

Sequence Stratigraphy of the Inyan Kara Formation, North Dakota*

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Search and Discovery Article #51414 (2017)**

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Abstract

The Inyan Kara Formation of North Dakota is the lowermost unit of the Lower Cretaceous Dakota Group. The formation is the primary subsurface injection zone for produced water where over a million barrels/day is injected. This work examines the subsurface stratigraphy of the Inyan Kara within North Dakota to identify potential areas for produced water injection. A partial core from the Amerada Petroleum Corporation, Math Iverson #1 (NDIC: #165, API: 33-105-00097-00-00) in Williams County was used along with wireline logs from thousands of wells to map the Inyan Kara in the subsurface and develop a working sequence stratigraphic model. Five detailed 1:100,000 scale Inyan Kara sandstone isopach maps (Crosby, Parshall, Stanley, Watford City, and Williston) from the heart of the Bakken in northwestern North Dakota have been published to date, with three more (Grassy Butte, Kenmare, Killdeer) planned for 2017. Numerous sedimentary structures and sequence stratigraphic surfaces are observed in both core and on logs. Gamma-ray signatures from well logs are characterized by a distinct, blocky pattern for coarser-grained sandstone deposits, commonly over 100 feet thick. These sandstones then grade upwards into finer-grained units of interbedded sand, silt, and clay.

Based on these observations, the Inyan Kara can be subdivided into two units that reflect the overall sea-level rise of the Early Cretaceous. The lower half is interpreted to be a "fluvial-dominated, incised valley-fill complex that can be subdivided into the following systems tracts: (1) initial incising of the lowermost valley during falling stage; (2) filling of the valley during lowstand and early transgression; (3) initial incursion of the seaway with subsequent flooding and development of estuarine deposits during transgression; and (4) progradational marine deposits of the highstand. This same depositional sequence is repeated in the

upper Inyan Kara and into the overlying lower shales of the Skull Creek Formation, with the lower sequence capped by a subaerial unconformity. The model shows coastline evolution through time and correlation of sequence stratigraphic surfaces basinward/landward from northwestern North Dakota. It can be used to predict the presence and extent of incised-valley-fill sandstone bodies for produced water disposal, as well as distinguishing such bodies from other coarser-grained units that have lesser potential for injection. Results indicate that sandstones of the valley fills are well connected along valley trends (10's of km) and within valleys (km); whereas, coarser deposits of the estuarine, marginal marine, and interfluvial facies are not as laterally continuous or well connected.

References Cited

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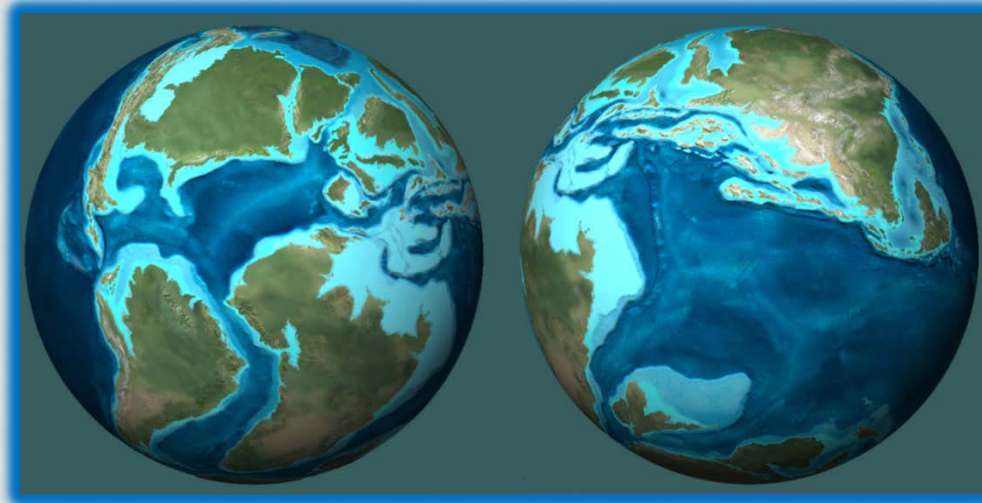
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SEQUENCE STRATIGRAPHY OF THE INYAN KARA FORMATION NORTH DAKOTA

Jeffrey W. Bader

North Dakota Geological Survey

AAPG Rocky Mountain Section

June 26, 2017

ALBIAN (106 MA)



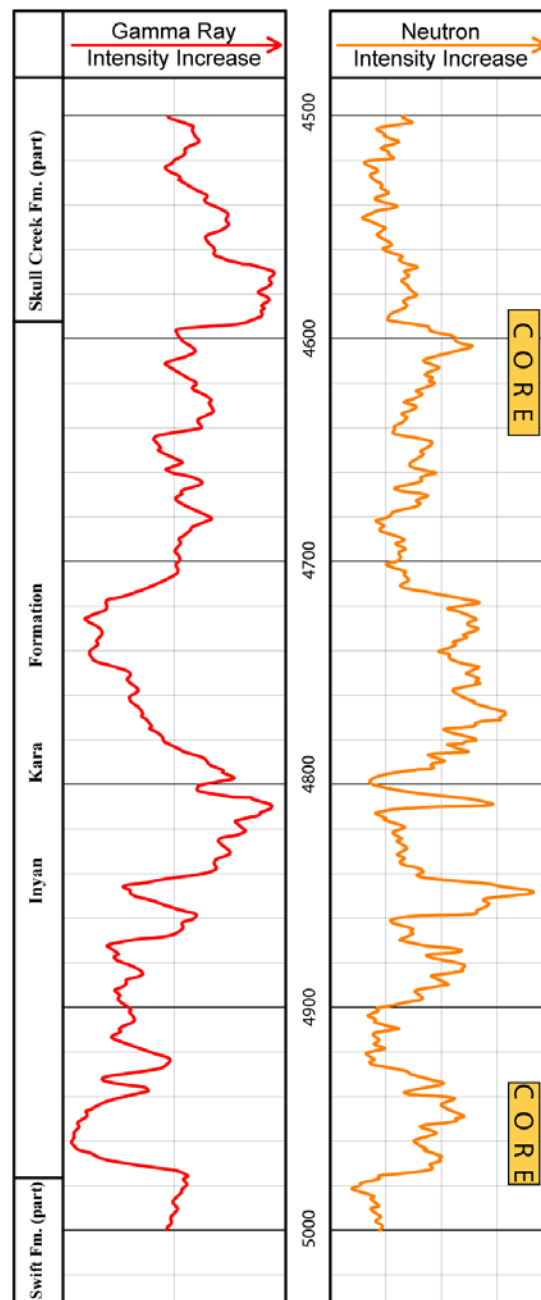
Modified from Blakey, 2014



MATH IVERSON #1 (WILLIAMS COUNTY)

Inyan Kara Fm.

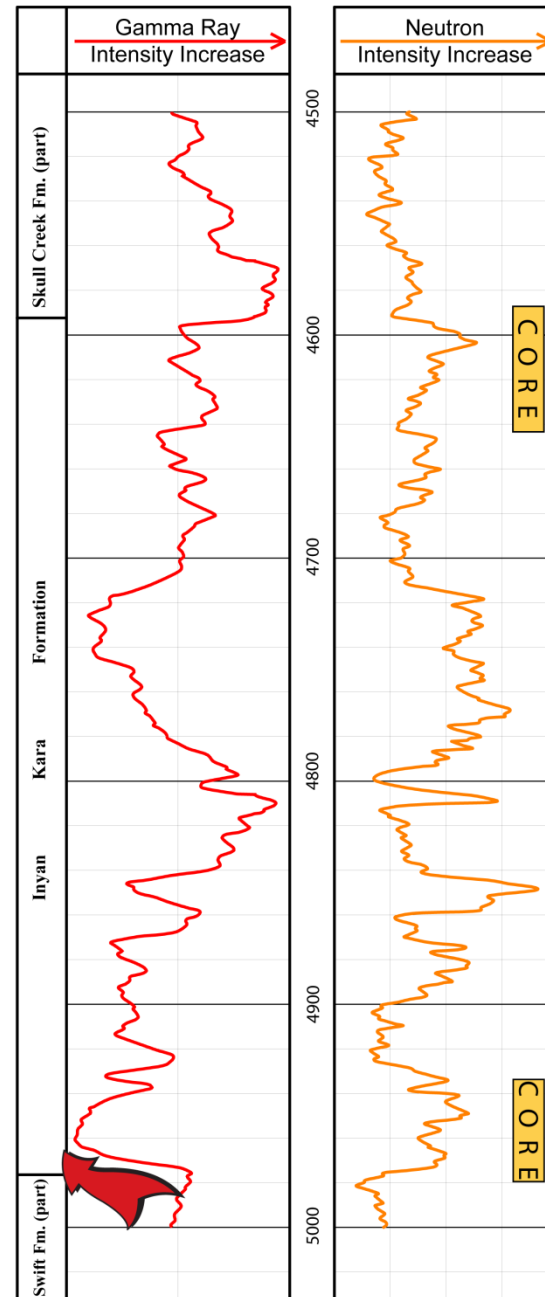
- Kik @ 4,594'-4,970'
- Unconformable above Js
- Conformable below Ksc
- Core
 - 4,586'-4,644'
 - 4,937'-4,980'



MATH IVERSON #1 (WILLIAMS COUNTY)

Inyan Kara Fm.

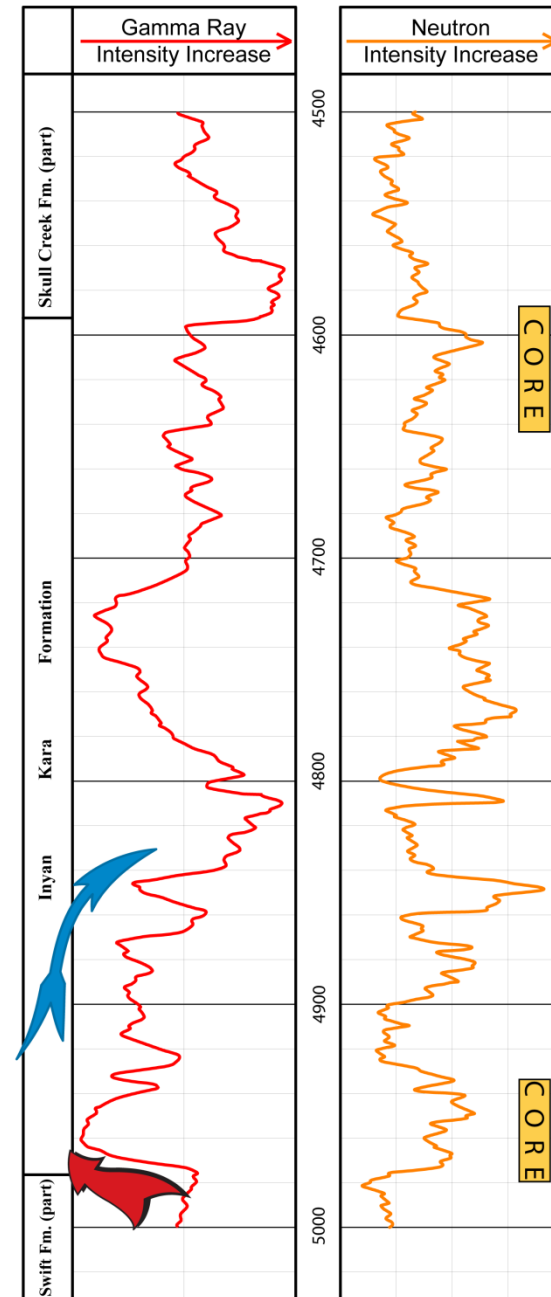
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- Conformable below Ksc
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MATH IVERSON #1 (WILLIAMS COUNTY)

Inyan Kara Fm.

