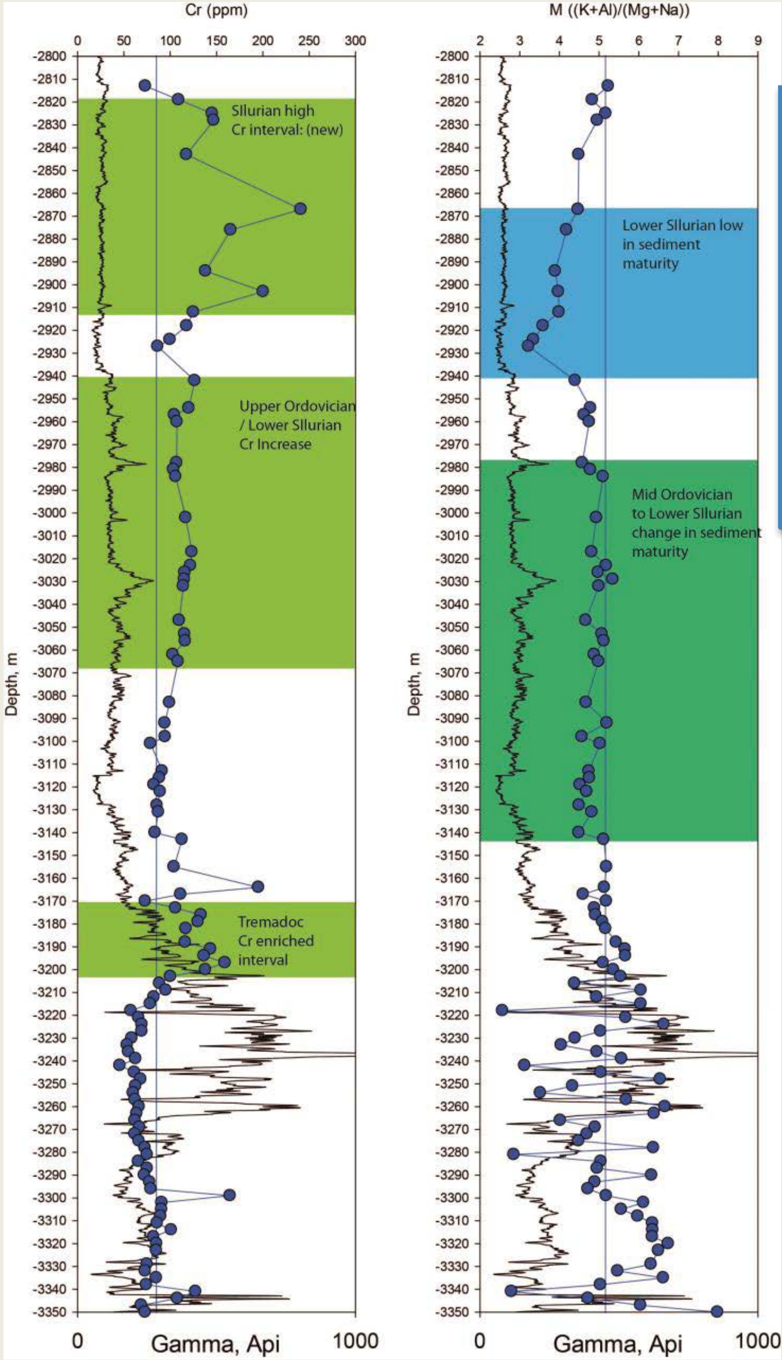
40 xrf samples measured incl TOC. Data delivered as excel file

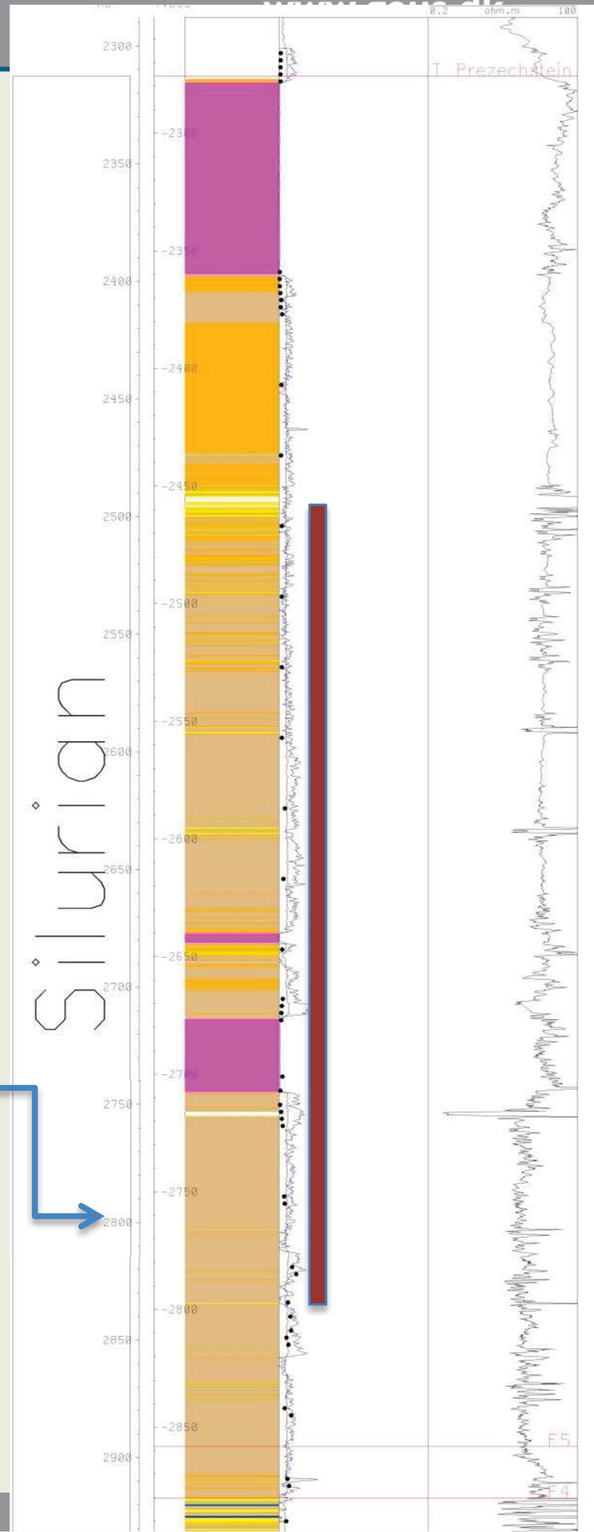
No data interpretation yet. Awaits completeness of other profiles

Item 3c Terne-1

GEUS

- Xrf made in interval 2500 – 2894 (about 100 cuttings). Measured interval stops in the F4 (same as for Sommerodde-1)
- Previous ICPMS elements measured on few cutting samples below 2820 m.
-





- **Item 4: Assisting with Geolog calibration process.**
-
- Ensure data consistence between the work of GEUS and what could be measure by GEOLOG onsite.
-
- *Deliveries: Access to relevant Alum Shale cores and relevant well data already acquired by the Client from GEUS.*

GEUS

Budget control pr 1. October 2014

	Hours	Spend	left
Item 1			
Sampling of Sommerodde	7	7	0
Item 2			
data Inventory	37	30	7
description and analysis	80		80
Item 3a			
Sommerodde-1 XRF profiling 90 m	60	40	20
PCA-PLS model	35		35
Recommendations	35		35
Item 3b			
Lövestad, 40 cuttings	14	14	20
Item 3c			
Terne-1, 100 cuttings	60	40	20
Total Item 1-3c	328	131	217
Item 4			
Preparing of cores for inspection at GEUS core store: 6000 Dkkr pr. day. General assistance 1100 Dkr pr hour for GEUS straff.			
Miscellaneous			
Attending agreed project meetings		7	

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Possible additional work

- Elaboration on present day stress from borehole breakout
- Analysis of fractures in the Billegrav-2 core

GEUS

Status and budget for Engineering study between Total E&P and GEUS

Prepared by Niels Schovsbo

6th November 2014

- **Item completed:**

- **Item 1: Select samples from the Sommerodde-1 core for testing by FracTech**

- **Item 3: Determining key elements to focus on, when doing onsite drilling real time Xrf / Xrd analysis.**

- **Item 4:** *Delivery: Preparation of 6 cuttings from Terne-1 and 6 core samples from Sommerodde-1 incl analysis of samples with ha-XRF*

- **Additional 1:** Delivery: Geological analysis of the Fjerritslev Fm Northern Jutland and selection of relevant samples. 7 samples picked based on geological analysis

- **Additional 2:** Assist Geolog International with samples

GEUS

- **In progress**

- **Item 2: Develop a stress / strain history to understand the natural fractures occurrence and current stress anisotropy.**

- The GEUS input on the stress-strain history will be a supplement to 3 key scientific papers summarizing the development Emphasis will be of the Lower Palaeozoic.
- This work could be supported by the fracture description report made in Billegrav-2.
- Milestone:
- Late September: Data inventory and scope of future work (Completed)

To come

- Late October/November: Progress report
- Early December: Final report
-
- *Delivery: PowerPoints and excel spreadsheets: Data inventory report. Progress reports, Final stress-strain history.*

GEUS

Budget control pr 6. November 2014: Agreed budget

	Budget hours	Spend	left	Status
Item 1				
Sampling of Sommerodde	7	7	0	completed
Item 2				
data Inventory	37	37	0	completed
description and analysis	80	0	80	not started
Item 3a				
Sommerodde-1 XRF profiling 90 m	60	60	0	completed
PCA-PLS model	35	27	8	near completed
Recommendations	35	27	8	near completed
Item 3b				
Lövestad, 40 cuttings	14	14	0	completed
Item 3c				
Terne-1, 100 cuttings	60	60	0	completed
Total Item 1-3c	328	232	96	

Budget control pr 6. November 2014: Additional work

Item 4				
Miscellaneous				
Preparation of cores and cuttings to Geolog		24	-24	completed
Preparation of cores and geological analysis of sampels from Fjerritslev Fm		10 + one day at core store	-10	completed
Attending agreed project meetings		7	-7	
Cost for attending meeting at Fractech 1/10				
Preparing of cores for inspection at GEUS core store: 6000 Dkkr pr. day. General				

- Budget total 34 750 DKKR for preparation of cores and cuttings to geolog and preparation of core from Fjerritrslev cores

Possible additional work

- Elaboration on present day stress from borehole breakout

- Analysis of fractures in the Billegrav-2 core

GEUS

Status and budget for Engineering study between Total E&P and GEUS

21 November 2014

- **Status of deliveries – approved by Total E&P**
- **Item 1: Select samples from the Sommerodde-1 core for testing by FracTech**
- **Item 3: Determining key elements to focus on, when doing onsite drilling real time Xrf / Xrd analysis.**
- **Item 4:** Delivery: Preparation of 6 cuttings from Terne-1 and 6 core samples from Sommerodde-1 incl analysis of samples with ha-XRF
- **Additional 1:** Delivery: Geological analysis of the Fjerritslev Fm Northern Jutland and selection of relevant samples. 7 samples picked based on geological analysis
- **Additional 2:** Assist Geolog International with samples

Omitted:

- **Item 2: Develop a stress / strain history to understand the natural fractures occurrence and current stress anisotropy**

GEUS

Budget 21. November

At the project meeting 18/11 it was decider to omit the delivery of Item 2.

The budget has accordingly been restructured:

- The cost for sampling of Fjeritslev Fm has been include

and

- 14% of the agreed sum is not used corresponding to 52000 Dkr or 47 hours

	Budget hours	Spend	left	Status
Item 1				
Sampling of Sommerodde	7	7	0	completed
Item 2				
data Inventory	37	37	0	completed
description and analysis	80	0	80	Not initiated
Item 3a				
Sommerodde-1 XRF profiling 90 m	60	60	0	completed
PCA-PLS model	35	27	8	near completed
Recommendations	35	27	8	near completed
Item 3b				
Lövestad, 40 cuttings	14	14	0	completed
Item 3c				
Terne-1, 100 cuttings	60	60	0	completed
Attending agreed project meetings		14	-14	
Total Item 1-3c	328	246	82	
Preparation of cores and geological analysis of sampels from Fjerritslev Fm	34750	Dkr		
Cost for attending meeting at Fractech	3404	Dkr		
Total argreed sum	360800	DKr		
Remaining pr 21/11	52046	DKr	14 %	

GEUS

Spending of remaining budget in December 2014

Proposed Activities in December	Budget hours	Spend	left	Status
Assist Geolog Int	25		25	
Scientific reporting	22		22	

The remaining time on the project will be used to assist Geolog Int and to Scientific reporting of the PCA rock typing

Final invoice will be issued in mid December on the Total Agreed sum

Cd with reports of Deliveries 1-4 will be prepared in early December

2. Stress Strain inventory

Inventory of present day stress, stress-strain history and natural fractures development

Niels Schovsbo,

Arne Thorshøj Nielsen

- Presented to Total E&P 1th October 2014

GEUS

Outline

- Present day stress
  - Well breakout (bore hole shape)
  - Present day stress map
  - seismological data

- Stress-strain history (Phanerozoic development in tectonic mode and style)
  - Scania
  - Bornholm
  - Oslo

- Description of fracture occurrences in the Alum Shale on Bornholm

- Way ahead

GEUS

TERRA RESEARCH

In situ stress determination from breakouts in the Tornquist Fan, Denmark

Maria V.S. Ask[1], Birgit Müller[2] and Ove Stephansson[1]
[1]Engineering Geology, Royal Institute of Technology, 100 44 Stockholm, Sweden, [2]Geophysical Institute, University of Fridericana Karlsruhe, Hertzstrasse 16, 7500 Karlsruhe 21, Germany

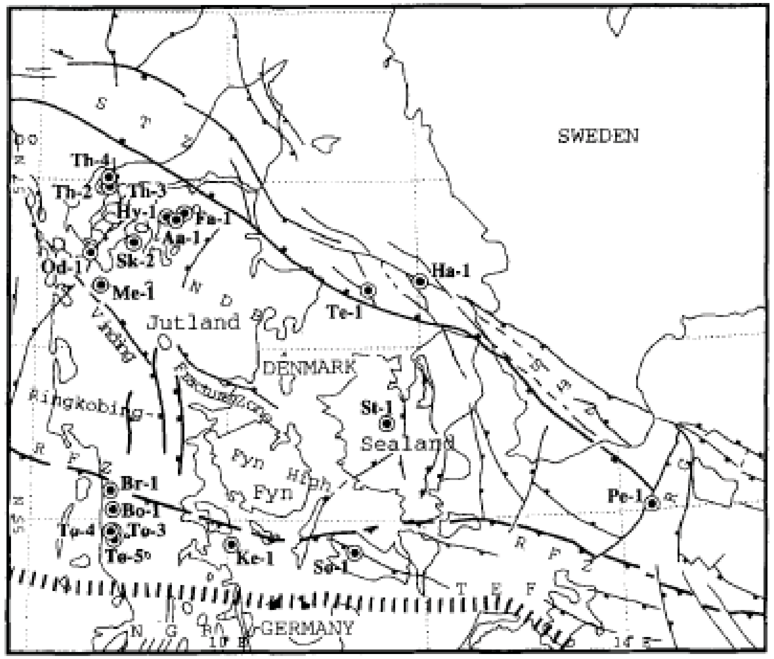


Table 2. Borehole breakouts for wells within the Tornquist Fan.

Tectonic Region	Well	Logged Interval (mbsf)	Mean S_H Orientation (°N)	No of B	Total length of B (m)	Ratio of Breakout Occurrence (%)	Quality
SRFZ	Br-1	2533–1771	116° ± 2°	4	202	26	B
	Bo-1	3070–2180	177° ± 16°	5	383	43	B
	Tø-3	1836–1495	146°	1	11	3	D
	Tø-4	1863–878	164° ± 14°	5	161	17	B
	Tø-5	1902–892	104° ± 51°	3	117	12	E
	Ke-1	2537–644	148° ± 51°	13	225	15	A
	Sø-1	2685–1799	–	0	0	0	E
NDB	Th-2	3277–1159	62° ± 37°	13	219	10	D
	Th-3	1235–1193					
		1183–816	77° ± 0°	3	150	37	B
	Th-4	3407–1164	111° ± 26°	6	84	4	C
	Fa-1	2090–1940	–	0	0	0	E
	Hy-1	2873–1053	107° ± 50°	13	510	28	E
	Aa-1	3384–1504	79° ± 18°	19	557	30	B
	Od-1	3124–2479	50°	1	9	1	E
	Me-1	2560–603	63° ± 32°	10	690	35	D
	Sk-2	1444–939	155° ± 7°	3	69	14	C
	St-1	1663–1048	133°	1	45	7	D
STZ	Te-1	3046–1294	108° ± 13°	3	92	5	C
	Ha-1	2988–222	144° ± 12°	24	361	13	A
	Pe-1	3542–695	109° ± 37°	23	353	12	D

Notes: B, Borehole Breakouts; SRFZ, South of Rømø Fracture Zone; NDB, Norwegian-Danish Basin; STZ, Sorgenfrei Tornquist Zone; Br-1, Brøns-1; Bo-1, Borg-1; Tø-3, Tønder-3; Tø-4, Tønder-4; Tø-5, Tønder-5; Ke-1, Kegnæs-1; Sø-1, Søllested-1; Th-2, Thisted-2; Th-3, Thisted-3; Th-4, Thisted-4; Fa-1, Farsø-1; Hy-1, Hyllebjerg-1; Aa-1, Aars-1; Od-1, Oddesund-1; Me-1, Mejrup-1; Sk-2, Skive-2; St-1, Stenlille-1; Te-1, Terne-1; Ha-1, Hans-1; Pe-1, Pernille-1.

- No wells investigated in N Jutland. 4 arm calliper data exist in Sæby-1 well. Maybe also in other wells.

GEUS

- Area difference in present day stress

- Present day stress is parallel to main fault direction in northern Denmark. Author interpreters this to indicate non-sealing properties of fault and possible also of natural fractures

- Occurrence of pre-Permian breakout is low (7%)

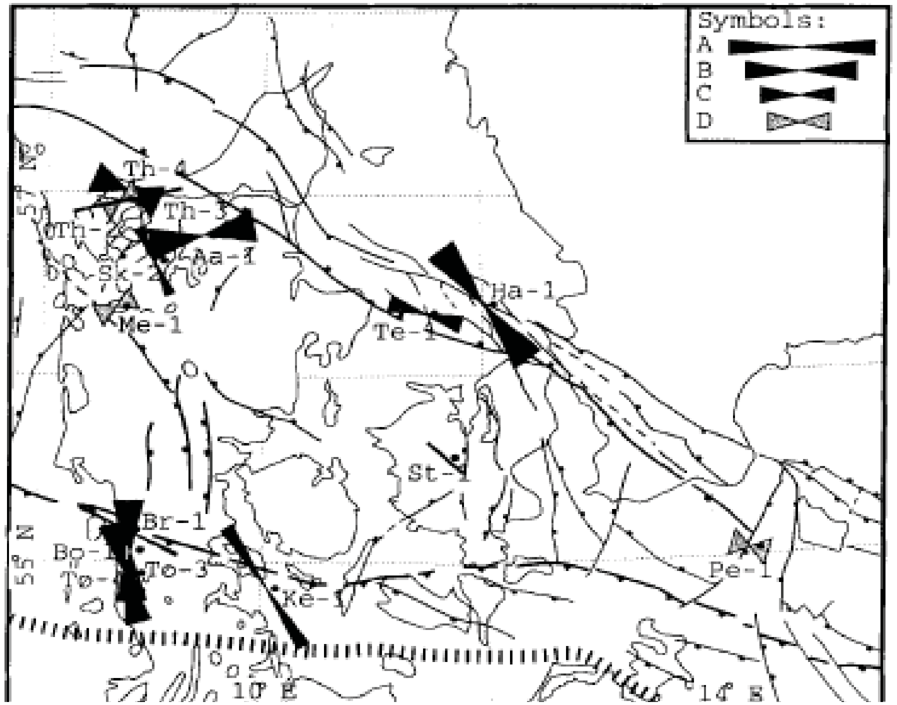


Table 4. Summary of borehole breakouts in stratigraphic units for the three tectonic regions within the Tornquist Fan.

Stratigraphic Unit	Tectonic Region	Mean S_H Orientation (°N)	No of B	Total Length of B (m)	Ratio of Breakout Occurrence (%)
Tertiary	NDB	*140°*	*1*	*17*	*8*
	TF	***140°***	***1***	***17***	***8***
Cretaceous	SRFZ	99° ± 18°	2	89	40
	NDB	90° ± 26°	15	1057	43
	TF	**91° ± 26°**	**17**	**1146**	**40**
Jurassic	NDB	53° ± 36°	34	937	27
	STZ	*163° ± 5°*	*2*	*13*	*1*
	TF	**53° ± 37°**	**36**	**950**	**21**
Triassic	SRFZ	145° ± 23°	23	621	15
	NDB	78° ± 43°	23	322	5
	STZ	129° ± 33°	34	562	17
	TF	**134° ± 37°**	**80**	**1505**	**11**
Permian	SRFZ	177° ± 17°	6	389	19
	STZ	133° ± 12°	4	132	9
	TF	**167° ± 25°**	**10**	**521**	**15**
pre-Permian	STZ	122° ± 26°	10	100	7
	TF	**122° ± 26°**	**10**	**100**	**7**

Notes: B, Borehole Breakouts; SRFZ, South of Rømø Fracture Zone; NDB, Norwegian Danish Basin; STZ, Sorgenfrei–Tornquist Zone; TF, Tornquist Fan. Values in italics style are considered to be inconclusive (Total Length of B < 30 m).

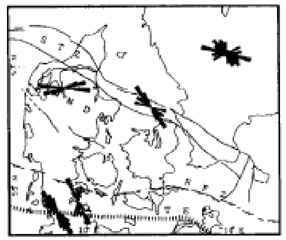


Fig. 6. *Summarized stress map of the Tornquist Fan area showing the regional stress field. The mean S_H orientations for 'A' to 'C' quality wells are shown for the area south of the Rømø Fracture Zone, in the Norwegian–Danish Basin and within the STZ, respectively. The black bars show our data; grey bars show the results according to Müller et al. (1992). NDB, Norwegian–Danish Basin; NGB, North German Basin; RFZ, Rømø Fracture Zone; STZ, Sorgenfrei–Tornquist Zone; TEF, Trans-European Fault.*

- Down-hole variation of breakout

- In Terne-1 no significant difference top and base of hole (1700 m is mid Triassic)

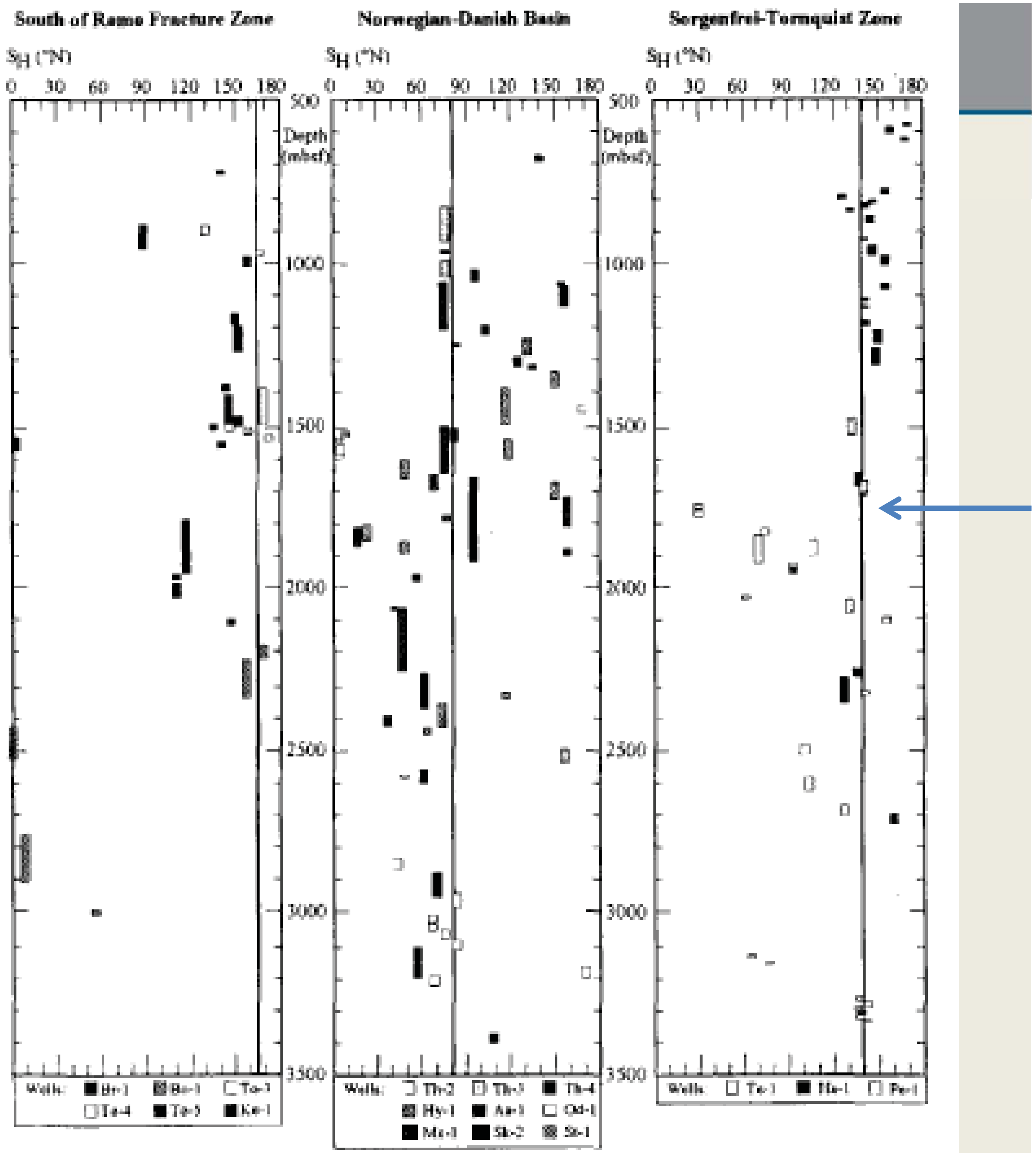
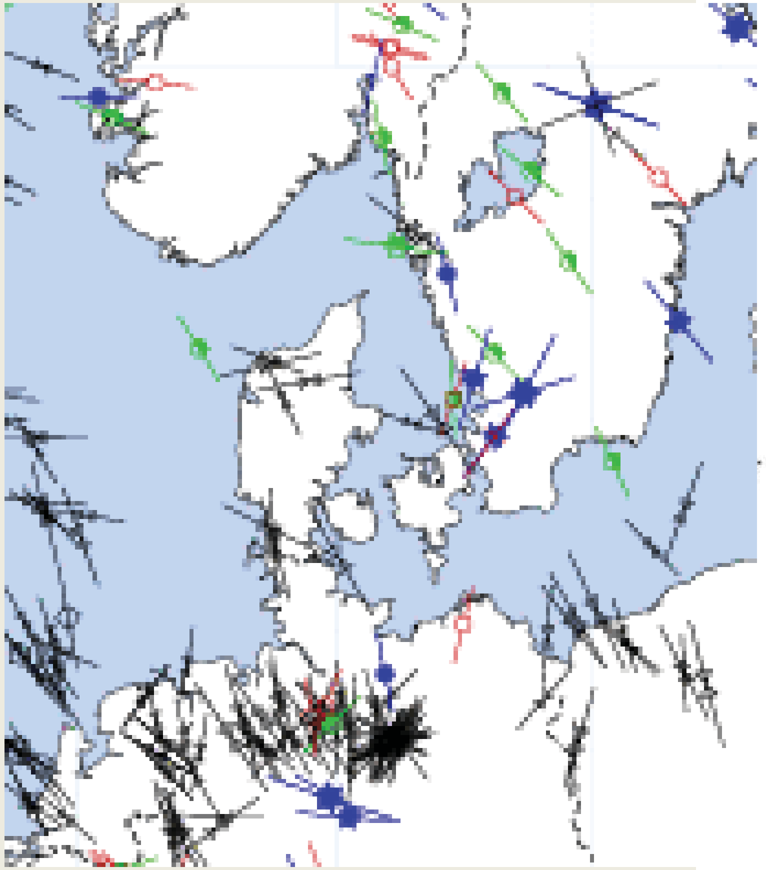


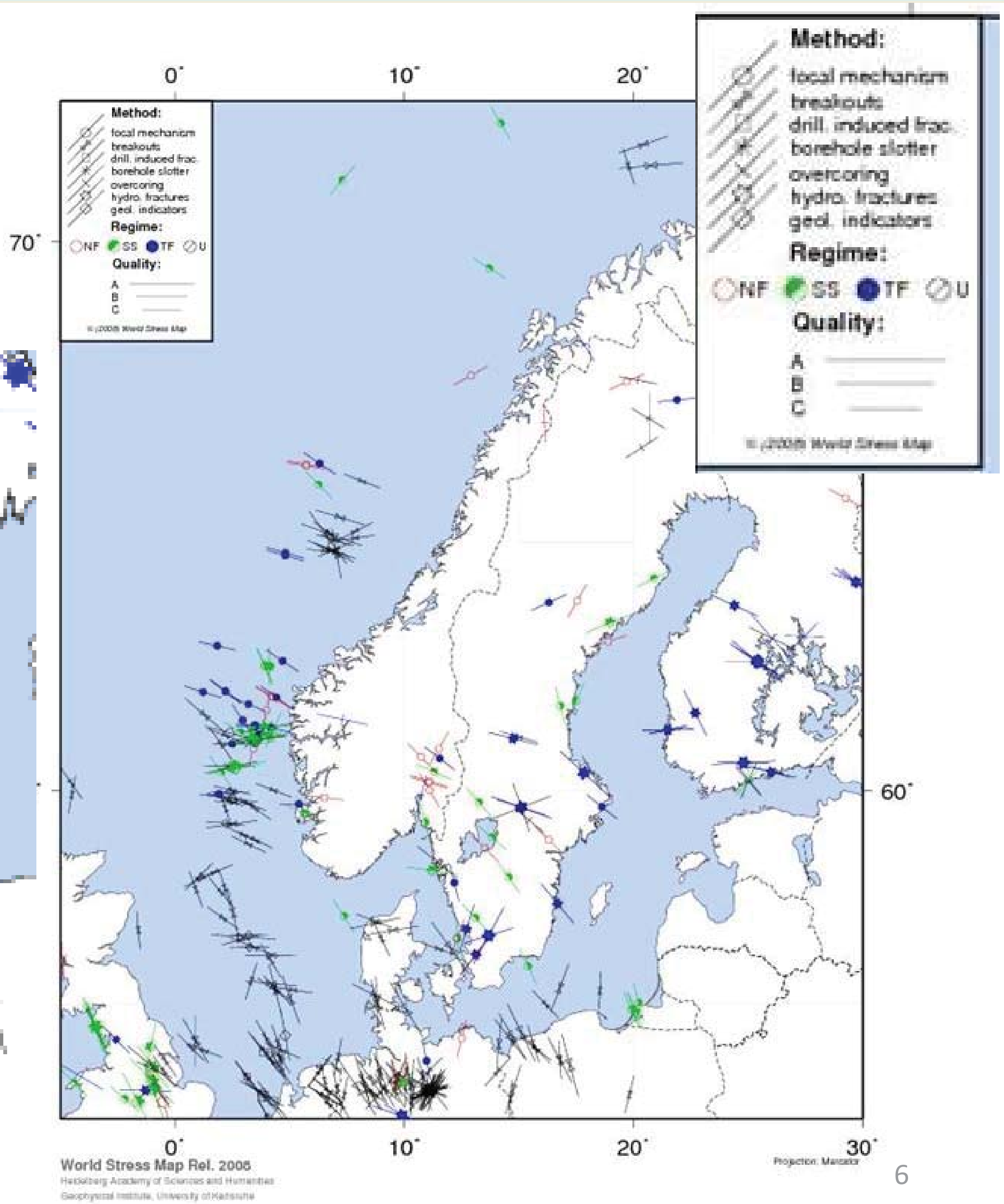
Fig. 5. S_H orientation vs. depth for wells south of the Rømø Fracture Zone, Norwegian–Danish Basin and Sorgenfrei–Tornquist Zone. Solid lines show the mean S_H orientation for A to C quality data in the respective tectonic regions disregarding the results from the Brøns-1 and Skive-2 wells. The accuracy with which C quality data is believed to record the horizontal tectonic stress data according to Zoback (1992) is shown in grey.

Present day stress

GEUS

- Present day stress:
- www.**world-stress-map**.org/
- The World Stress Map
-





GEUS

Seismic activity

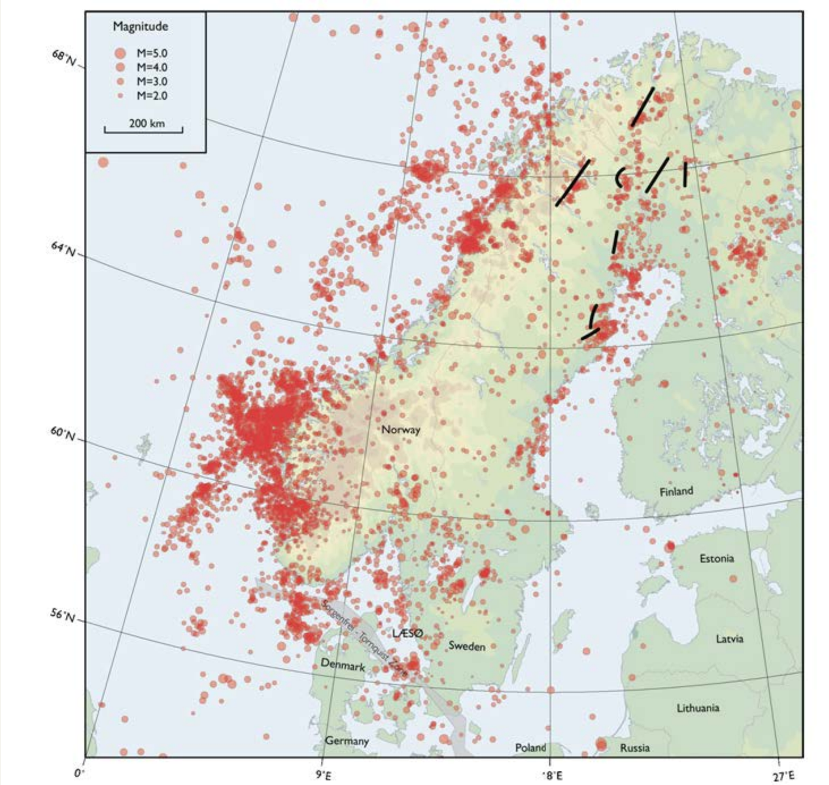
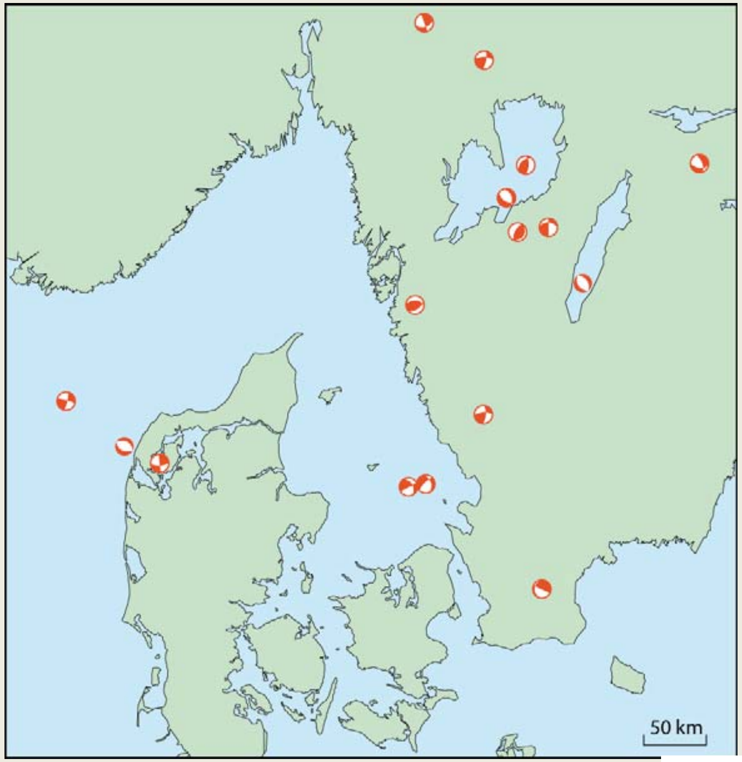
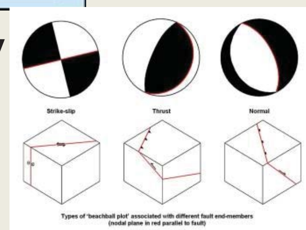


Fig. 2. Map of the earthquake geography in Scandinavia covering the years from January 1970 to December 2004. Earthquakes in the Danish area are extracted from the GEUS earthquake catalogue and earthquakes located outside this area are extracted from the Scandinavian catalogue from Helsinki University. The earthquake magnitude scale is given in the upper left corner. Very thick black lines show the large postglacial faults of age close to 9000 years (Lagerbäck, 1991). Updated earthquake files for Denmark are available in home page www.geus.dk under seismology, and for the rest of Scandinavia in home page www.seismo.helsinki.fi. From Gregersen and Voss (2009).