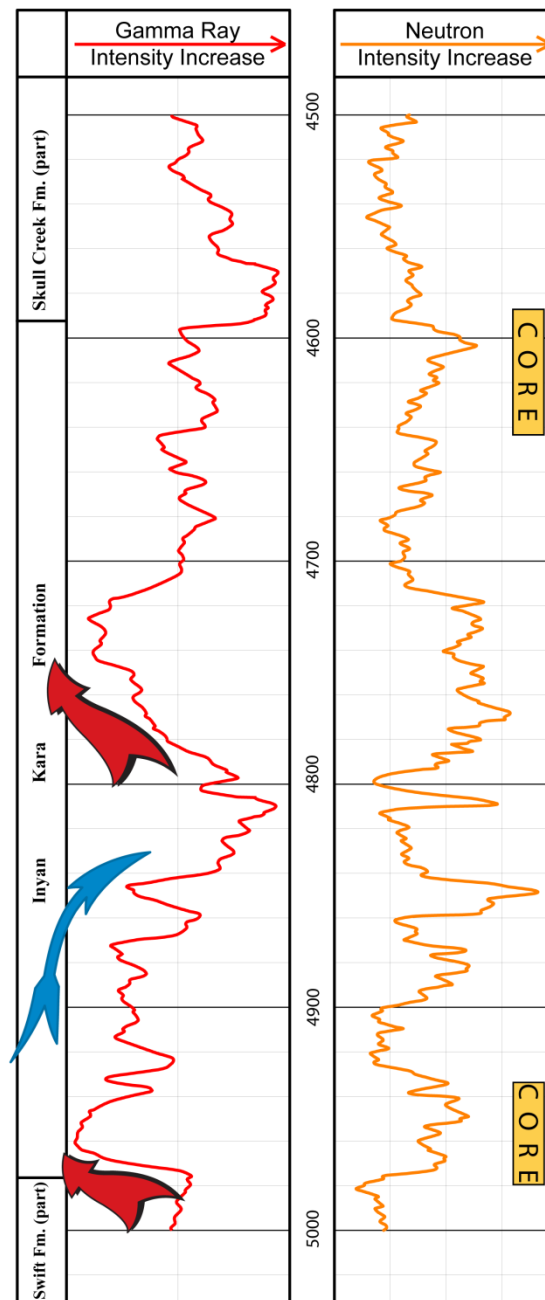
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- Unconformable above Js
- Conformable below Ksc
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MATH IVERSON #1 (WILLIAMS COUNTY)

Inyan Kara Fm.

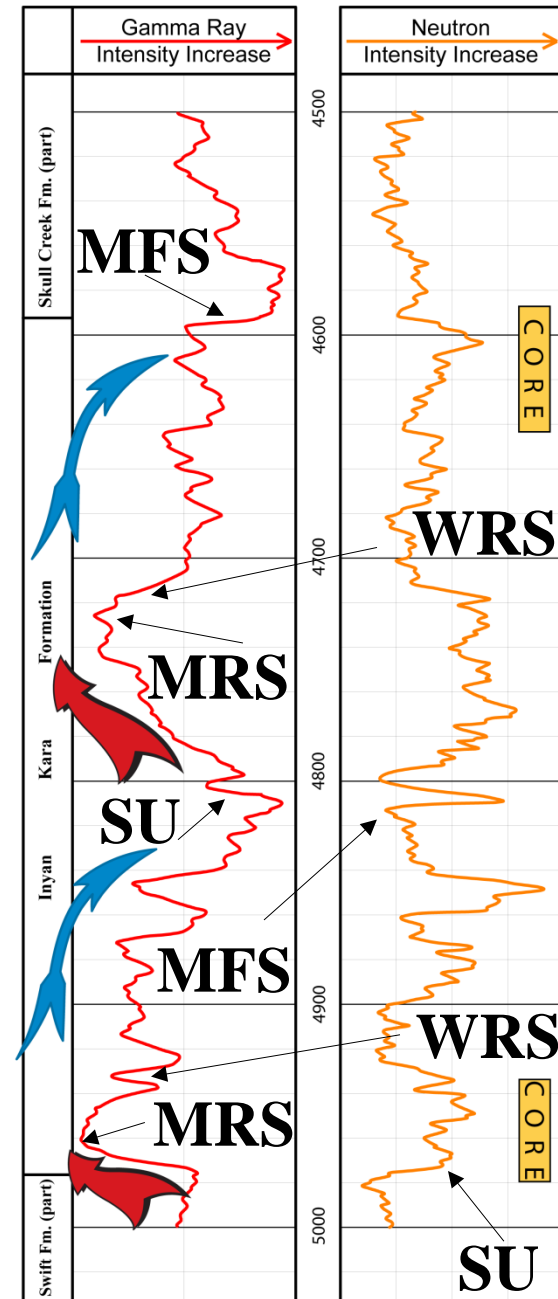
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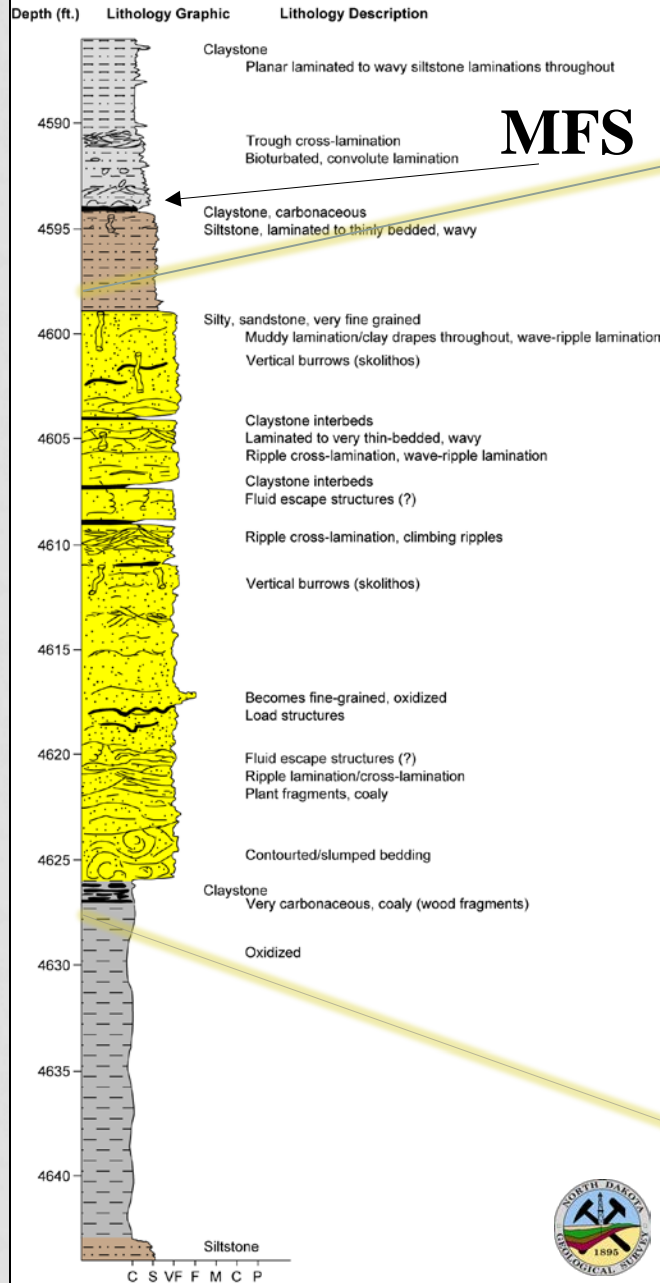
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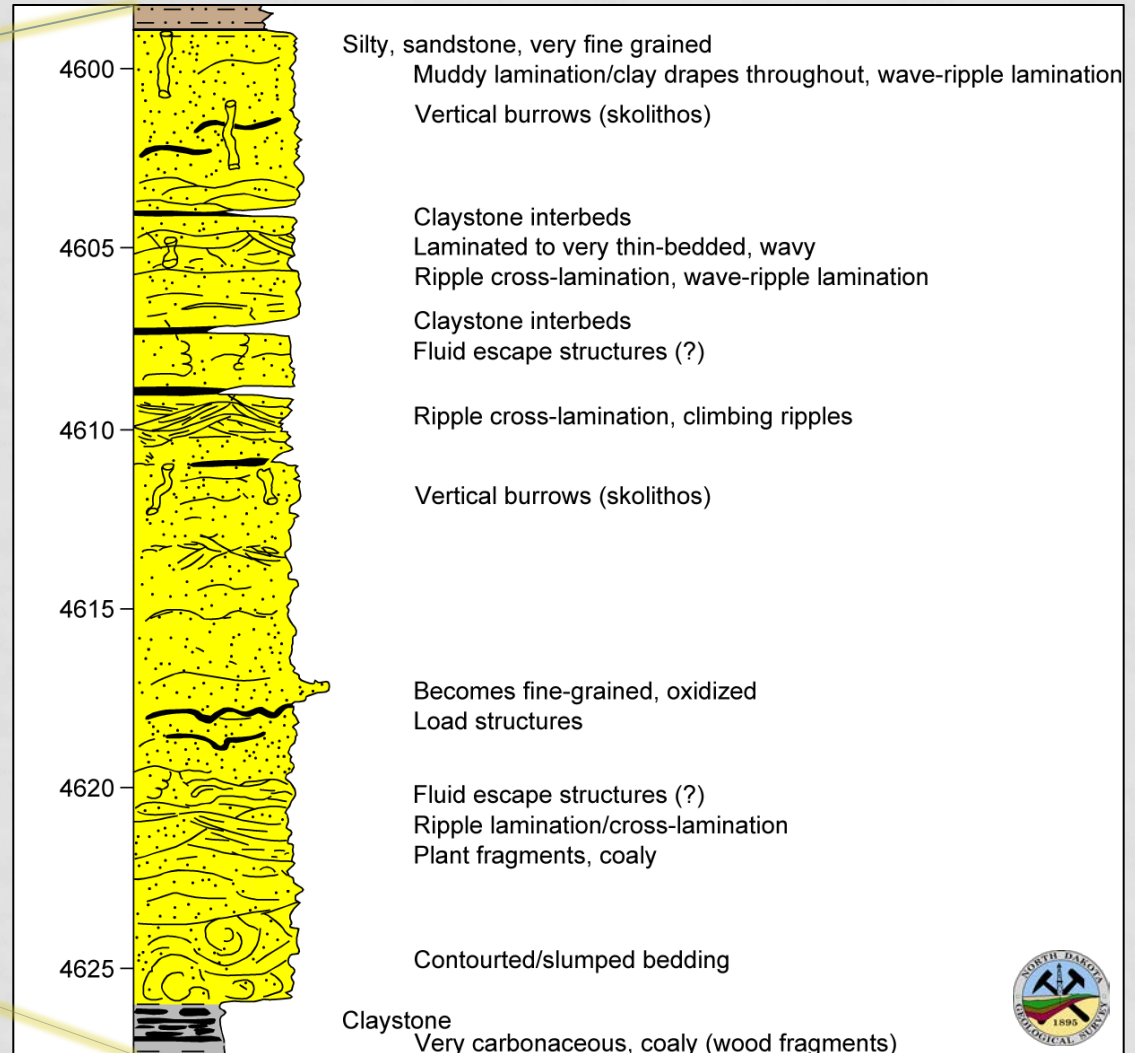


Math Iverson #1
3310500097
#165
4586 - 4644 ft.

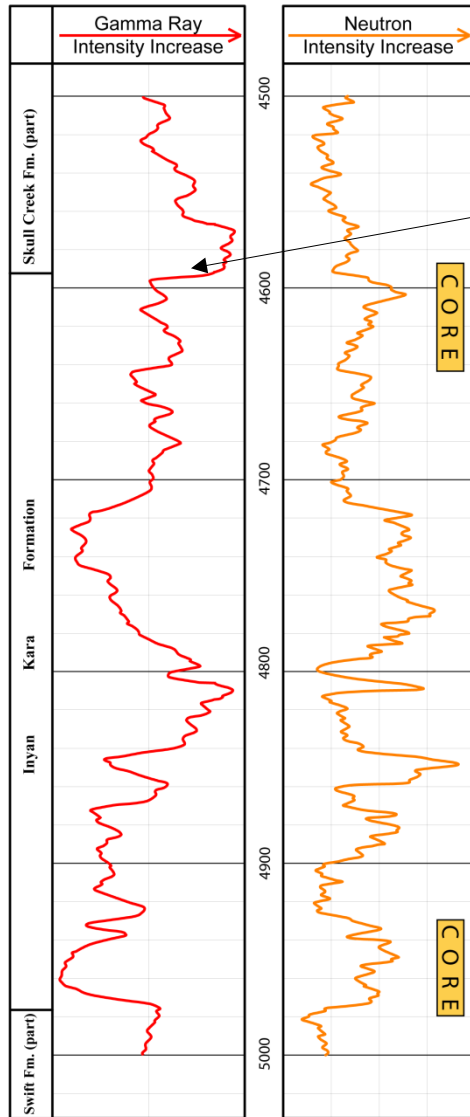


MATH IVERSON #1

4,586 - 4,644 FEET



#165
 33-105-00097-0000
 SWNW Sec. 1, T155N R96W
 Amerada Hess Corporation
 Beaver Lodge-Madison Unit G-11
 K.B. = 2,340 ft.



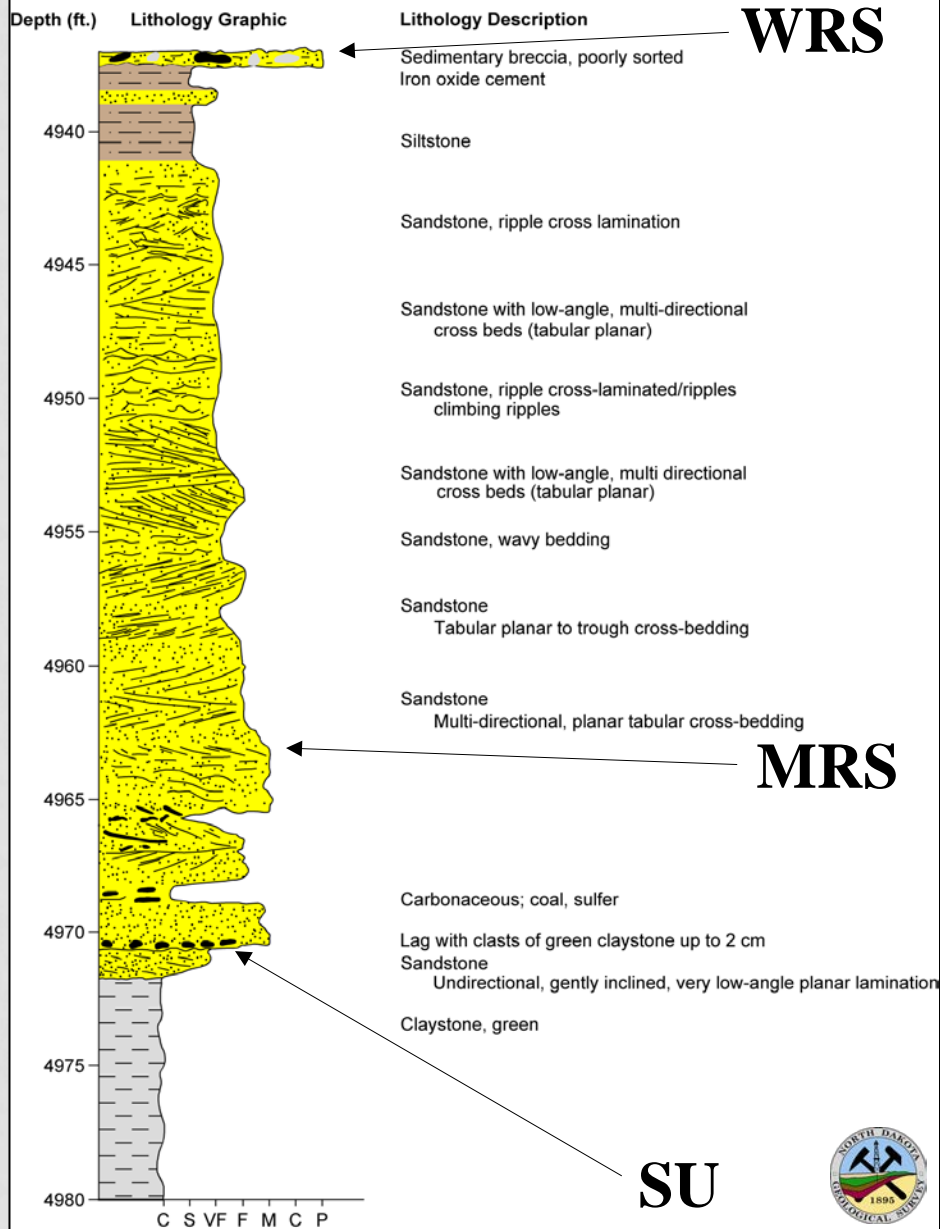
MFS



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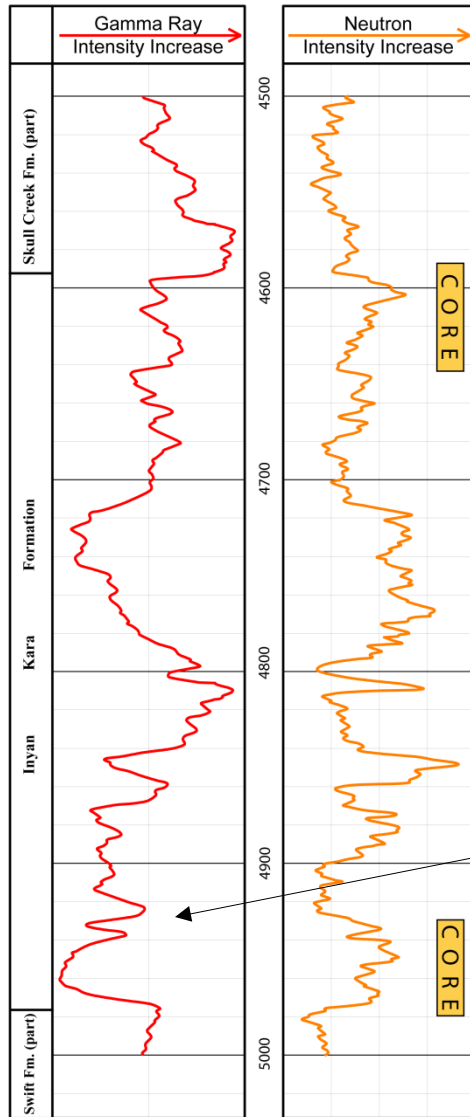
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4,937 - 4,980 FEET



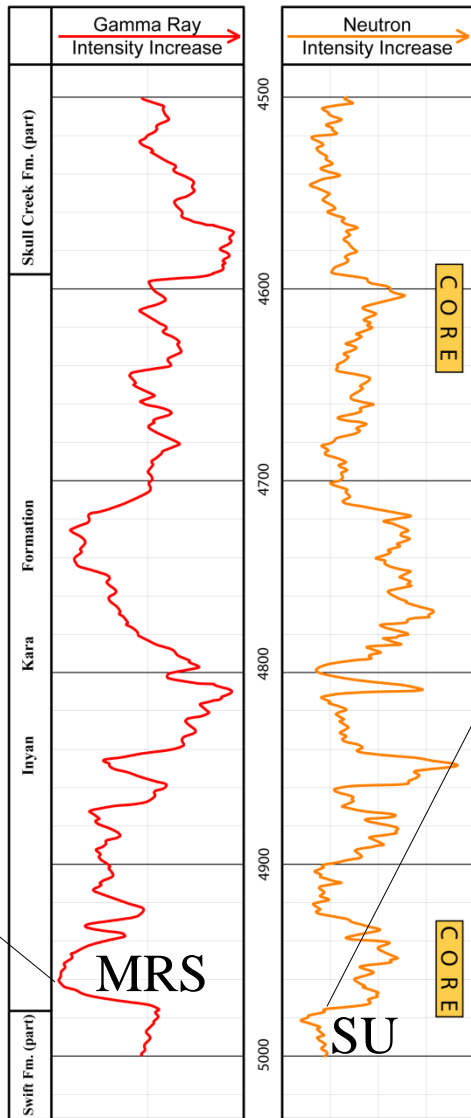
TRANSGRESSIVE LAG

- Shale clasts
- Phosphate nodules
- Coaly/carbonaceous clasts
- Larger clasts in finer-grained matrix