- Strike-slip motion mostly

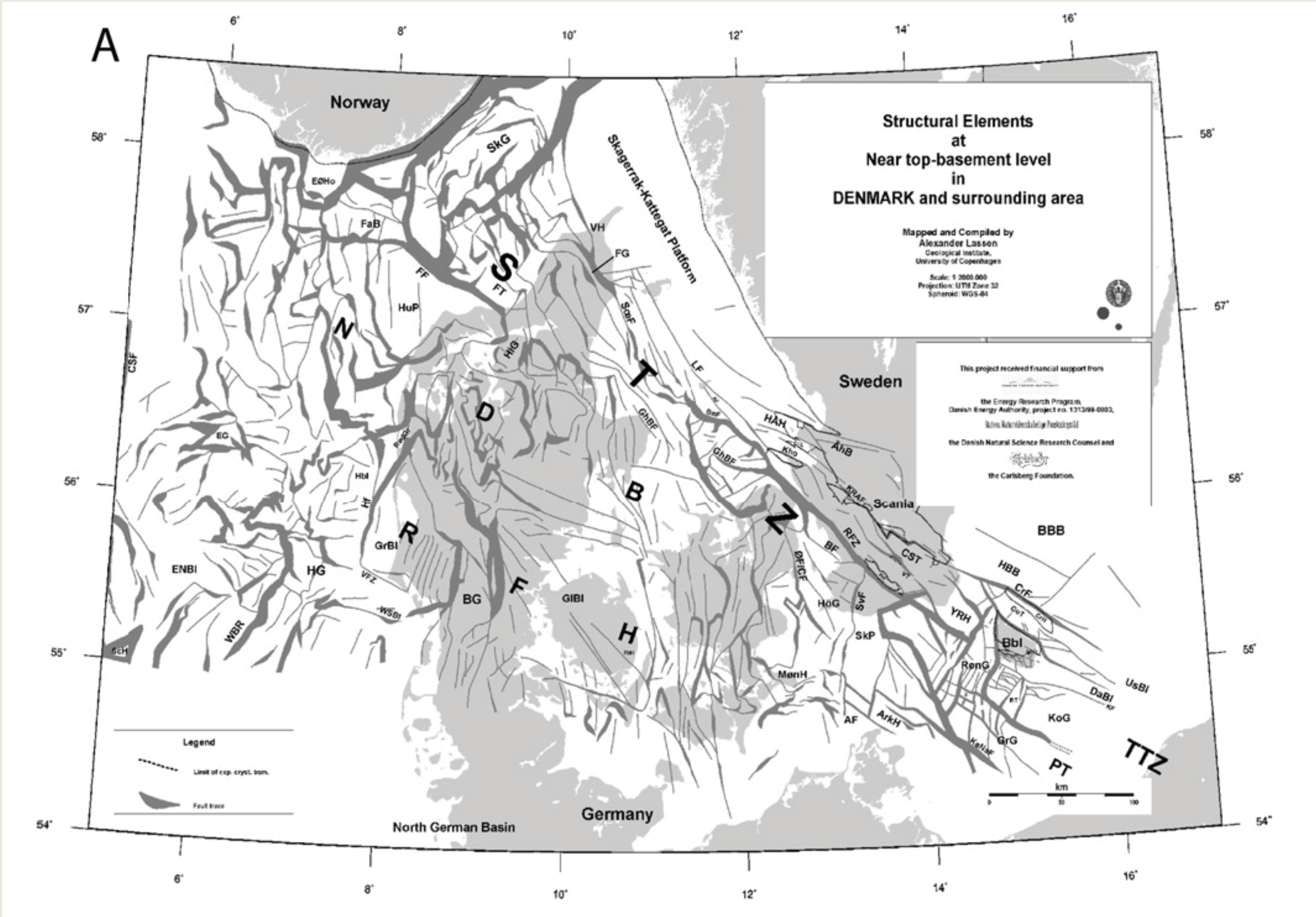


GEUS

Summary present day stress

- Low earth quakes frequency and intensity suggest general low present day stress
- Present day stress in Denmark constitutes of 3 difference directions. In the TTZ and north hereof general NNE-SSV (parallel with main fault zone) exist
- Present day stress from borehole data can be investigated further since data exist in at least the Sæby-1

Stress-Strain history analysis



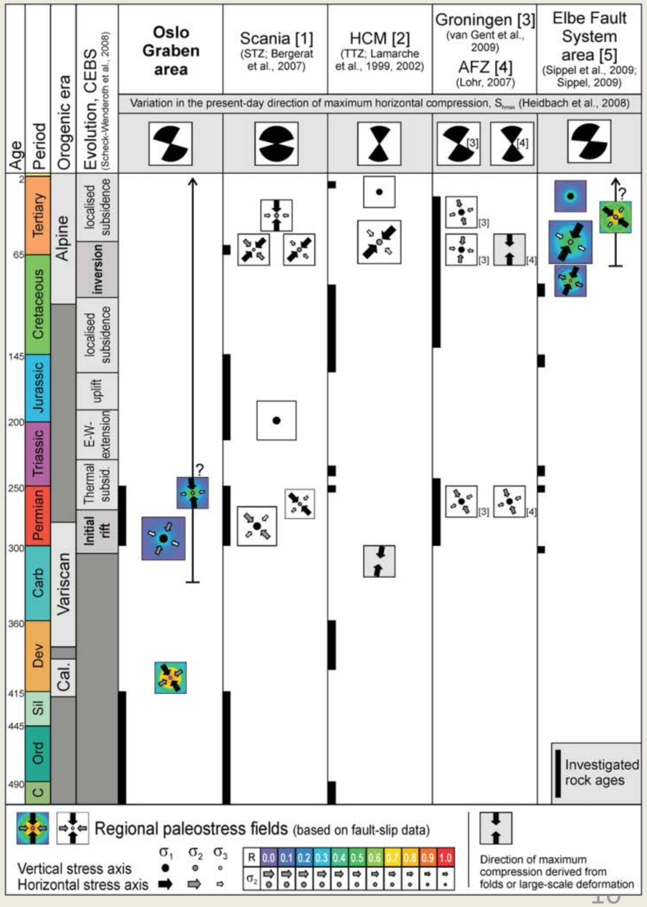
Main structural elements from Lassen and Thybo 2012

GEUS

Main summary

- Paleostress field econstruction in the Oslo region by
- Judith Sippel a,*, Aline Saintot b, Michel Heeremans c, Magdalena Scheck-Wenderoth. Marine and Petroleum Geology 27 (2010) 682–708

Main diagram from the publication showing the current best regional summary of tectonic Development.

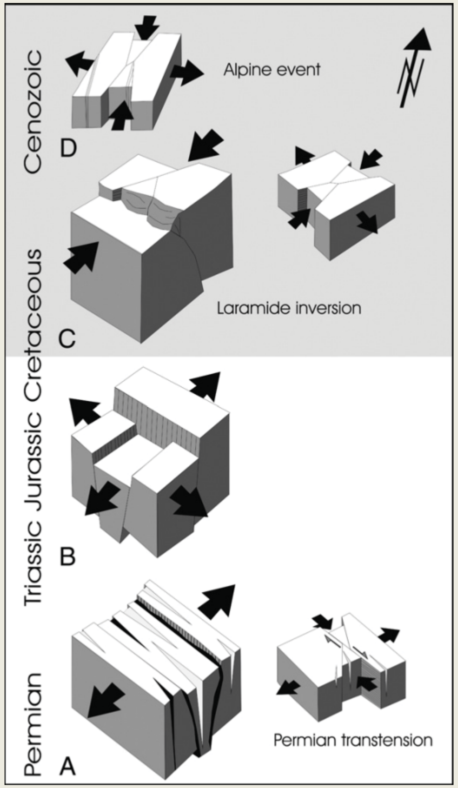


GEUS

Sweden

- Evolution of paleostress fields and brittle deformation of the Tornquist Zone in Scania (Sweden) during Permo-Mesozoic and Cenozoic times by:
- Françoise Bergerat a, , Jacques Angelier b, Per-Gunnar Andreasson c. Tectonophysics 444 (2007) 93–110

Main diagram from the publication showing the different tectonic development in Scania



GEUS

Bornholm

- Structural analysis of superposed fault systems of the Bornholm horst block, Tornquist Zone, Denmark
- OLE GRAVERSEN. Bulletin of the Geological Society of Denmark, Vol. 57,
- pp. 25–49.

Main diagram from the publication showing the different tectonic development on Bornholm

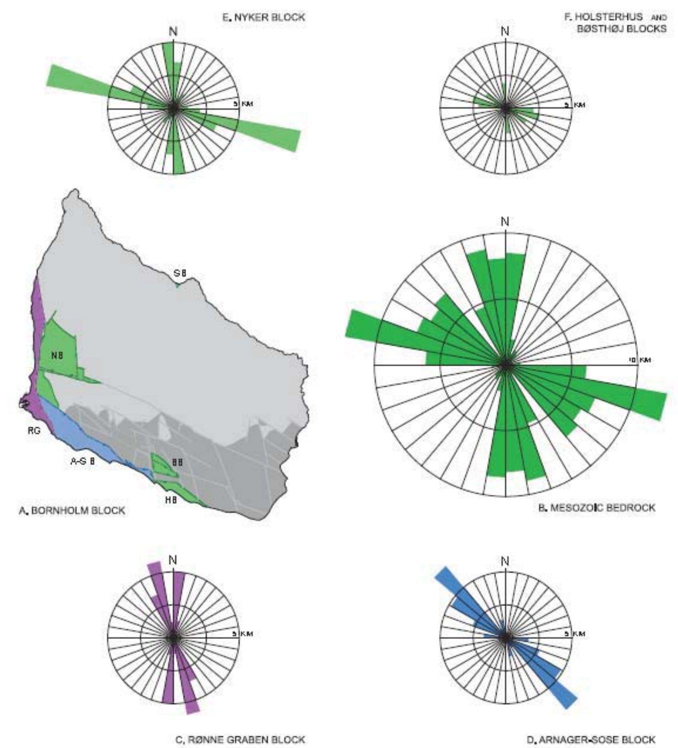


Fig. 12. Map and rose diagrams of the Mesozoic fault blocks of Bornholm where Mesozoic sediments are preserved. A: Mesozoic faulting was initiated in the Rønne Graben in the Triassic; in the Jurassic, faulting was extended onto the Arnager-Sose block, and in the Cretaceous, the faulting was extended into the Nyker, Bøsthøj, Holsterhus and Salene blocks. (RG: Rønne Graben block; A-SB: Arnager-Sose block; NB: Nyker block; BB: Bøsthøj block; HB: Holsterhus block; SB: Salene block). B: Rose diagram of the faults limiting the Mesozoic bedrock of Bornholm. C: Rose diagram of the Rønne Graben faults onshore Bornholm. D: Rose diagram of the Arnager-Sose block onshore Bornholm. E: Rose diagram of the Nyker block. F: Rose diagram of the Bøsthøj and Holsterhus blocks.

Graversen: Structural analysis of superposed fault systems of the Bornholm · 37

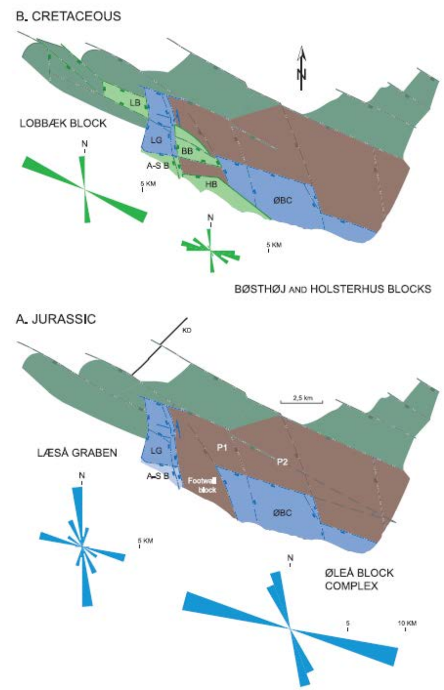
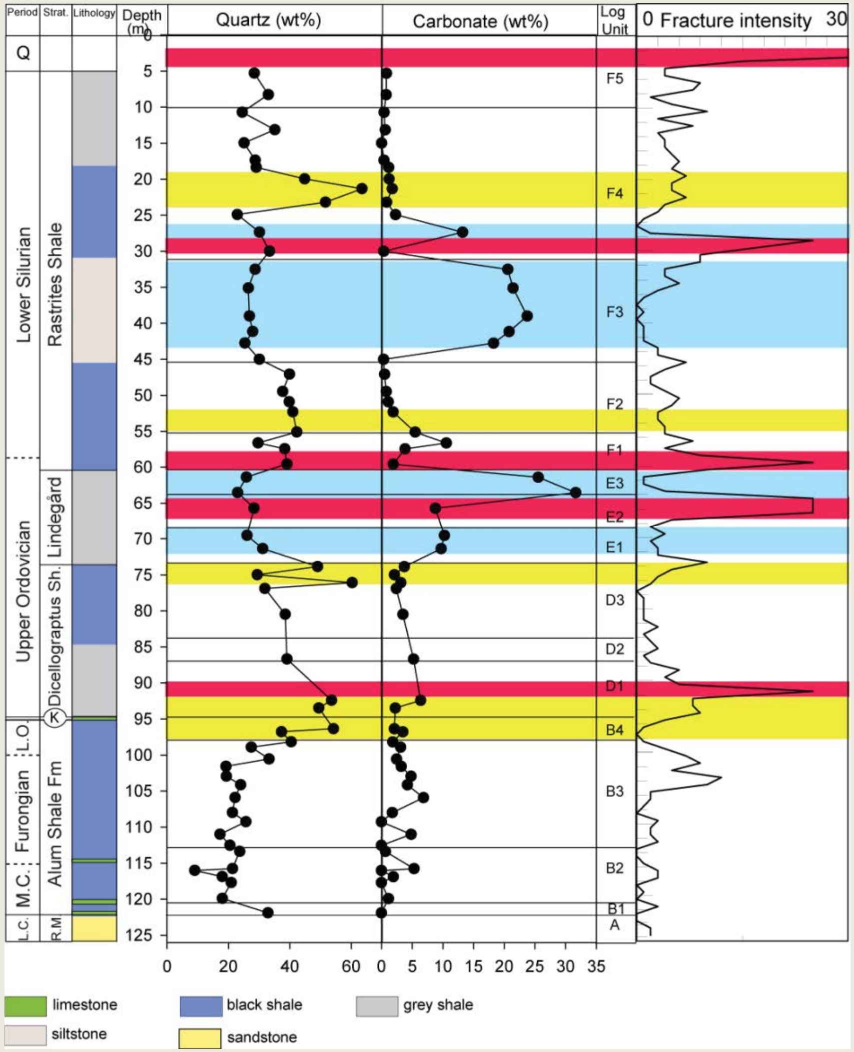


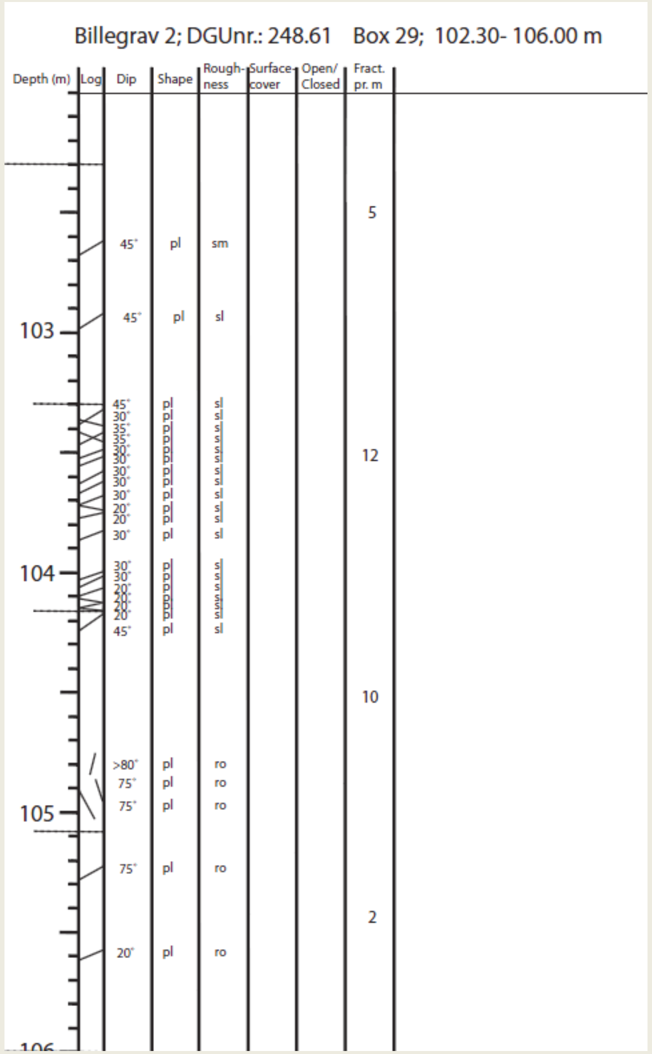
Fig. 13. Jurassic and Cretaceous fault blocks interpreted within the Palaeozoic bedrock outside the present distribution of the Mesozoic sediments. A: Jurassic – Map and rose diagrams of the Læså Graben and the Øleå block complex. A-S B: Arnager-Sose block; LG: Læså Graben; ØBC: Øleå block complex; KD: Keldseå dyke. B: Cretaceous – Map and rose digrams of the Lobbæk block (LB) and associated fault blocks with Cretaceous sediments preserved. A-S B: Arnager-Sose block; BB: Bøsthøj block; HB: Holsterhus block.

Graversen: Structural analysis of superposed fault systems of the Bornholm · 39

Description of fracture occurrence in Billegrav-2 well on Bornholm



- Example of fracture description in the Alum Shale



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Description of fracture modes in the Alum Shale on Bornholm

Description of the mode of occurrence of fractures in the Alum Shale of Bornholm based on the Billegrav-2 and Sommerodde-1 wells.

Required additional purchase of the Fracture description report of Billegrav-2 of 100.000 DKKR. The costs include reports with a supplement summation description of the mode of occurrences of calcite healed fractures in the Alum Shale

GEUS

Summary

- The data inventory show that data exist in the literature to give a regional overview of both the present day stress and the pale-stress-strain development
- Data suggests that similar development in the Pre-Permian between Oslo and Scania/Bornholm. This suggests that the synthesis here from will be valid in the licences areas aswell

GEUS

Way ahead

Based on inventory:

- Synthesis of published data
- Stress –strain analysis in time and space
- Paleo-Activity of the structural elements in Denmark

Additional

Fracture occurrence in Billegrav-2

- Analysis of borehole shape not done N of the Tornquist Zone ie in wells within the L10/1.
  - Analysis of borehole shale in Sæby-1 (drilled 1985).
  - Possibility also to obtain main failure trends in the older wells i.e. drilled before 1960

3. Chemostratigraphical analysis

Feasibility report: Chemostratigraphical analysis of the Silurian section in Sommerodde-1, Terne-1 and Lövestad A3-1

Part of item 3 of the engineering study between Total E&P and GEUS

Version 1 prepared by Niels H. Schovsbo

6 November 2014 (updated 17.11.2014)

GEUS

Outline

- Aim and status of study (item 3)
- GR-Resistivity logstratigraphy in the Silurian section
- Ha-XRF profiles, PCA and rock types in
  - Sommerodde-1
  - Terne-1
- Recommendations

GEUS

Aim and status

- **Aim with study: Determine the key elements to focus on, when doing onsite drilling real time, Xrf / Xrd analysis**

- Agreed work: Perform a chemostratigraphical analysis on the Silurian section in the Sommerodde-1 well by preforming high resolution XRF profiles

- Data collected:
  - Item 3a: ha- XRF profiles of the upper 90 m in the Sommerodde-1 well
  - Item 3b: ha-XRF analysis of 40 cutting samples from the Lovestad A-3 well, Scania
  - Item 3c: ha-xrf measurements of 100 cutting samples in the Silurian section in Terne-1 well

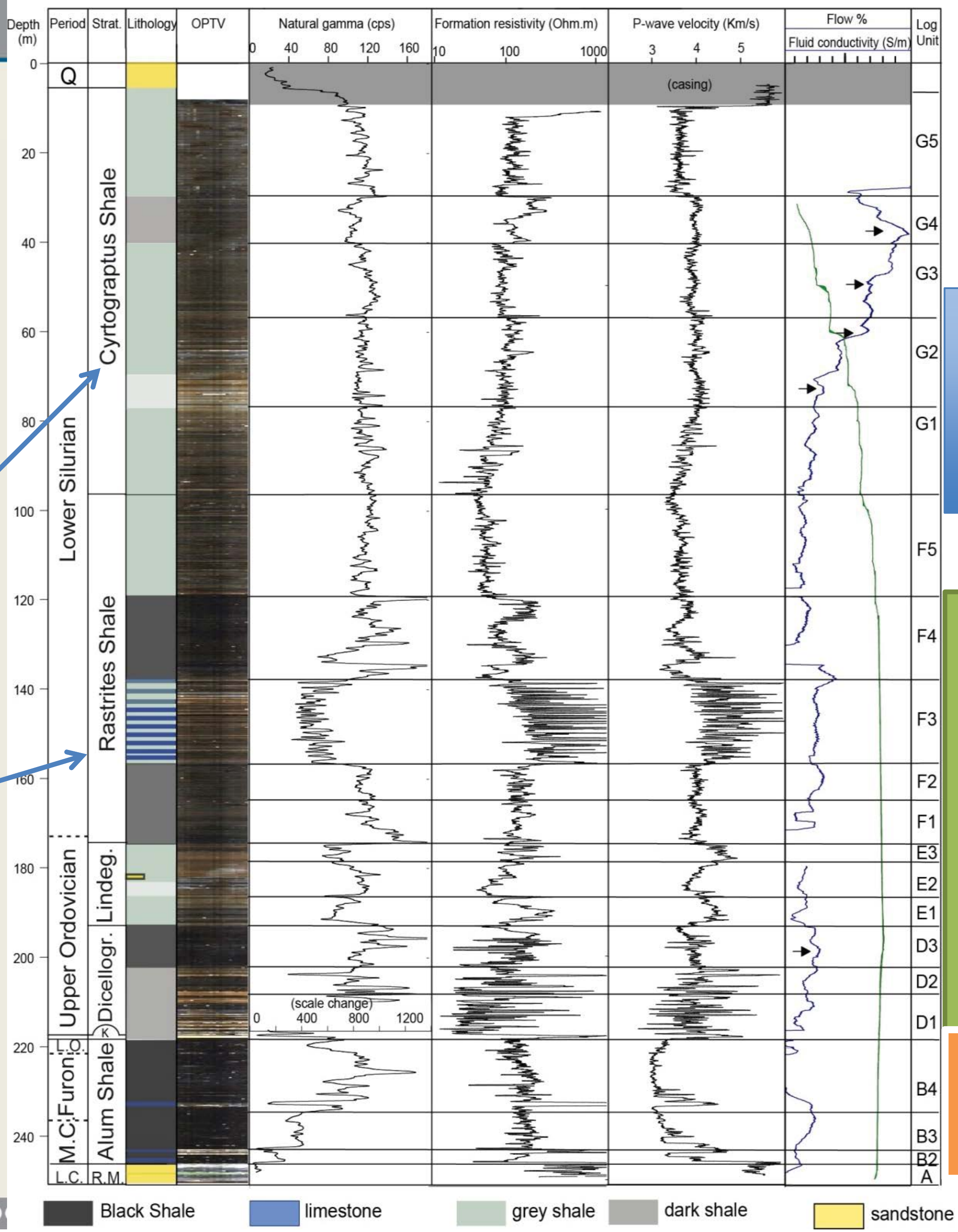
- Interpretations (this report):
  - PCA and PLS analysis
  - Recommendation for selecting key important elements to analysis during drilling operation for determine the casing point for the 9-5/8 based on Mud-logging data

Log stratigraphy

Tie between wells are made based on log stratigraphy i.e. independent of ha-XRF data

- The Cyrtograptus shale subdivided into 5 log units: G1-G5
- The Rastrites shale subdivided into 5 log units: F1-F5

Sommerodde-1: Stratigraphical reference well with core data



9-5/8 Casing point

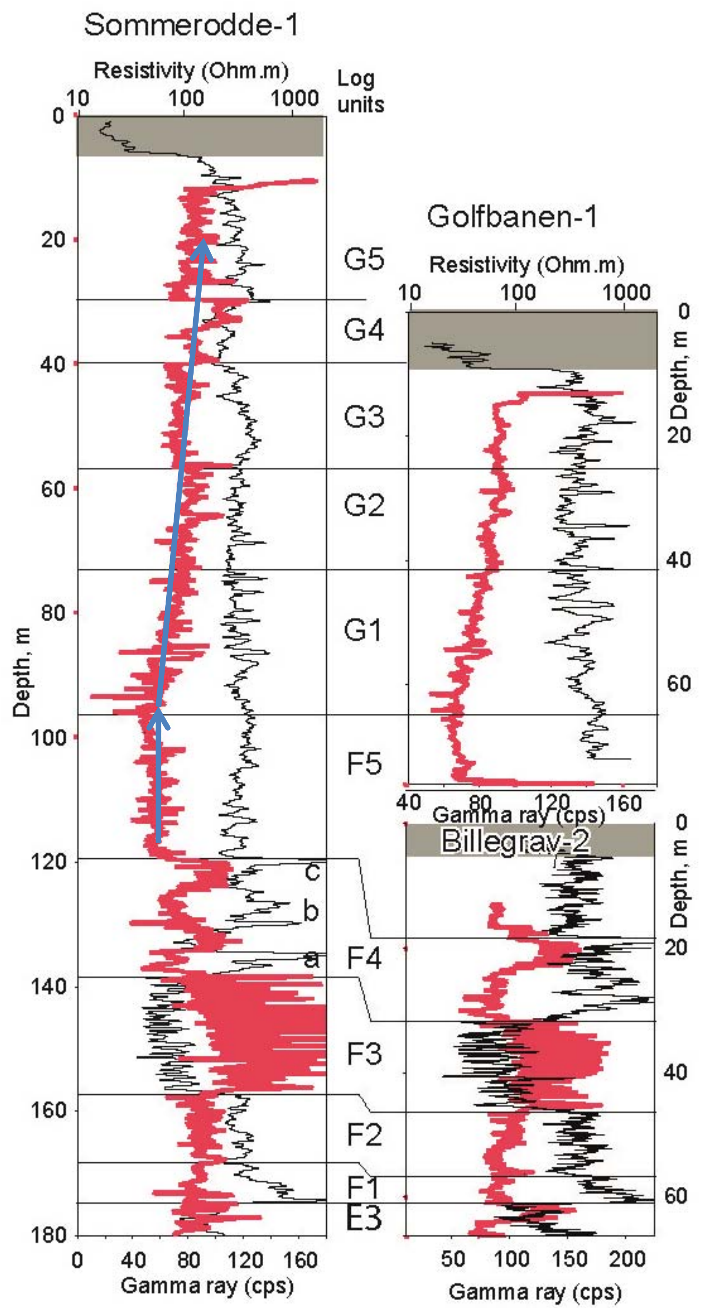
Zone of high TOC shales

Target: core

GEUS

- Log based correlation made based on all scientific and logged water wells on Bornholm

- Main features:
  - The F/G boundary is based mostly on the Resistivity log. The G unit is more resistive than the F unit
  - The resistivity increases upwards in the G unit.
  - Subunits in the F unit is based both on the Gr and resistivity log



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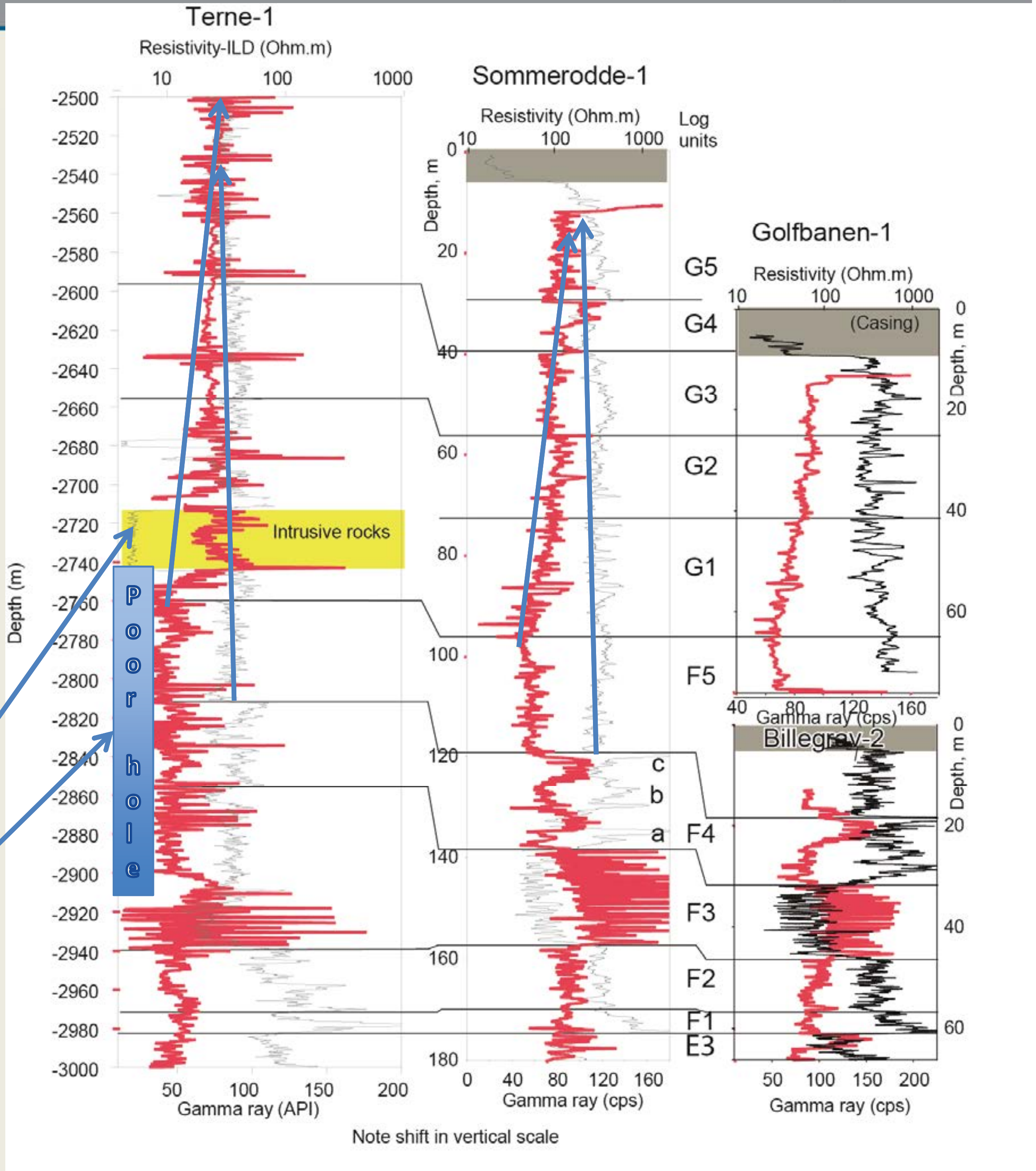
- Updated log correlation (gr-Resistivity) between Terne-1 and Sommerodde-1

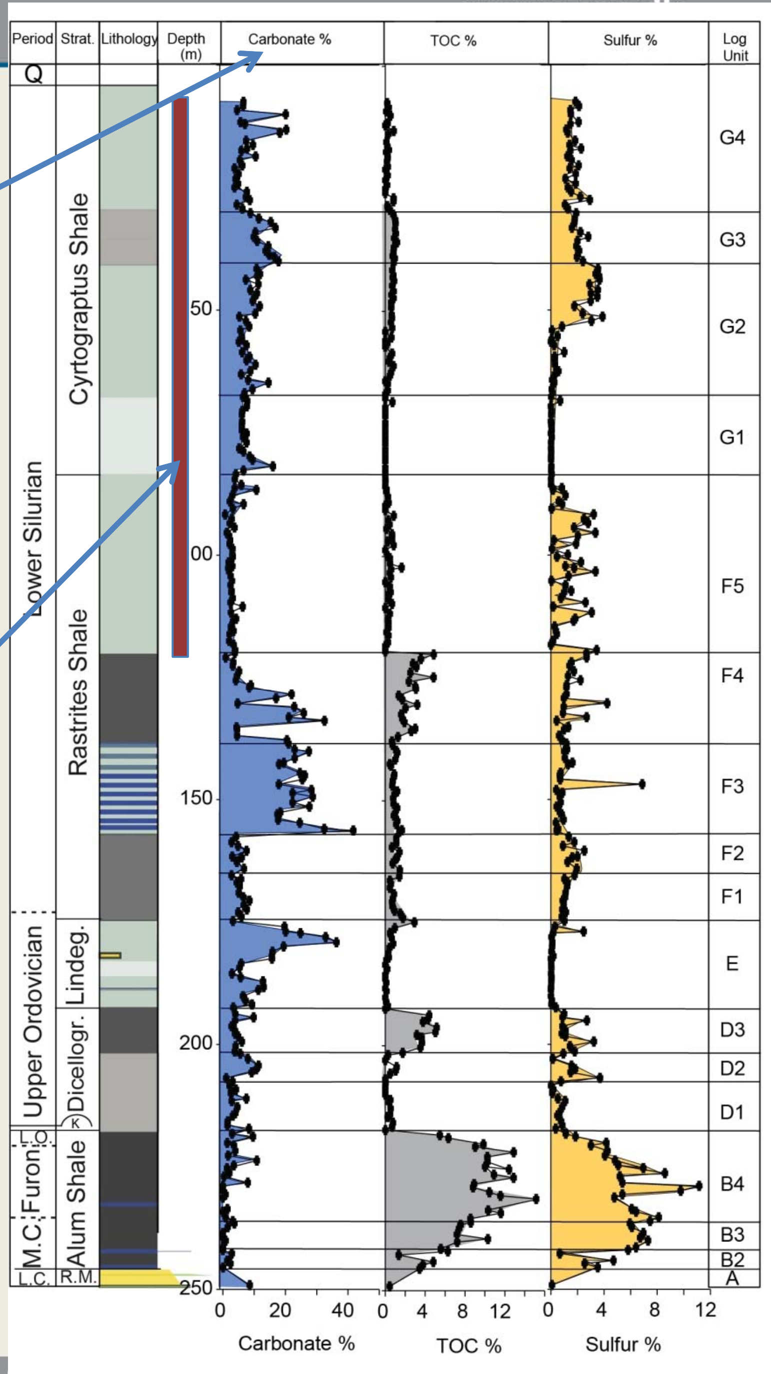
- Same long term trend between F an G unit is seen: an increase in Resistivity and stable Gr level (going from base to top)

- Terne-1 drilled diorite rock between 2720-2740. Section between 2760 and 2900 characterised by poor hole conditions – enlarged 450%. This interpreted to affect the Resistivity log response



Geochemical profiles in Sommerodde-1

- Existing screening data in Sommerodde-1:
-
- Each 80 cm: TOC, Carbonate, sulphur,
- In interval 0-140 m ICPMS data of trace and major elements
- Made on project: 600 XRF scanning are made in the upper part to the F4 unit (i.e. 10-120 m) to detail the top Rastrites shale.



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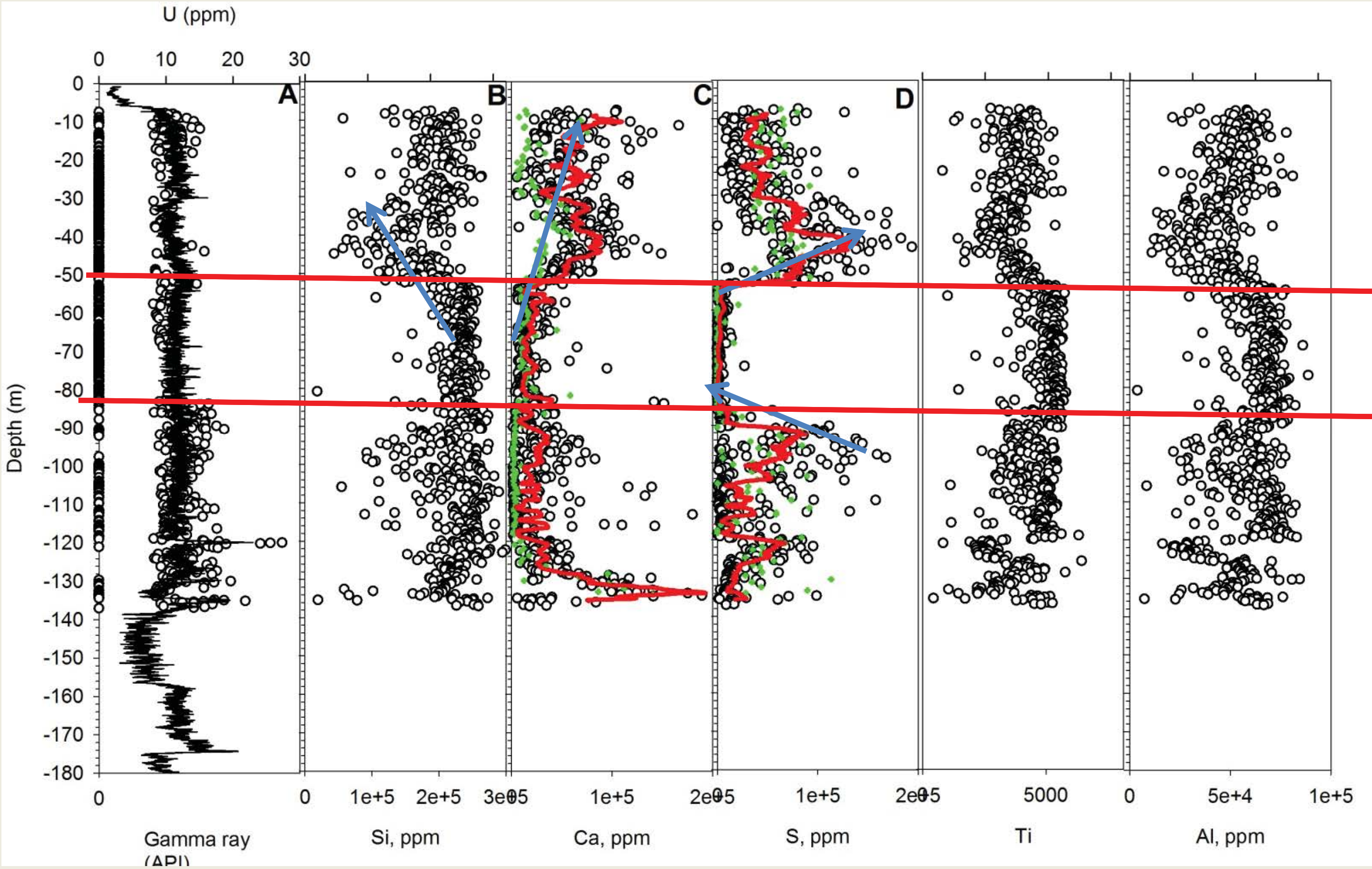
Ha-XRF Sommerodde-1



Chemostratigraphy

Cyrtograptus (unit G)

Transition interval

Rastrites (unit F)

Selected element variation (Red line running avg of 6 m, green dots ICPMS data). Prominent changes in carbonate content from top to base of section. Decrease concentrations of Si, Al and increase in S

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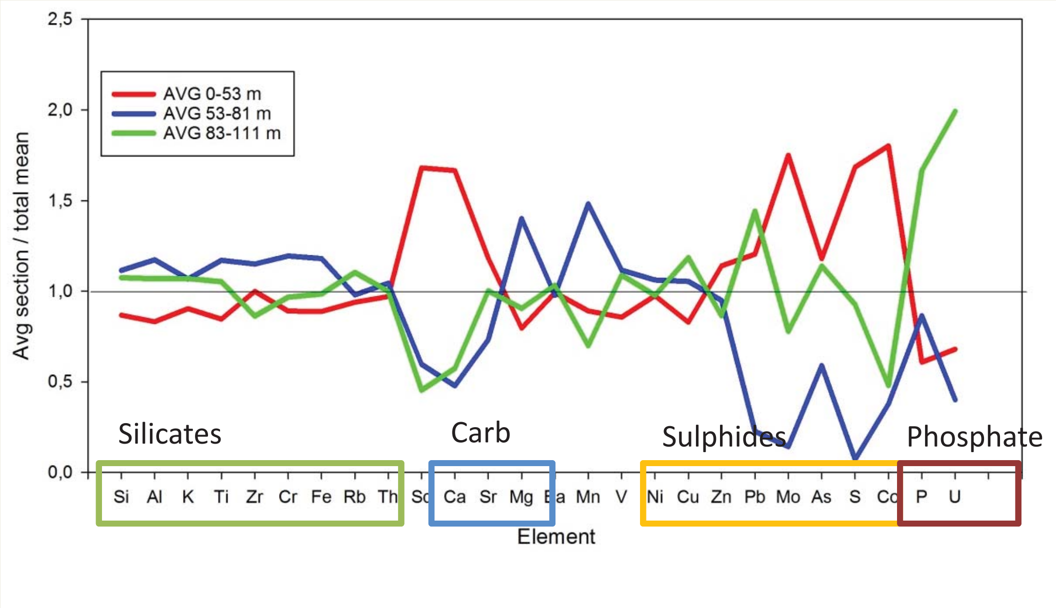
Sommerodde-1

- Stratigraphical variation illustrated by avg XRF composition:
- AVG 0-53 m Cyrtograptus shale – carbonate rich
- AVG 53-81 m Transition interval to Rastrites shales – Carbonate poor and S poor
- AVG 81-111 m Rastrites Shale - Carbonate poor Phosphate and U rich
-