WRS





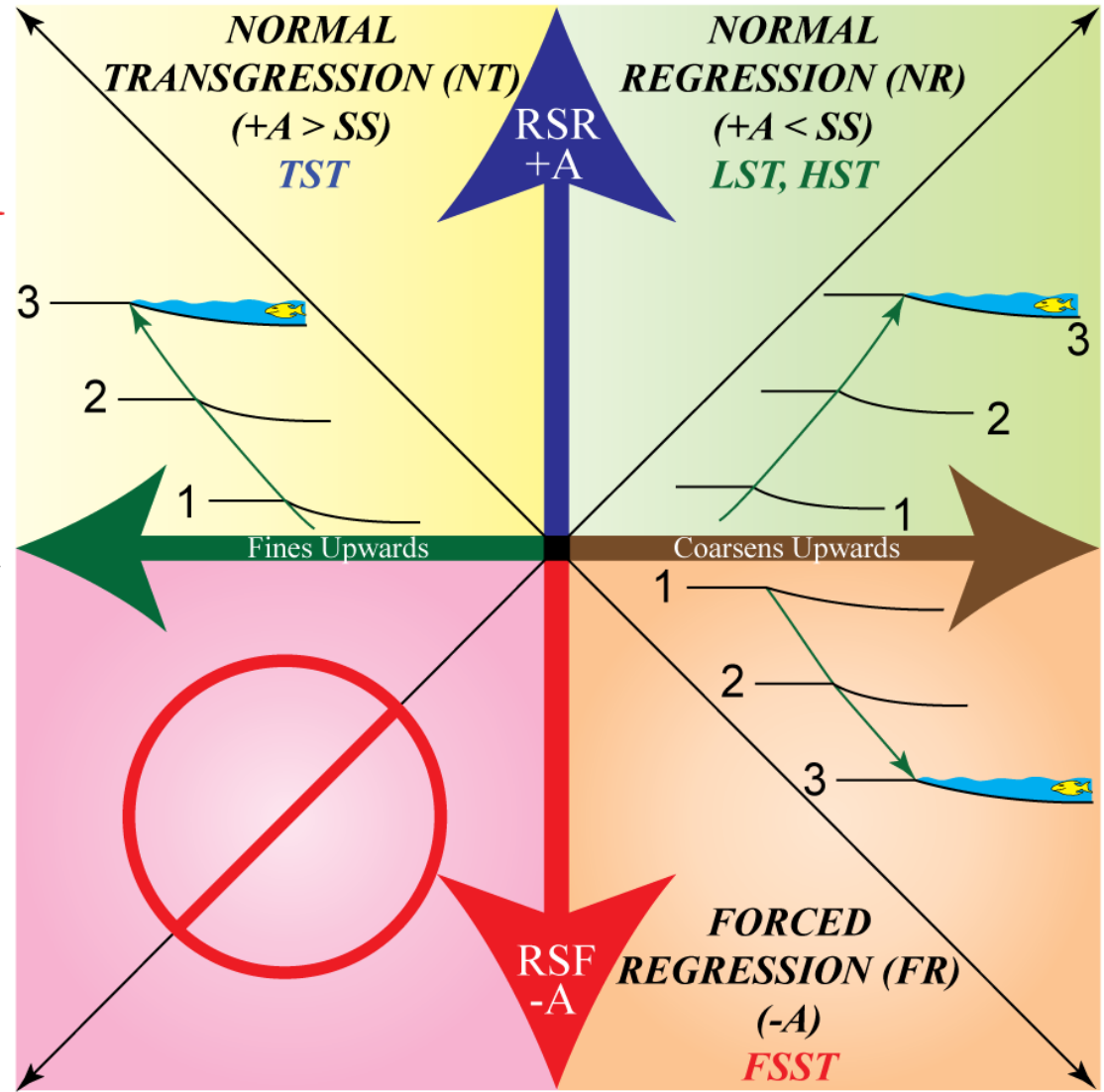
KEYS TO THE STUDY

- Core (One, Uno, Ichi, Un, Eins...)
 - Sedimentary structures
 - **Sequence stratigraphic surfaces**
- **Logs** (Tens of Thousands)
 - Over 8,100 wells in NW ND; hundreds across state
 - Stacking patterns
 - **Sequence stratigraphic surfaces**
- Sea-Level Curve (known model)
 - **Sequence stratigraphic surfaces**
 - Sequence stratigraphic systems tracts

= **Depositional Environment**



LAND Aggradation SEA



GR

GR

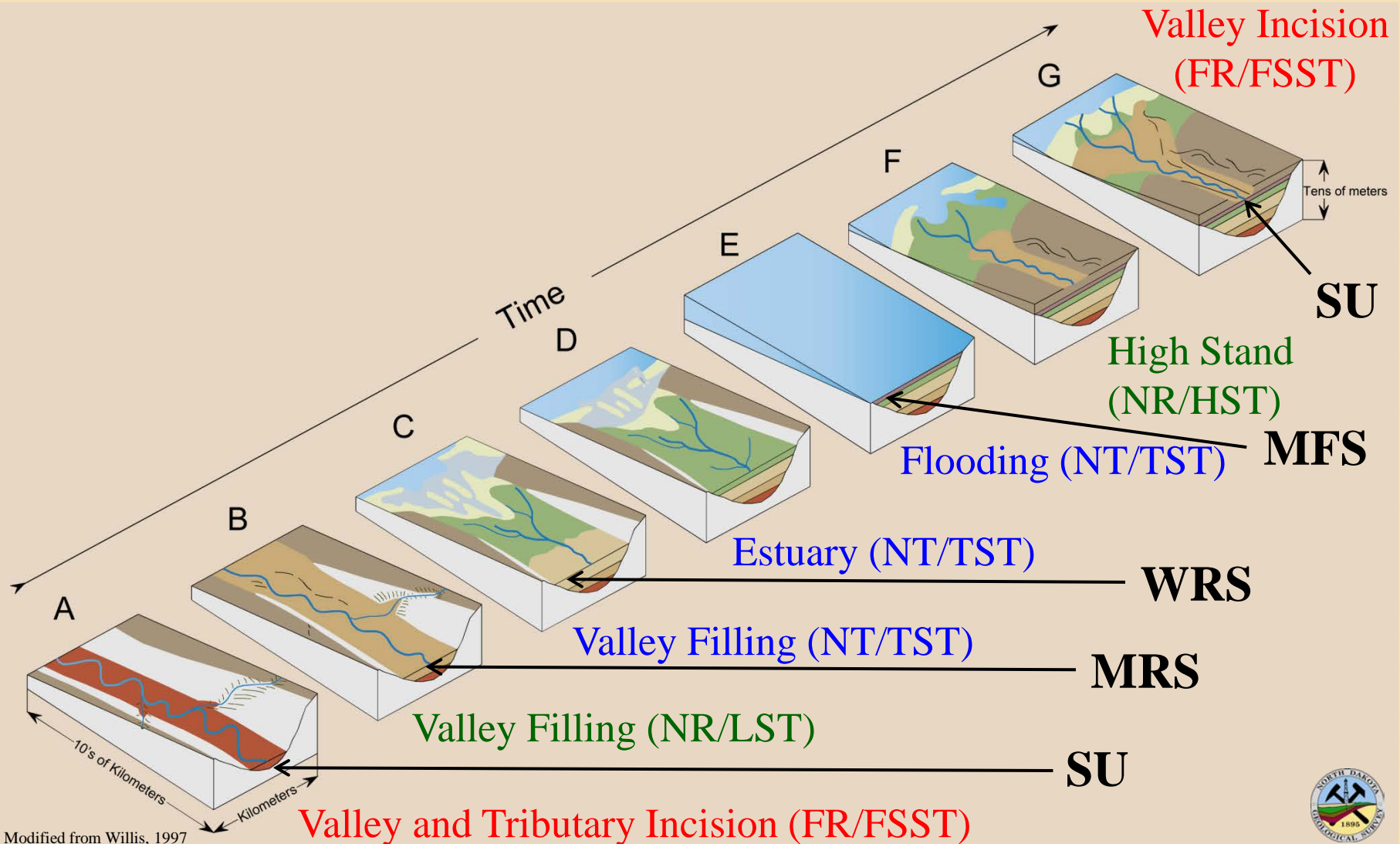
Retrogradation

Progradation

Degradation



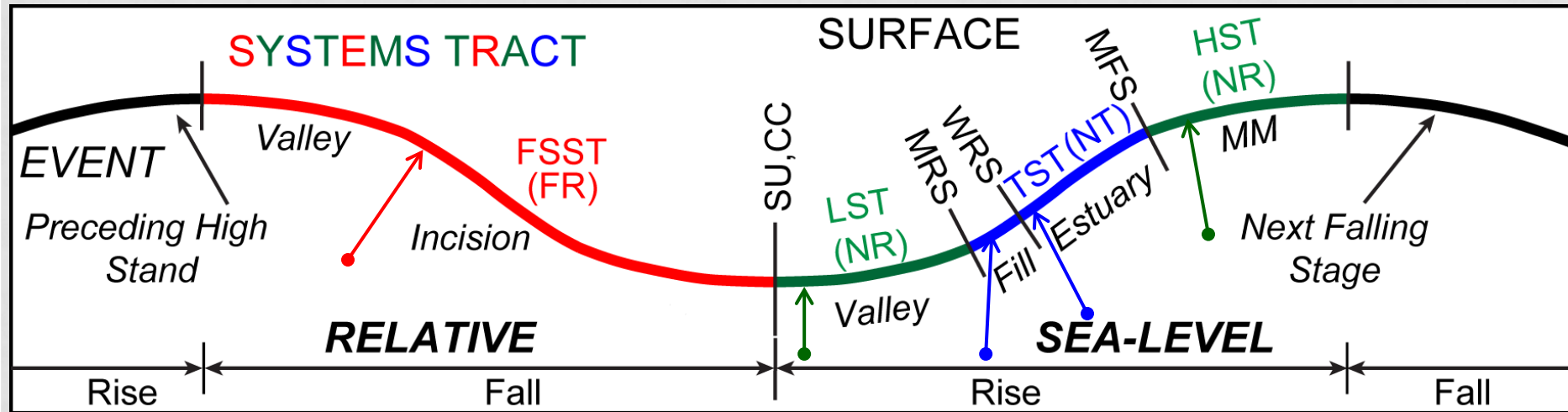
EVOLUTION OF AN INCISED VALLEY TRANSGRESSIVE RIVER MOUTH



Modified from Willis, 1997

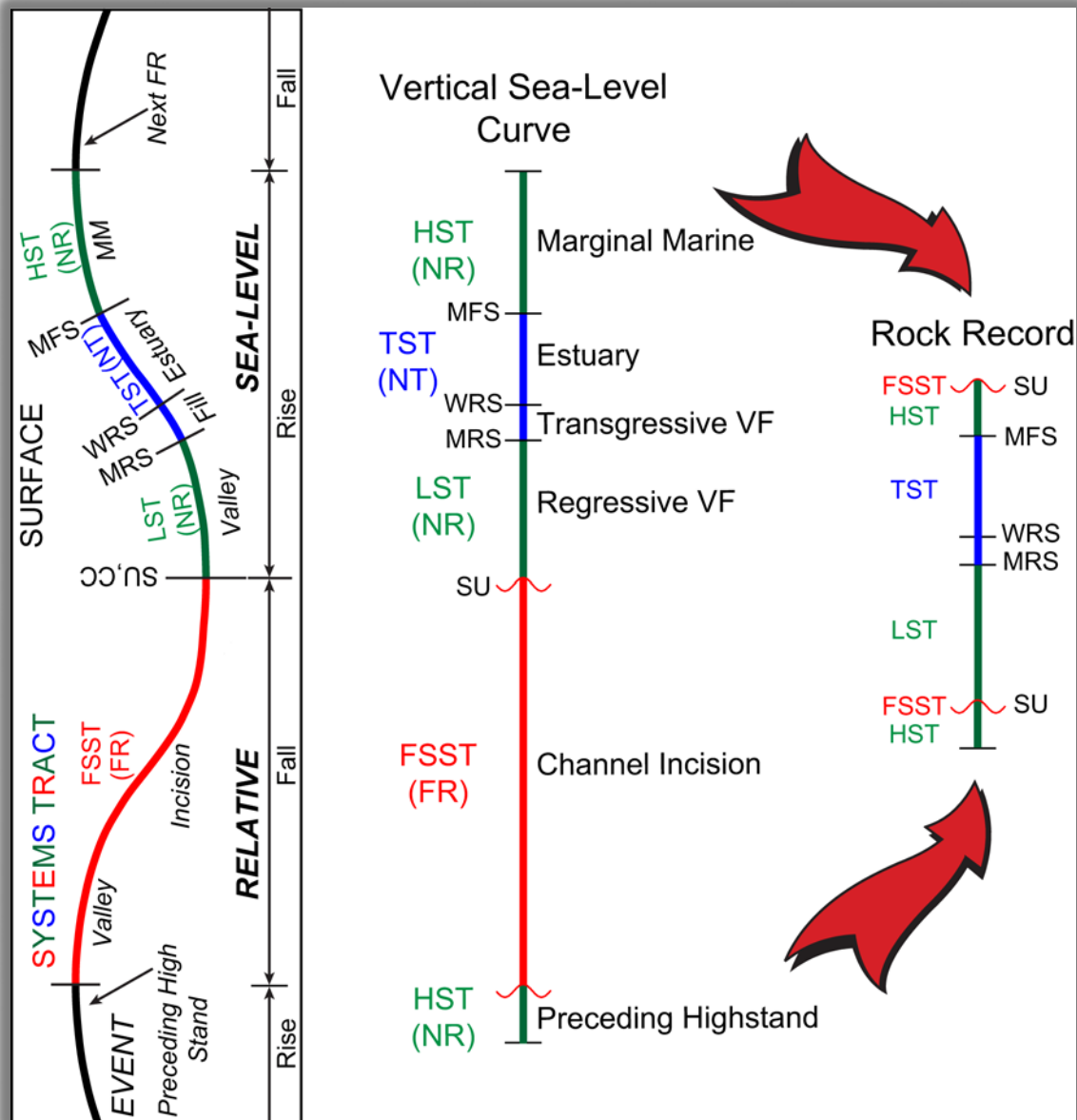


EVOLUTION OF AN INCISED VALLEY RELATIVE SEA-LEVEL CURVE



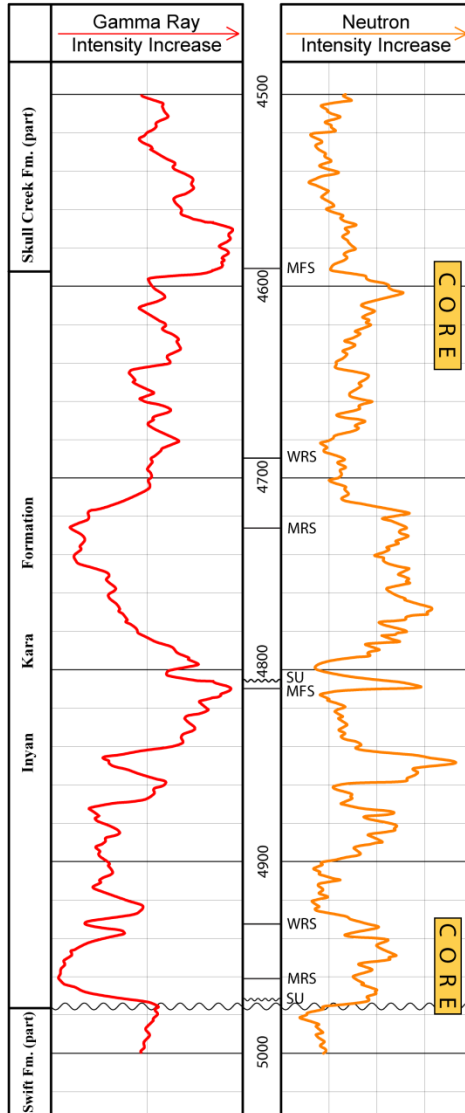
EVOLUTION OF AN INCISED VALLEY

RELATIVE SEA-LEVEL CURVE





#165
33-105-00097-0000
SWNW Sec. 1, T155N R96W
Amerada Hess Corporation
Beaver Lodge-Madison Unit G-11
K.B. = 2,340 ft.



MATH IVERSON #1

SURFACES AND EVENTS

Nearshore Marine Deposits

Maximum Flooding

Shallow Marine Deposits

Estuarine Deposits = Transgression = Flooding

RSLR-Valleys Filled

Maximum Flooding

Shallow Marine Deposits

Estuarine Deposits = Transgression = Flooding

Wave Ravinement = Transgression Underway

RSLR-Valleys Filled

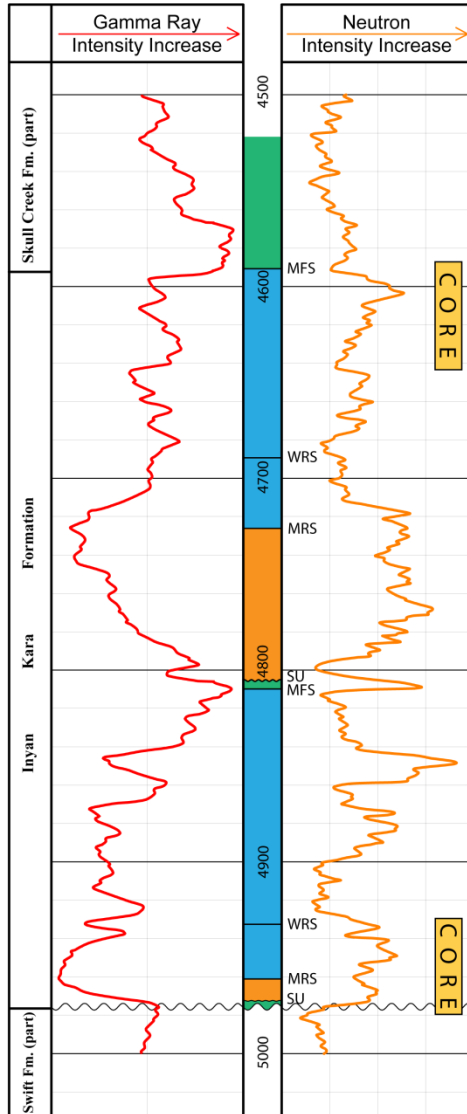
RSLR

FR-Valleys Incised = SU

FR-Valleys Incised = SU



#165
33-105-00097-0000
SWNW Sec. 1, T155N R96W
Amerada Hess Corporation
Beaver Lodge-Madison Unit G-11
K.B. = 2,340 ft.



MATH IVERSON #1 SYSTEMS TRACTS

HST

Regression

TST

Transgression

LST

Regression

HST

FSST

Transgression

TST

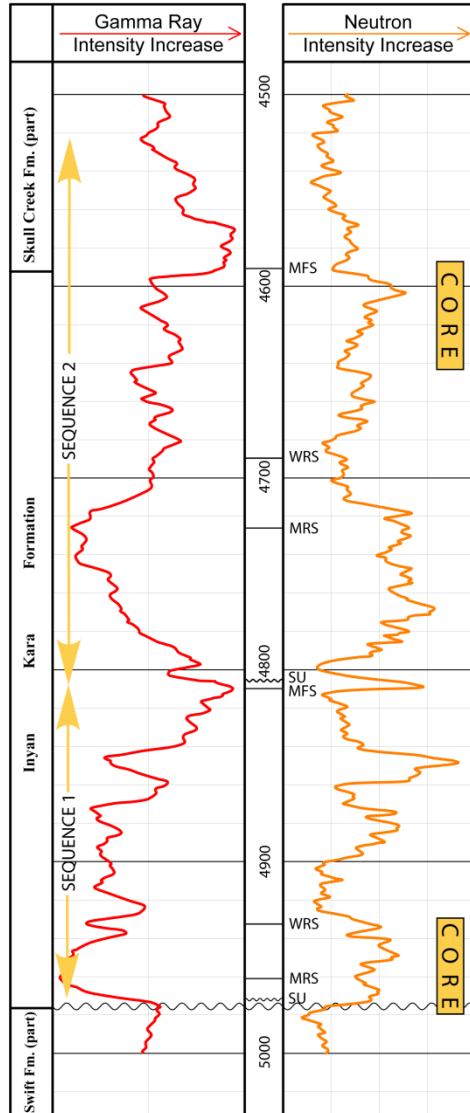
LST
HST

FSST

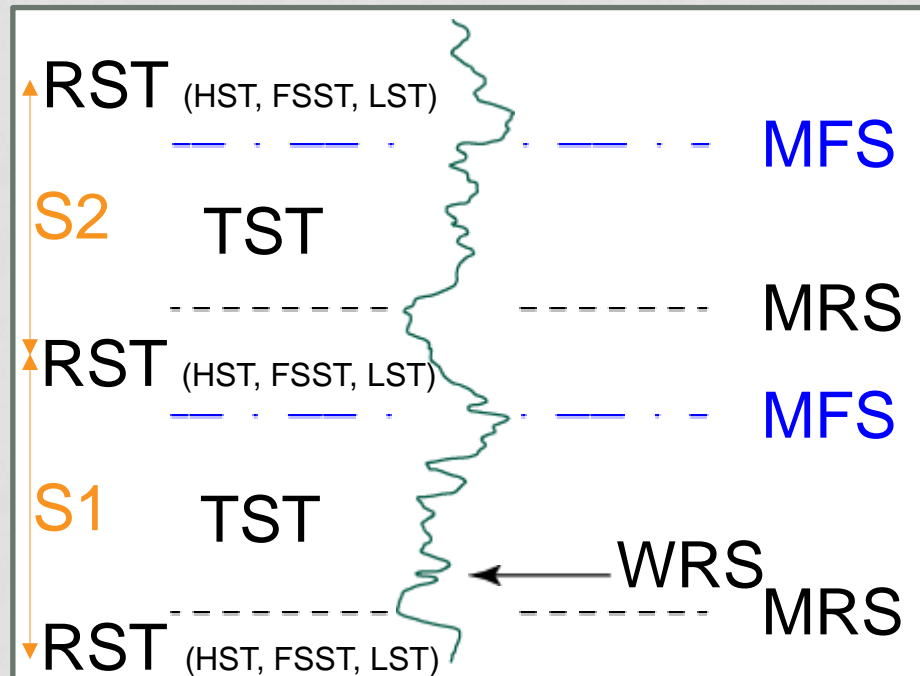
Regression



#165
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Amerada Hess Corporation
Beaver Lodge-Madison Unit G-11
K.B. = 2,340 ft.