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Mean compositions

ppm	Mean composition 0-111	Mean composition 0-53 m	Mean Composition 53-81m	Mean Composition 81-111m
Si	205164	178048	228705	220348
Al	55057	45800	64591	58843
K	24007	21699	25615	25683
Ti	4290	3628	5021	4515
Zr	163	163	187	141
Cr	144	128	171	139
Fe	48164	42755	56850	47435
Rb	74	69	72	82
Th	13	13	14	13
Sc	18	31	11	8
Ca	38168	63579	18249	21912
Sr	113	133	83	113
Mg	7020	5587	9838	6351
Ba	748	742	731	772
Mn	1464	1304	2169	1023
V	168	144	187	183
Ni	106	103	112	103
Cu	49	40	51	58
Zn	78	88	74	67
Pb	25	30	6	35
Mo	3	5	0	2
As	18	22	11	21
S	37867	63797	2691	35071
Co	37	67	14	18
P	324	197	280	540
U	4	3	2	9

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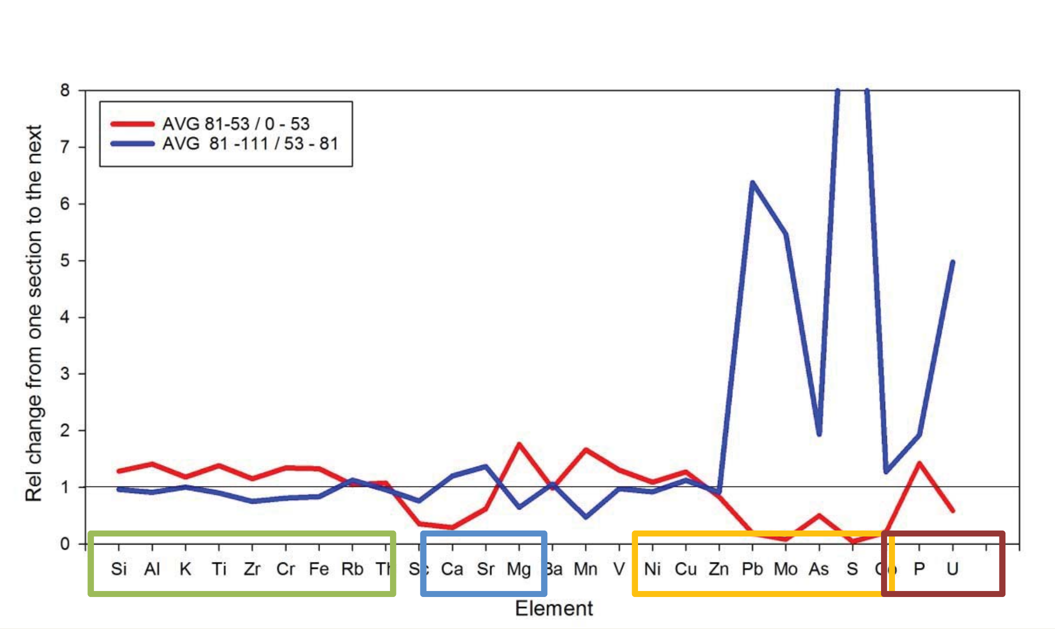
Sommerodde-1

- Diagram illustrates the relative changes between the main units if observed when drilling:

- Drilling the 0-53 m section to the 53-81 section a decrease in carbonate (Ca, Sr, Mg), pyrite (Pb, As, S, Co) and an and organics will be seen (U, Mo)

- Drilling the 53-81 m section to the 81-111 m section a increase in pyrite (Pb, As, S, Co), organics (U, Mo) and P will be seen



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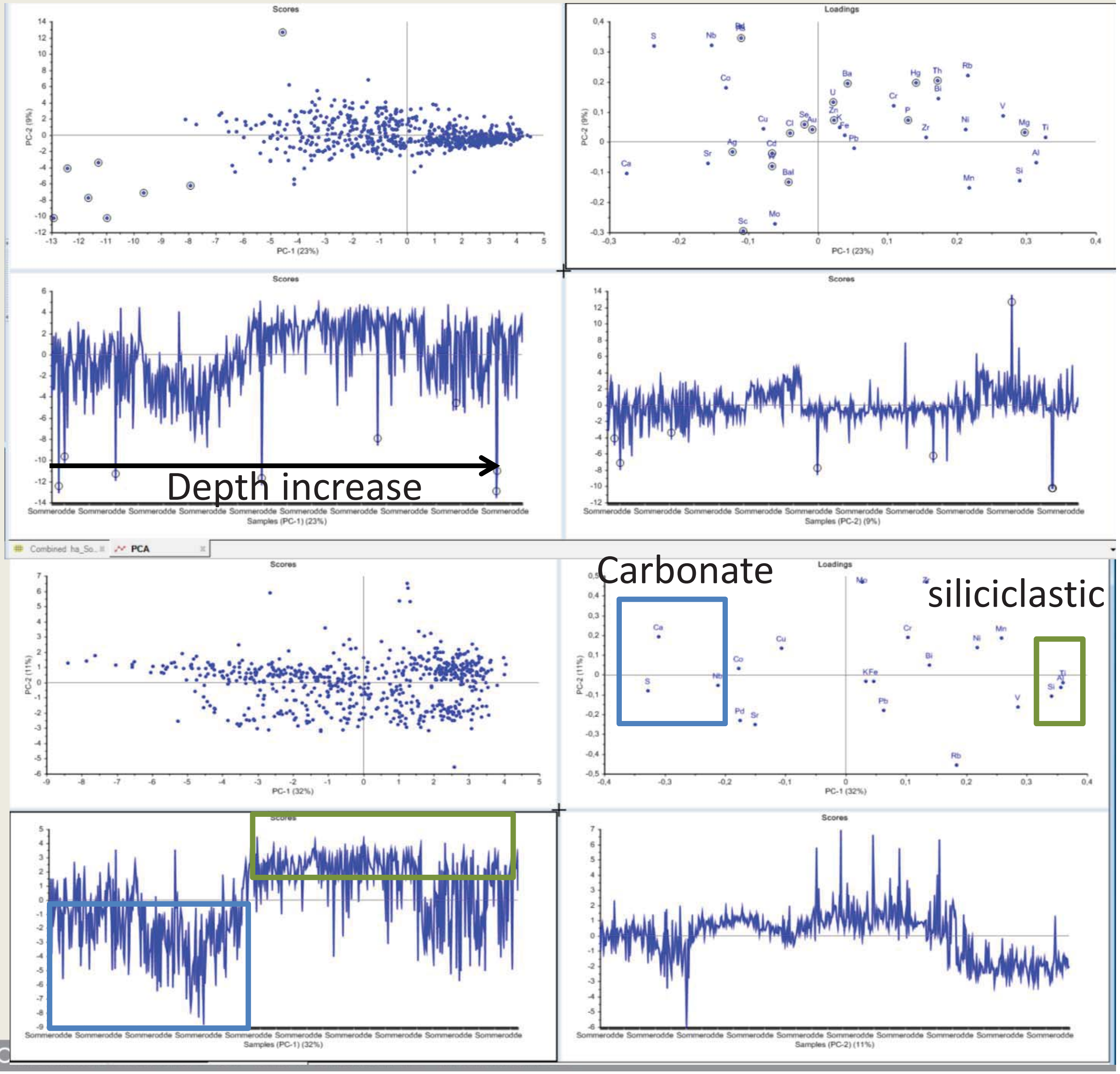
Sommerodde-1

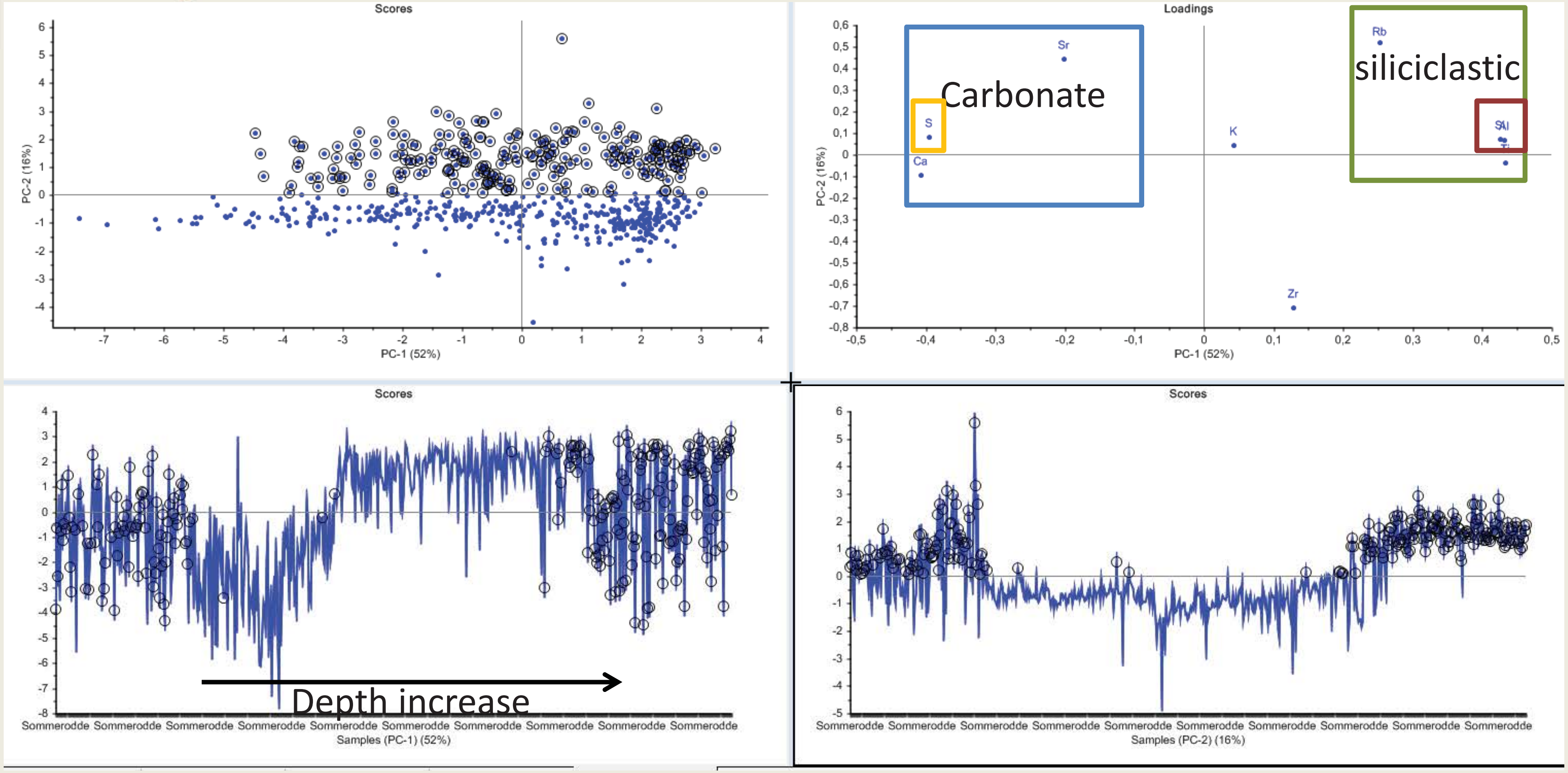
PCA of all samples and xrf elements

PCA without outliers and elements with low information or high noise level

Two main two rock types: Carbonate vs siliciclastic rich



Sommerodde-1



Further selection of elements that is most impotent for rock type definition:
Main rock types Ca rich (with pyrite) and siliciclastic rich .
Minor trend defined on 2. PCA axis by Zr and Rb. Interpreted to reflect grain size (Zr: sand, Rb: clay)

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Sommerodde-1

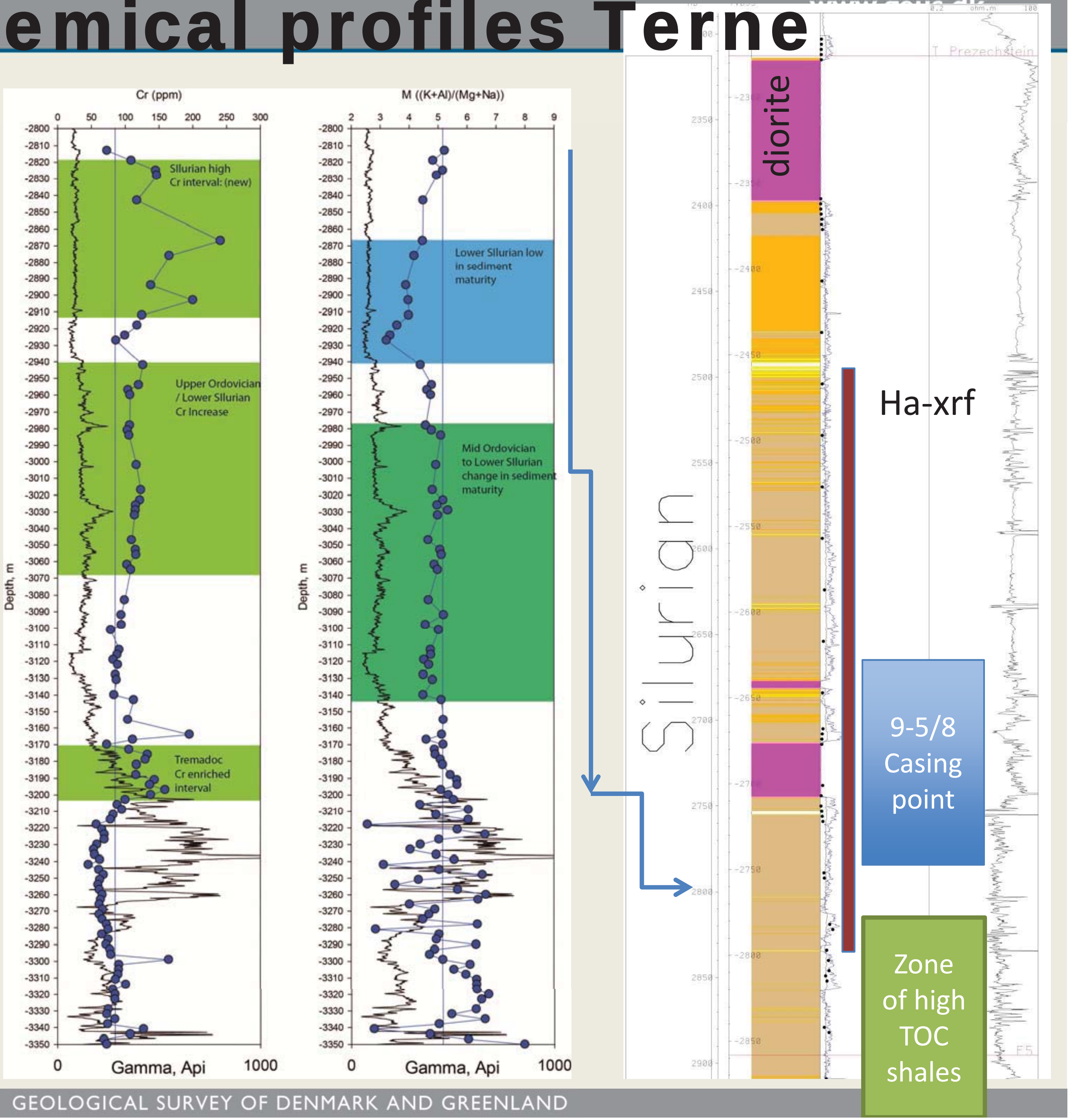
- The ha-XRF data defines 3 main units in that has very distinctive different expression
- The likely casing point at the base of the Cyrtograptus shale is characterised by TOC lean shale with low carbonate and low sulphur content compared to the section above
- The casing point interval can be defined downwards based on the sulphur and U content that is higher in the unit below related to high S and U associated with higher P content and slightly higher TOC.

Geochemical profiles Terne

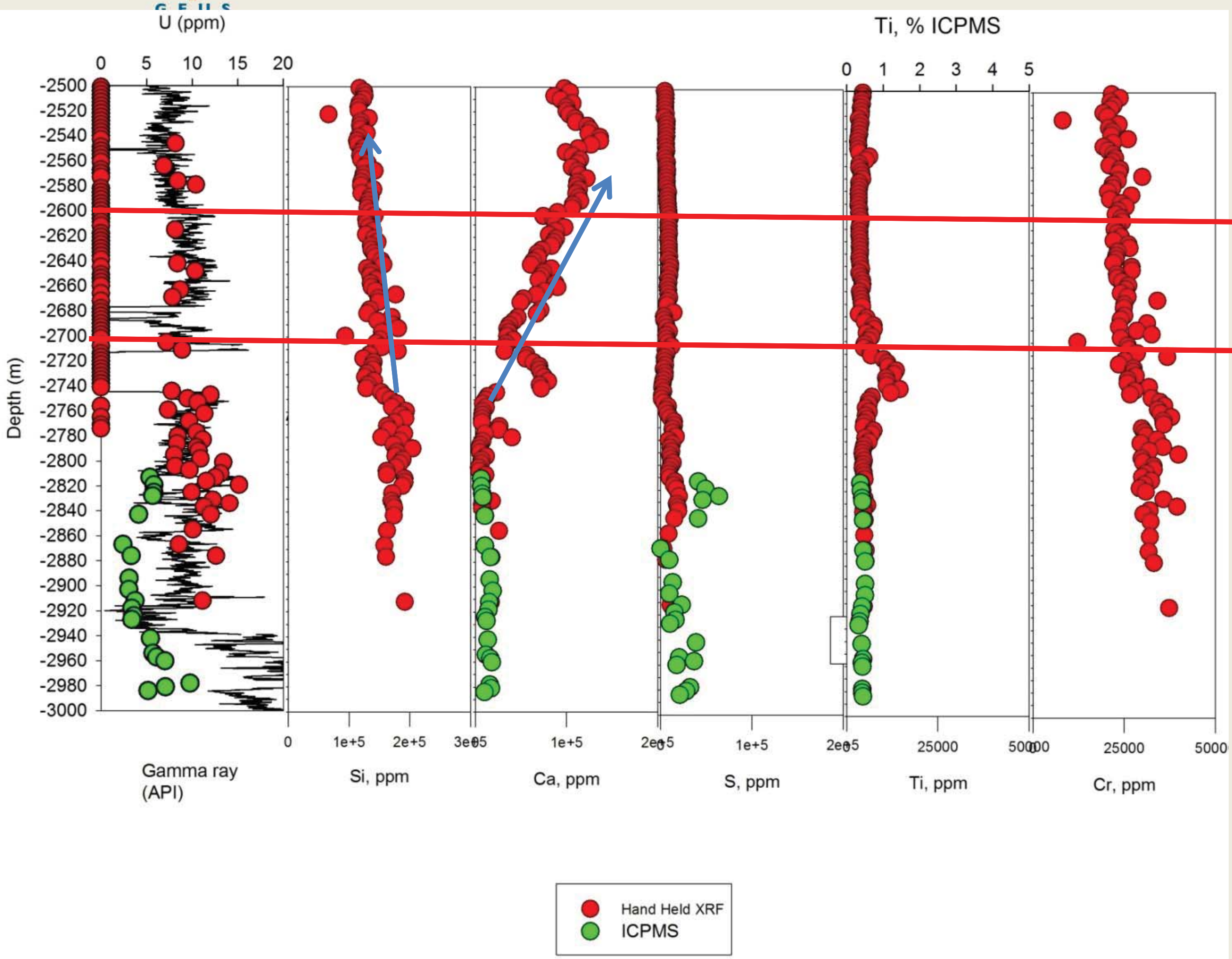
- Ha-Xrf made in interval 2500 – 2894 (about 100 cuttings). Measured interval stops in the F4 (same as for Sommerodde-1)

- Previous ICPMS elements measured on few cutting samples below 2820 m.

-



Ha-XRF Terne-1



Chemostratigraphy

Cyrtograptus (unit G)

Transition interval

Rastrites (unit F)

Profile in Terne-1 on cuttings picked every 3 m. Very distinctive trends in most of the elements: High Ca between 2500-2600 m (Cyrtograptus), intermediated Ca levels between 2600 -270, Low Ca between 2700 -2800 m (Rastrites shales).

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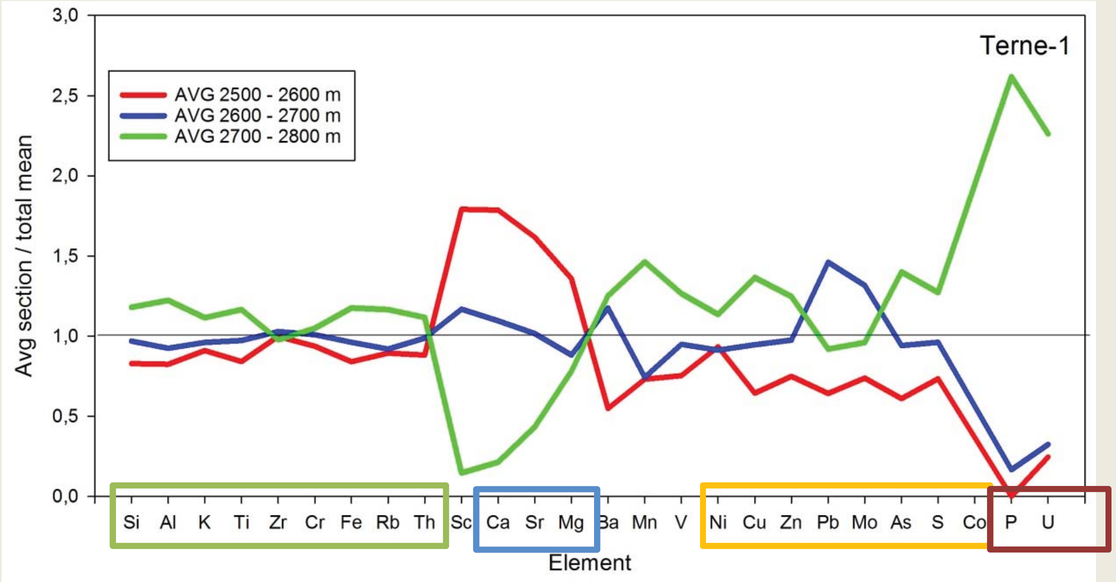
Terne-1

- Stratigraphical occurrence of xrf defined rock units is illustrated by avg XRF composition
- AVG 2500-2600 m Cyrtograptus shale – carbonate rich and sulfide poor
- AVG 2600-2700 m Transition interval to Rastrites shales – Carbonate on average AVG 2700-2800 m Rastrites Shale - Carbonate poor, Sulphide rich and phosphate and U rich
-



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Mean compositions

ppm	Mean composition	Mean composition 2500-2600 m	Mean composition 2600-2700 m	Mean composition 2700-2800 m
Si	147579	122292	143078	174112
Al	26886	22153	24846	32892
K	21984	19996	21120	24511
Ti	4411	3712	4289	5143
Zr	145	144	149	141
Cr	127	119	128	133
Fe	41755	35093	40156	49106
Rb	57	51	52	66
Th	9	8	9	11
Sc	115	207	135	17
Ca	61848	110492	67752	13197
Sr	253	409	257	110
Mg	2249	3056	1984	1756
Ba	385	211	452	481
Mn	496	363	369	726
V	183	138	174	232
Ni	46	43	42	52
Cu	44	29	42	61
Zn	70	53	69	88
Pb	37	24	54	34
Mo	4	3	5	4
As	14	8	13	19
S	8638	6337	8303	10988
Co				
P	122	0	20	319
U	4	1	1	9

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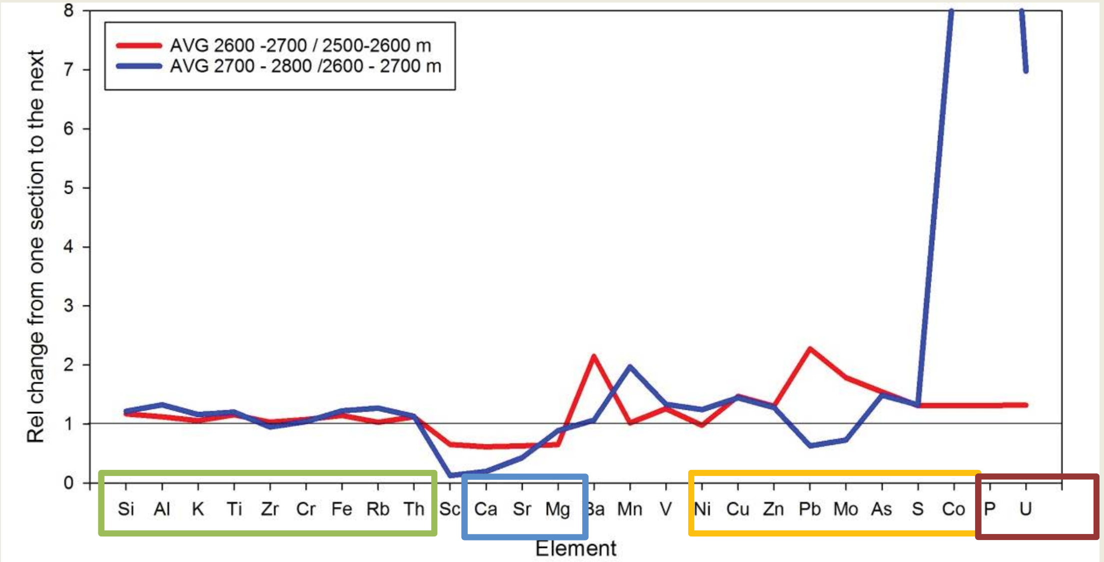
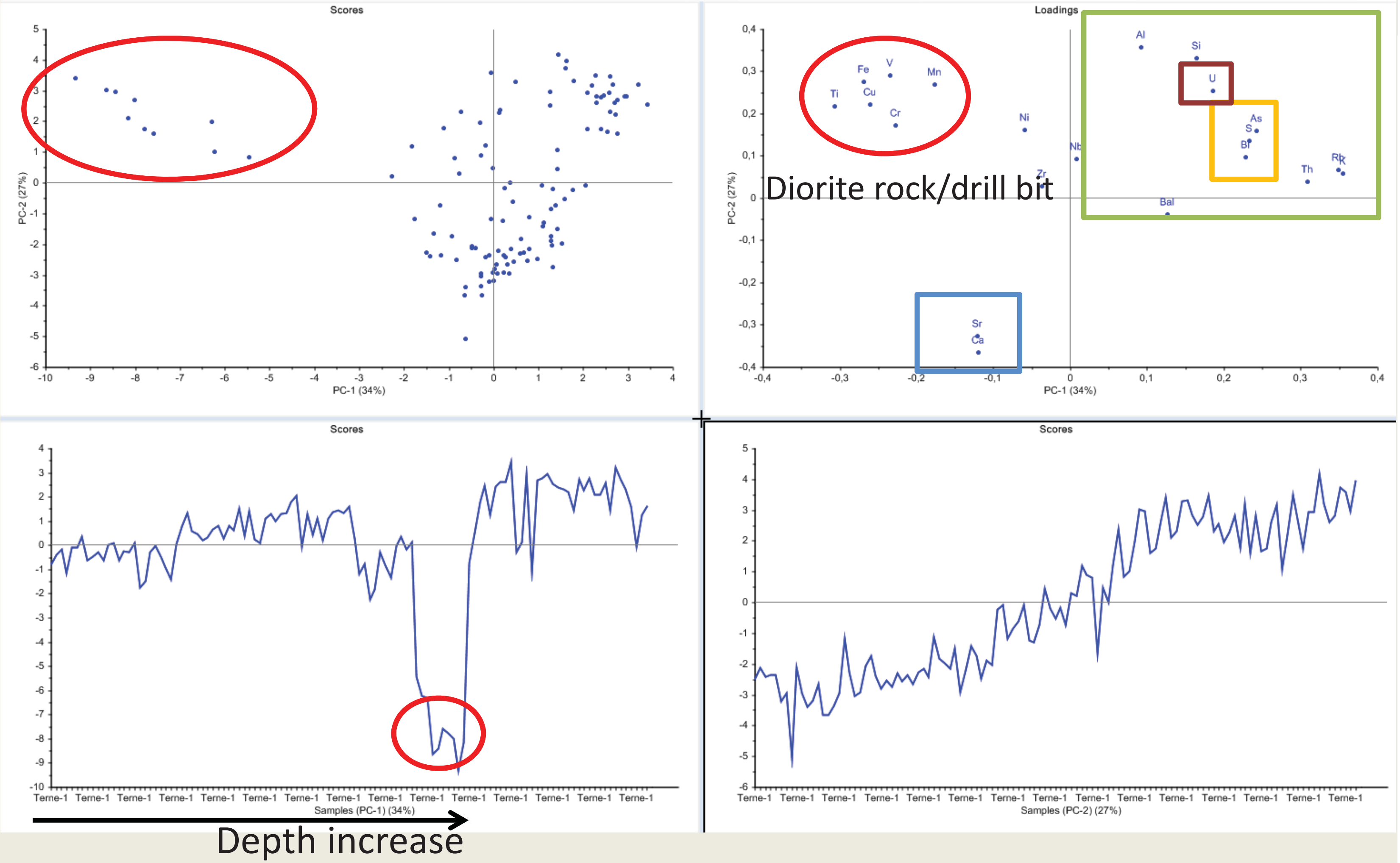
Terne-1

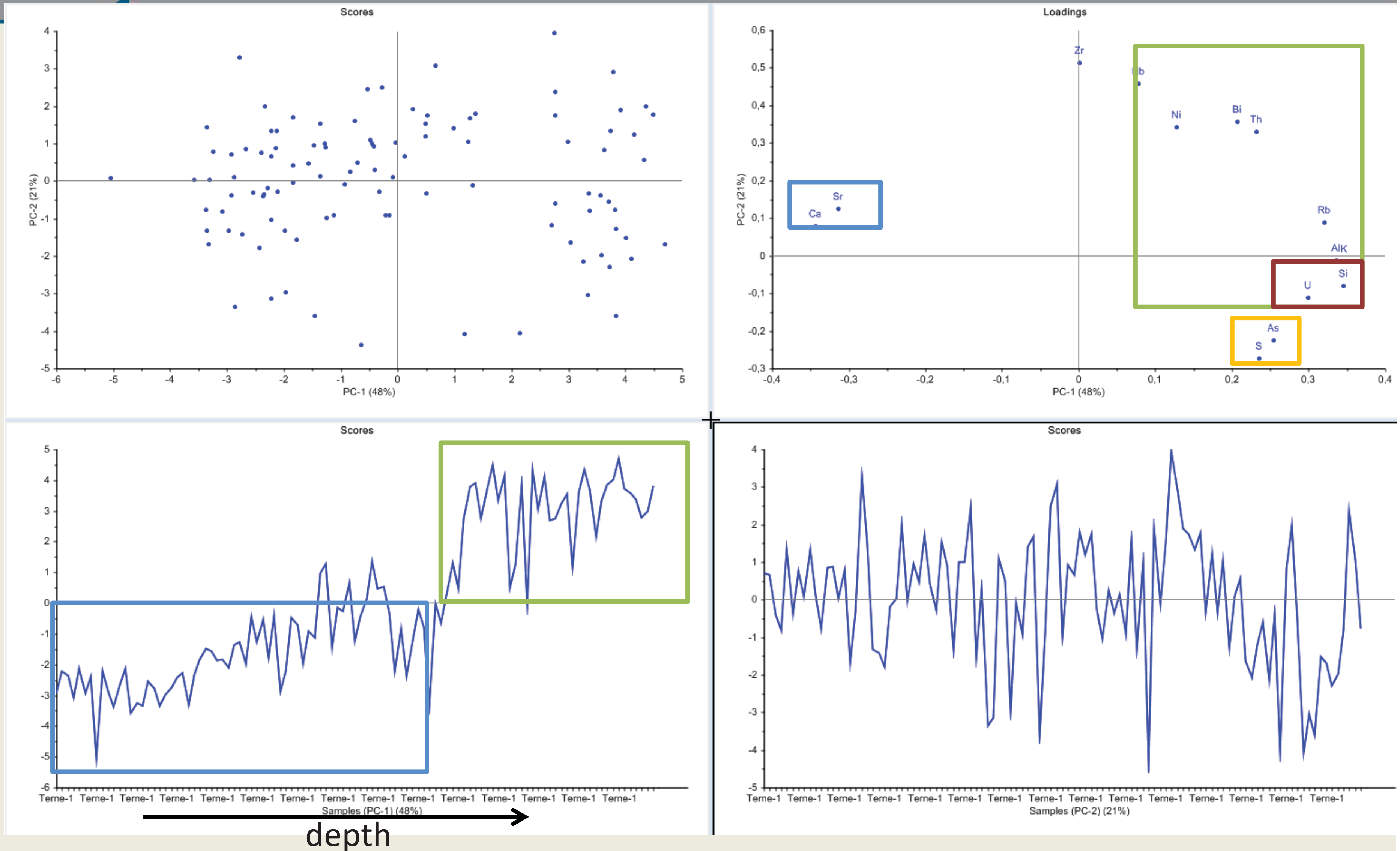
- Diagram illustrates the relative changes between the main units if observed when drilling:
- Drilling the 2500-2600 m section to the 2600-2700 m section a decrease in carbonate (Ca, Sr, Mg) will be seen
- Drilling the 2600-2700 m section to the 2700-2800 m section a further decrease in carbonate and a marked increase in S, P and U will will be seen



Terne-1



PCA analysis on all elements – Influence of diorite and or drill-bit contaminations is very clear



Terne: Selected elements -two main rock types: Carbonate rich and carbonate poor.
Same rock types as in Sommerodde. However pyrite (S) is associated with the siliciclastic and in Terne and NOT with carbonate as in Sommerodde-1

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Terne-1

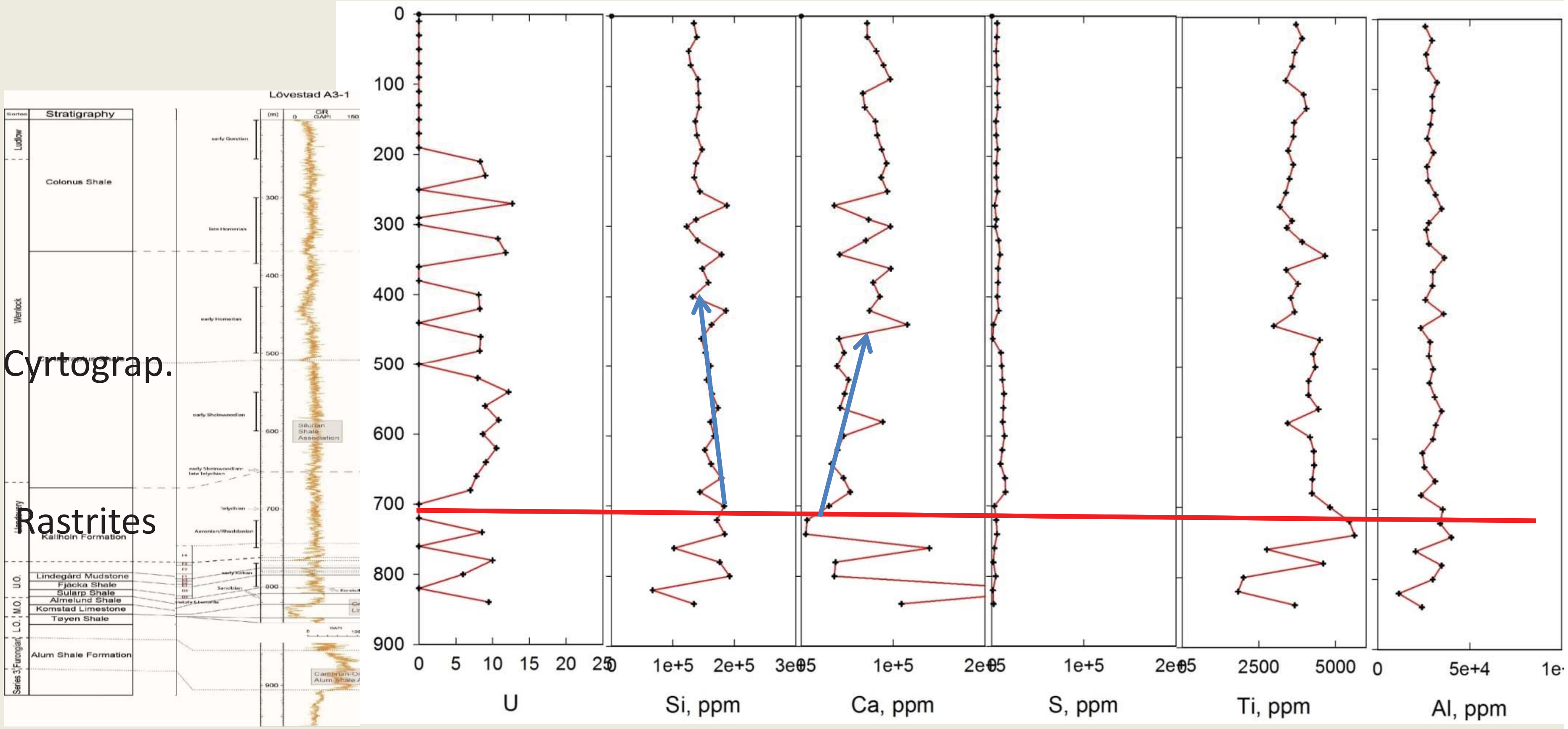
- The transition from Cyrtograptus shale and to Rastrites shale is seen as a change in carbonate content between. The transition between the two units is gradual and not sharp as in Sommerodde-1. This might be an artefact and reflect caving

- The sulphur content is much lower in Terne-1 than in Sommerodde-1. In addition the PCA analysis suggest that S is associated with other minerals in the two wells. The lower S content in Terne-1 may reflect the difference in sample material (core vs cuttings), drilling process and/or sample preparation since magnetic material is routinely removed from cuttings as part of the GEUS procedure.

- Care should be taken to use pyrite or associated elements in a chemostratigraphy as the primary marker

- It is noted that the section with poor hole conditions in Terne-1 is occurring in the low carbonate shale. High carbonate shale has relative good hole. It is speculated weather we see a common relationship between rock strength and hole conditions

Lövestad A3-1



Eriksson, 2012

Profile in Lövestad A3-1 on cuttings picked every 20 m.

Low in Ca level at 700-740 m occur across the Cyrtograptus/Rastrites boundary interval.