MATH IVERSON #1 SEQUENCES





#165

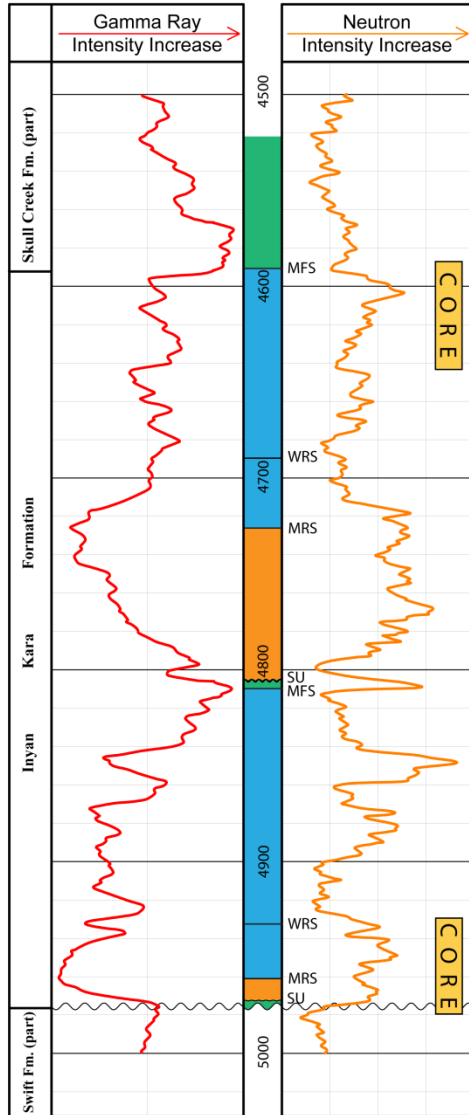
33-105-00097-0000

SWNW Sec. 1, T155N R96W

Amerada Hess Corporation

Beaver Lodge-Madison Unit G-11

K.B. = 2,340 ft.



MATH IVERSON #1

REGIONAL T & R EVENTS

Skull Creek High Stand
(105-102 Ma)

Skull Creek
Transgression
(106 Ma)

Fall River Low Stand
(107 Ma)

Fall River High Stand
(110-108 Ma)

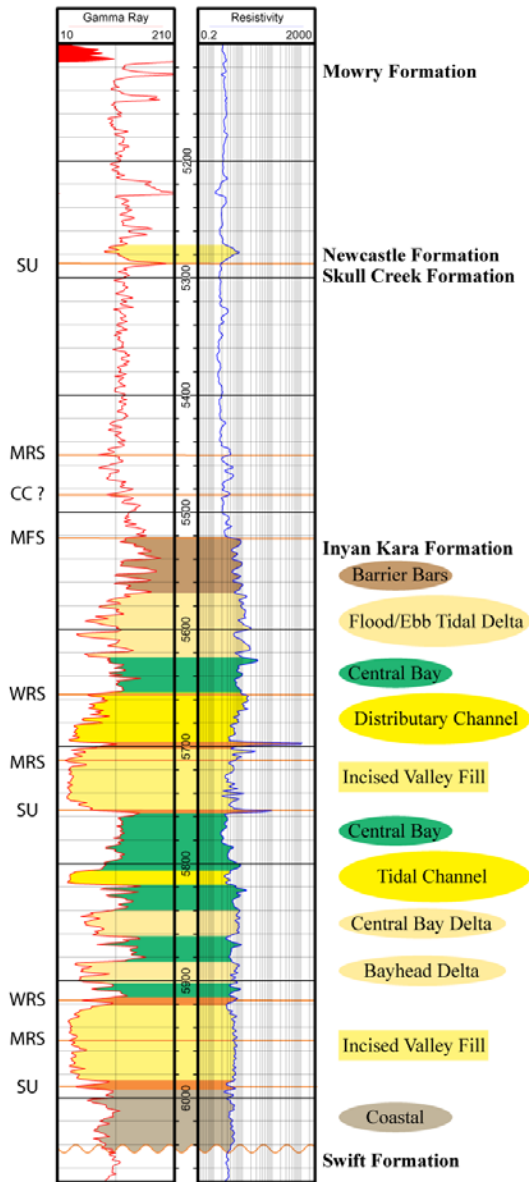
Fall River
Transgression
(113-111 Ma)

Aptian Low Stand
(120-115 Ma)

Modified from Blakey, 2014



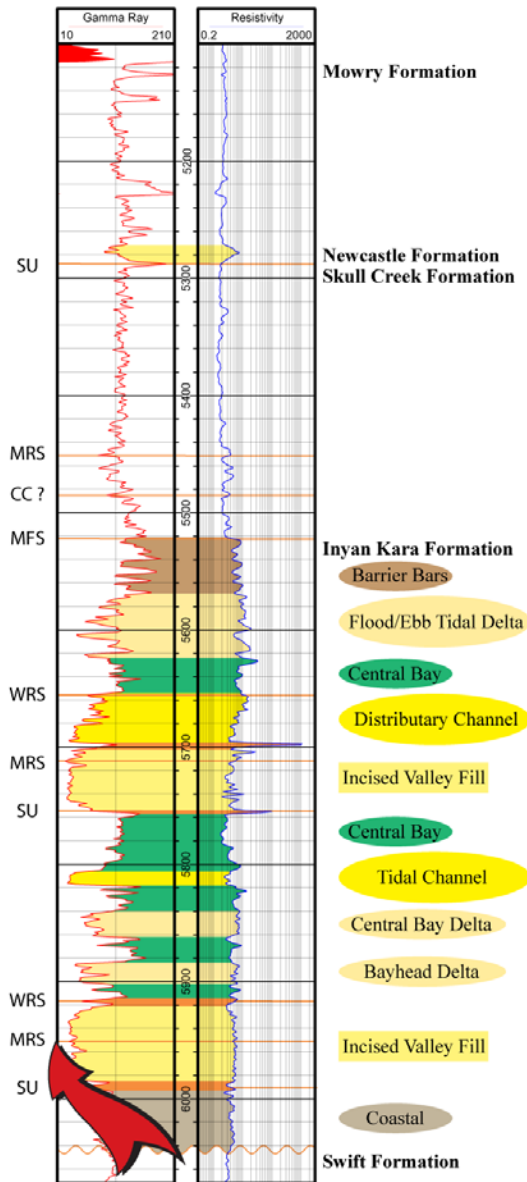
90233
33-053-90233-0000
Sec 30 T152N R101W
ECS 1
K.B. = 2,217 ft.



ECS #1

MCKENZIE COUNTY

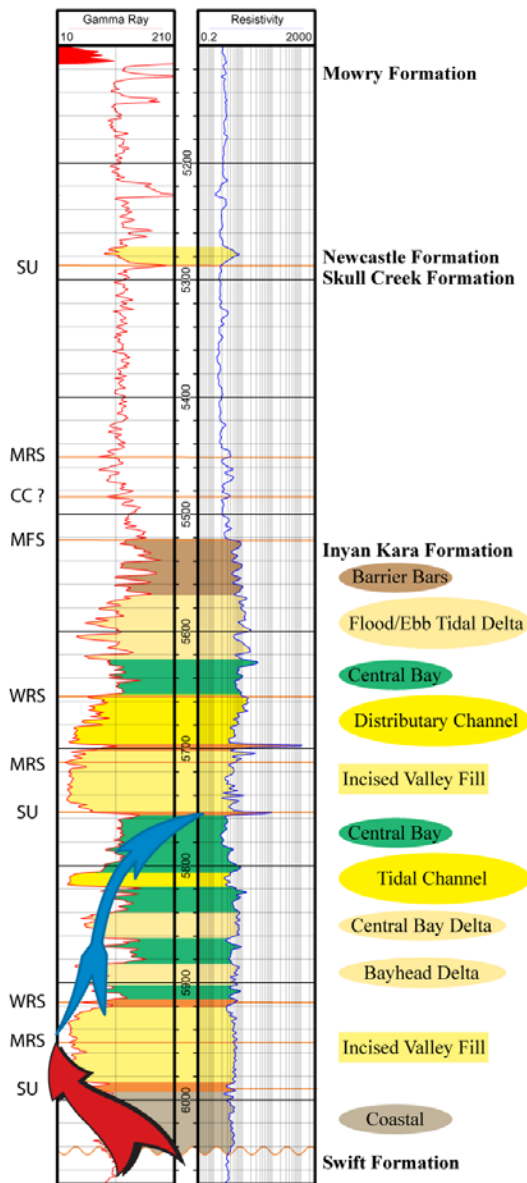
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Sec 30 T152N R101W
ECS 1
K.B. = 2,217 ft.



ECS #1

MCKENZIE COUNTY

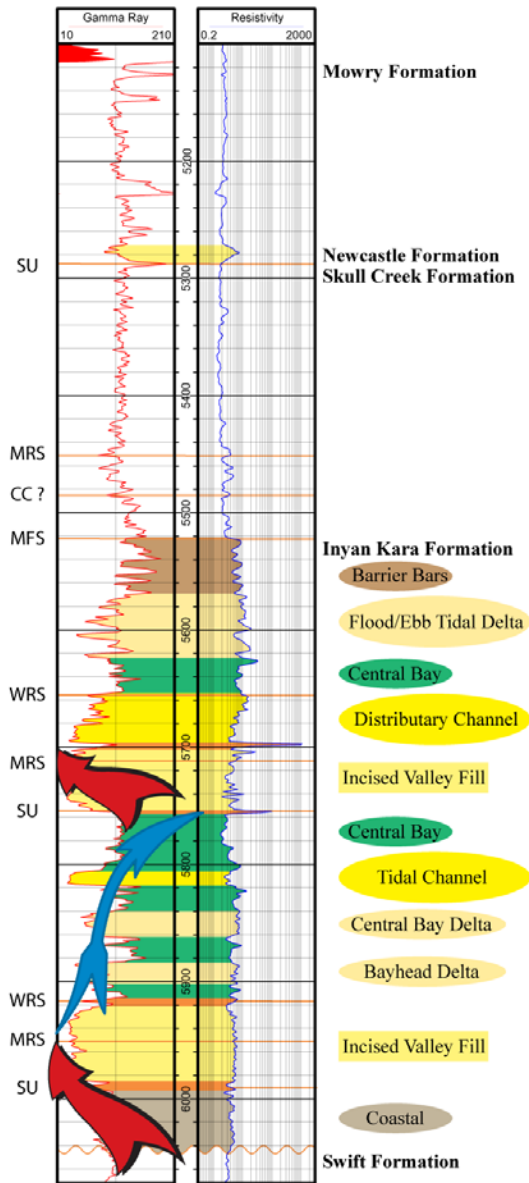
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ECS 1
K.B. = 2,217 ft.



ECS #1

MCKENZIE COUNTY

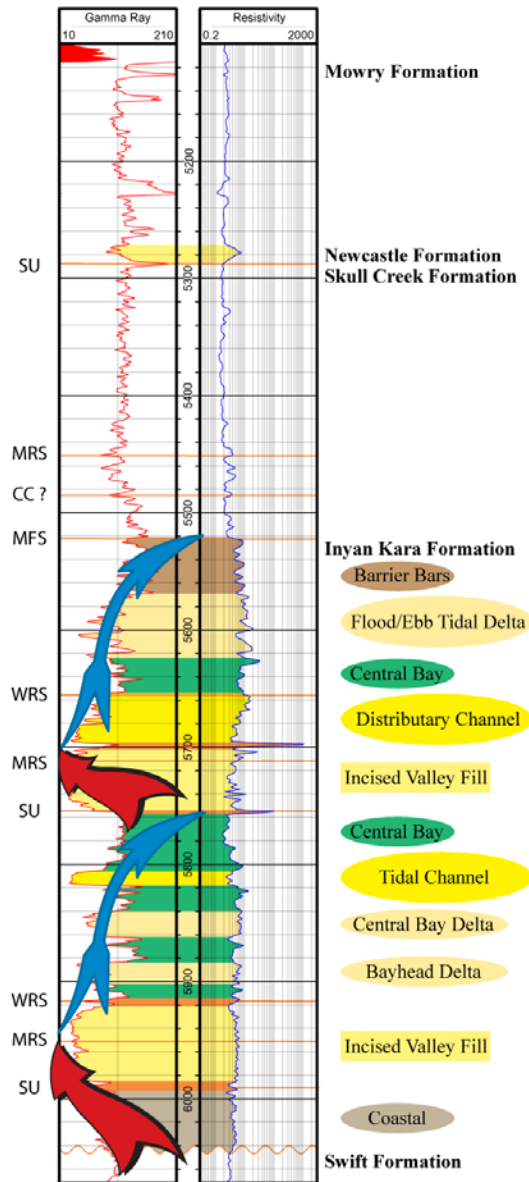
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ECS #1

MCKENZIE COUNTY

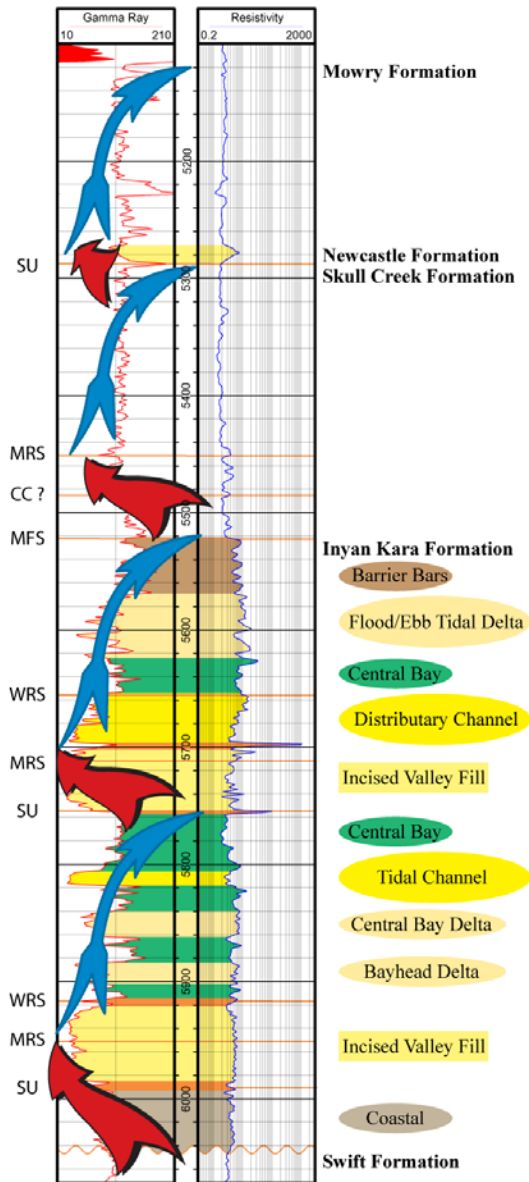
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Sec 30 T152N R101W
ECS 1
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ECS #1

MCKENZIE COUNTY

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Sec 30 T152N R101W
ECS 1
K.B. = 2,217 ft.



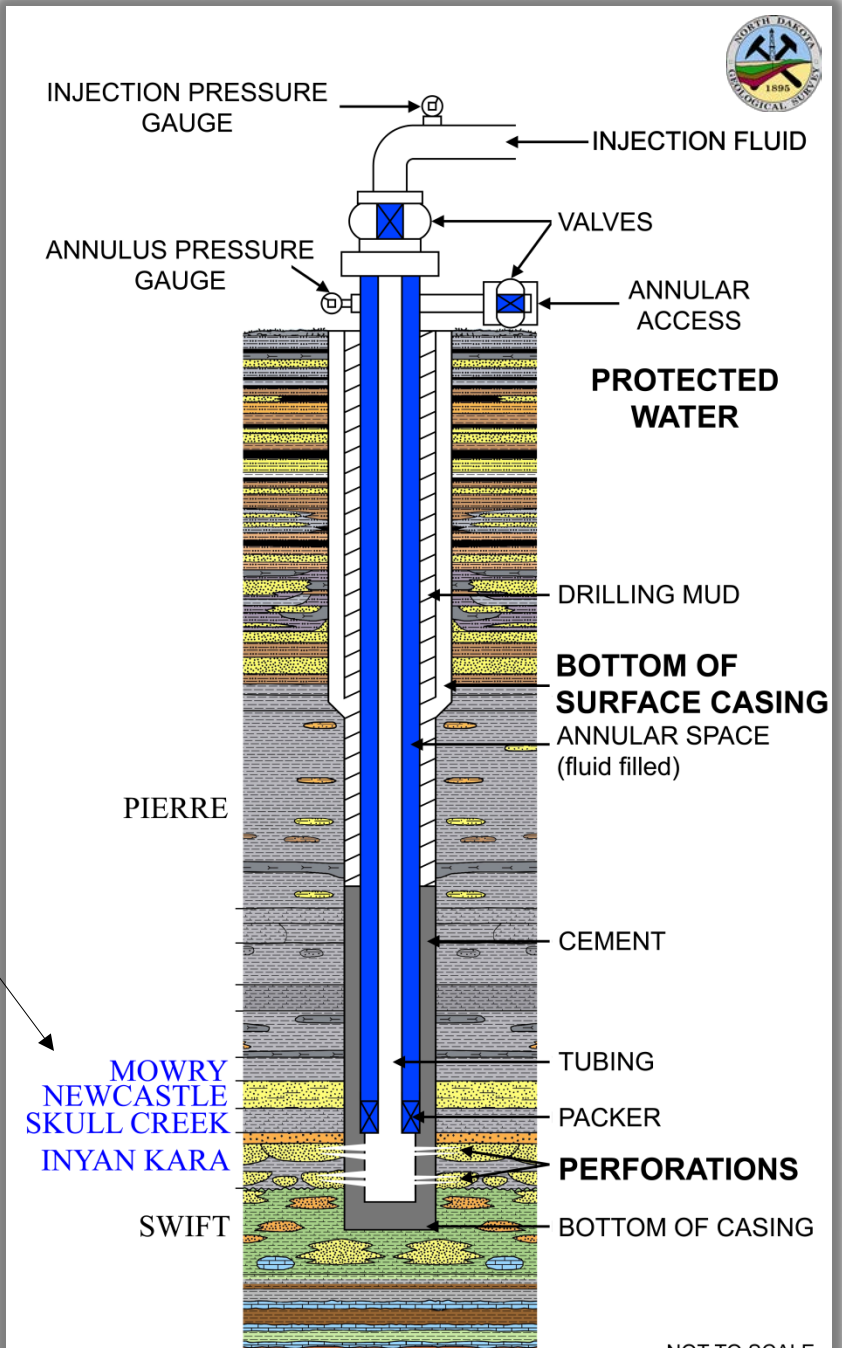
ECS #1

MCKENZIE COUNTY

NORTH DAKOTA CLASS II INJECTION WELL SCHEMATIC

Dakota Group Ideal

- ~ 5,000' depth
- Thick IK sandstones
 - Continuous
 - Good Phi and K
- Excellent seals