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Lövestad

- The profile illustrates that even a very crudely sampled profile can be interpreted and precisely correlated by use of ha-XRF data

- As in Terne-1 the Lövestad A3-1 well cuttings are low in S suggesting that the drilling process significantly influences the XRF analysis pattern

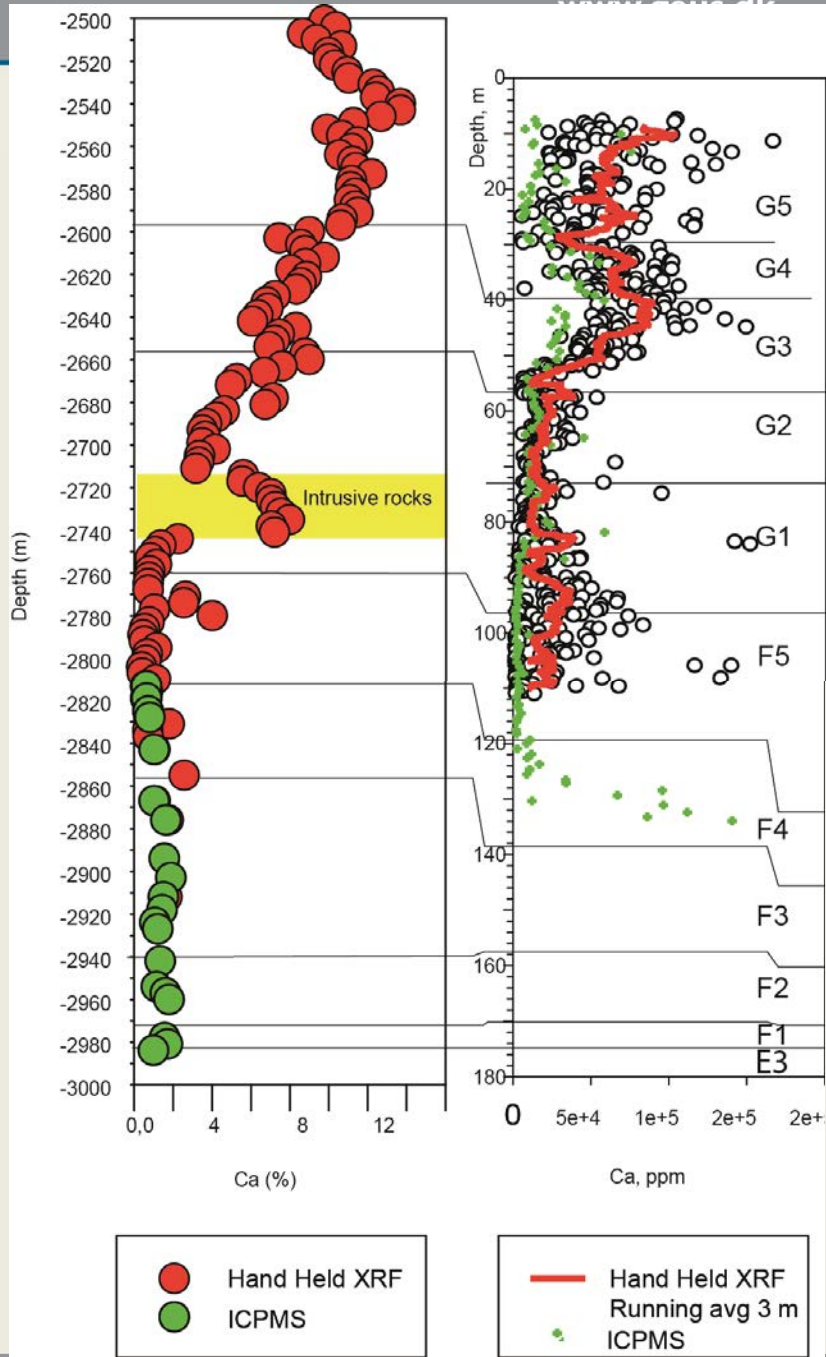
Recommendations

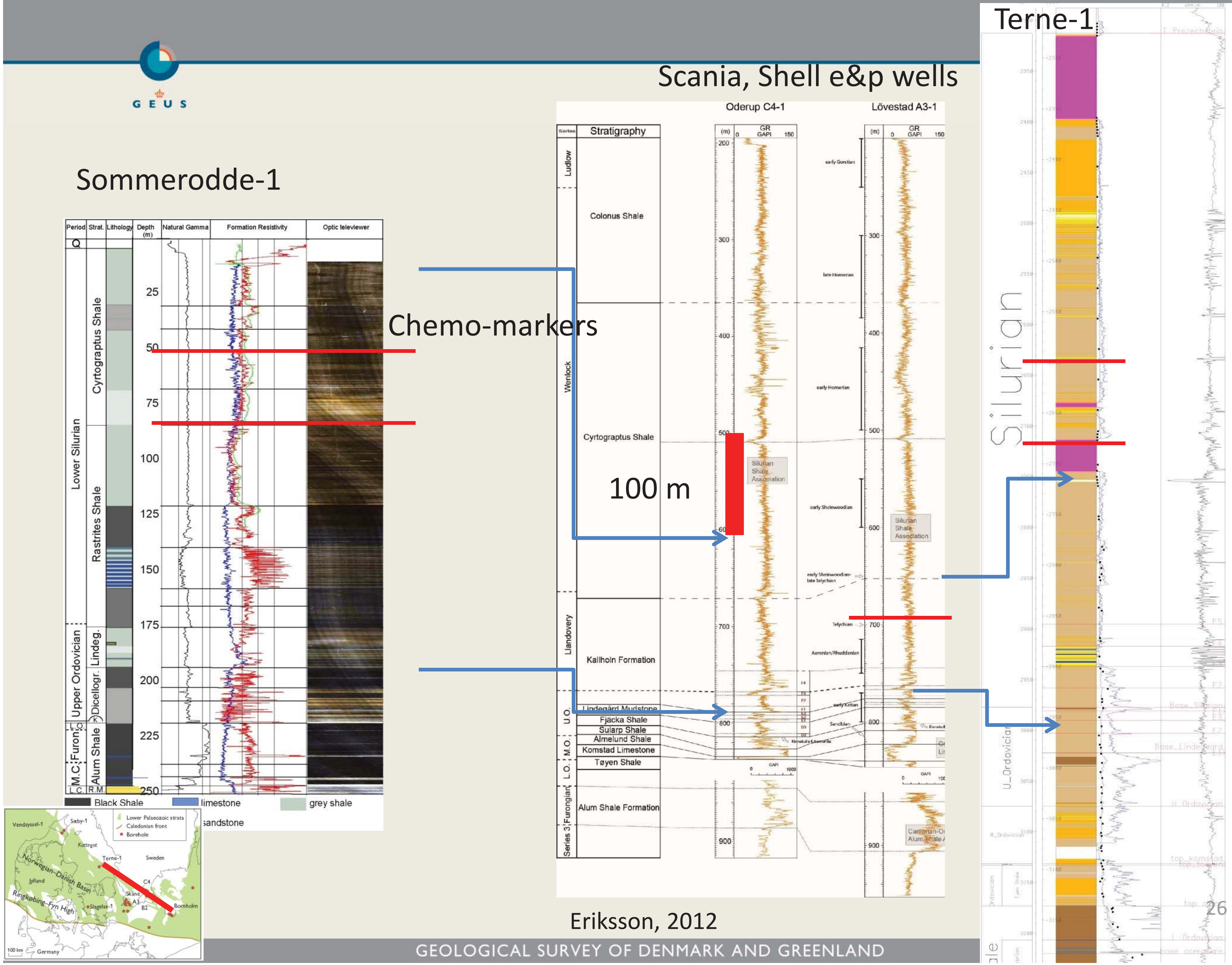
Two main rock types occur in the Rastrites and Cyrtograptus shales: A carbonate rich rock and a siliciclastic rick rock

The Rock types have been identified in Sommerodde-1, Terne-1 and Lovestad.

The Cyrtograptus shales is dominantly a carbonate rock type and the Silurian Shale is pre-dominatly a siliciclastic rich rock type

A chemostratigraphy based on this change in rock types are thus favoured




GEUS
Terne-1
Scania, Shell e&p wells
Sommerodde-1
Chemo-markers
100 m
Odderup C4-1
Lövestad A3-1
Stratigraphy
Ludlow
Wenlock
Landovery
Colonus Shale
Cyrtograptus Shale
Kallholn Formation
Lindegård Mudstone
Fjäcka Shale
Sularp Shale
Almelund Shale
Komstad Limestone
Tøyen Shale
Alum Shale Formation
Silurian Shale Association
Period
Strat.
Lithology
Depth (m)
Natural Gamma
Formation Resistivity
Optic televiewer
Lower Silurian
Upper Ordovician
Cyrtograptus Shale
Rastrites Shale
Alum Shale
Black Shale
limestone
grey shale
sandstone
Silurian
Norwegian-Danish Basin
Ringkøbing-Fyn High
Sweden
Germany
Bornholm
Terne-1
Eriksson, 2012

4. Comparison of XRF methods

GEUS

Comparison between XRF measurements made by Geolog International and GEUS on selected samples

PowerPoint is part of Engineering study between Total E&P and GEUS

Prepared by Niels Schovsbo

11th November 2014

GEUS

Outline

- Samples
- GEUS hand-held XRF procedure
  - Data
  - Standards and certified values
- Comparison of analytical results of 20 elements
- Summary
- Recommendations

GEOLOG international and GEUS analysis

- GEOLOG international measured 12 samples and reports concentrations on 25 elements
- GEUS analysed ha-XRF on representative sample splits
- GEUS analysis made in a similar manner routinely done: Samples crushed to rock powder, pressed to pellet form and analysed for 2 minutes

GEUS

Samples

- In Terne (cuttings) and Sommerodde (core):

6 samples each well:

- Samples selected to represent Alum shale (4 samples – one each rock type)
- Cyrtograptus shale (1 sample) and Rastrites shale (1 sample)

Well	Sample number	Depth top, m md	depth base,m md	remarks
Terne-1	2014027-25660	2600	2603	cuttings 1-4mm
Terne-1	2014027-25661	2798	2801	cuttings 1-4mm
Terne-1	2014027-25662	3194	3197	cuttings 1-4mm
Terne-1	2014027-25663	3218	3221	cuttings 1-4mm
Terne-1	2014027-25664	3254	3257	cuttings 1-4mm
Terne-1	2014027-25665	3302	3305	cuttings 1-4mm
Sommerodde-1	50,14	50,1	50,14	core
Sommerodde-1	84,64	84,6	84,64	core
Sommerodde-1	220,28		220,28	core
Sommerodde-1	228,15		228,15	core
Sommerodde-1	233,44		233,44	core
Sommerodde-1	245,4		245,4	core

GEUS

Geus hand –held XRF

Device: Nithon XL3 hand held XRF

- Usage of data at GEUS:
  - screening tool for core analysis. Reports 38 elements typical measured each 15 cm on a core
  - Focus detailed analysis by means of other analysis i.e. ICPMS analysis
  - define rock types by use of multivariate statistical methods (PCA, PLS)

ha_XRF #		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
SAMPLE #		50,1-50,14	84,6-84,64	220	228	233	245	2603	2801	3197	3221	3257	3305
WELL	unit	Sommerodde-1	Sommerodde-1	Sommerodde-1	Sommerodde-1	Sommerodde-1	Sommerodde-1	Terne-1	Terne-1	Terne-1	Terne-1	Terne-1	Terne-1
Ag	ppm	6	< LOD	7	< LOD	< LOD	< LOD	< LOD	< LOD	14	< LOD	< LOD	< LOD
Al	ppm	30766	34503	13000	31907	35068	44625	23258	31096	35734	25700	30306	29834
As	ppm	44	< LOD	58	148	520	54	15	16	50	41	34	52
Au	ppm	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Ba	ppm	< LOD	157	275	5808	6015	216	< LOD	300	1552	745	2307	1905
Bal	ppm	677902	709694	793546	637203	575002	651384	675972	#####	685242	694165	719052	699510
Bi	ppm	11	13	11	18	16	11	8	11	18	9	15	16
Ca	ppm	31034	6419	16712	13480	8232	2793	98161	3282	14298	58819	8520	22046
Cd	ppm	9	< LOD	< LOD	< LOD	< LOD	9	< LOD	< LOD	34	< LOD	< LOD	< LOD
Cl	ppm	< LOD	< LOD	188	154	210	< LOD	< LOD	< LOD	< LOD	376	947	578
Co	ppm	< LOD	< LOD	228	< LOD	< LOD	170	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Cr	ppm	153	94	116	122	158	98	113	102	203	109	135	133
Cs	ppm	< LOD	< LOD	< LOD	51	54	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Cu	ppm	43	46	186	175	144	87	32	37	150	115	146	202
Fe	ppm	54601	50627	34392	67467	105774	40651	37602	43194	34853	33434	23512	43297
K	ppm	24770	28713	26348	33865	29662	42031	22046	25568	31622	23292	32145	29425
Mg	ppm	< LOD	< LOD	< LOD	< LOD	< LOD	5083	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Mn	ppm	1388	932	283	447	321	345	294	332	373	1593	210	552
Mo	ppm	10	< LOD	75	214	132	36	6	4	27	51	55	67
Nb	ppm	12	12	17	25	19	15	12	10	19	13	22	19
Ni	ppm	54	66	135	165	343	76	26	33	119	57	49	65
P	ppm	< LOD	336	561	1532	< LOD	< LOD	< LOD	< LOD	847	< LOD	< LOD	396
Pb	ppm	73	7	30	32	44	119	29	19	103	70	40	137
Pd	ppm	5	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Rb	ppm	67	86	80	86	72	118	58	71	93	61	93	86
S	ppm	26757	1133	15962	56242	96649	24555	7111	6874	10129	21054	24371	18736
Sb	ppm	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	19	< LOD	< LOD	< LOD
Sc	ppm	61	< LOD	< LOD	< LOD	< LOD	< LOD	157	< LOD	52	117	< LOD	50
Se	ppm	< LOD	< LOD	5	8	< LOD	< LOD	< LOD	< LOD	23	3	< LOD	4
Si	ppm	147472	158849	92308	144118	135937	180015	126655	#####	175337	134795	149647	146047
Sn	ppm	< LOD	14	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Sr	ppm	87	70	61	111	72	53	351	66	134	286	133	166
Ta	ppm	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Te	ppm	< LOD	< LOD	< LOD	57	91	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Th	ppm	10	14	14	17	16	13	10	10	18	10	14	17
Ti	ppm	4479	5341	4555	4483	3862	5843	3561	4653	5271	3775	5429	5158
U	ppm	< LOD	< LOD	58	96	95	24	< LOD	< LOD	43	54	85	42
V	ppm	194	223	1213	714	1525	544	114	188	3114	897	1037	1207
Zn	ppm	250	68	107	37	100	1121	59	76	633	132	191	254
Zr	ppm	156	170	139	163	108	173	146	127	149	80	153	153

GEUS Standards

- Certified standard material analysed in each run to monitor XRF apparatus functionality and data consistency through time

- Standards not used to correct measurements to certified values instead apparatus reported measurements are used using standard settings

ha_XRF #		2033	2175	2200	2201	2202	2203	2204
SAMPLE #		nist	nist	nist	QC	RCRApp	SiO2	CCRMP
WELL	unit	STANDARD	STANDARD	STANDARD	STANDARD	STANDARD	STANDARD	STANDARD
Ag	ppm	< LOD	< LOD	< LOD	< LOD	468	< LOD	< LOD
Al	ppm	46451	42496	46152	47198	37322	2187	50049
As	ppm	11	9	10	42	428	< LOD	100
Au	ppm	< LOD	6	< LOD	< LOD	30	< LOD	12
Ba	ppm	733	760	708	725	660	80	397
Bal	ppm	638939	654418	636430	574961	637820	635245	621407
Bi	ppm	11	7	8	24	11	< LOD	55
Ca	ppm	23066	22903	25235	7829	10389	2397	11757
Cd	ppm	< LOD	< LOD	< LOD	< LOD	449	< LOD	< LOD
Cl	ppm	182	152	91	93	< LOD	458	< LOD
Co	ppm	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Cr	ppm	118	106	113	101	575	13	77
Cs	ppm	36	40	36	43	26	18	35
Cu	ppm	24	31	38	273	17	14	235
Fe	ppm	34509	33721	33241	30779	18165	121	39273
K	ppm	17565	16915	16663	26212	12637	435	22986
Mg	ppm	9149	4754	6338	4015	< LOD	2064	< LOD
Mn	ppm	495	480	482	4175	174	63	484
Mo	ppm	< LOD	< LOD	< LOD	13	< LOD	< LOD	16
Nb	ppm	8	7	7	32	11	< LOD	14
Ni	ppm	92	83	81	70	56	24	65
P	ppm	566	686	860	959	< LOD	< LOD	1193
Pb	ppm	16	18	15	1025	516	< LOD	51
Pd	ppm	< LOD	< LOD	< LOD	< LOD	24	< LOD	< LOD
Rb	ppm	49	46	47	75	33	< LOD	87
S	ppm	1621	1414	1625	3133	974	751	1951
Sb	ppm	13	18	10	23	< LOD	9	10
Sc	ppm	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Se	ppm	< LOD	< LOD	< LOD	< LOD	465	< LOD	4
Si	ppm	222513	217254	228139	290513	275925	356427	244619
Sn	ppm	< LOD	8	< LOD	13	< LOD	< LOD	10
Sr	ppm	216	212	211	143	74	< LOD	110
Ta	ppm	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Te	ppm	49	61	45	59	31	36	39
Th	ppm	11	9	10	30	16	< LOD	47
Ti	ppm	3958	3577	3711	4001	3699	< LOD	4964
U	ppm	< LOD	< LOD	9	< LOD	< LOD	< LOD	13
V	ppm	156	167	148	122	158	< LOD	154
Zn	ppm	87	92	74	828	40	< LOD	58
Zr	ppm	165	162	172	460	325	< LOD	370

GEUS

Certified analysis

Thermo Scientific Niton XRF Analyzers

CERTIFICATE OF ANALYSIS

Key to Energy Values: Ag (K_α, K_β, L_α, L_β)

Standard Reference Material — 2709a

Part Number: 180-469a

Element	Mass Fraction (%)		
Al	7.37	±	0.16
Ca	1.91	±	0.09
Fe	3.36	±	0.07
Mg	1.46	±	0.02
P	0.0688	±	0.0013
K	2.11	±	0.06
Si	30.3	±	0.4
Na	1.22	±	0.03
Ti	0.336	±	0.007

Element	Mass Fraction (mg/kg)		
Sb	1.55	±	0.06
Ba	979	±	28
Cd	0.371	±	0.002
Cr	130	±	9
Co	12.8	±	0.2
Pb	17.3	±	0.1
Mn	529	±	18
Sr	239	±	6
V	110	±	11
Zr	195	±	46

Element	Mass Fraction (mg/kg)		
As	10.5	±	0.3
Ce	42	±	1
Cs	5.0	±	0.1
Cu	33.9	±	0.5
Eu	0.83	±	0.02
Gd	3.0	±	0.1
La	21.7	±	0.4

Element	Mass Fraction (mg/kg)		
Hg	0.9	±	0.2
Ni	85	±	2
Rb	99	±	3
Sc	11.1	±	0.1
Tl	0.58	±	0.01
Th	10.9	±	0.2
U	3.15	±	0.05
Zn	103	±	4

Standard Reference Material — Silicon Oxide

Part Number: 180-472

Silicon (IV) Oxide	99.8%

Standard Reference Material — RCRA STD

Part Number: 180-436

Parameter	Certified Value (mg/kg)[1]	NIST SRM Number	Traceability Recovery
As	500	3103	99.7
Ba	630	NA[2]	
Cd	500	3108	100
Cr	500	3112	97.6
Pb	500	3128	99.6
Se	500	3149	98.5
Ag	500	3151	101

[1] Based on the actual 'made to' values for each element

[2] Soil background only, no analyte was added

■ Requires GOLDD technology for metal alloys

■ Requires GOLDD technology for mining & minerals mode

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Thermo SCIENTIFIC
Part of Thermo Fisher Scientific

1-204 11/2010

Thermo Scientific Niton XRF

CERTIFICATE OF ANALYSIS

Standard Reference Material Till-4

(mg/kg)-except as noted

Part Number: 108-601

As	111
Au (ppb)	5
Ba	395
Be	3.7
Bi	40
Br	8.6
Ce	78
Co	8
Cr	53
Cs	12
Cu	237
Eu	<1.0
Er	3.2
Fe (%)	3.97
Hf	10
La	41
Li	30
LOI (500°C) %	4.4
Lu	0.5
Mn	490
Mo	16

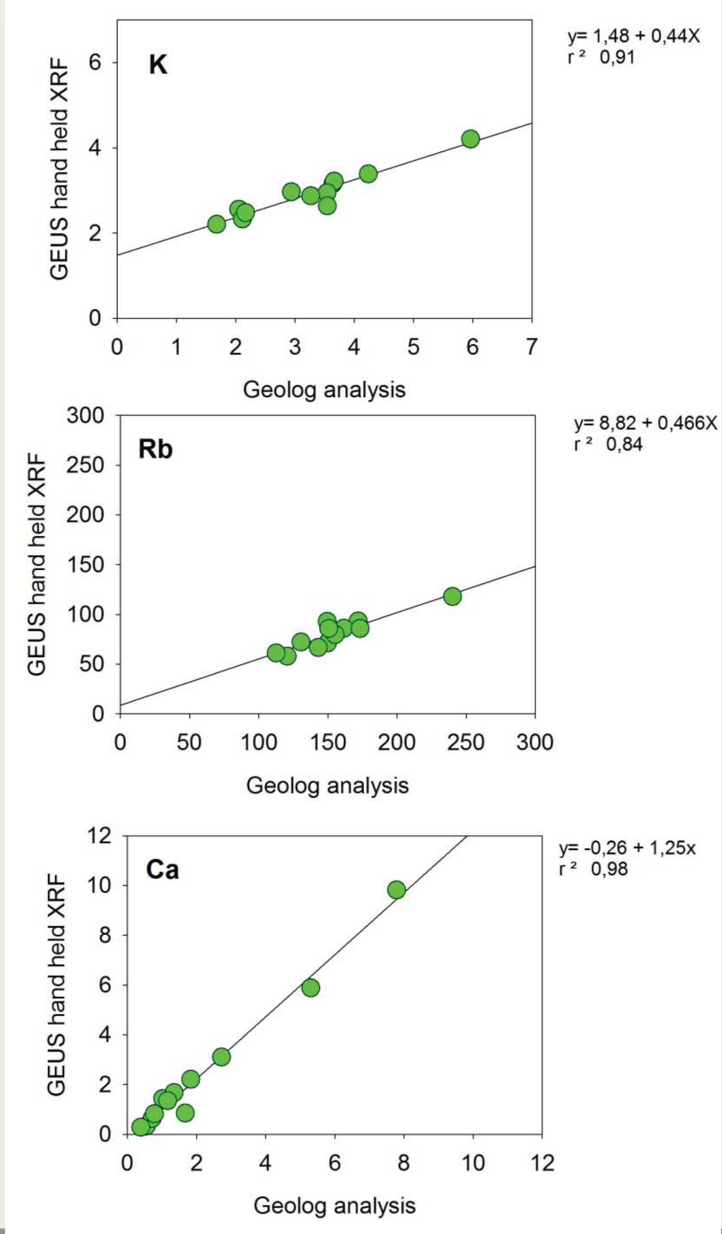
Nb	15
Nd	30
Ni	17
P	880
Pb	50
Rb	161
S (%)	0.08
Sb	1.0
Sc	10
Sm	6.1
Sr	109
Ta	1.6
Tb	1.1
Th	17.4
Ti	4840
U	5.0
V	67
W	204
Y	33
Yb	3.4
Zn	70
Zr	385

GEUS

K, Rb, Ca

- **Comparison between laboratories**

- For all elements strong correlations exist: r^2 0.84-0.96
- Slope is 1.3 for Ca and about 0.5 for K and Rb suggesting that GEUS reports lower concentrations than GEOLOG for these elements

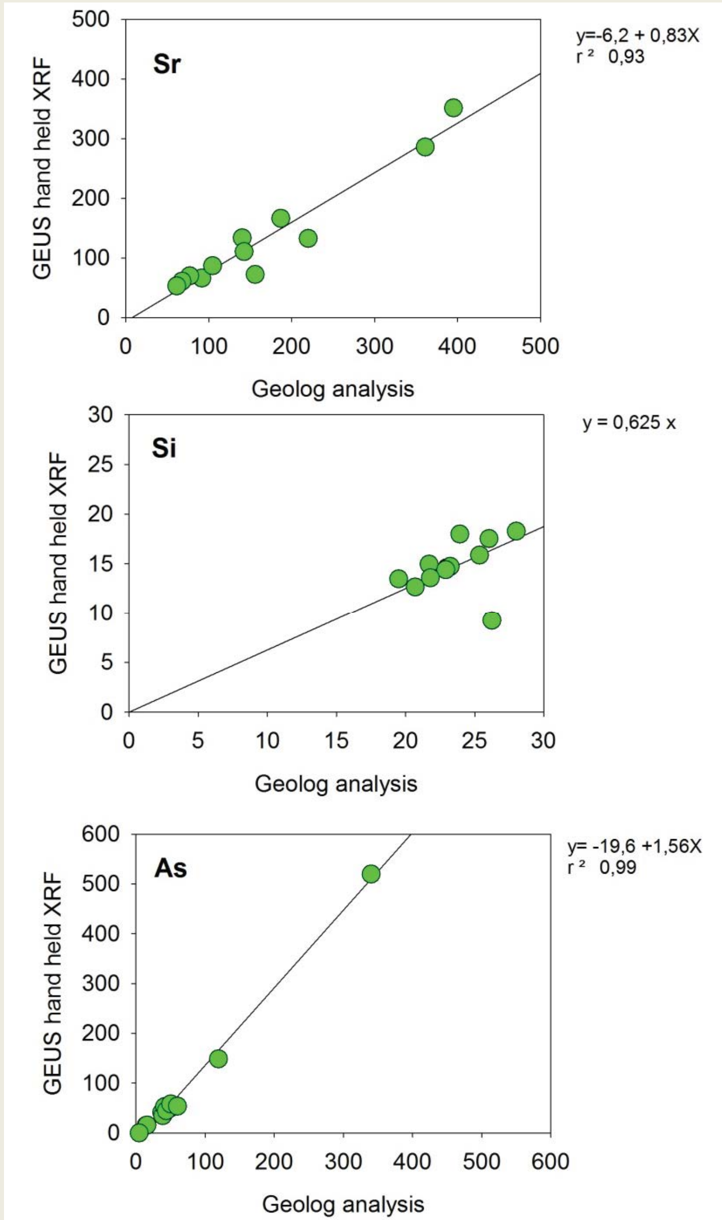


GEUS

Sr, Si, As

- **Comparison between laboratories**

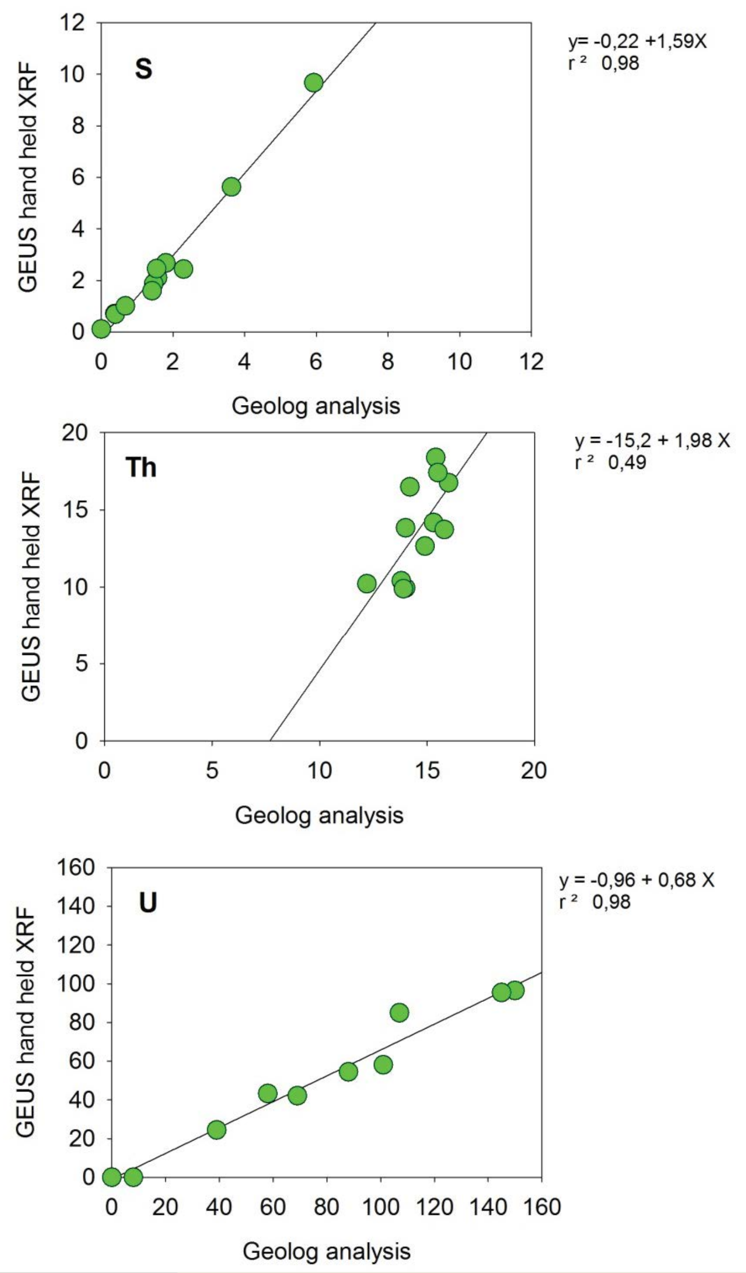
- For all elements strong correlations exist: r^2 0.93-0.99.
- For Si the range in values are too limited to define a regression line
- Slope is 1.6 for As and about 0.6 for Si suggesting that GEUS reports lower concentrations than GEOLOG for Si



S, Th, U

- **Comparison between laboratories**

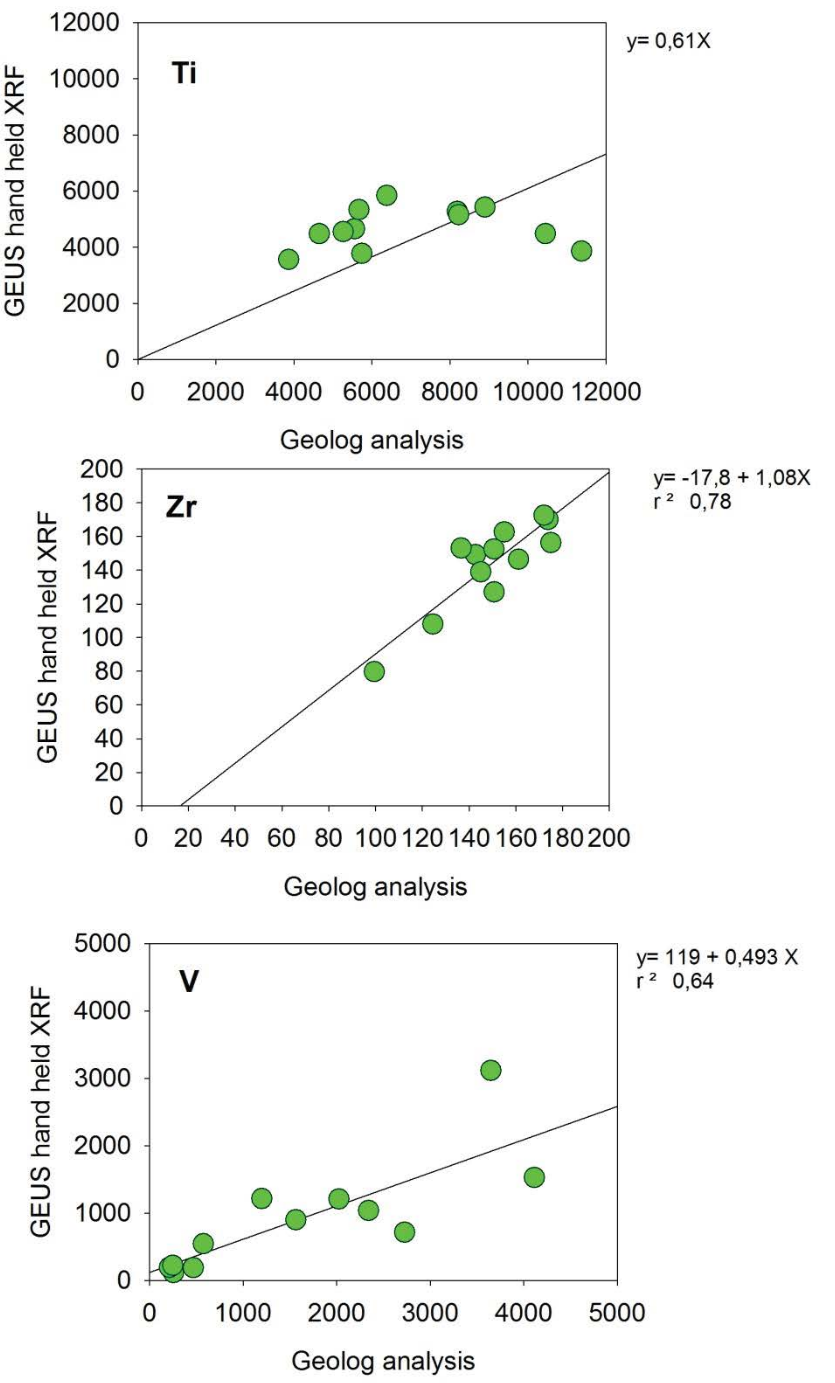
- For S and U strong correlations exist: r^2 0.96-0.99.
- For Th the range in values are too limited to define a good regression line
- Slope is 1.6 for S and about 0.7 for U suggesting that GEUS reports lower concentrations than GEOLOG for U



Ti, Zr, V

- **Comparison between laboratories**

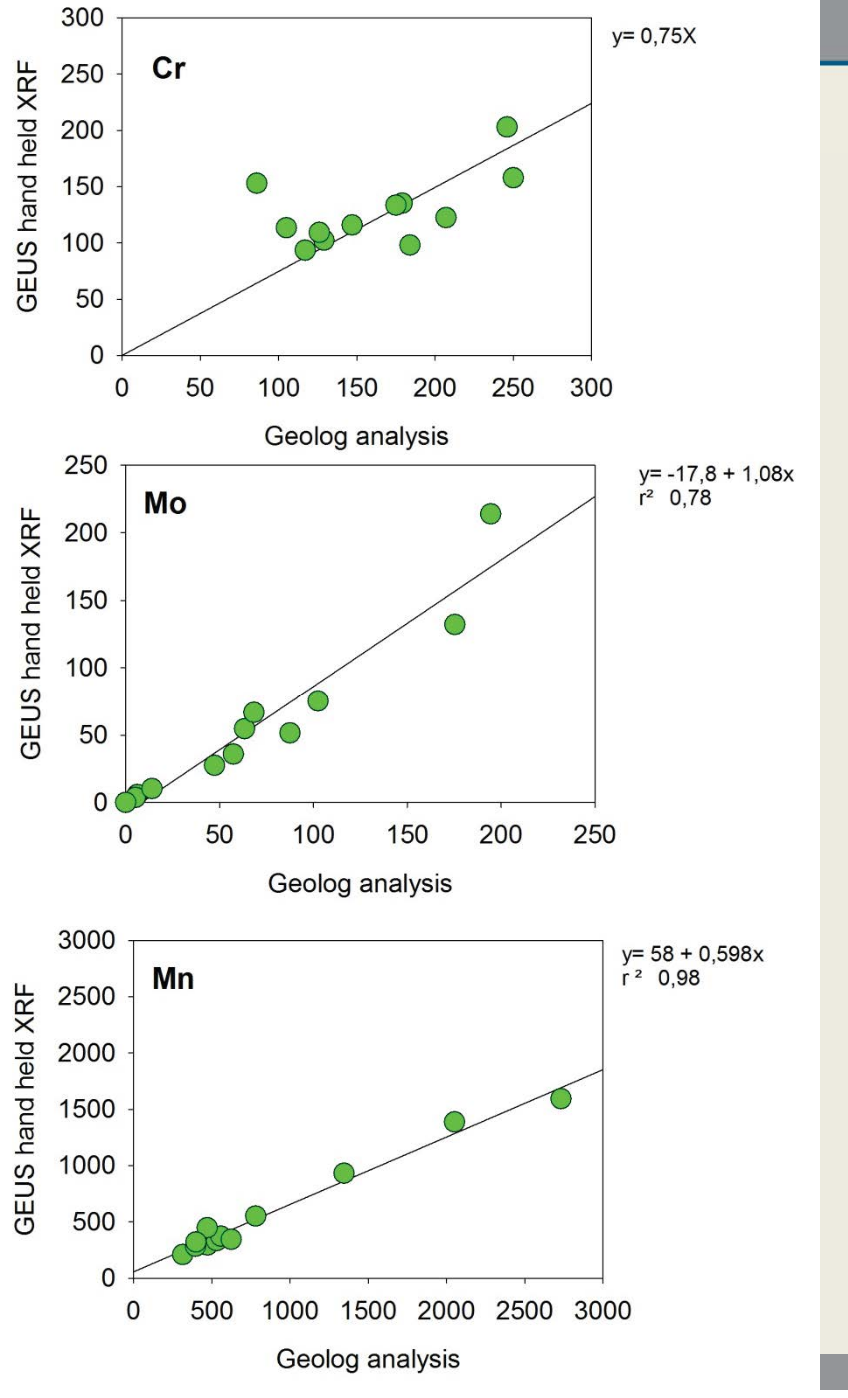
- For the elements less strong correlations exist than is typical seen: r^2 0.64-0.78.
- For Ti no correlation exist
- Slope is 1.1 for Zr and about 0.5 for V suggesting that GEUS reports lower concentrations than GEOLOG



Cr, Mo, Mn

- **Comparison between laboratories**

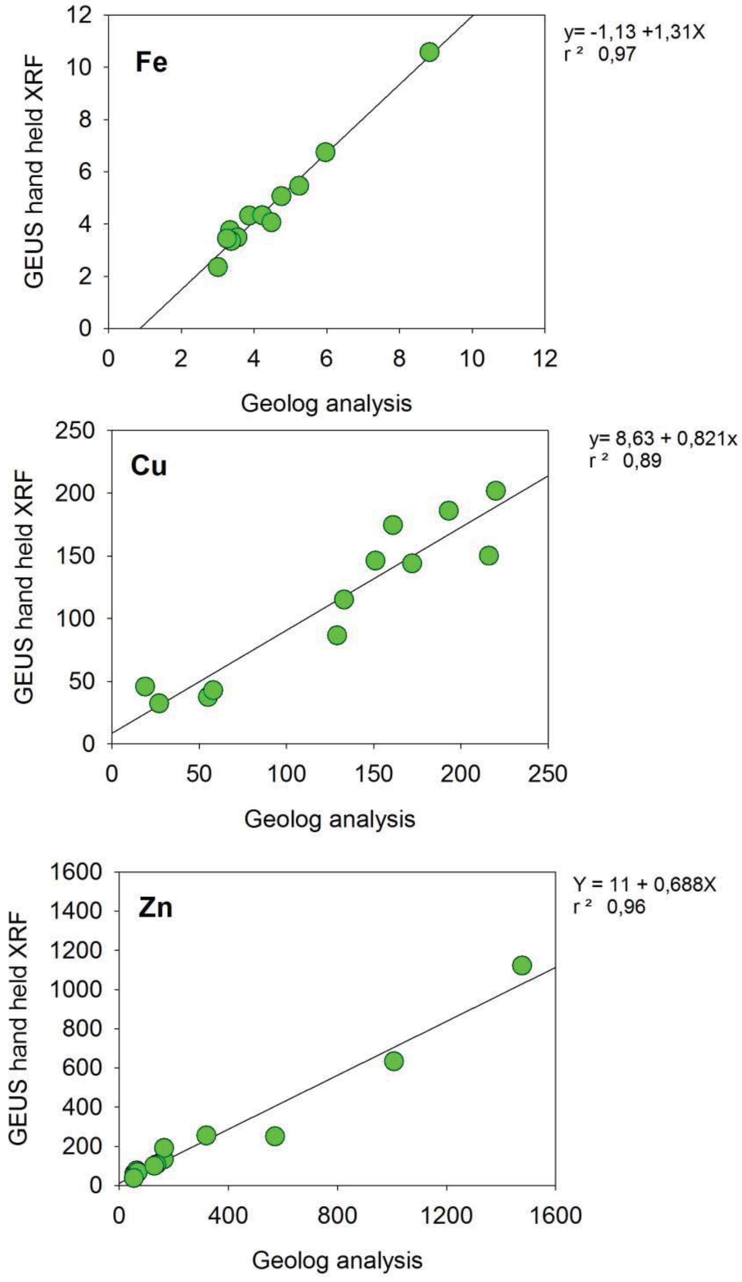
- For all elements strong correlations exist: r^2 0.78-0.98. For Cr no correlation exist
- Slope is 1.1 for Mo and about 0.6 for Mn suggesting that GEUS reports lower concentrations than GEOLOG for Mn



Fe, Cu, Zn

- **Comparison between laboratories**

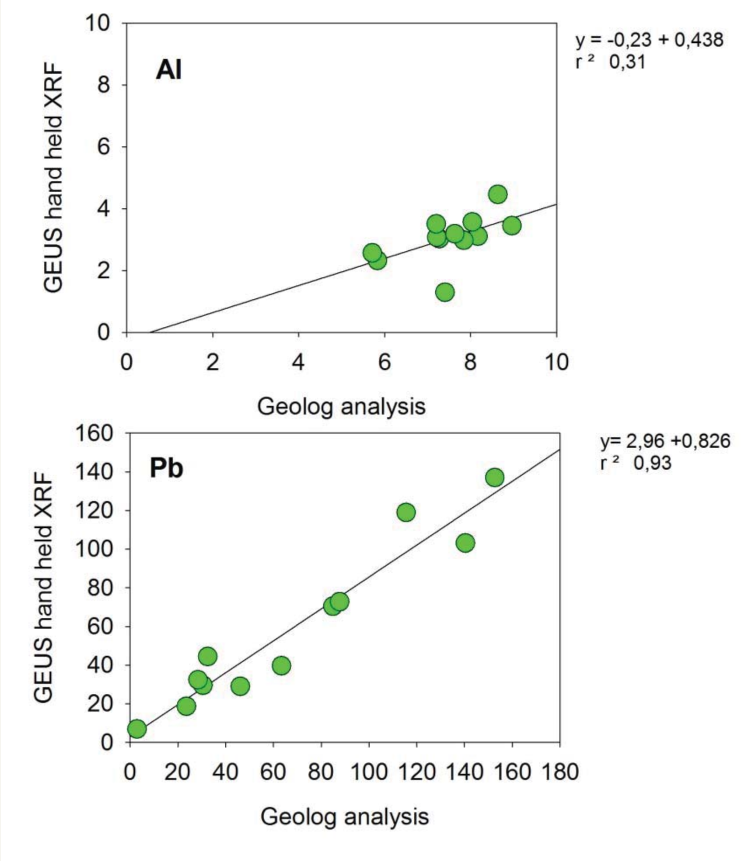
- For all elements strong correlations exist: r^2 0.89-0.97.
- Slope is 1.3 for Fe and about 0.7 for Zn suggesting that GEUS reports lower concentrations than GEOLOG for Zn



Al, Pb

- **Comparison between laboratories**

- For Pb a strong correlations exist: r^2 0.93. For Al the correlation is less strong.
- Slope is 0.8 for Pb and about 0.4 for Al suggesting that GEUS reports lower concentrations than GEOLOG for Al.