Modified from Bader, 2016a

MATH IVERSON #1

PERMEABILITY/POROSITY

Permeability in millidarcies (avg.) Porosity in % (avg.) Environment

24

13

Estuary Mouth

1,000

13

WRS

5

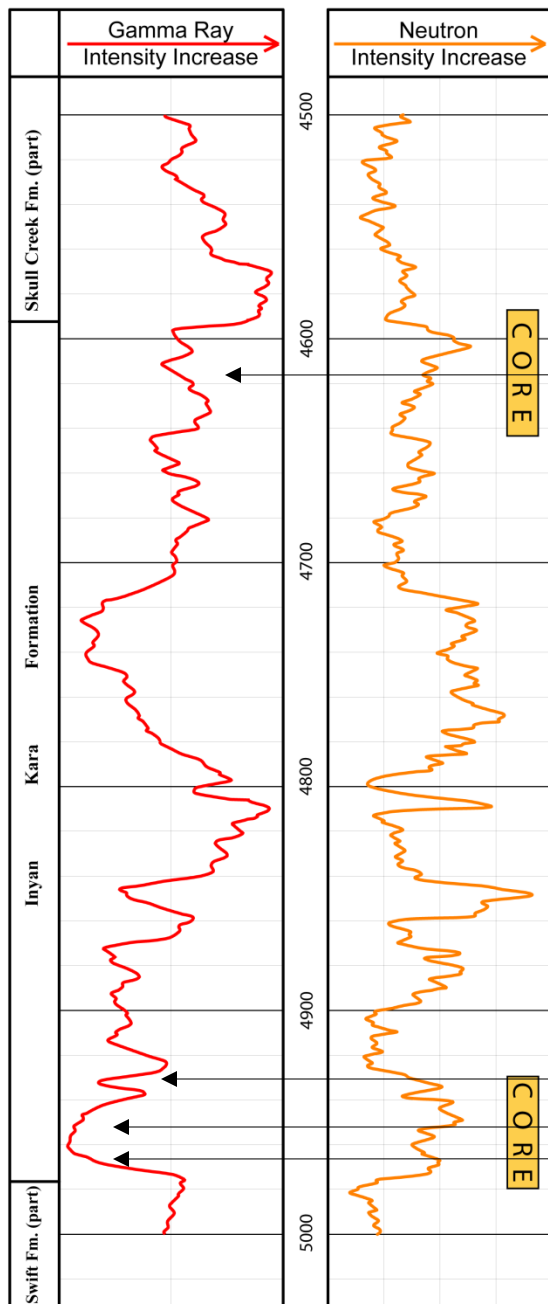
24

TVF

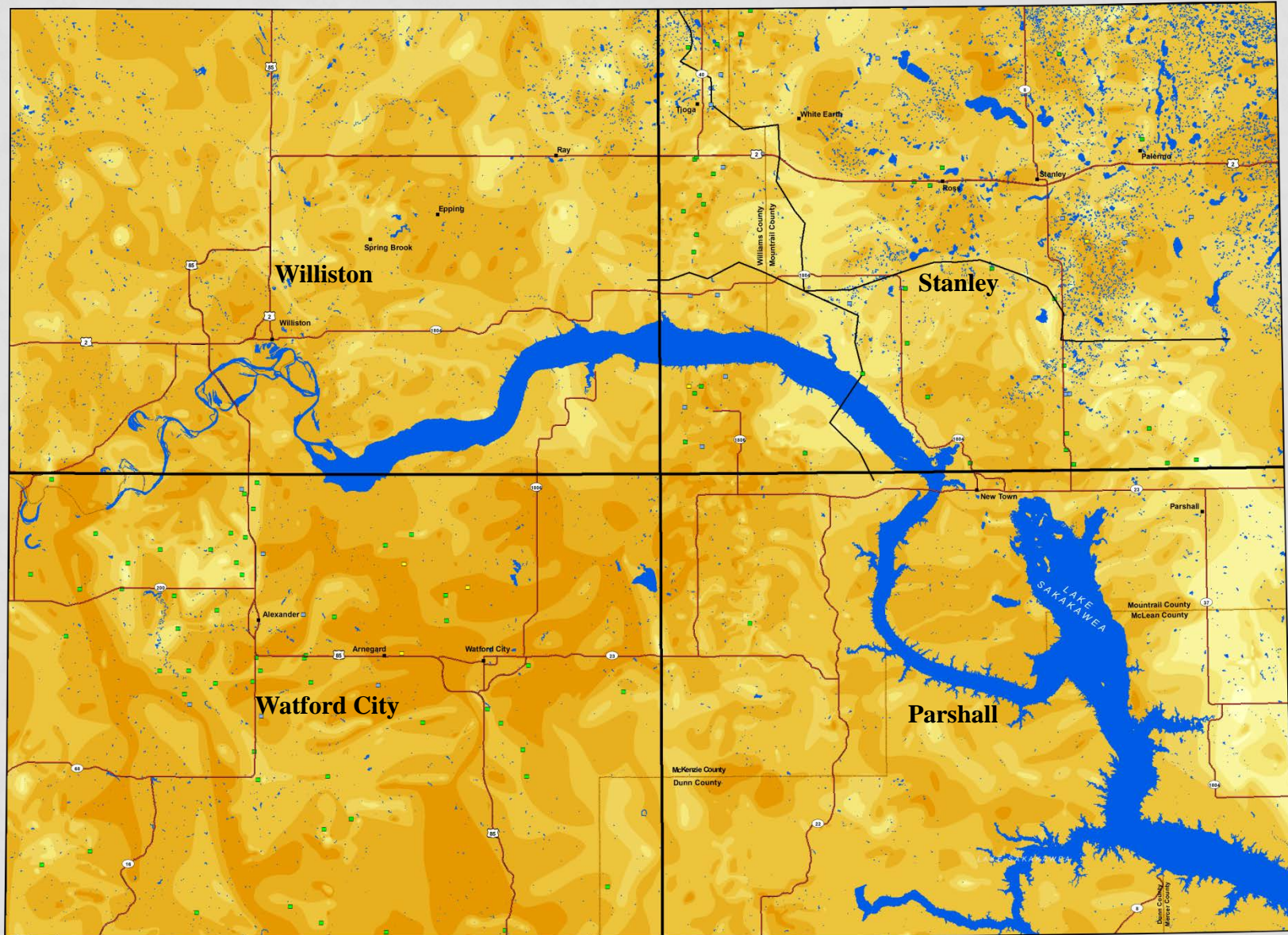
350-1,300

23

RVF



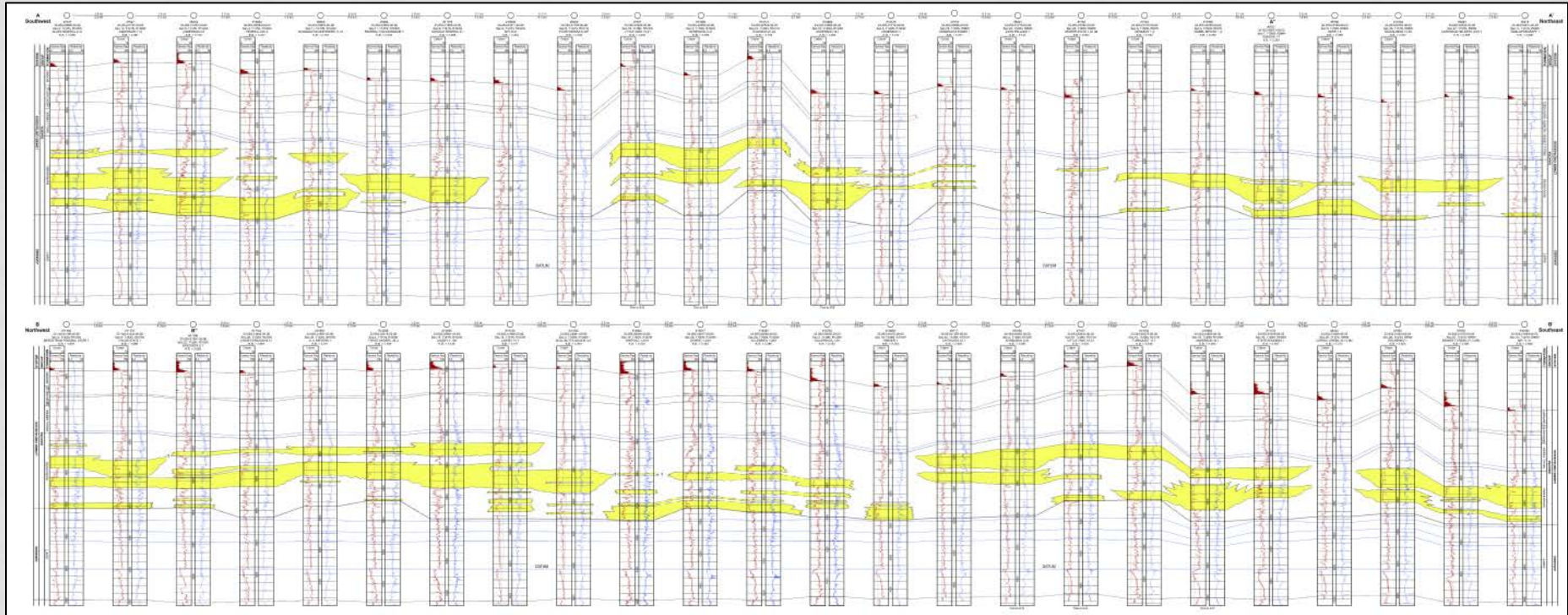
INCISED VALLEYS



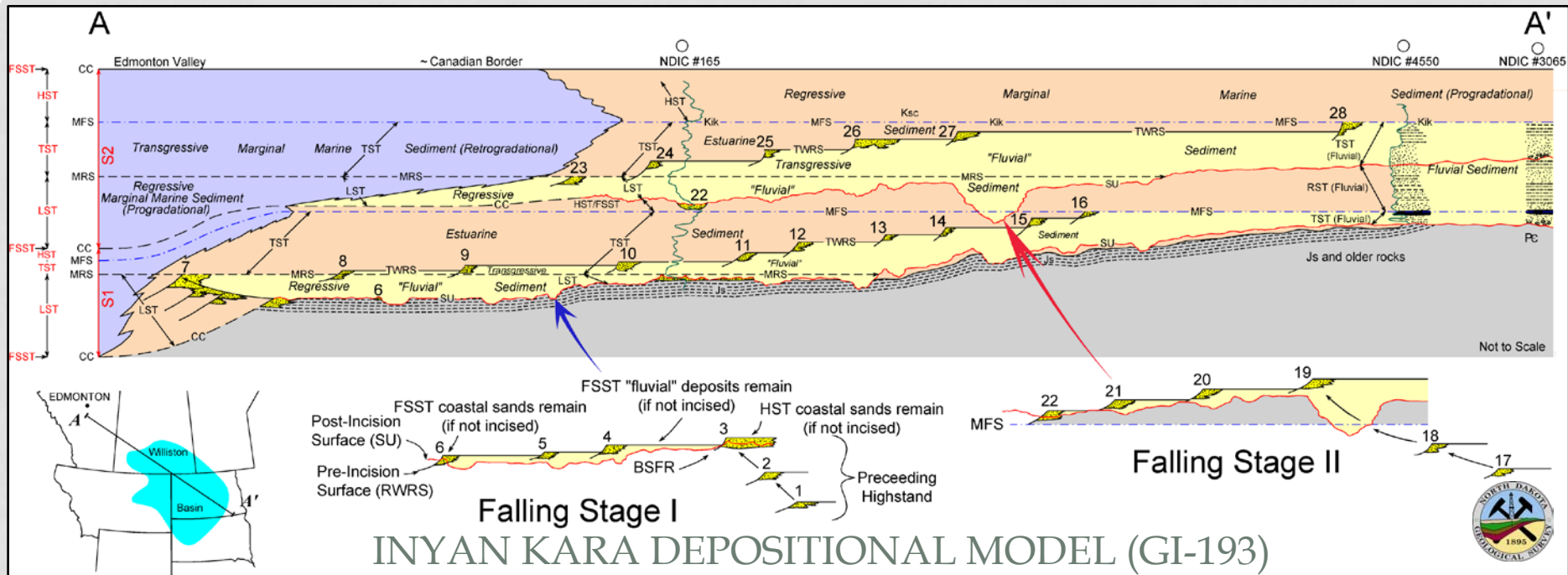
Modified from Bader, 2015; Bader and Nesheim, 2016; Bader and others 2016a, 2016b

INCISED VALLEYS-WATFORD CITY 100K (GI-189)

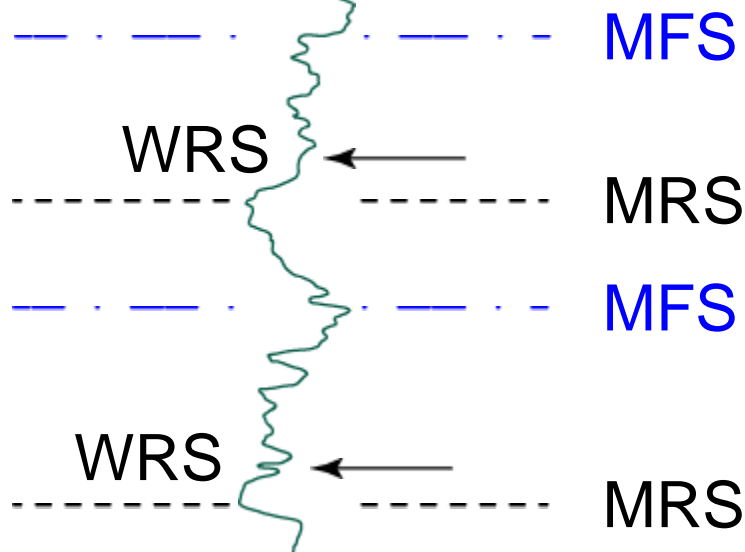
A-A' Transverse to Paleovalleys



B-B' Parallel to Paleovalley



Math Iverson #1



FUTURE WORK

- Grassy Butte, Kenmare, and Killdeer 100Ks
- Other 100Ks
- Publish, publish, publish
- Core Workshops
- Need more cores ☺