GEUS

Summary

- There is general very strong correlation ($r^2>0.90$ for most elements) between elements measured by Geolog Int and GEUS
- Compared with certified concentrations the measurements made by Geolog Int. is judge to be most accurate
- There is a significant difference in slope (1.3-0.5) between elements despite the very strong correlation
- No difference in analytical quality is seen between samples from Terne-1 (cuttings) or Sommerodde (core) or between Alum Shale (High TOC) and Silurian shales (low TOC)

Element	F (Geolog=GEUSxF)
K	1,180
Rb*	1,936
Mg	n.d.
Ca	0,839
Sr*	1,208
Si	1,478
As*	0,931
P*	n.d.
S	0,656
Cl	n.d.
Th*	1,065
U*	1,519
Ti*	1,544
Zr*	1,065
V*	1,859
Cr*	1,095
Mo*	1,142
Mn*	1,525
Fe	0,933
Co*	n.d.
Ni*	n.d.
Cu*	1,118
Zn*	1,424
Al	2,239
Pb*	1,011

Green: slope near identical. Blue >1.2 Red <0.8

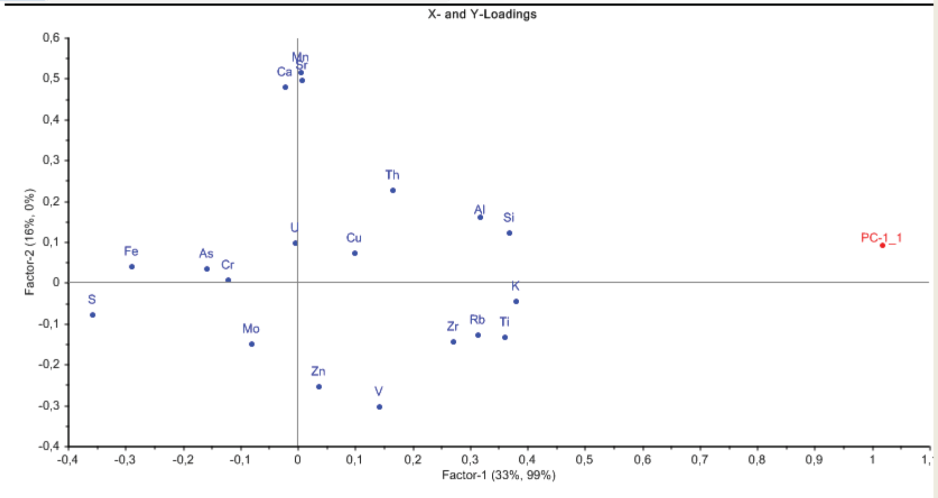
GEUS

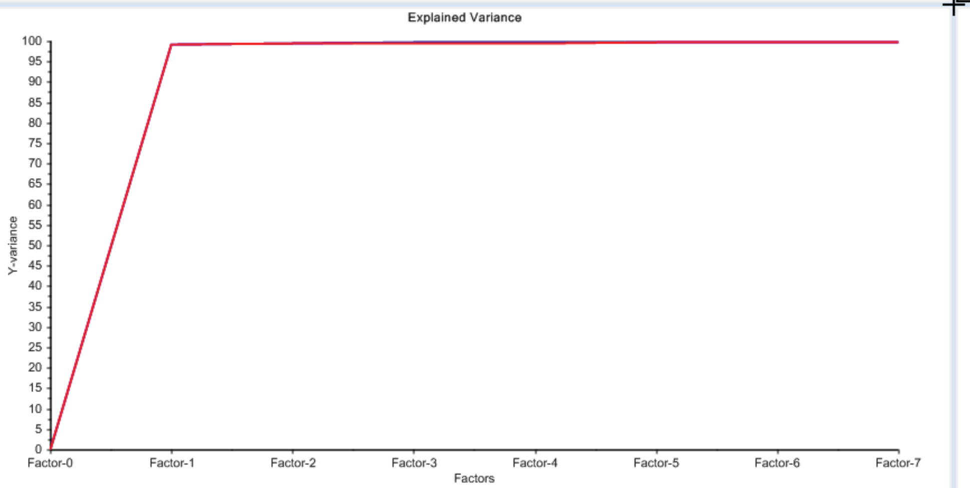
Recommendations

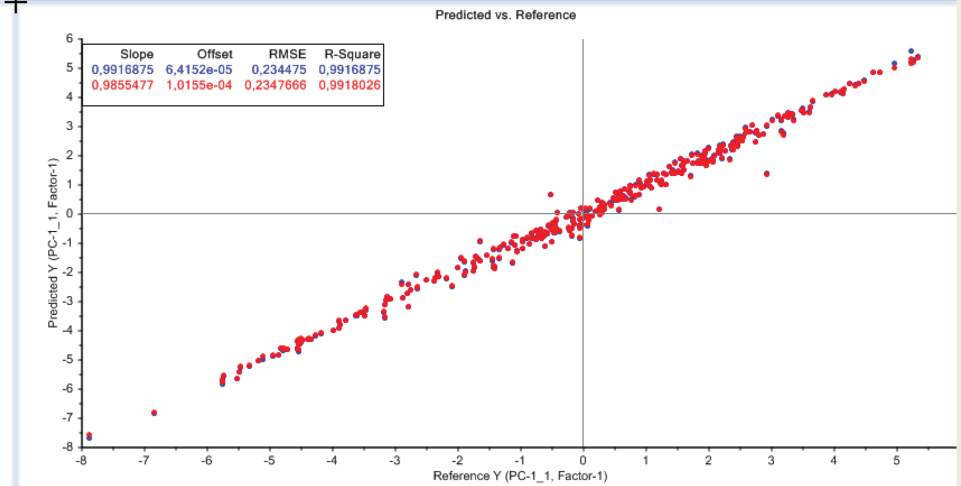
- The combination of very high statistical correlation but highly variable slopes between the two laboratories points to a situation where both laboratories produces highly precise data.
- Comparison with certified sample material suggest that the measurements made by Geolog Int. is most accurate it is recommended that GEUS hand-held XRF data is recalibrated using existing certified values in order to provide guide-line (cuff-off) for use of GEOLOG Int at well site
- The calibration does not affect the statistical interpretation of elements associations since these are made on mean standardised data. Since Geolog measures fewer elements than it is recommended to re-running PCA models with a reduced matrix

Rock Typing in the Alum Shale

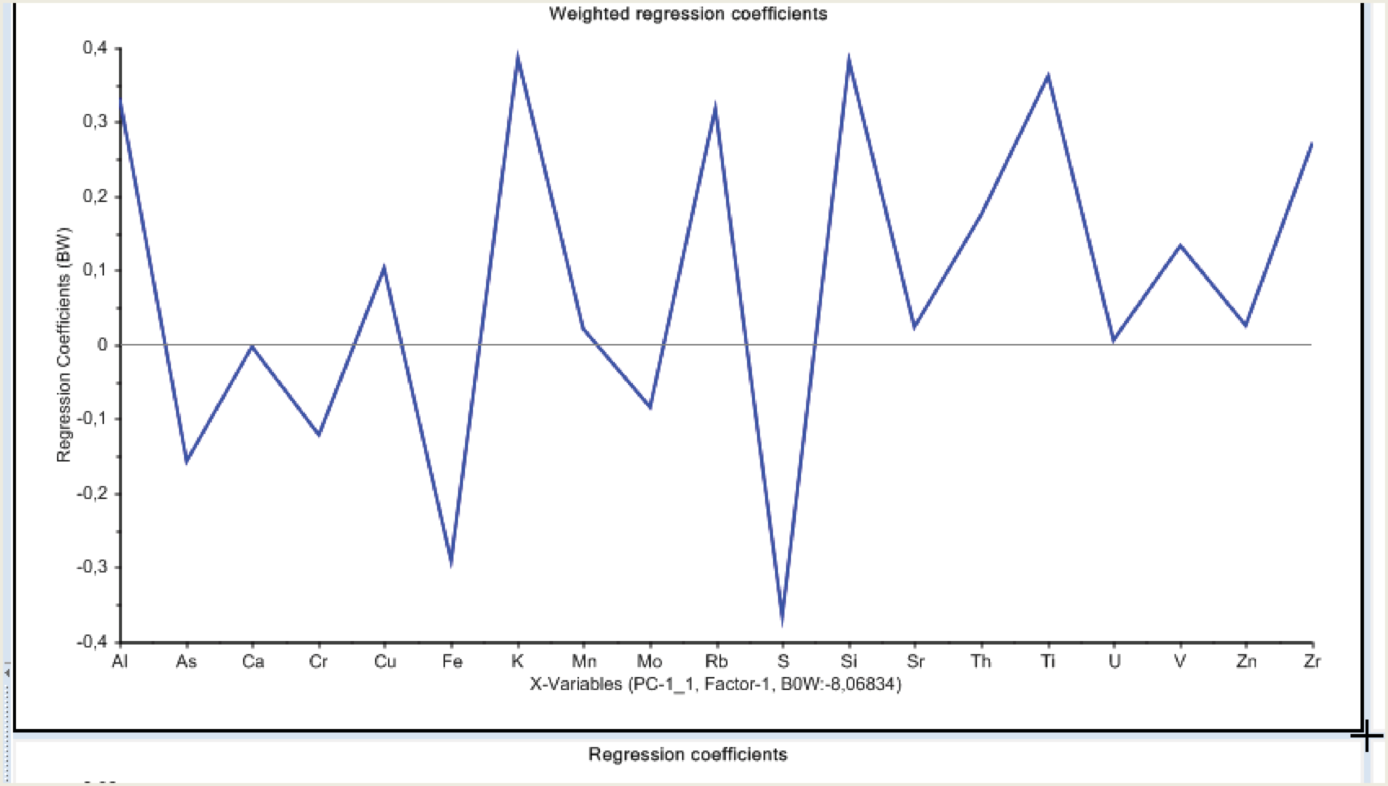
We can perfectly predict the results of the original PCA that defined the rock types based on the elements that GEOLOG measures at drill site







GEUS



Coefficients. Most important for rock type definitions in the Alum Shale: Elements associated with pyrite (Fe, S, As) vs elements associated with siliciclastic's (K, Rb, Si, Ti)

5. Geological analysis Fjerritslev Fm

Fjerritslev samples

Inventory and recommendations

Niels Schovsbo

- Prepared to Total E&P 21 October 2014

G E U S

Litterature:

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/128

Source rock evaluation of the Danish Basin and Fennoscandian Border Zone

EFP-2000; ENS J.nr. 1313/00-0005

Jørgen A. Bojesen-Koefoed and Henrik I. Petersen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

G E U S

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND BULLETIN 16 · 2008

Evaluation of the quality, thermal maturity and distribution of potential source rocks in the Danish part of the Norwegian–Danish Basin

Henrik I. Petersen, Lars H. Nielsen,
Jørgen A. Bojesen-Koefoed, Anders Mathiesen,
Lars Kristensen and Finn Dalhoff

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

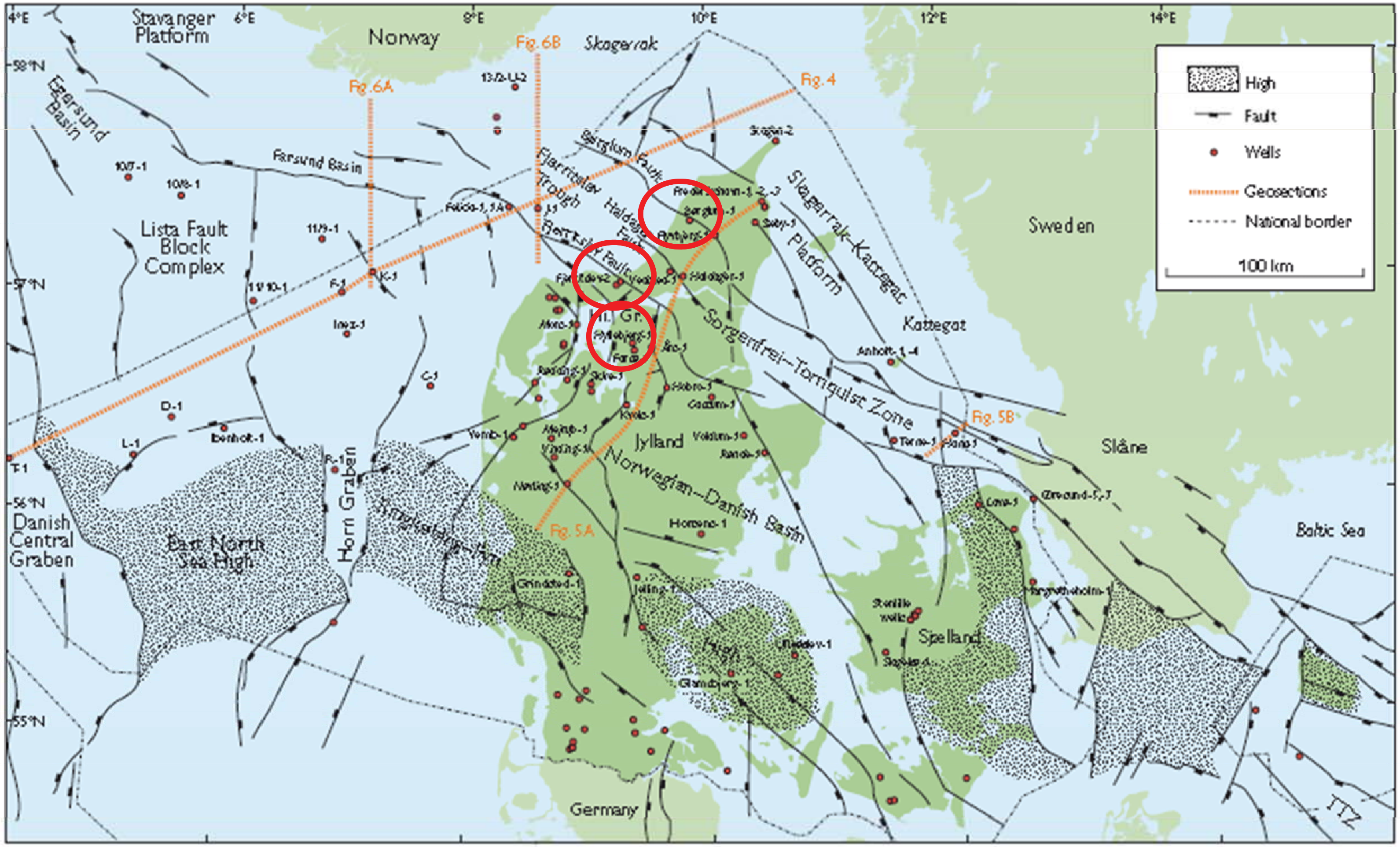
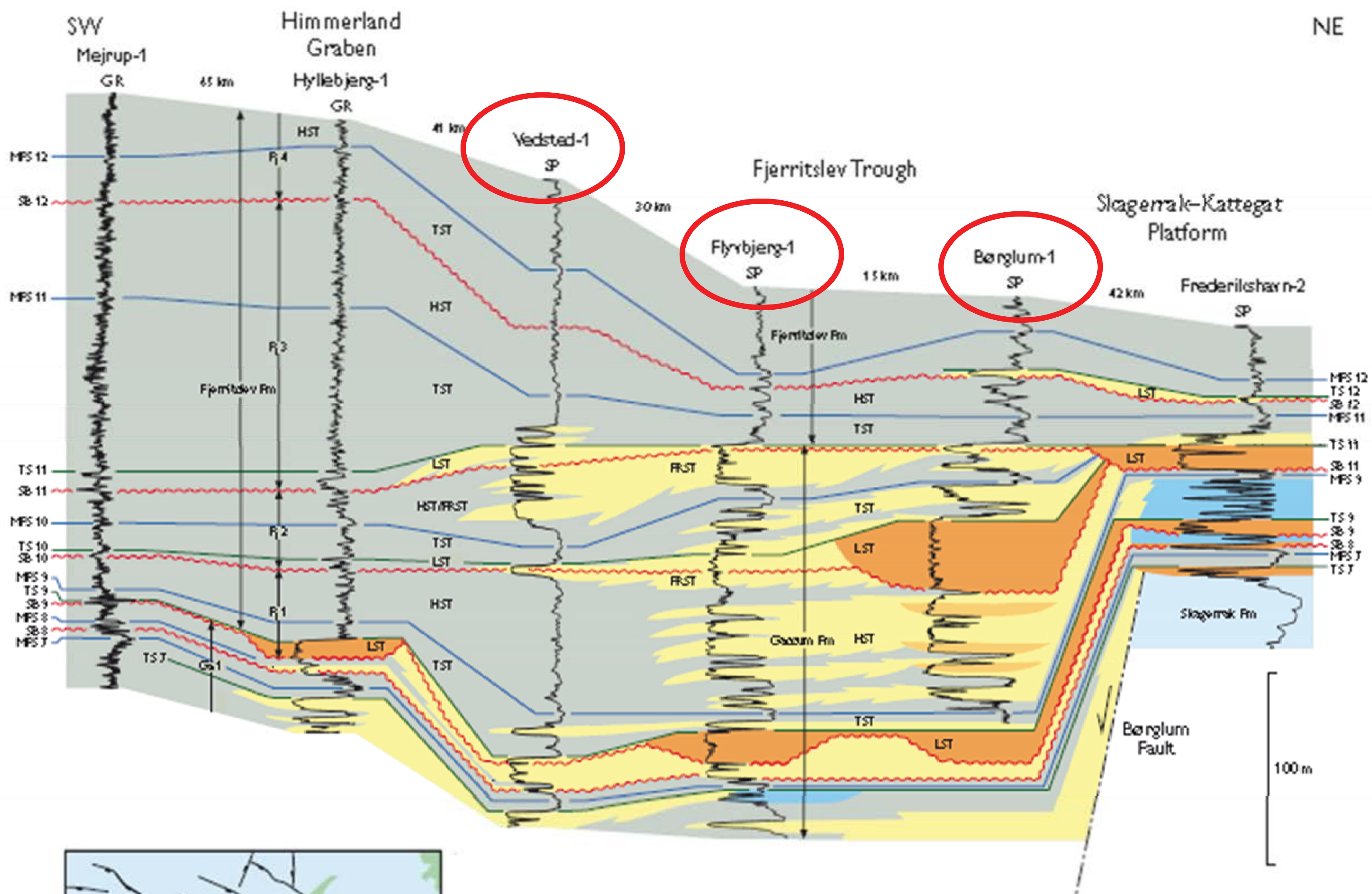


Fig. 1. Map showing well positions and the structural outline of the Norwegian–Danish Basin, the Sorgenfrei–Tornquist Zone, including the Fjerritslev Trough and the Himmerland Graben (Hi. Gr.), and the Skagerrak–Kattegat Platform. The major fault systems indicated are those active in the Mesozoic (cf. Figs 2, 3). Positions of geosections displayed in Figs 4–6 are also shown. Named wells are discussed in the text or used in log-panels; unnamed wells are indicated to illustrate the deep wells used in map compilation (e.g. Fig. 15). Assessment of the source-rock potential is based on data from wells indicated in italics. TTZ, Teisseyre–Tornquist Zone.



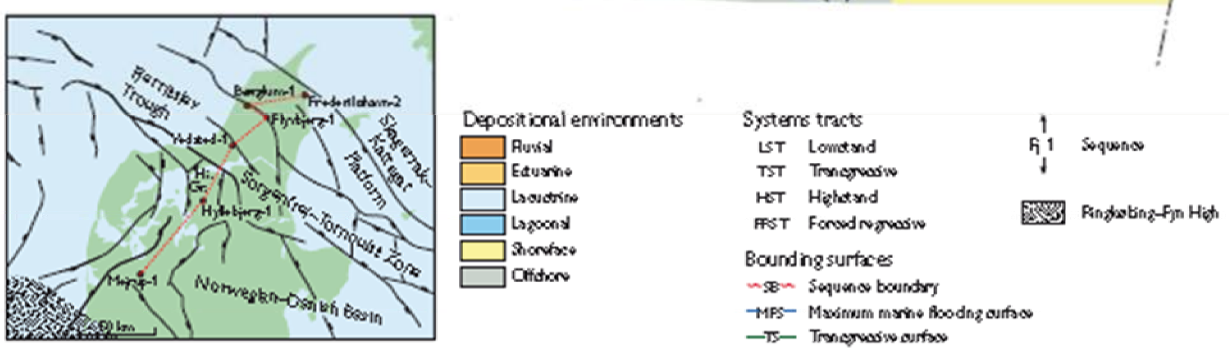


Fig. 11. Well-log panel trending SW–NE across the Norwegian–Danish Basin (see inset map; Hi. Gr., Himmerland Graben) showing the Rhaetian–Sinemurian depositional environments of the upper Gassum and lower Fjerritslev Formations. Modified from Nielsen (2003).

Børglum-1

Børglum-1				
Stratigraphy (b.rfl)	Rfl:	74	feet a. msl	
	Top (feet)	Top (m)	b. msl (m)	Thk (m)
L. Cretaceous	1551	473	450	283
Frederikshavn Fm.	2479	756	733	224
Børglum Fm.	3213	979	957	34
Flyvbjerg Fm.	3323	1013	990	34
Haldager sand Fm.	3435	1047	1024	29
Fjerritslev Fm. F-IV	3529	1076	1053	109
Fjerritslev Fm. F-III	3887	1185	1162	101
Fjerritslev Fm. F-II	4217	1285	1263	60
Fjerritslev Fm. F-I	4414	1345	1323	11
Gassum Fm.	4449	1356	1334	171
TD	5010	1527	1504	

Top	Bottom	Unit
ft. below ref. level		
11	388	Quaternary
388	2478	Cretaceous
2478	4655	Jurassic
4655	5010	Triassic

Samples

Cores

core	top	bottom	recovery
no.	ft. below ref. level		
1	1587.00	1607.00	73.5
2	1800.00	1820.00	100.0
3	2018.00	2038.00	94.5
4	2260.00	2280.00	65.0
5	2505.00	2525.00	70.0
6	2750.00	2770.00	80.0
7	3000.00	3010.00	60.0
8	3235.00	3255.00	70.0
9	3361.00	3370.00	20.0
10	3370.00	3380.00	14.0
11	3423.00	3433.00	32.0
12	3433.00	3439.00	80.0
13	3655.00	3675.00	92.5
14	3874.00	3884.00	67.0
15	4095.00	4105.00	75.0
16	4294.00	4314.00	48.0
17	4494.00	4513.00	85.0
18	4697.00	4717.00	90.0
19	4798.00	4815.00	35.0
20	4898.00	4918.00	100.0
21	5000.00	5010.00	100.0

Cuttings

from	to	distance
ft. below ref. level.		bt. cuttings
10.00	605.00	15.00
605.00	1115.00	5.00
1115.00	1250.00	15.00
1250.00	4990.00	5.00

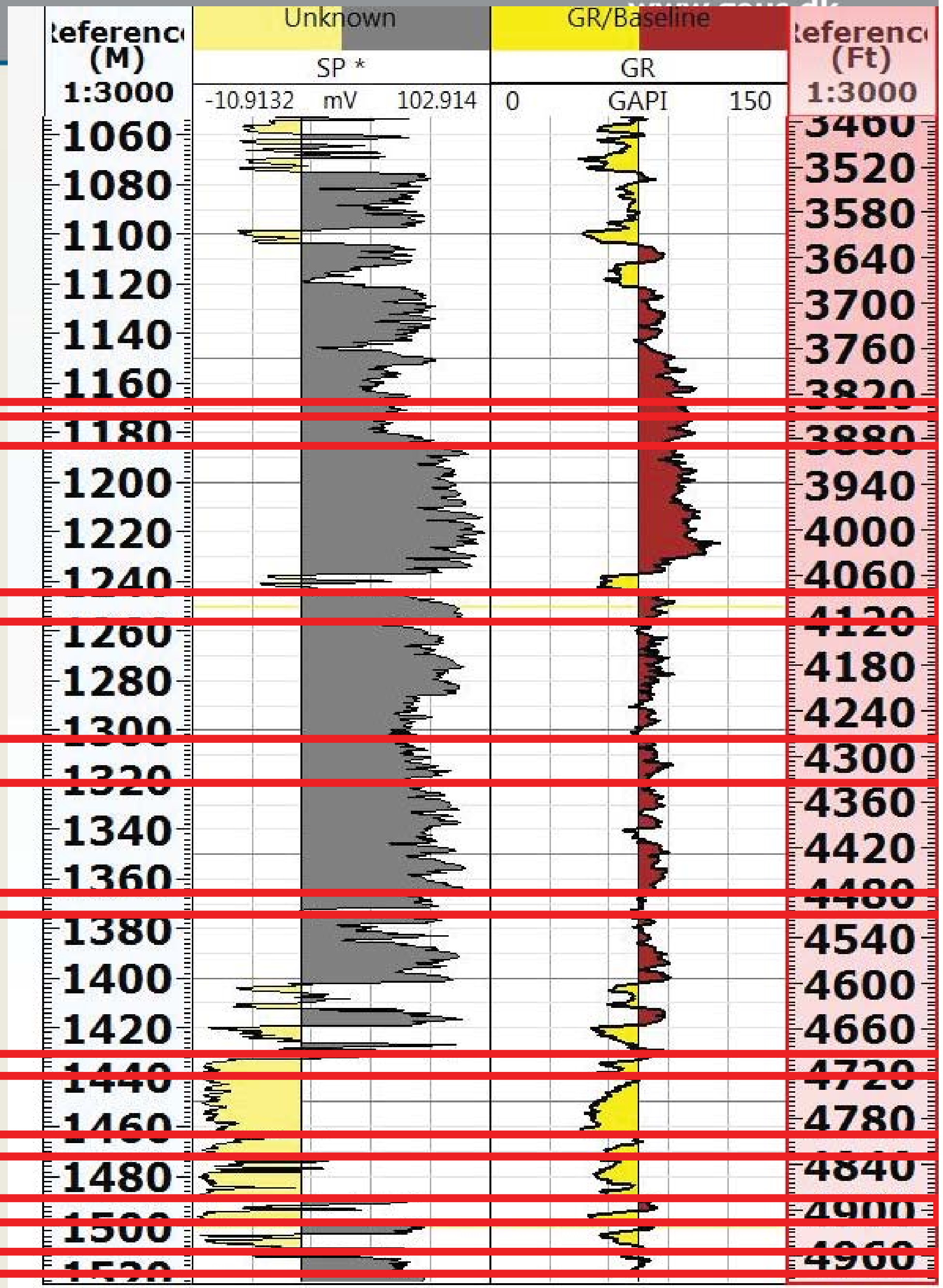
Samples from core 14 to 16 will provide good coverage of Fjerritslev

Børglum-1

Fjerritslev

Sample unit Fj1 to Fj3
Propose 3 samples:
core 14, 17, 21

Core 13
Core 14
Core 15
Core 16
Core 17
Core 18
Core 19
Core 20
Core 21



GEUS

Flyvbjerg

Flyvbjerg-1

Stratigraphy (b.rfl)	Rfl:	155,5	feet a. msl	
	Top (feet)	Top (m)	B.msl (m)	Thk (m)
L. Cretaceous	1716	523	476	227
Frederikshavn Fm.	2461	750	703	171
Børglum Fm.	3022	921	874	29
Flyvbjerg Fm.	3117	950	903	40
Haldager sand Fm.	3248	990	943	54
Fjerritslev Fm. F-IV	3425	1044	997	52
Fjerritslev Fm. F-III	3596	1096	1049	89
Fjerritslev Fm. F-II	3888	1185	1138	86
Fjerritslev Fm. F-I	4170	1271	1224	37
Gassum Fm.	4291	1308	1261	196
Skagerrak Fm.	4934	1504	1456	195
TD	5574	1699	1652	

Samples from core 4 and 5 will provide Fjerritslev

Casing

top depth		shoe depth		diameter	
ft.	m.	ft.	m.	inch	inch (decim)
0.0	0.0	40.4	12.3	18"	18.000
0.0	0.0	580.7	177.0	13 3/8"	13.375

Lithostratigraphy (Groups)

Top	Bottom	Unit
m. below ref. level.		
3.4	148.4	Post Chalk Group
148.4	523.4	Chalk Group
523.4	750.4	L. Cretaceous units
750.4	1504.0	Jurassic units
1504.0	1698.4	Triassic units

Chronostratigraphy (Periods)

Top	Bottom	Unit
m. below ref. level.		
3	148	Quaternary
148	780	Cretaceous
780	1483	Jurassic
1483	1698	Triassic

Samples

Cores

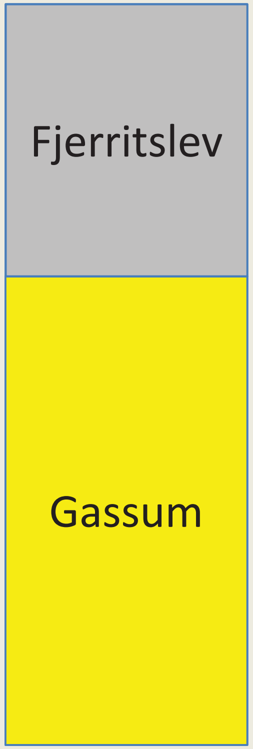
core	top	bottom	recovery
no.	m. below ref. level		
1	804.00	810.00	100.0
2	879.00	885.00	61.5
3	979.00	985.00	79.0
4	1116.00	1122.00	26.0
5	1190.00	1193.80	92.0
6	1316.00	1322.00	100.0
7	1396.00	1402.00	77.0
8	1483.00	1489.00	100.0
9	1550.00	1553.00	32.0
10	1696.00	1698.00	55.0

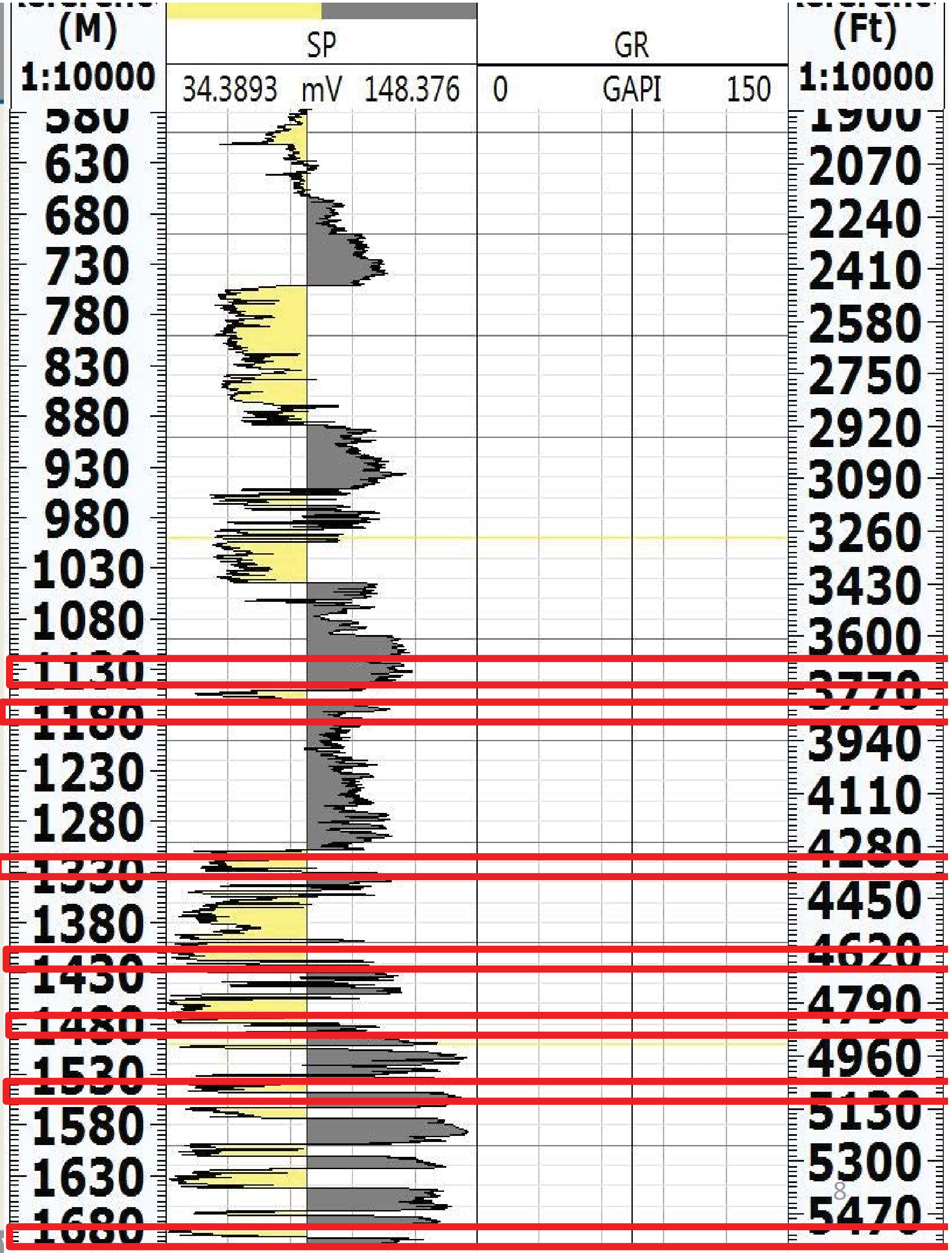
Cuttings

from	to	distance
m. below ref. level		bt. cuttings
23.00	1698.00	5.00

Flyvbjerg

Propose 2 samples:
core 4, 9/10 (Clay rich Gassum)





Vedsted

Vedsted-1

Stratigraphy (b.rfl)	Rfl:	17,3	feet a. msl.	
	Top (feet)	Top (m)	b. msl (m)	Thk (m)
L. Cretaceous	1509	460	455	381
Frederikshavn Fm.	2759	841	836	7
Børglum Fm.	3530	1076	1071	48
Flyvbjerg Fm.	3688	1124	1119	25
Haldager sand Fm.	3770	1149	1144	75
Fjerritslev Fm. F-IV	4016	1224	1219	34
Fjerritslev Fm. F-III	4127	1258	1253	217
Fjerritslev Fm. F-II	4839	1475	1470	129
Fjerritslev Fm. F-I	5262	1604	1599	145
Gassum Fm.	5738	1749	1744	288
Skagerrak Fm.	6683	2037	2032	36
TD	6801	2073	2068	

Samples from core 5 and 6 will provide Fjerritslev

Casing

top depth		shoe depth		diameter	
ft.	m.	ft.	m.	inch	inch (decim)
0.0	0.0	52.5	16.0	18"	18.000
0.0	0.0	326.6	99.5	13 3/8"	13.375

Lithostratigraphy (Groups)

Top	Bottom	Unit
m. below ref. level.		
3.0	40.0	Post Chalk Group
40.0	460.0	Chalk Group
460.0	841.0	L. Cretaceous units
841.0	2037.0	Jurassic units
2037.0	2073.0	Triassic units

Chronostratigraphy (Periods)

Top	Bottom	Unit
m. below ref. level.		
3	40	Quaternary
40	979	Cretaceous
979	1902	Jurassic
1902	2068	Triassic

Samples

Cores

core	top	bottom	recovery
no.	m. below ref. level.		
1	814.00	820.00	82.0
2	1034.00	1040.00	48.0
3	1145.00	1151.00	68.0
4	1151.00	1157.00	100.0
5	1227.00	1230.70	100.0
6	1403.00	1409.00	100.0
7	1775.00	1780.00	74.0
8	1865.00	1870.00	100.0
9	2006.00	2012.00	75.0
10	2062.00	2068.00	100.0

Cuttings

from	to	distance
m. below ref. level.		bt. cuttings
116.00	2067.00	5.00

Vedsted-1

Propose 2 samples:
core 6, 9/10 (Clay rich Gassum)

Fjerritslev

Gassum

(Depth discrepancy in base Fj between the two GEUS litterature sources)

Core 5

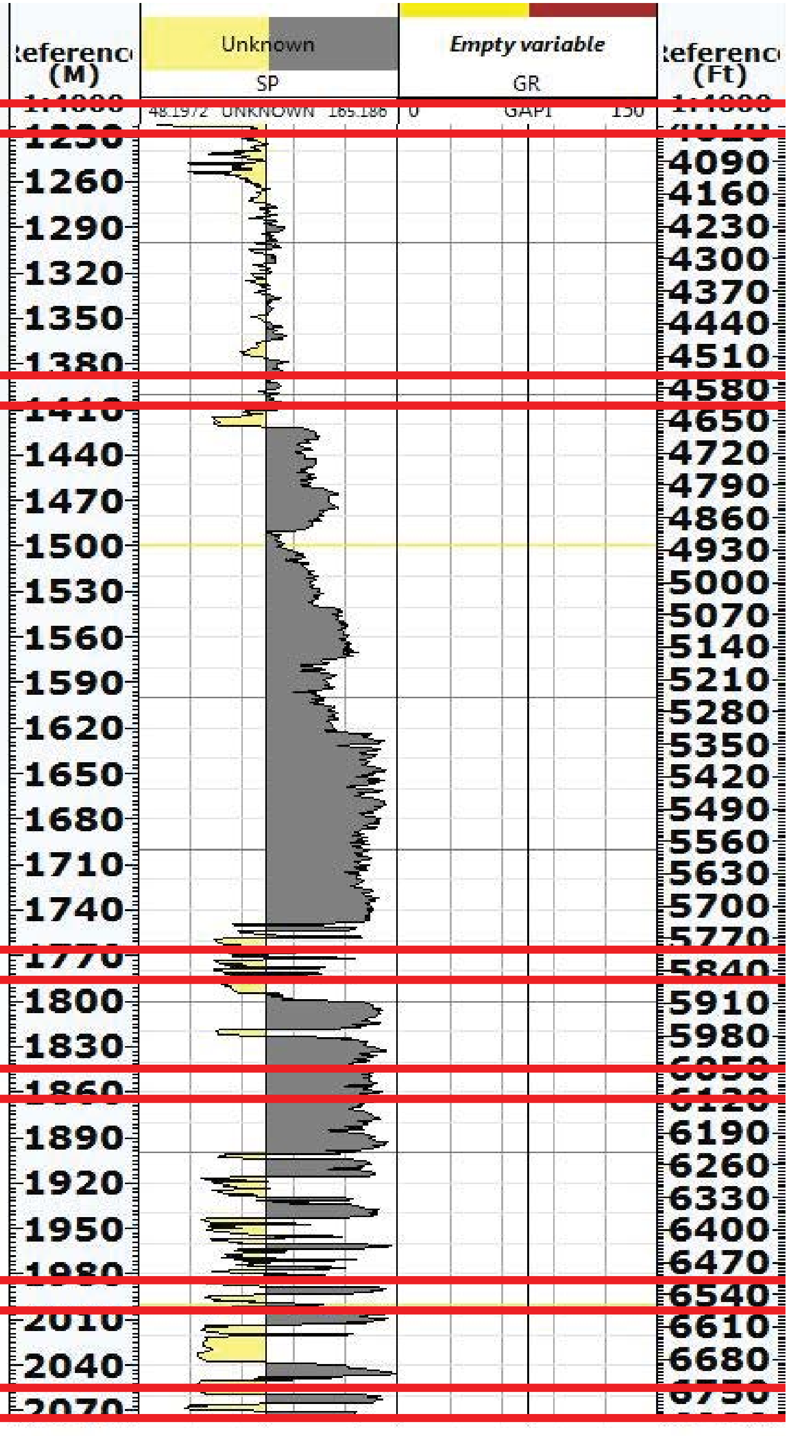
Core 6

Core 7

Core 8

Core 9

Core 10



GEUS

Conclusions

Based on inventory then 3 wells in relative closeness to the Vensyssel well is available for sampling of cored Fjerrislev Fm.

State of preservation unknown.

6. Project meetings

GEUS

Sampling methodology and Rock types in the Alum Shale

Niels H. Schovsbo, Kim Esbensen

De Nationale Geologiske Undersøgelser for Danmark og Grønland
Klima-,Energi- og Bygningsministeriet

Aims of study

- Define criteria and a work flow for rock type definitions with respect to geo-mechanical data

- Allow to sample the Alum Shale representative for core testing in intervals most favourable for stimulation

- Enable an on-site evaluation of rock types during drilling/coring of the Vensyssel-1

- Full documentation of methodologies and various transform/algorithms developed

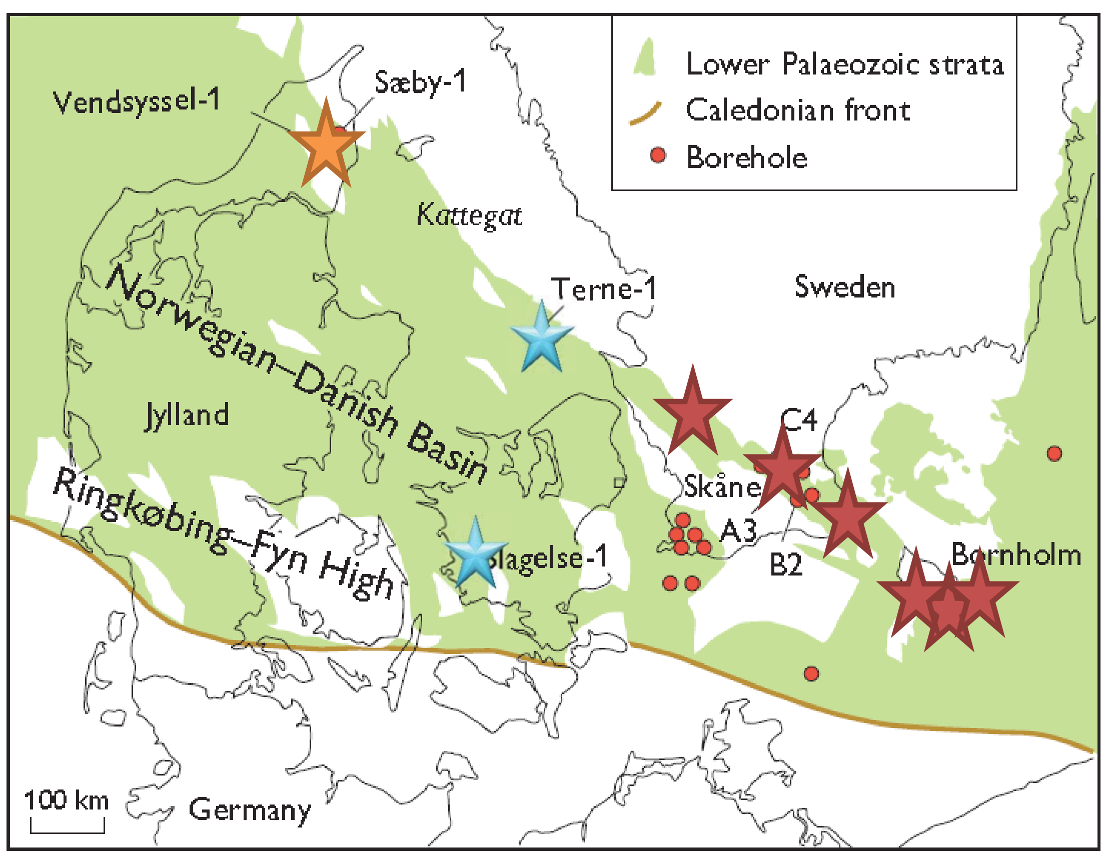
Main frame for workflow

- Geological correlation log correlation of all available wells
- Establish high resolution hand held XRF profiles in shale sections to provide basis for geochemical rock typing
- Multivariate statistical typing (PCA)
- Establish sedimentological/core description
- Integrated XRF data with log data by means of various statistical methods (e.g. PCA; PLS)
- Prediction of rock properties based on integrated core data-bore-hole database
- **Sampling of core material to FracTech done according to PCA rock typing i.e. within the integrated workflow**

Well data base

- Scientific wells:
  - Scania: Drilled during the 1990 by University of Copenhagen and GEUS
  - Bornholm: Drilled 2010 -2012 by GEUS and University of Copenhagen

Old exploration wells in Denmark only two drill the Alum



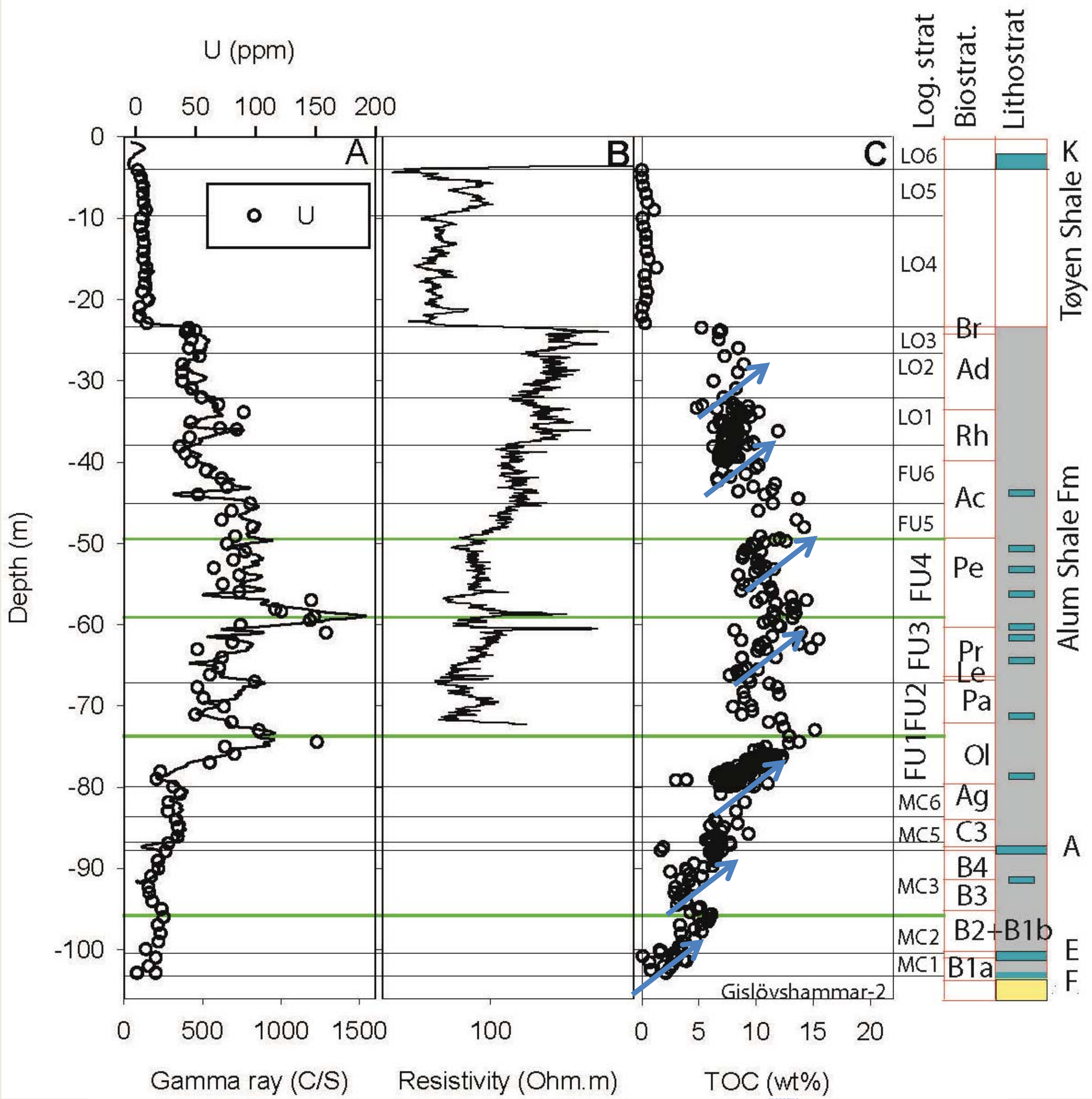
Scientific well

2015 well

Dk exploration well

Regional models for TOC

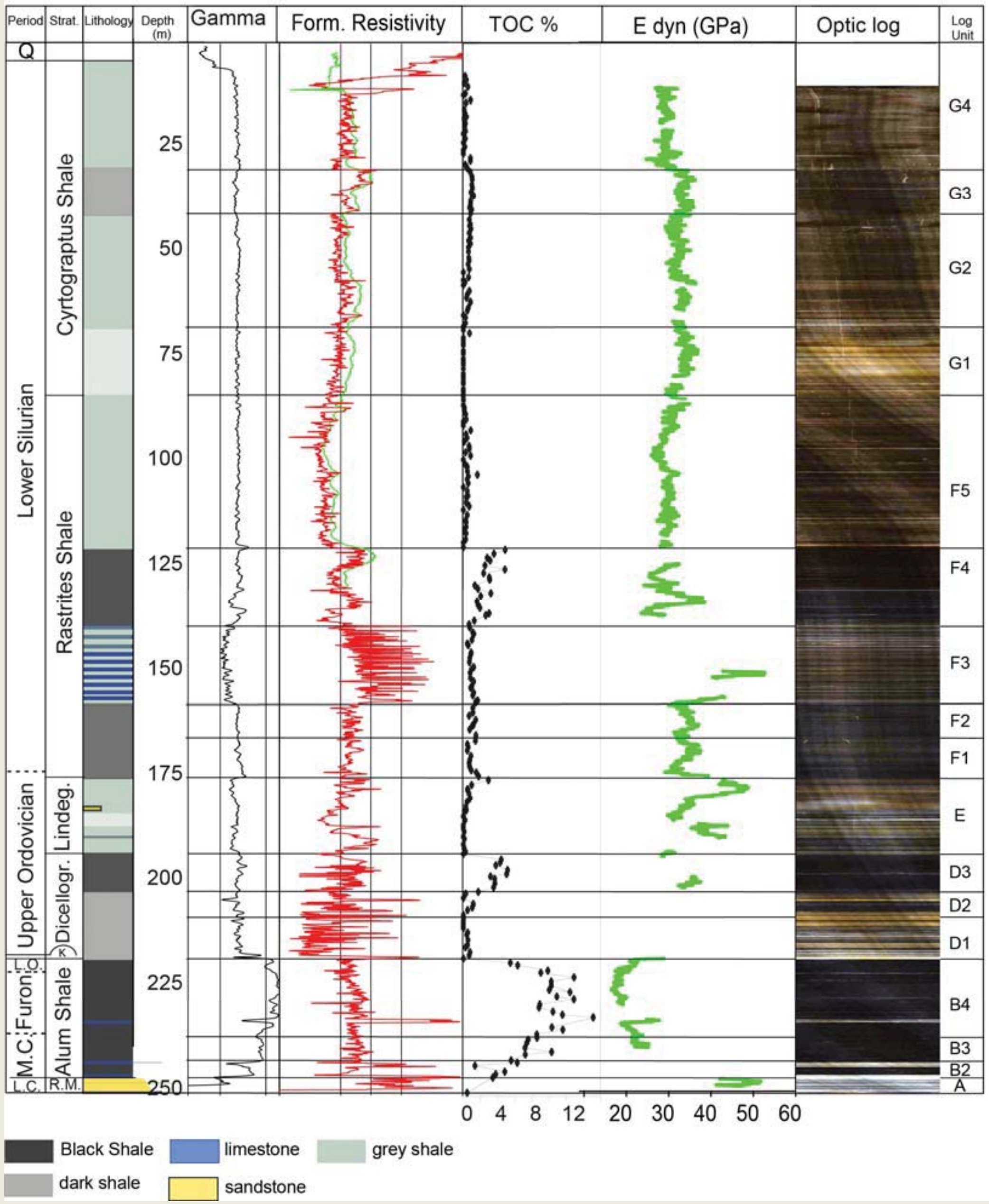
- TOC cycles reflect dysoxic to anoxic cycles
- We developed a log expression of the TOC variation based on Gr and Resistivity logs
- 15 log zones (MC1-6, FU1-6 and LO1-3)



Gislövshammar-2 well, Scania

Sommerodde-1

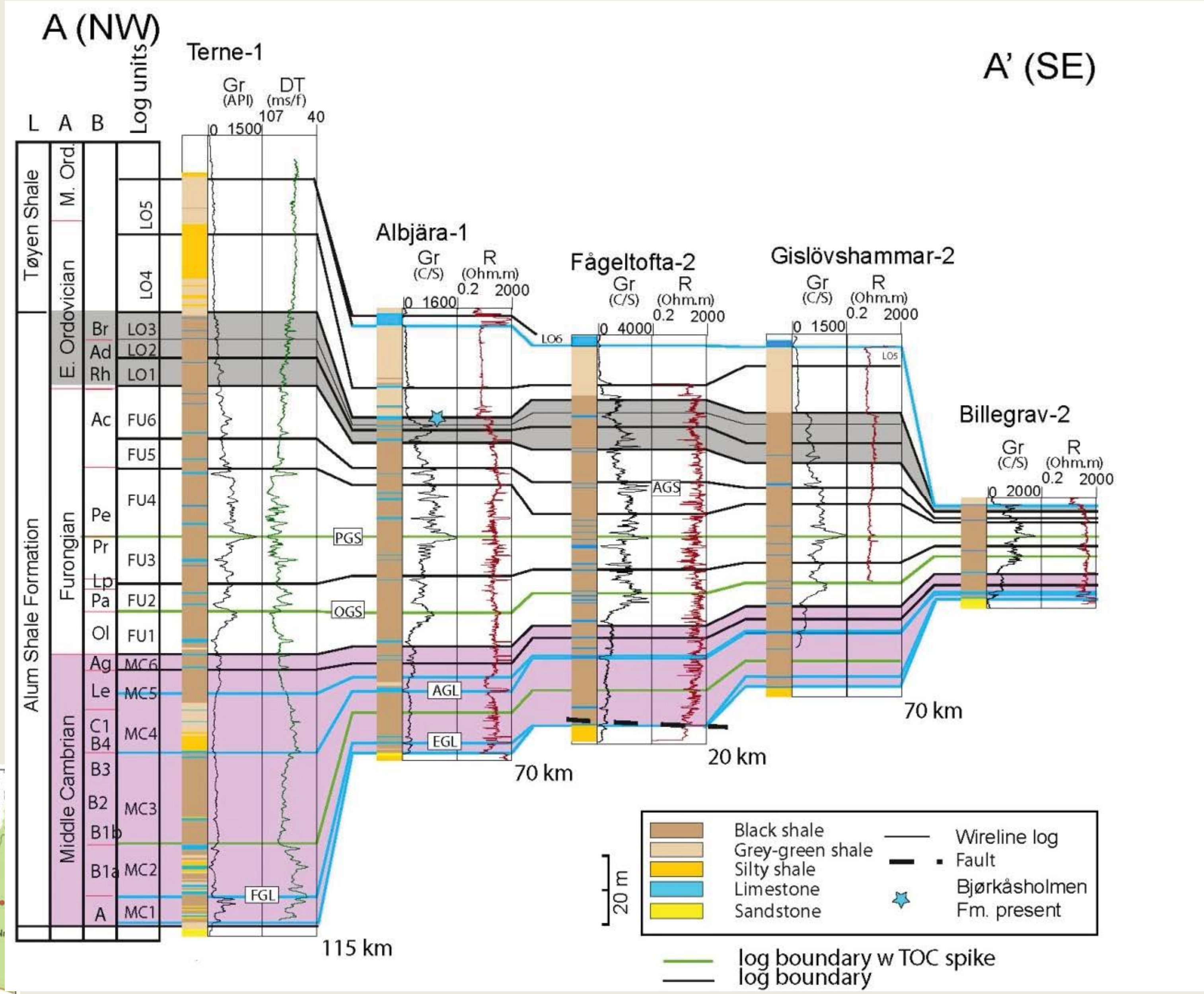
- Drilled in 2012; TD 250 m
- Comprehensive logging campaign including Vp, Vs logs

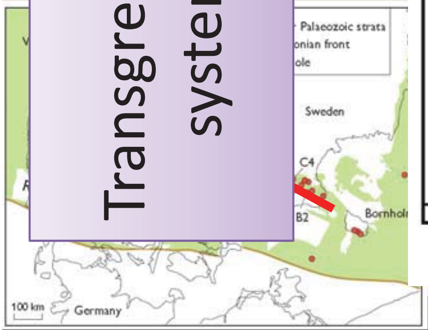


Regressive System

High stand System

Transgressive system





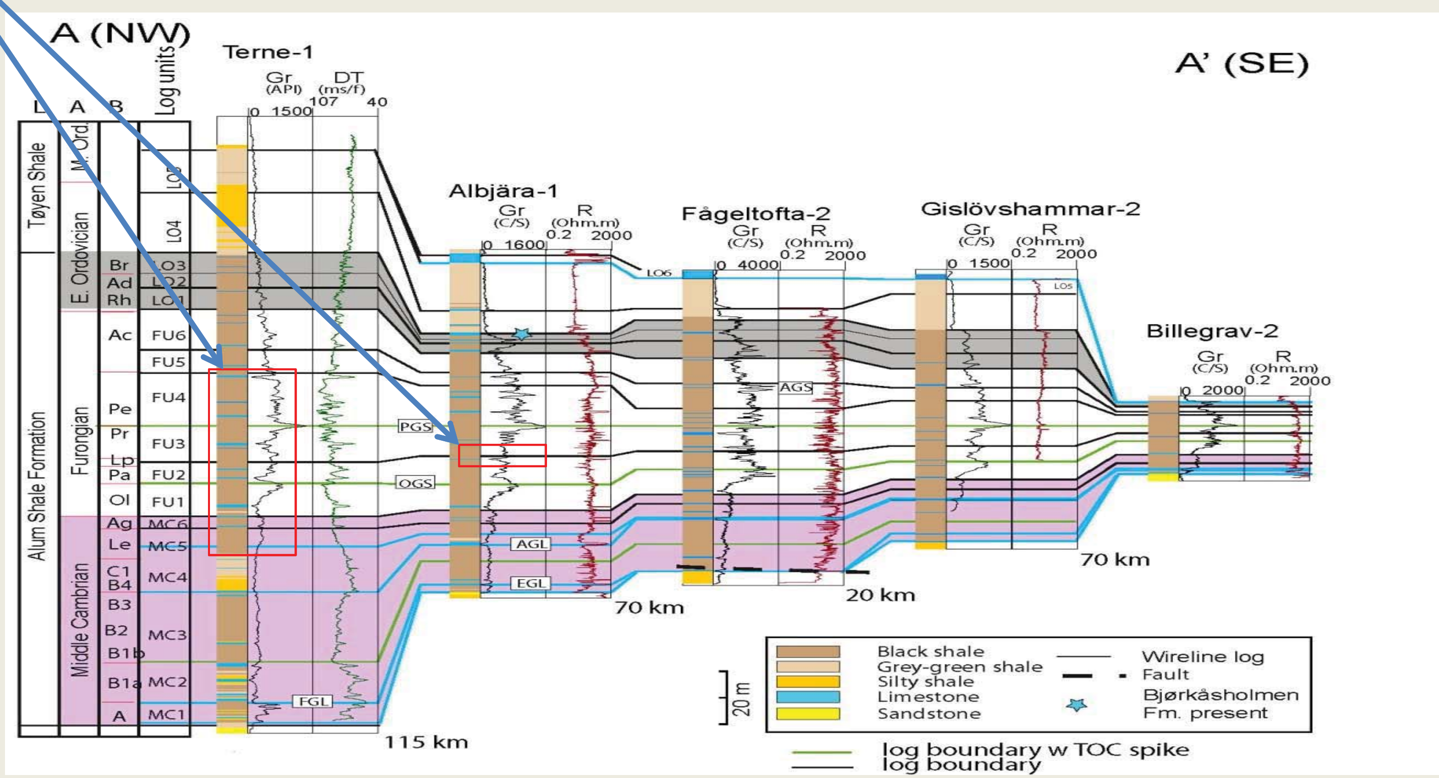
The Furongian holds the highest TOC content on average.

Formation/age	Terne-1					Albjära-1				
	Thick, m	Avg TOC	STD TOC	Max TOC	Min TOC	Thick. m	Avg TOC	STD TOC	Max TOC	Min TOC
Alum Shale:	180,0	6,4	2,6	13,7	1,8	97,8	8,2	3,2	15,3	0,5
Tremadoc	34,1	4,1	1,2	6,3	2,4	7,0	6,2	2,6	11,8	0,7
Bryograptus	13,4	3,0	0,6	3,8	2,4	3,0	4,4	2,0	7,1	0,7
Adelograptus	16,6	5,0	0,8	6,3	3,8	2,0	5,4	2,4	11,8	0,7
Rhapdinopora	4,4	5,4				2,5	6,5	2,3	11,8	1,7
Furongian	64,5	9,0	1,9	13,7	6,5	58,7	10,1	2,2	15,3	4,9
Acerocare	12,6	8,2	1,8	10,7	6,6	12,6	10,2	2,1	14,3	7,3
Peltura scarabaeoides	14,6	10,9	2,0	13,7	9,2	13,5	10,6	2,0	15,3	7,3
Peltura minor	5,4	10,2	0,0	10,3	10,2	4,1	11,5	1,7	14,3	8,8
Protopeltura praecursor	4,4	7,5				4,8	11,5	1,6	14,6	8,7
Leptoplastus	2,1	7,6				2,5	10,4	1,1	11,5	8,7
Parabolina spinulosa	10,1	7,3	0,8	7,9	6,5	9,0	7,8	1,2	10,0	5,4
Olenus	15,2	8,8	1,8	11,1	7,0	12,2	10,2	2,4	14,9	4,9
Mid Cambrian	79,7	5,2	1,5	7,2	1,8	32,0	5,3	2,1	10,4	0,5
Agnostus pisiformis	5,7	7,1	0,2	7,2	6,9	4,5	7,2	1,2	10,4	4,9
Paradoxides forchhammeri	28,4	5,7	1,0	6,8	4,2	9,8	5,9	2,4	8,4	0,7
Paradoxides paradoxissimus	51,2	5,0	1,5	6,8	1,8	17,7	4,4	1,6	7,4	0,5

Green: TOC >10%, orange TOC 8-10%

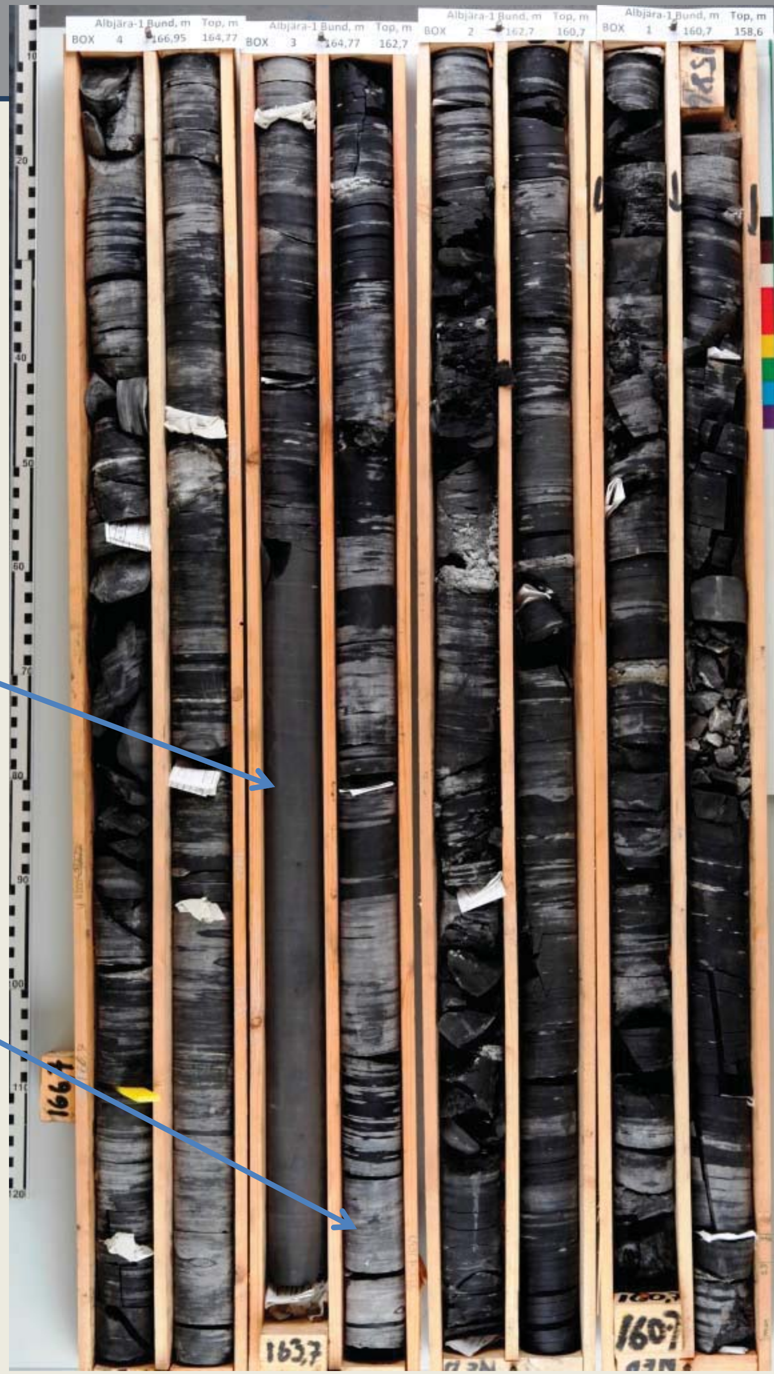
Furongian – most likely zone to fracture in

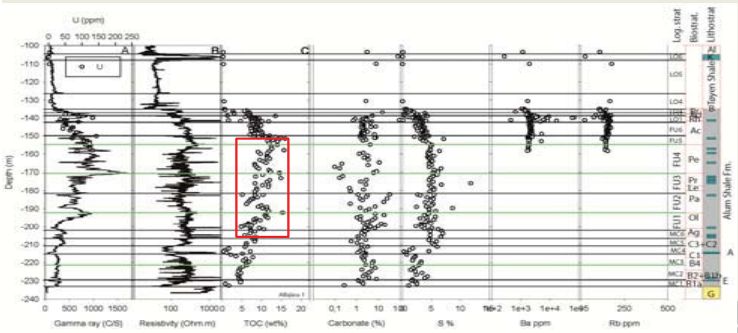
- Gas storage capacity known to be linked with TOC in Alum
- If the fracture initiation Zone is to be at least 40 m from top and base then the Furongian will the most likely spot



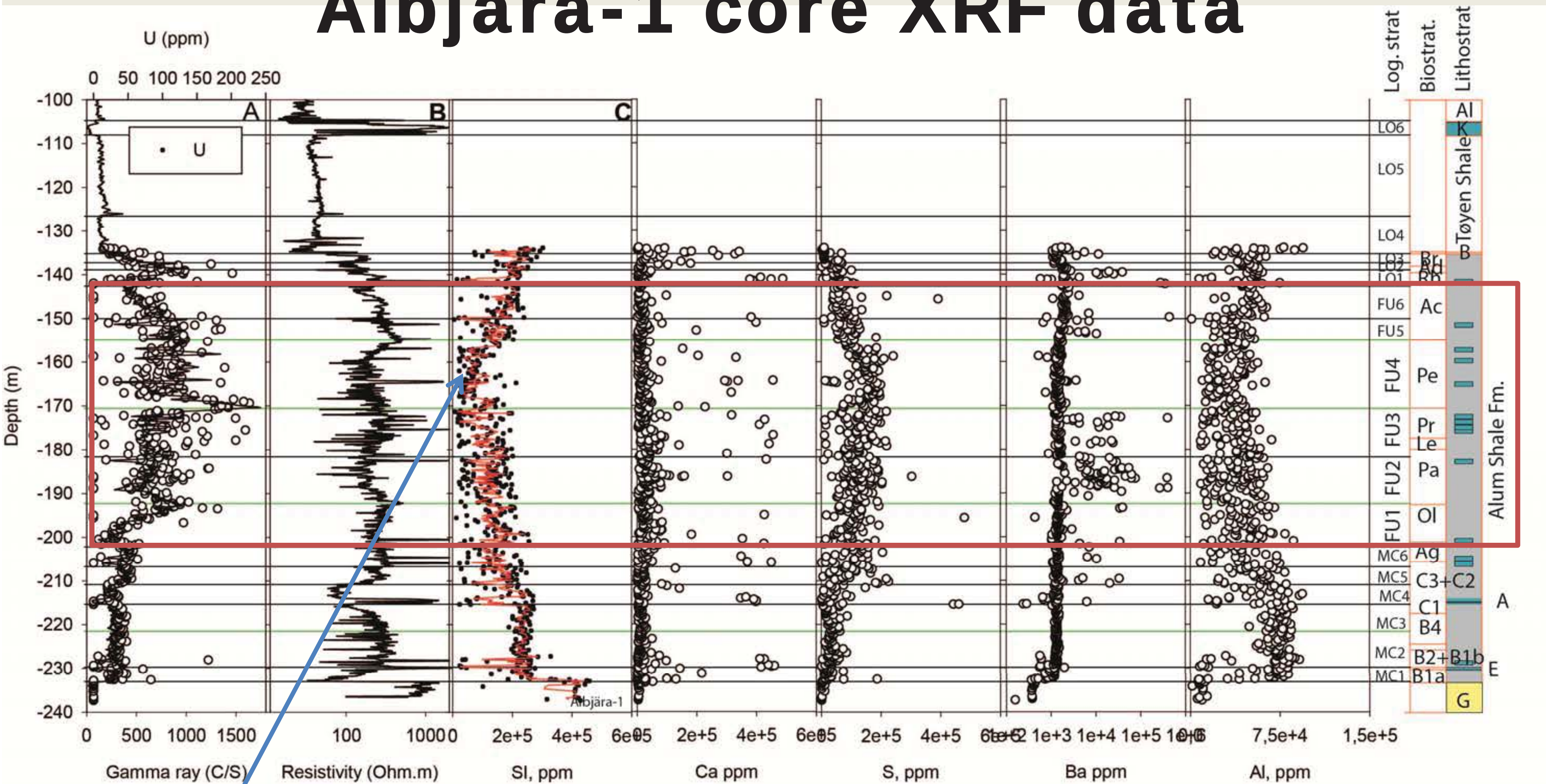
Facies in Furongian

- High TOC type, high sulphur and with carbonate concentrations
- The pyrite in the Albjära-1 core is weathered and particulate S rich intervals are white coloured.

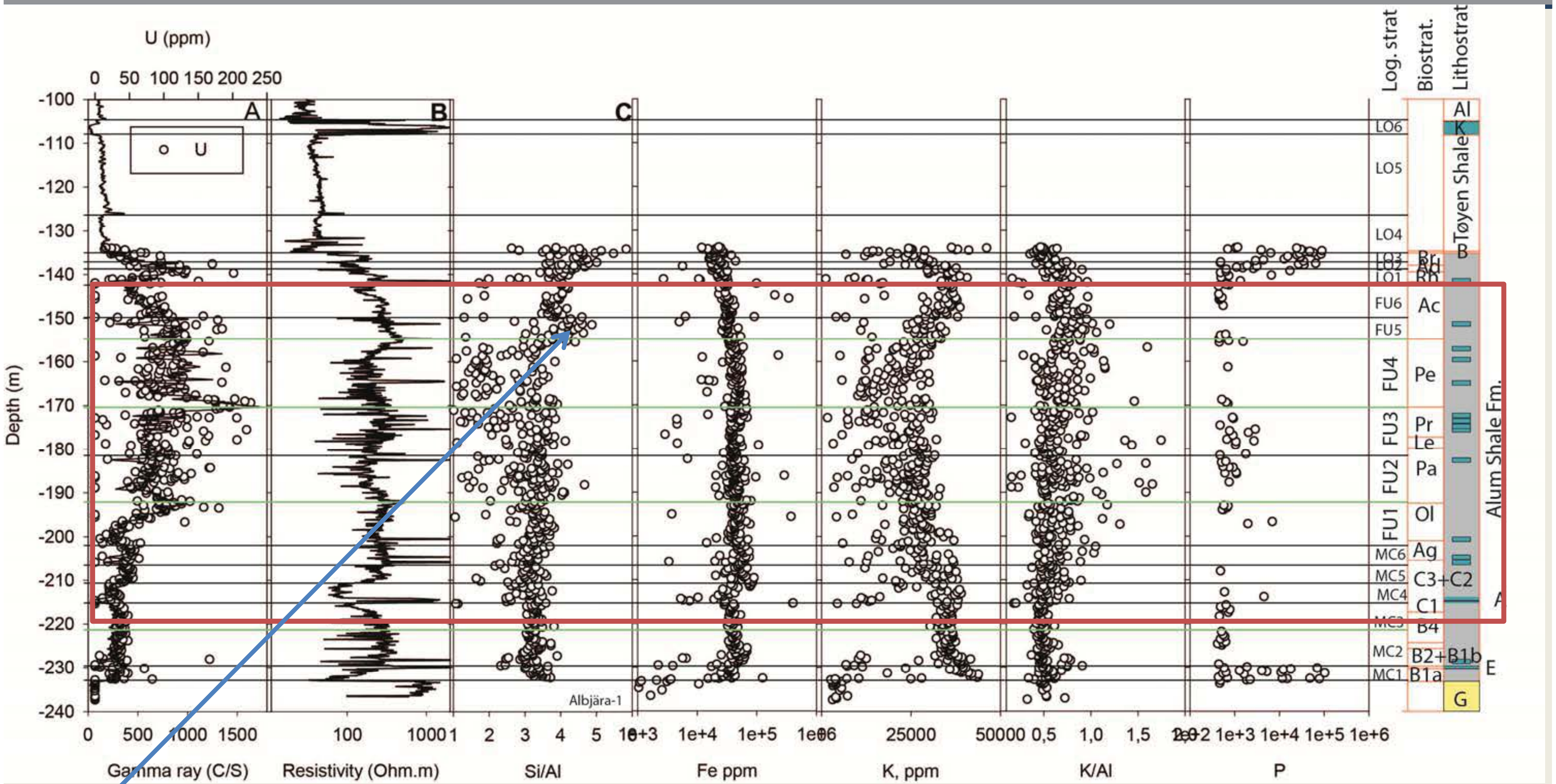




Albjära-1 core XRF data



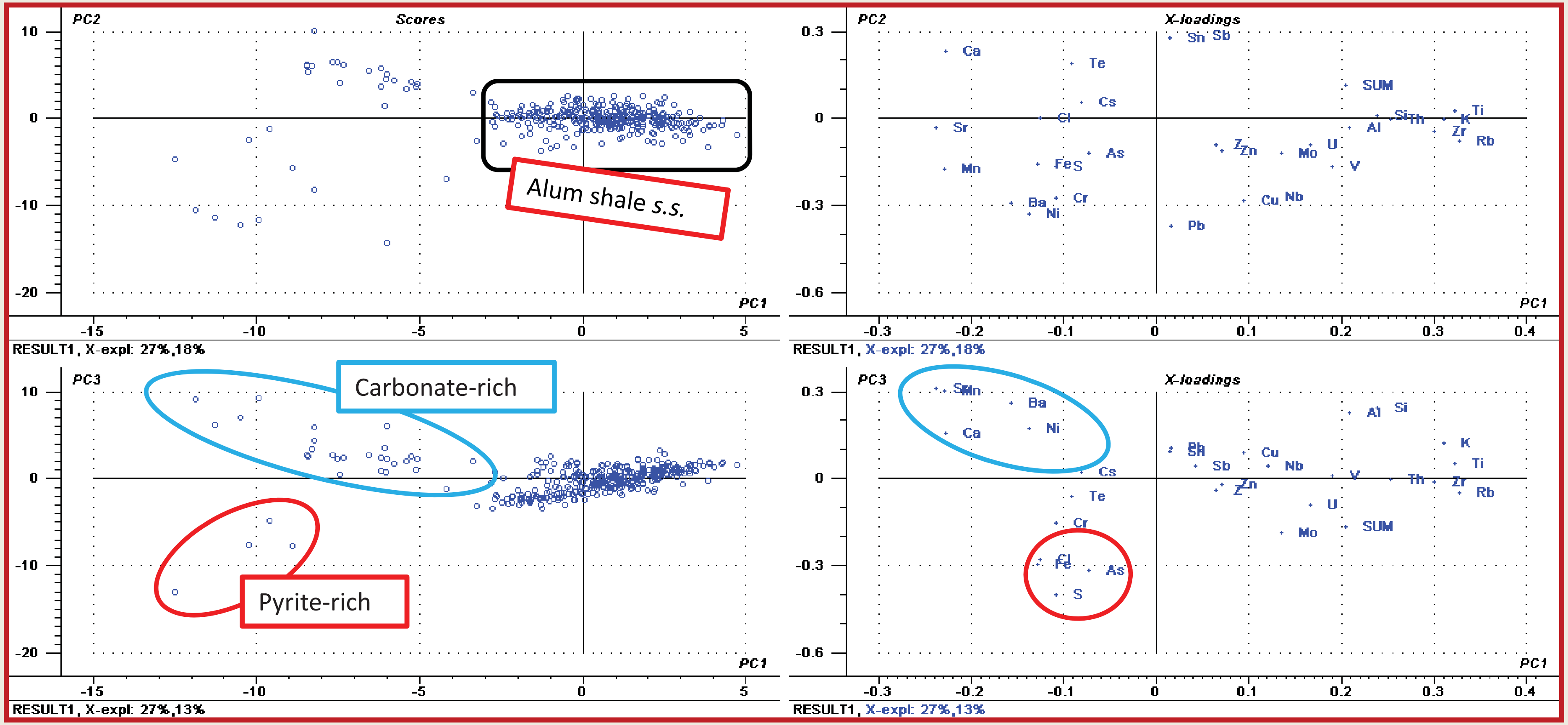
- Lowest Si content in the FU4 zone
  - Expected to be have the potential least rock strength



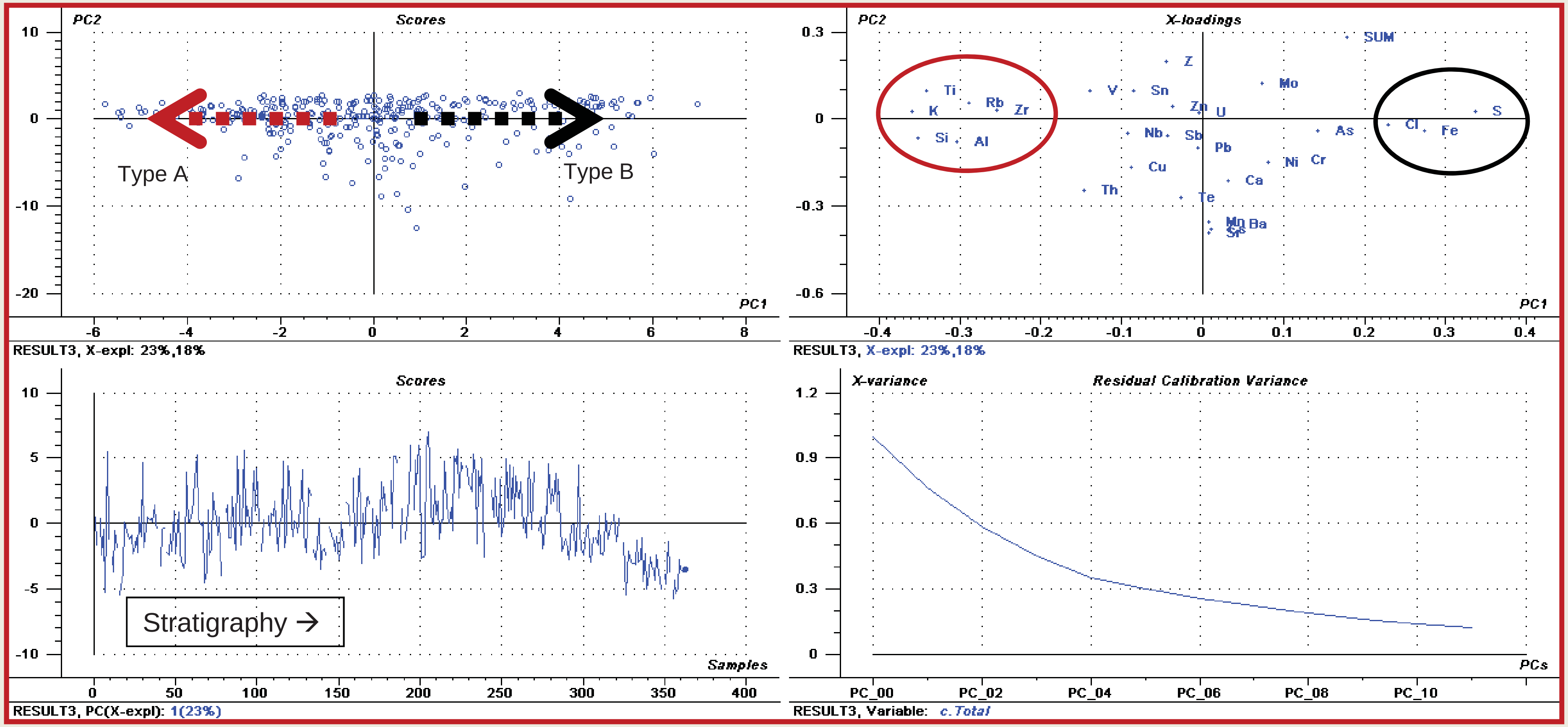
The Si/Al is fairly constant in the Furongian. Only the FU5 zone has relative high Si/Al ratio. This is also the zone with highest avg TOC content.

- High Si and highest Si/Al ratio in the zone FU5
  - Expected to have a potential high rock strength

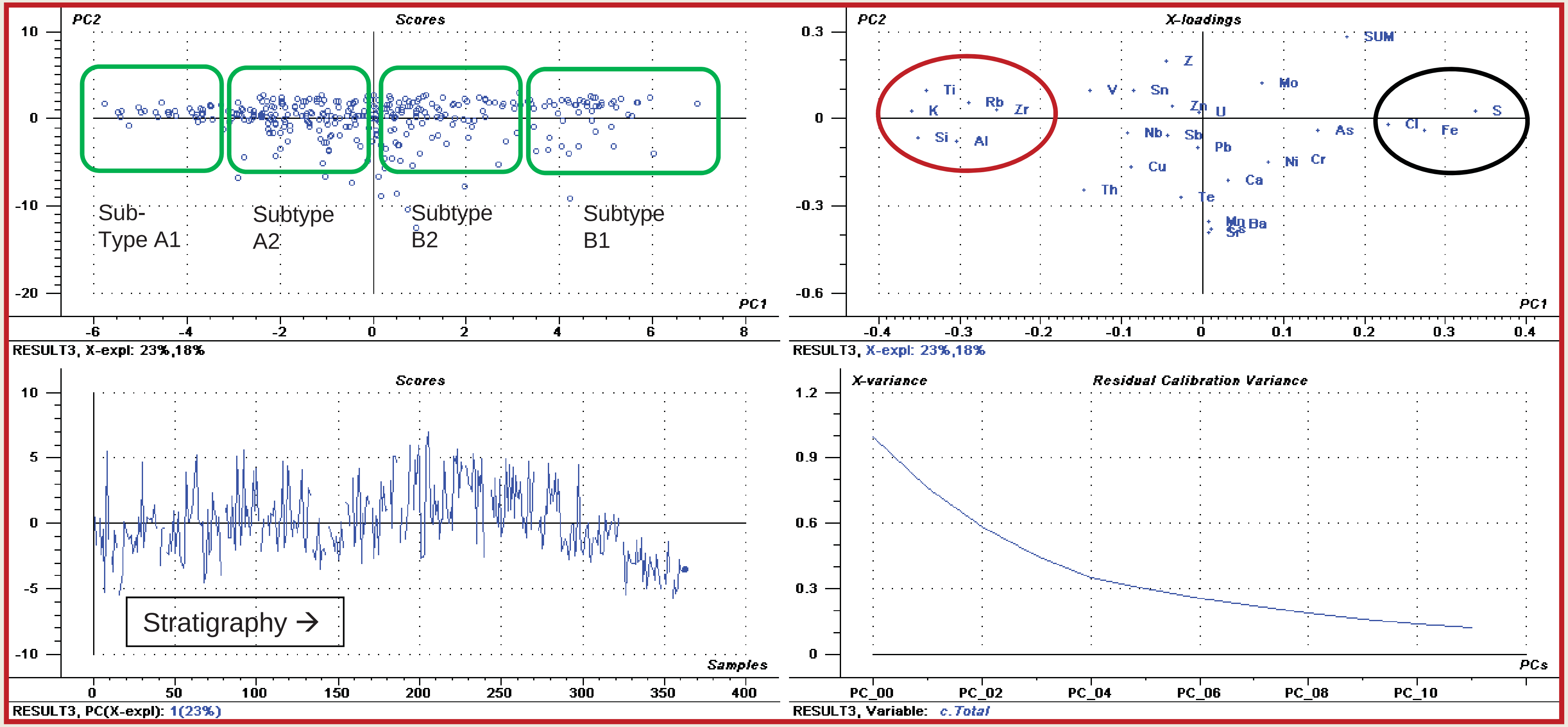
PCA analysis –Furongian only



Removing of outliers (concretions – non-shales).
Focus on Alum Shale s.s.



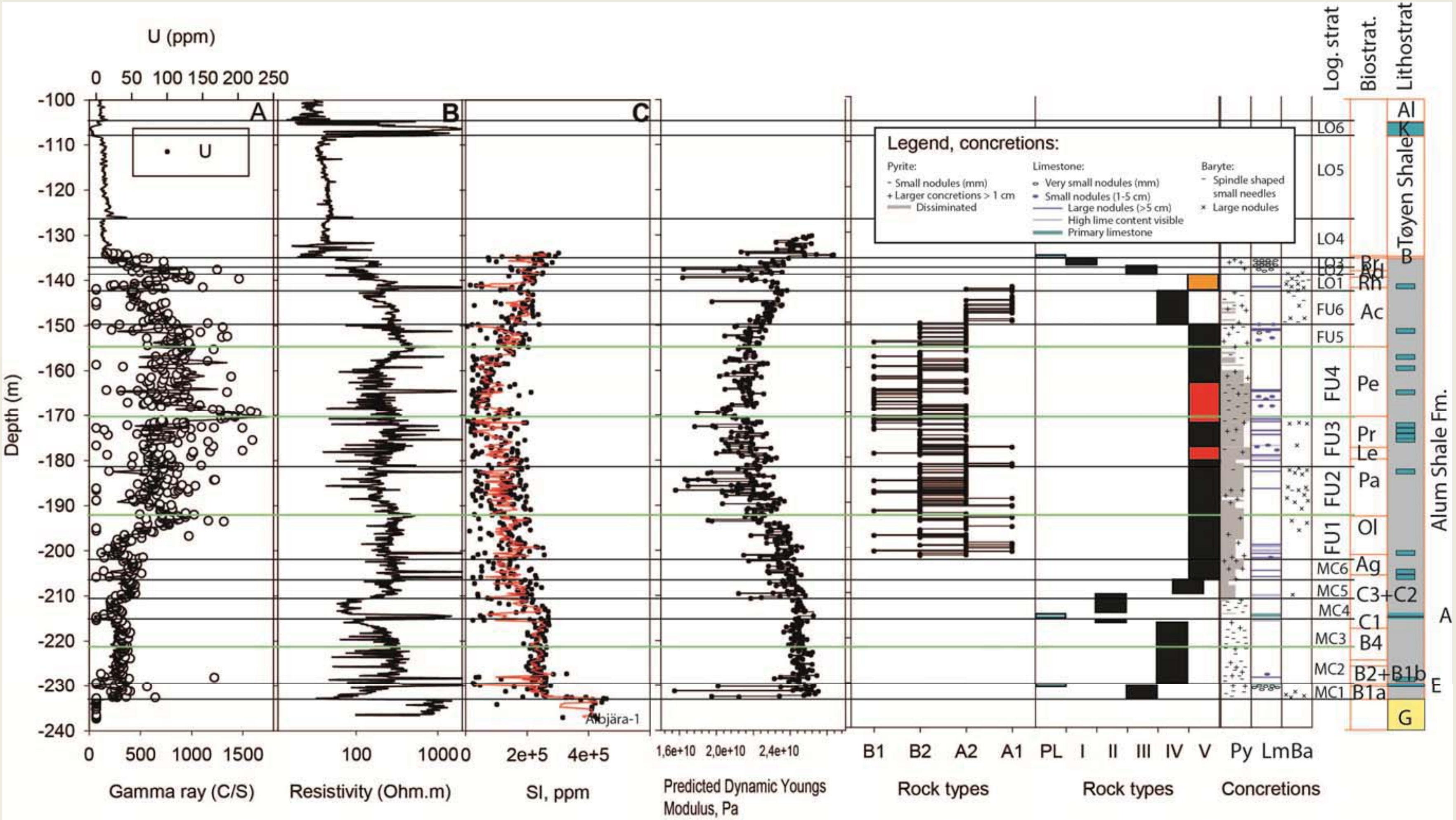
Two end-member system:
a silicate rich (Type A) and a sulphide rich (Type B)



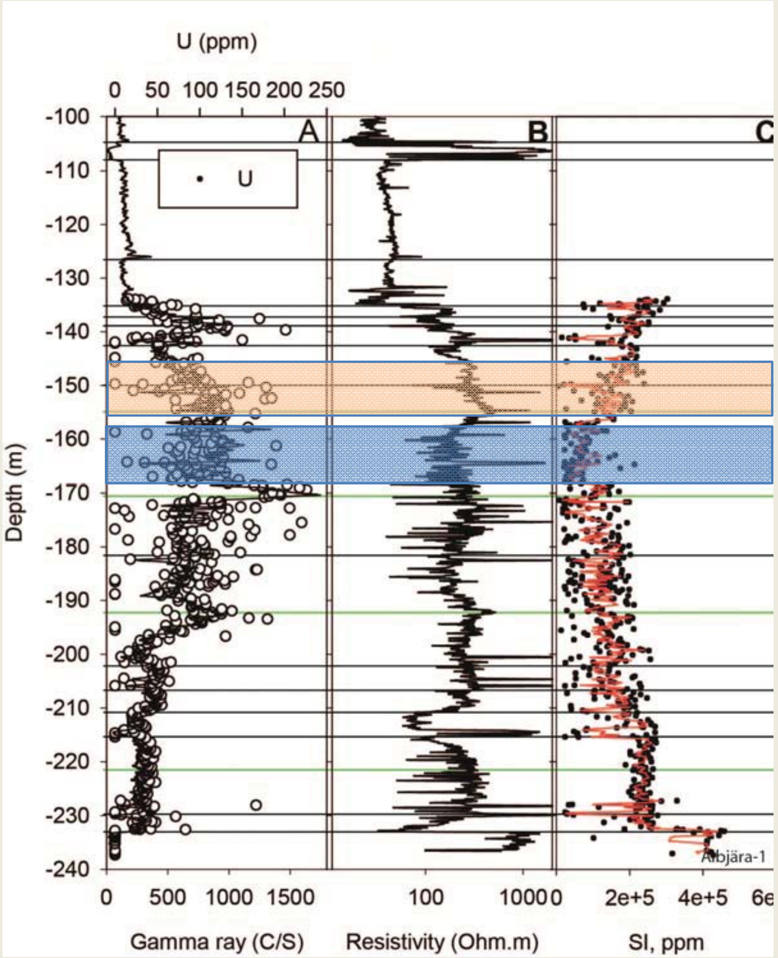
The two end-member system can be detailed:

a silicate rich (subtype A1, A2) and a sulphide rich (subtype B1,B2)

Albjära-1 summary



Rock types and logs



Dominantly A types

Dominantly B types

- As it looks now the PCA defined Type B correspond to low resistive high GR intervals and the PCA defined Type A to high resistive high GR intervals
- Resistivity is, however, influenced by also carbonate and TOC content and on the amount of pyrite and how it is distributed (isolated crystals vs. in a connected framework)

Samples - Conclusions

- PCA analysis suggest the presence of a two end-member rock system in the Furongian: A relative silicate rich sulphide poor type (Type A and its subtype A1 and A2) vs. a relative silicate poor and sulfide rich type (Type B and its subtypes B1 and B2)

- Type A and B occur mixed with each other in the Furongian. In a few zones one type dominate over the other. This is seen in FU4 that is dominated by type B1 and in zone FU6 that are dominated by Type A1

- We expect that the types will have different properties.
  - Type B will have least rock strength relative to A due to its low siliceous content
  - Type B is expected to be more heterogeneous on a cm-dm scale due to its higher content of pyrite

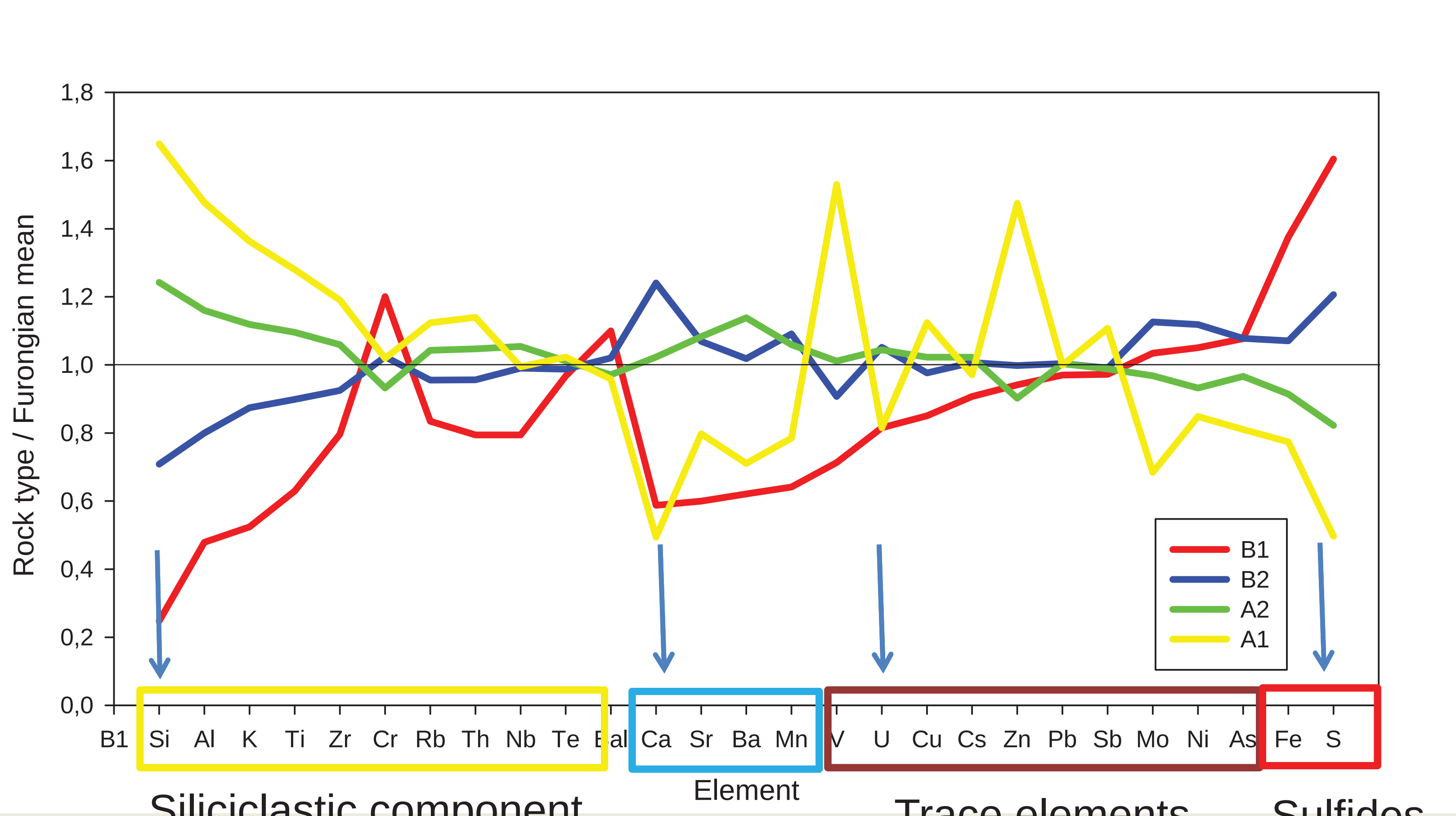
Aims

- Aim of study was to define a set of criteria and work flow for rock type definitions with respect to geo-mechanical data
- Allow to sample the Alum Shale representative for core testing in intervals most favourable for stimulation
- Workflow should enable an on-site evaluation of rock types during drilling/coring of the Vensyssel-1
- Full documentation of methodologies and various transform/algorithms developed

Rock type separators

- Diagram on next slide depict average RT compositions, normalised to the Furongian mean composition. Elements >1 are thus relatively enriched in the delineated rock type compared to average composition
- Elements are sorted according to main lithological associations

Albjära-1 (Furongian only)



Siliciclastic component

Carbonate and Barite Component

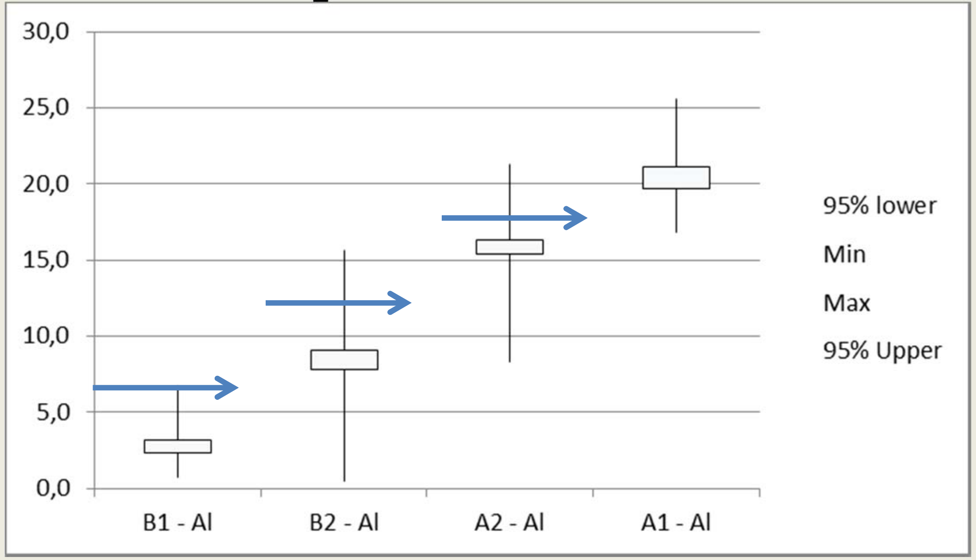
Trace elements

Sulfides

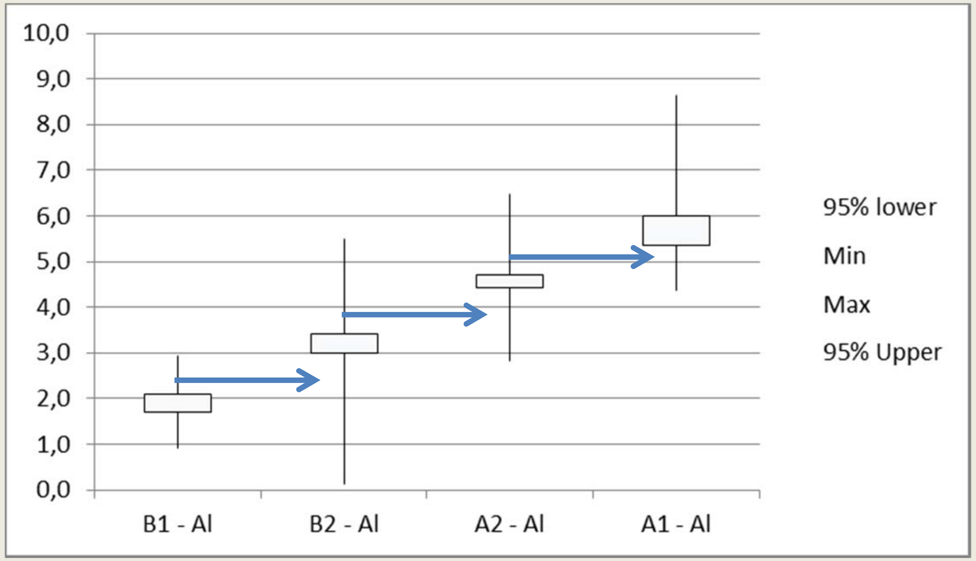
Discriminator elements (for each main element group) used in XRF-defining rock typing algorithm

Siliciclastic component

Si	B1 - Al	B2 - Al	A2 - Al	A1 - Al
95% lower	2,3355	7,8136	15,4128	19,7082
Min	0,7617	0,5067	8,3048	16,8164
Max	6,7430	15,6521	21,2747	25,5846
95% Upper	3,1856	9,0919	16,2819	21,1461
Mean	2,7606	8,4528	15,8473	20,4272



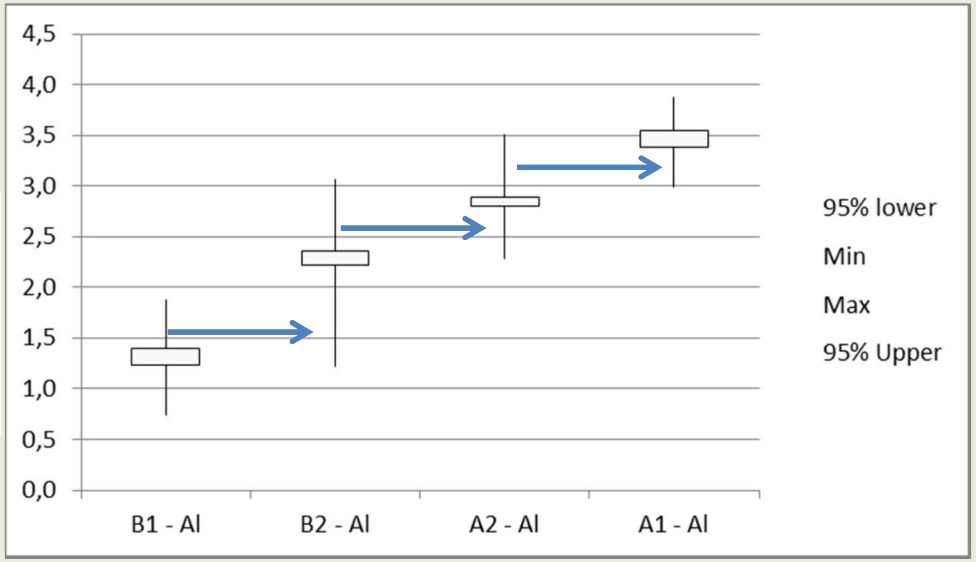
Al	B1 - Al	B2 - Al	A2 - Al	A1 - Al
95% lower	1,7110	2,9974	4,4223	5,3625
Min	0,9026	0,1182	2,8130	4,3570
Max	2,9355	5,4818	6,4917	8,6468
95% Upper	2,0925	3,4051	4,7048	6,0101
Mean	1,9018	3,2012	4,5636	5,6863



Rock type A is relative [Si, Al] rich; Si can be used as a main flag for discrimination A *vs.* B rock types

Siliciclastic component (cont.)

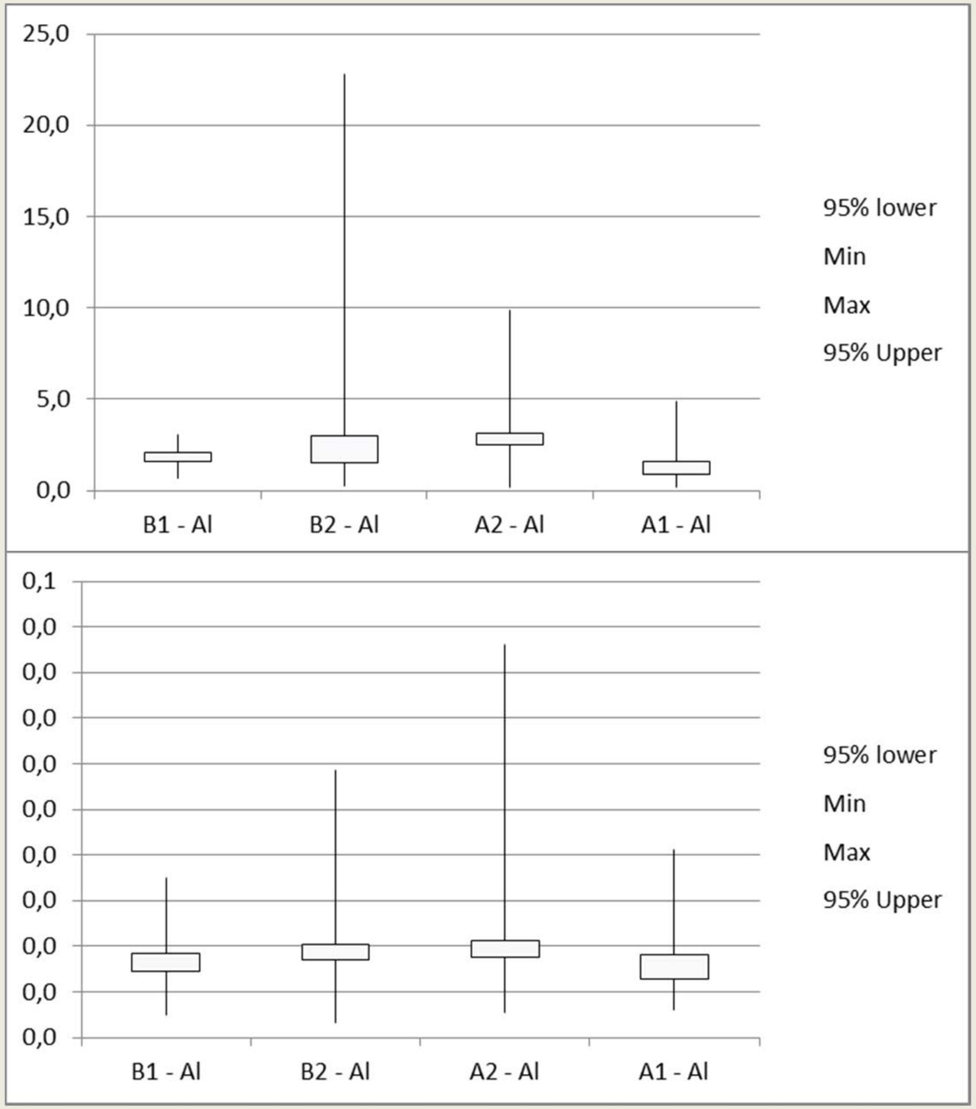
K	B1 - Al	B2 - Al	A2 - Al	A1 - Al
95% lower	1,2370	2,2224	2,8014	3,3793
Min	0,7428	1,2224	2,2851	2,9920
Max	1,8790	3,0657	3,5105	3,8725
95% Upper	1,3965	2,3603	2,8845	3,5470
Mean	1,3167	2,2913	2,8429	3,4631



Rock type A is also relatively K-rich; K may also perform as a flag for the A *vs.* B rock type discrimination

Ca	B1 - Al	B2 - Al	A2 – Al	A1 – Al
95% lower	1,5932	1,4855	2,4787	0,8489
Min	0,6931	0,2277	0,2059	0,1804
Max	3,0877	22,7765	9,8729	4,8642
95% Upper	2,0782	2,9638	3,1316	1,5807
Mean	1,8357	2,2246	2,8052	1,2148

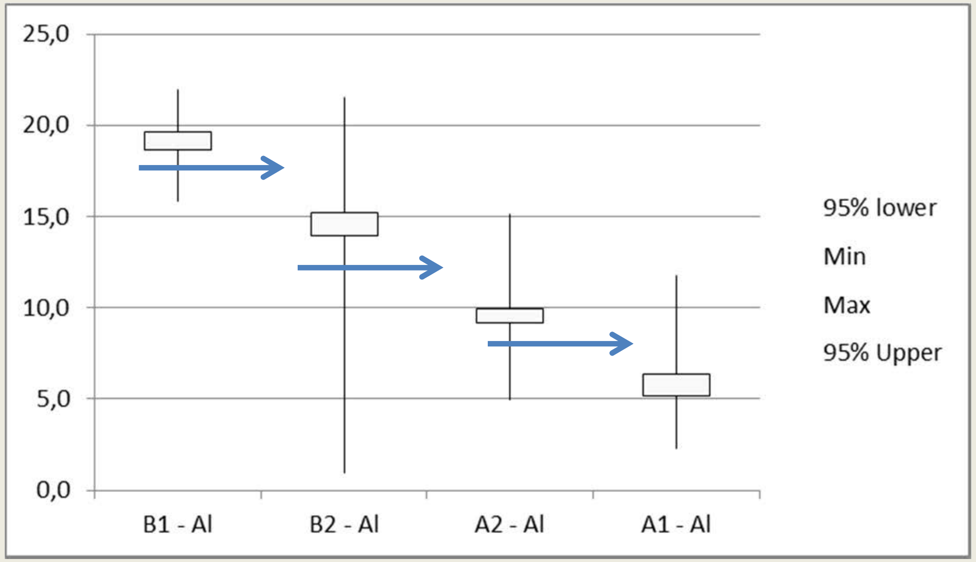
U	B1 - Al	B2 - Al	A2 - Al	A1 - Al
95% lower	0,0072	0,0085	0,0088	0,0064
Min	0,0024	0,0016	0,0027	0,0031
Max	0,0174	0,0293	0,0430	0,0206
95% Upper	0,0091	0,0101	0,0106	0,0090
Mean	0,0082	0,0093	0,0097	0,0077



Ca and U show a minor ability to be helpful in rock type discrimination, but partially overlapping statistics does not provide any significant separations.

Sulphides (S)

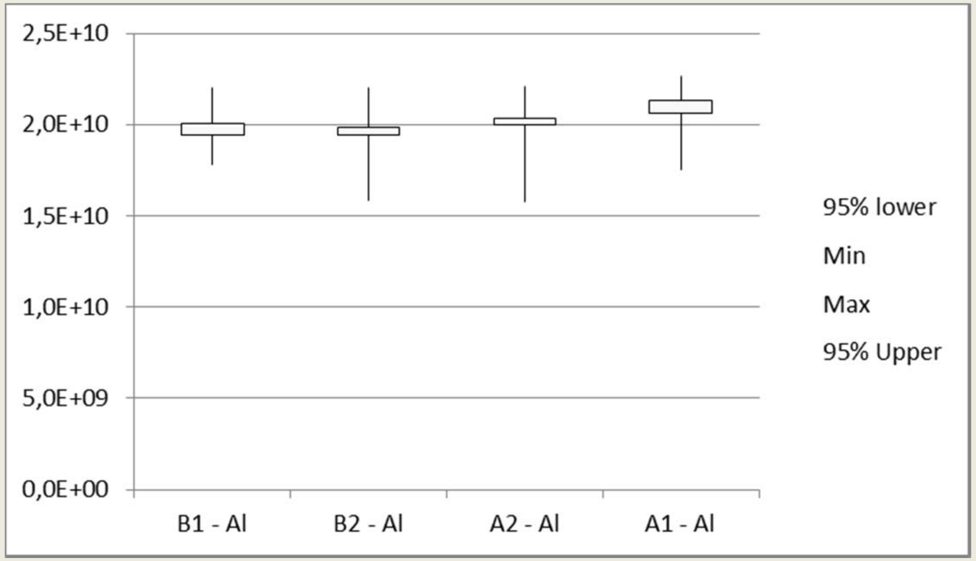
S	B1 - Al	B2 - Al	A2 - Al	A1 - Al
95% lower	18,6533	13,9452	9,1887	5,1533
Min	15,8422	0,9574	4,9616	2,2683
Max	21,9251	21,5142	15,1389	11,7598
95% Upper	19,6478	15,2155	9,9531	6,3482
Mean	19,1505	14,5804	9,5709	5,7508



Rock type B is relatively S-rich - S content Would appear to be a very good separator between the 4 rock types

Predicted Young modulus

E, Pa	B1 - Al	B2 - Al	A2 - Al	A1 - Al
95% lower	1,95E+10	1,94E+10	2,00E+10	2,06E+10
Min	1,78E+10	1,58E+10	1,58E+10	1,76E+10
Max	2,20E+10	2,20E+10	2,21E+10	2,26E+10
95% Upper	2,00E+10	1,98E+10	2,03E+10	2,13E+10
Mean	1,97E+10	1,96E+10	2,01E+10	2,10E+10



PLS predicted Young modulus show that the Alum Shale lies around 20 Gpa.
Rock type B1 is the weakest and the A1 type is the strongest. There is a gradual transition in the strength between the rock types

XRF discriminators based on XRF

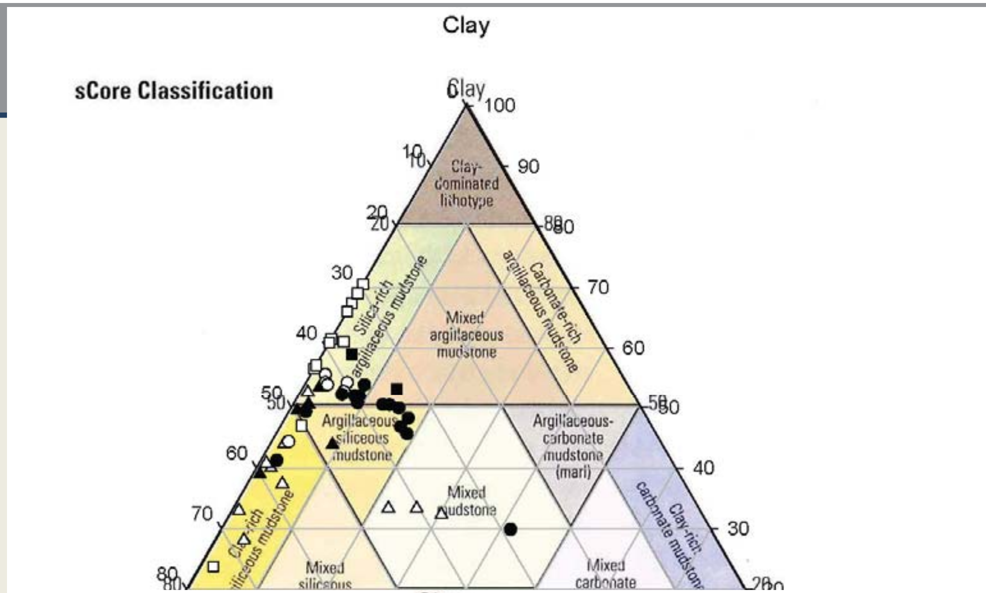
Rock types from XRF		
Si_flag	K_flag	S_flag
=IF(SI<5.5;"B1"; IF(SI<12;"B2"; IF(SI<17;"A2";"A1")))	=IF(K/10000<1.8;"B1"; IF(K/10000<2.6;"B2"; IF(K/10000<3.1;"A2";"A1")))	=IF(S/10000>16;"B1"; IF(S/10000>12;"B2"; IF(S/10000>8;"A2";"A1")))

The PCA defined rock types does not correlate precisely with the above rock type flags.
Use all three and solve for any inconsistencies with further analysis

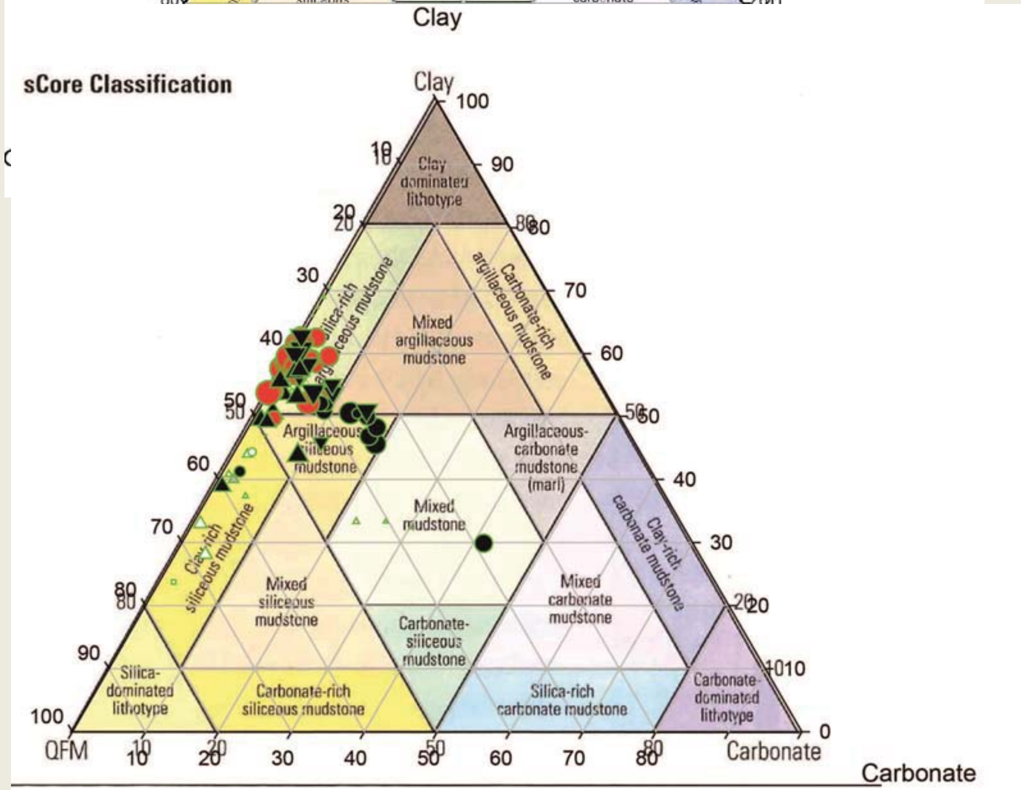
Rock types from Predicted E
=IF(E/1000000000<20;"B1 or B2"; IF(E/1000000000<20.45;"A2";"A1"))

Predicted E provide less accurate rock type predicting but allow for a main type A or B

- XRD analysis 1st May, 2014:

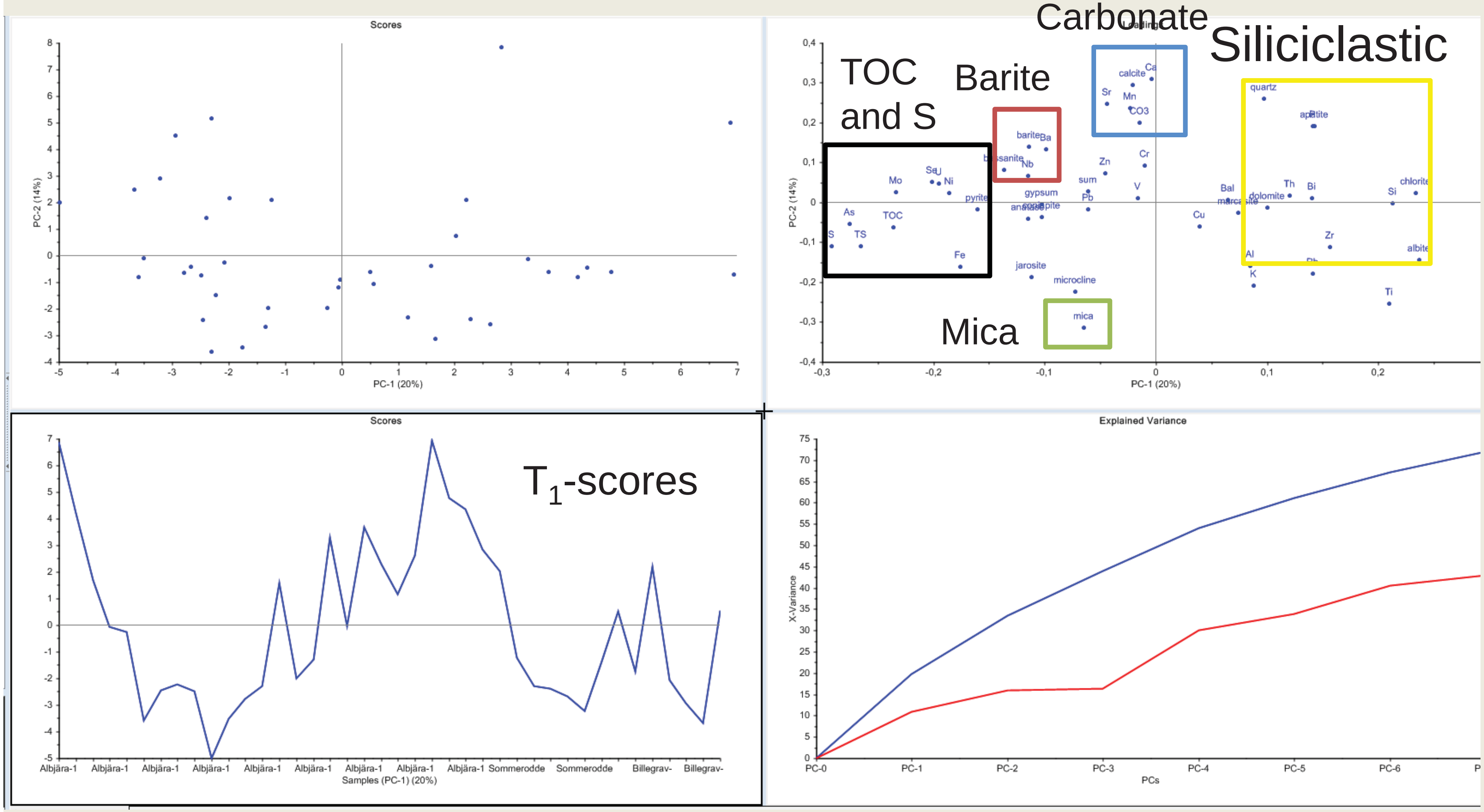


- With new data:
- New data confirms previous analysis: the Alum shale is a relative clay-rich shale
- QFM-clay ratio is between 40 and 50%, with a dilution trend towards carbonate

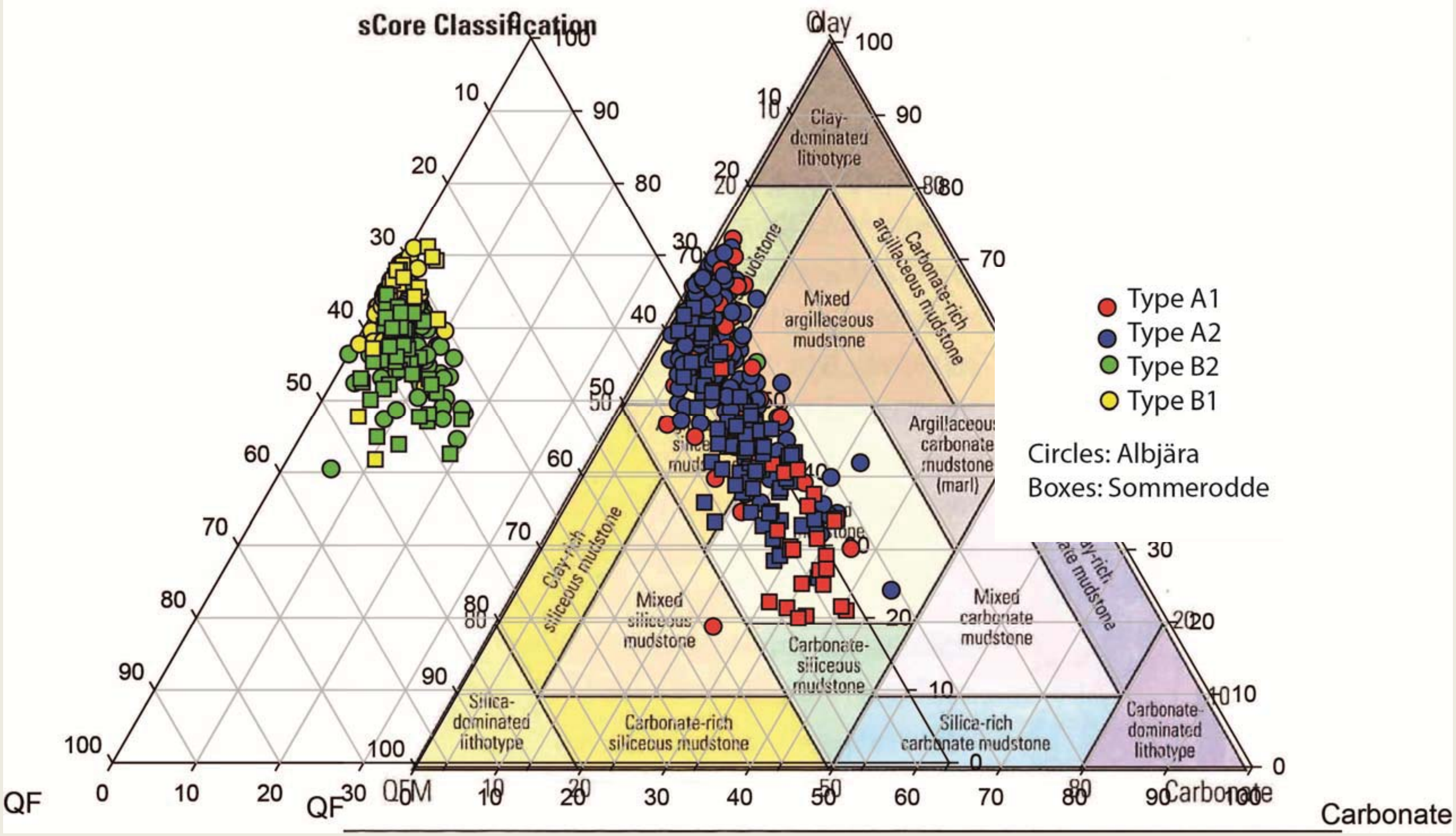


legend: red alum shale in Albjära-1, black: Alum Shale in Terne-1 (circle) and Bornholm (triangels). White: non alum shale. Symbols size proportional with TOC content.

PCA: XRD-XRF data



PCA of the XRD-XRF data set confirms previous mineralogical associations of the XRF dataset

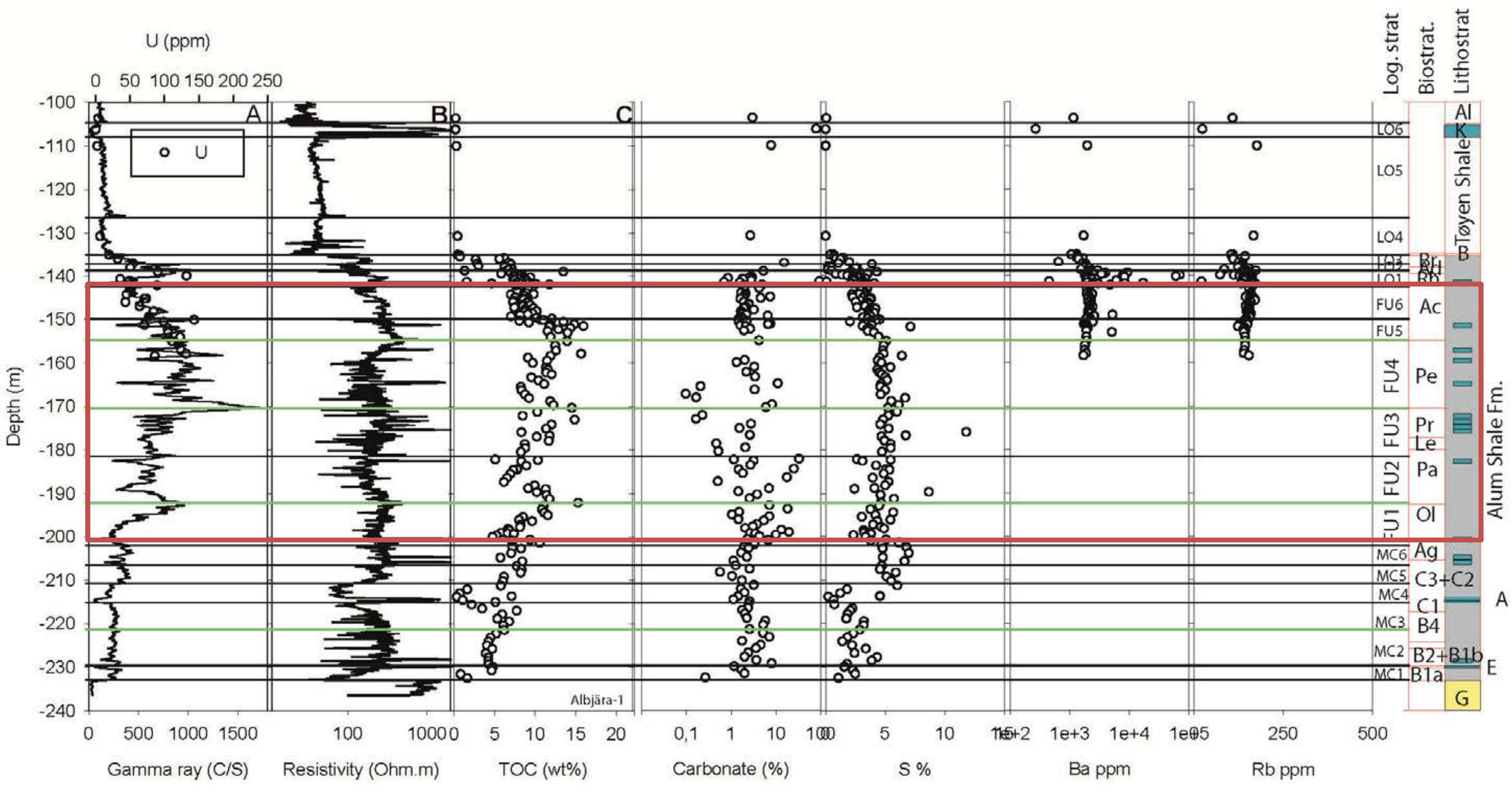


- Rock types A and B have near identical QF to total clay ratios and differ only w.r.t. carbonate content
- Sommerodde tends to have *higher carbonate content* that the Albjära

Conclusions

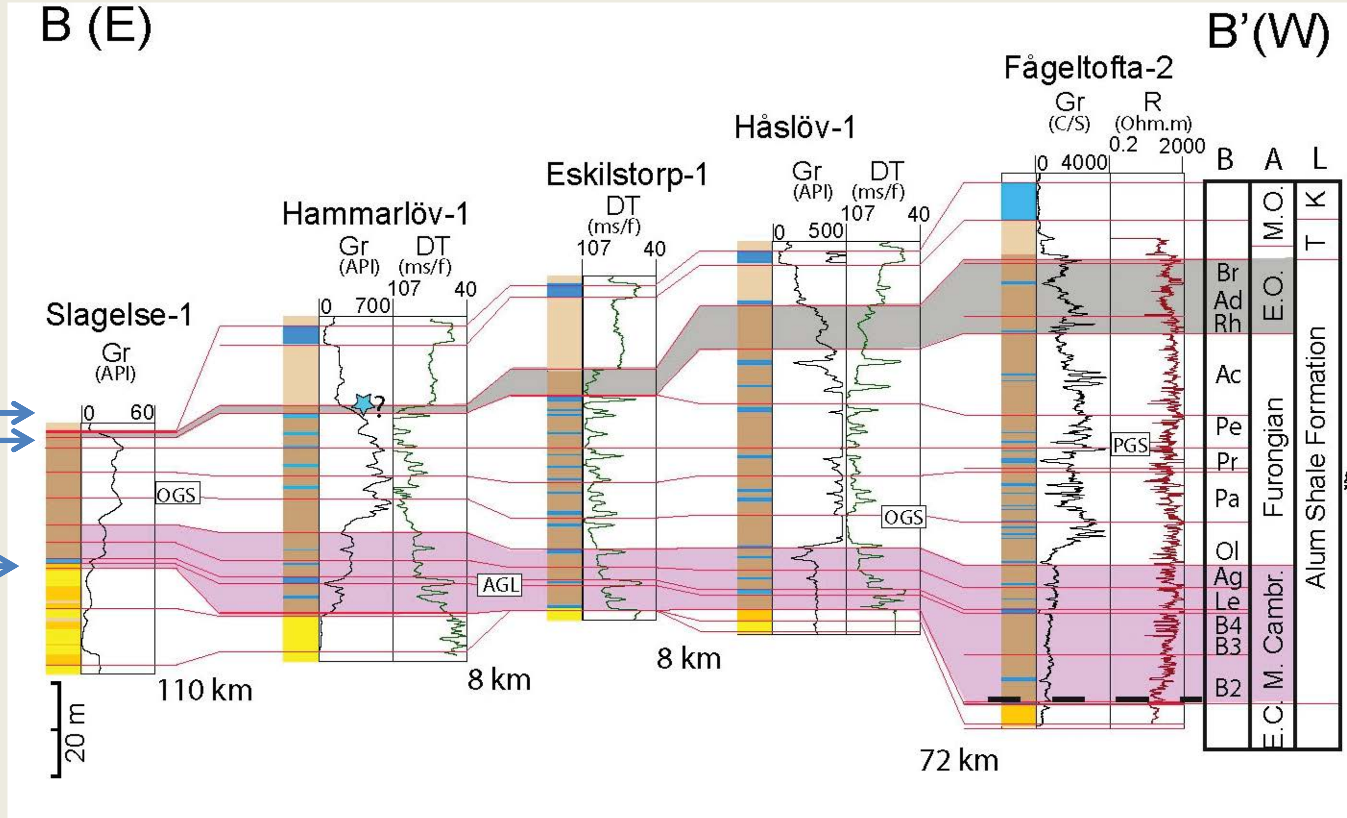
- Compositional differences between PCA-XRF rock types are delineated and single element rock types discriminators developed
- The PLS predicted rock types (defined elsewhere) suggest that rock type B is the weakest, and A1 the strongest (highest E) in the Alum Shale
- *XRF-discriminators can be further developed*

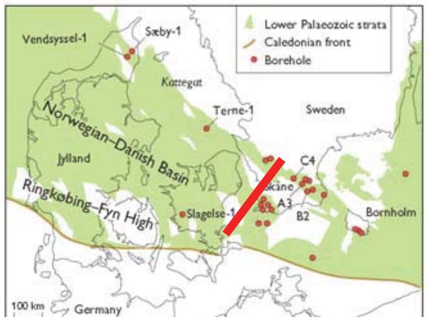
Albjära-1 core data before project start



- Furongian is 60 m thick and represent the on average highest TOC interval

Uplift and non-deposition/erosion

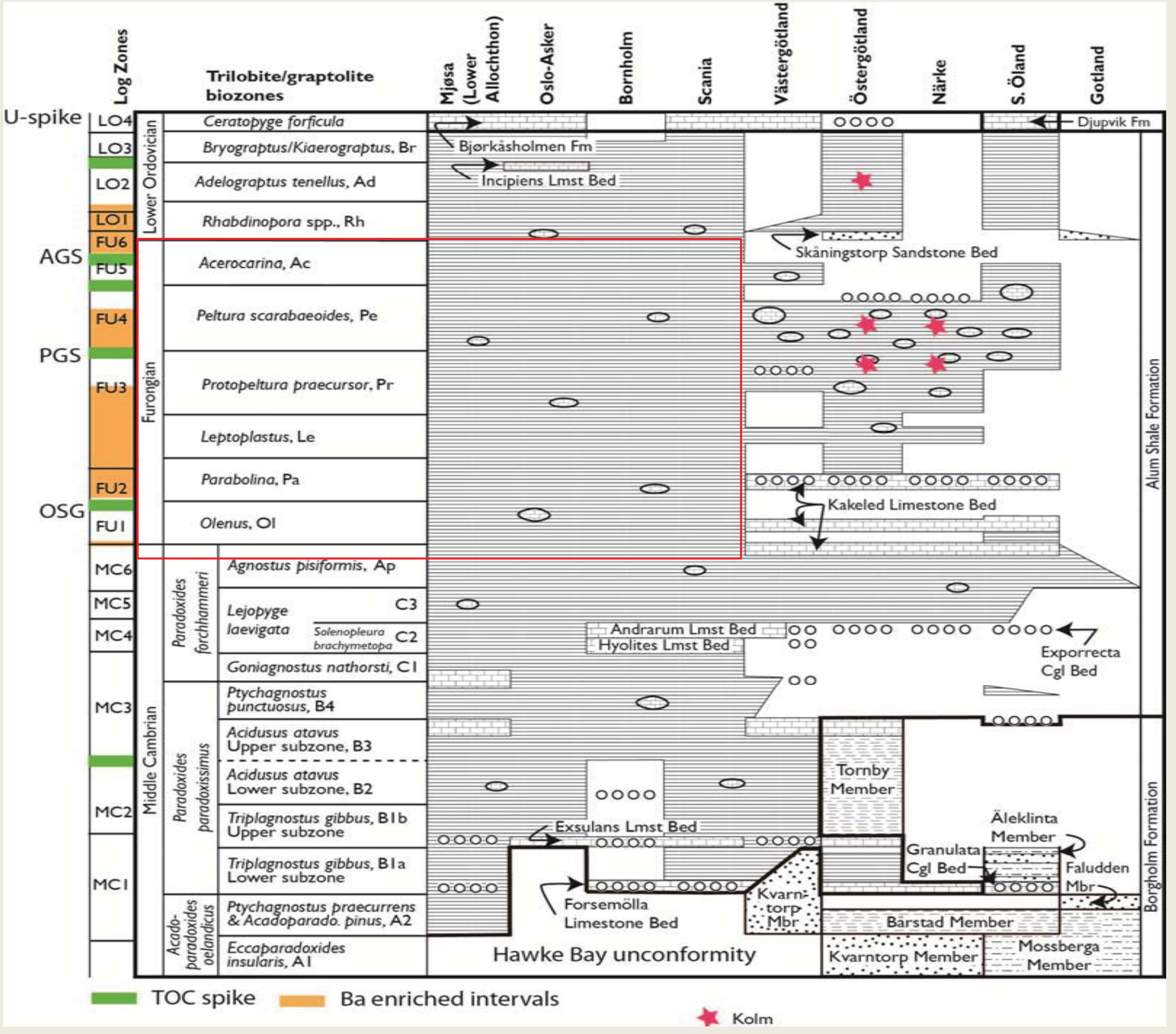




Publications with GEUS lead

- Abstract in EAGE 2015: ha-XRF composition of Alum Shale and Rock type definition based on PCA
- In prep. a paper on regional variation of Alum shale rock types in Denmark. Combine data with GEUS own on-going XRF study on Alum Shale from Telemarken area, Norway
- Future: Multi-source date integration work-flow for rock type prediction in the Alum gas play, Scandinavian

Stratigraphy



Shale with few concentrations (Ba, Ca, FeS) expected

GEUS

Rock type classification and property prediction in shales based on hand-held XRF data on core or cuttings

Niels H. Schovsbo, Kim Esbensen

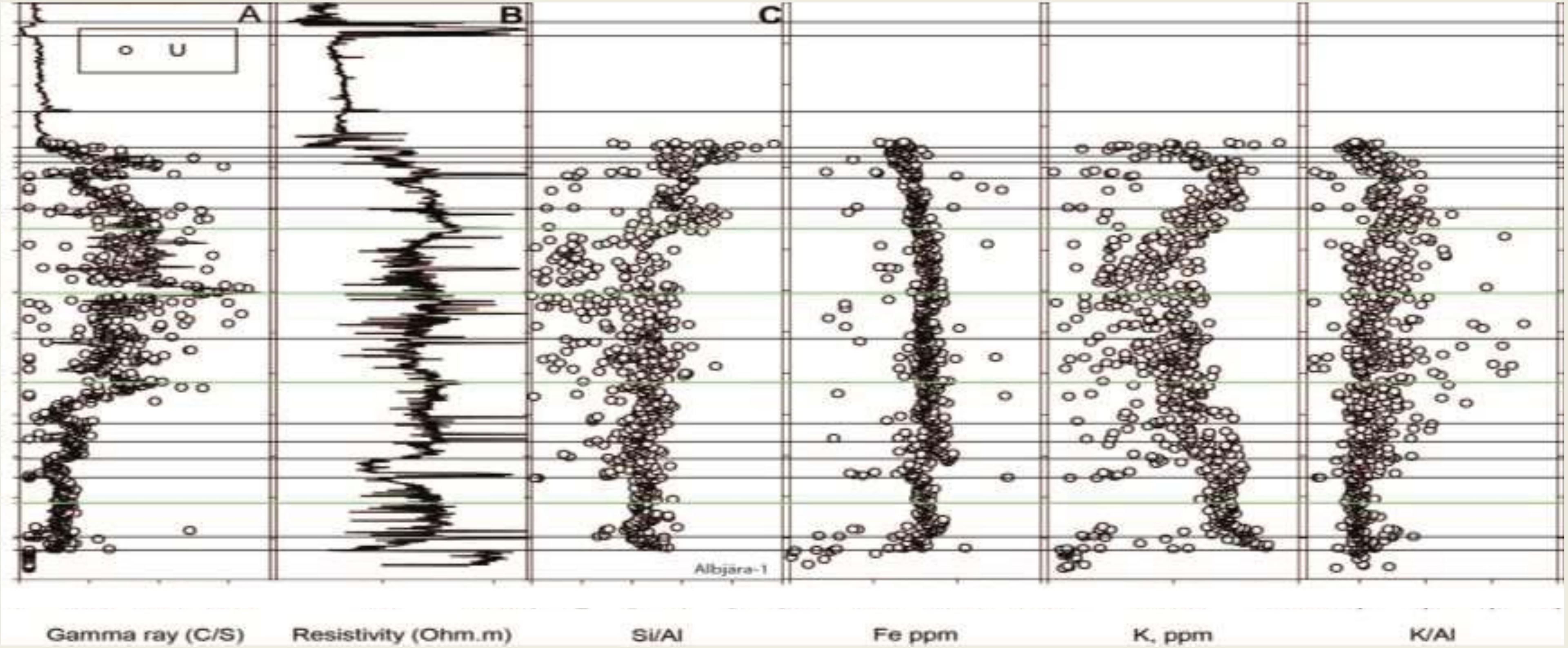
De Nationale Geologiske Undersøgelser for Danmark og Grønland
Klima-,Energi- og Bygningsministeriet

Prepared November 2014

Why

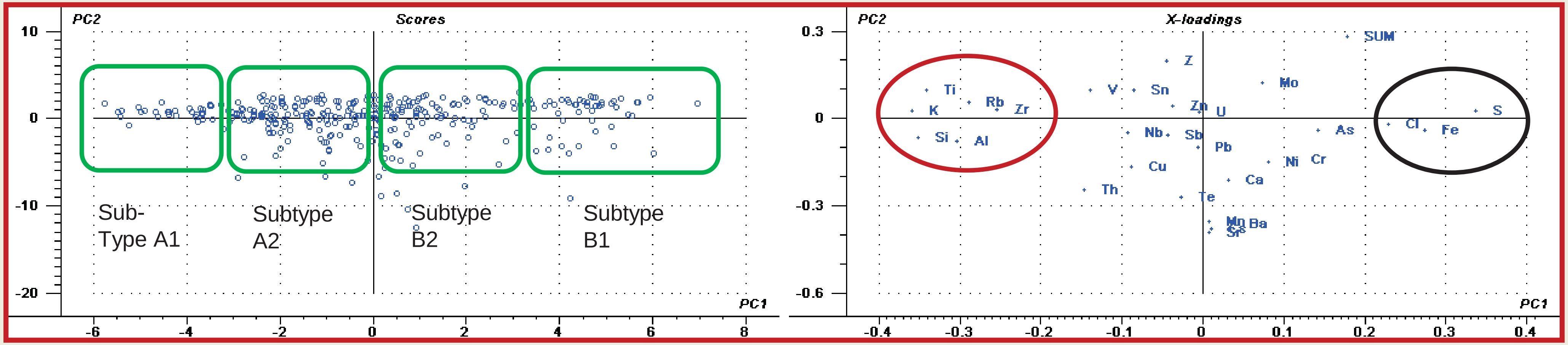
- Define criteria and work flow for rock type definitions with respect to key properties such as geo-mechanical properties
- Allow a representative sampling for advanced core testing in intervals most favourable
- Enable on-site evaluation of rock types during drilling
- Full documentation of methodologies and various transform/algorithms developed

Example of an analysed wells

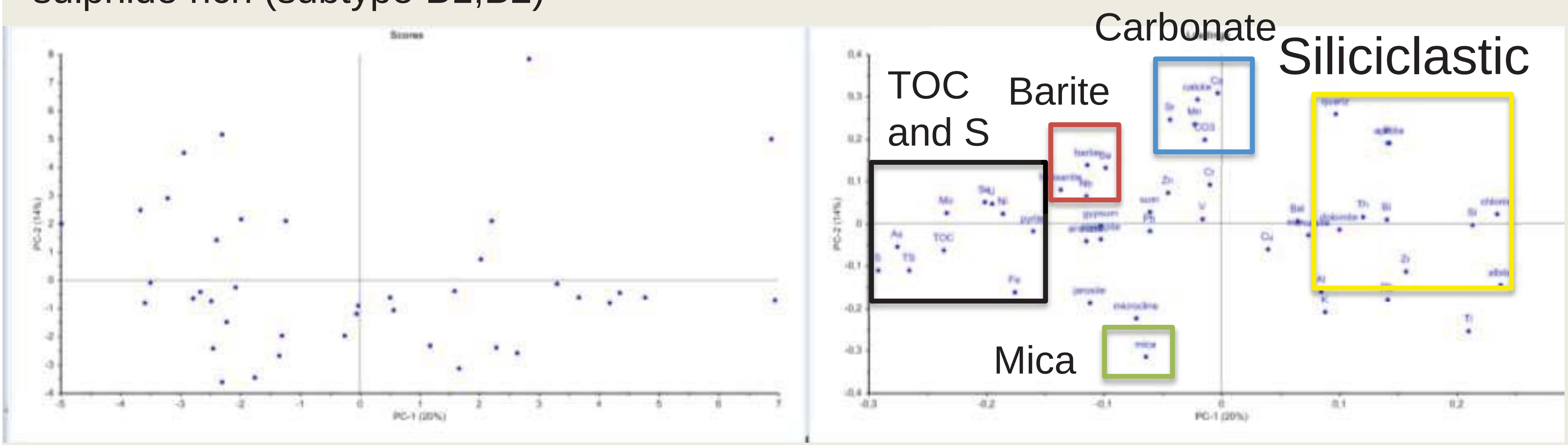


- Hand-held XRF measured 20+ elements. High resolution (8-10 samples pr m) profiles on core or cutting form basis for geochemical rock typing by multivariate statistical typing (PCA)
- U measured used to tie ha-XRF data to the wire-line logs and thus will assist the petrofysicist in interpreting the sections
- Fx. the Si/Al ratio is a proxy for sand/clay, the K/Al ratio for clay type

Example of analysis



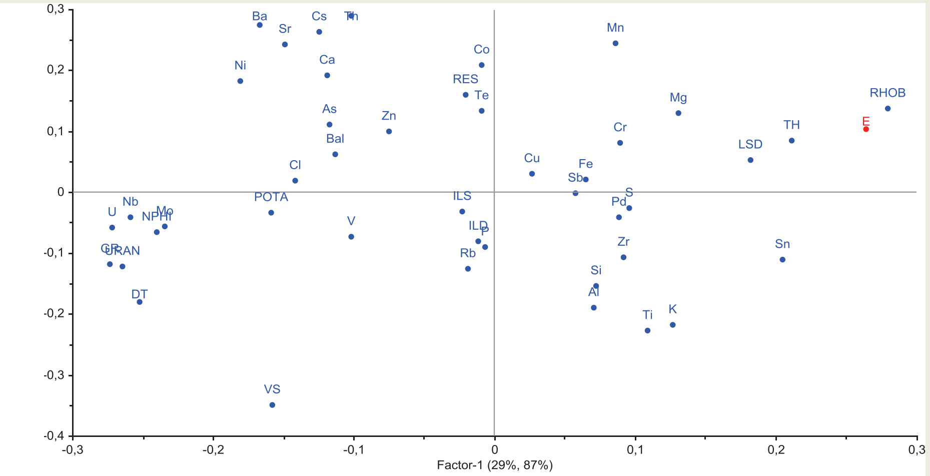
Rock types can be defined as a silicate rich (subtype A1, A2) as a sulphide rich (subtype B1,B2)

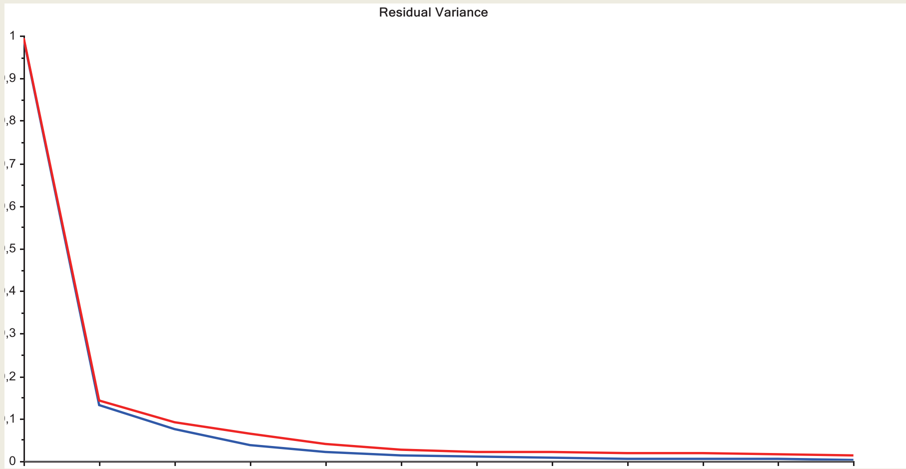


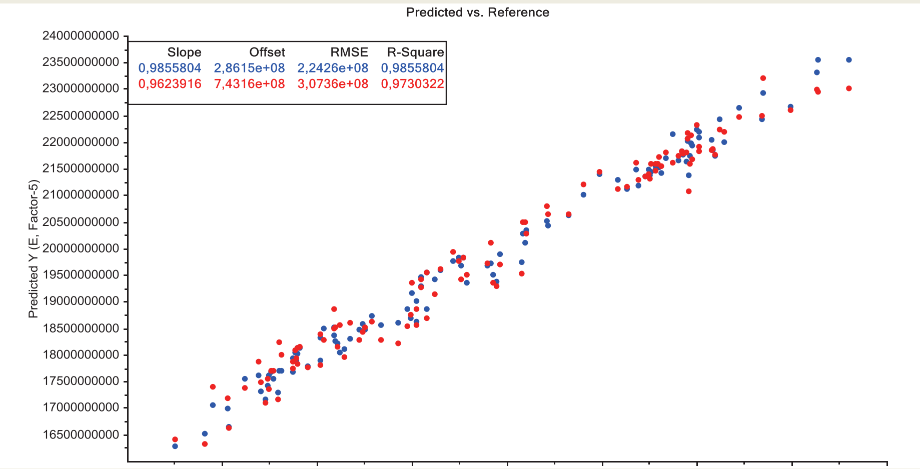
PCA of the XRD-XRF data to confirm mineralogical associations of the XRF dataset

Rock property prediction

Data input from the XX well.
Input similar as the PCA matrix (from which outliers have been removed
PLS1 model, 2-seg X-val, X = [logs, XRF], y = XX.
It is possible to establish an excellent model for XX-prediction based on logs + XRF data. Slope: 0.96; r^2: 0.97 This model uses all information available!

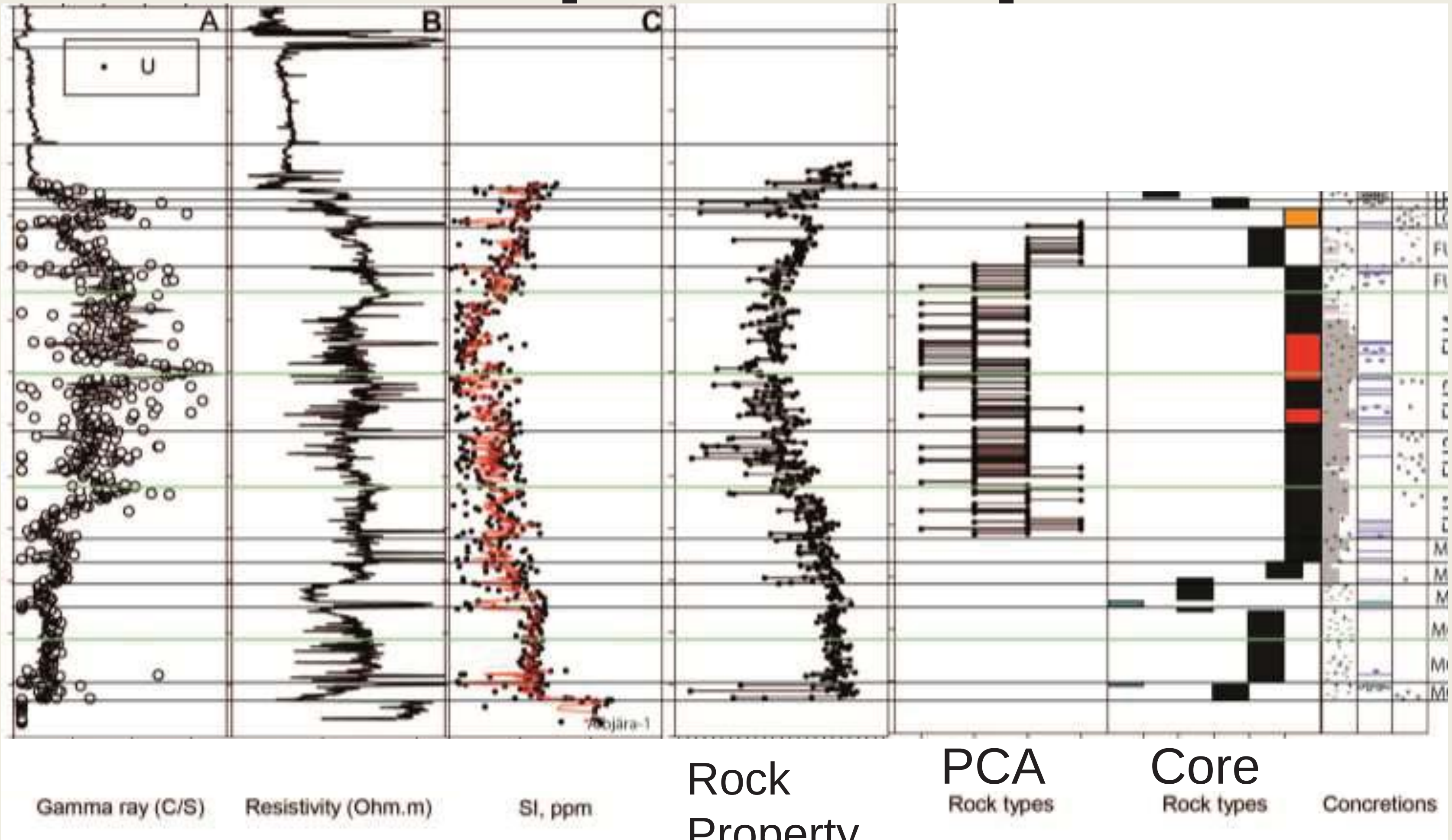






- Example of validation plot of a rock property prediction
- The resulting algorithm can be used directly in programs such as Techlog

Example of output



- PCA rock types calcification can be plotted vs depth and compared directly with other dataset i.e. core description
- Rock property predictions can be made on integrated ha-XRF and wireline log database

Deliveries

- Integrated XRF data with log data by means of various statistical methods (e.g. PCA; PLS) and prediction of rock properties

- Development of transforms that allow prediction of properties between wells or between vertical and horizontal sections of a well

- Definition of key chemostratigraphical markers that can be used when geo-steering or for casing point definitions