The Permian Zechstein Formation as a Potential Hybrid Unconventional Reservoir: A Sequence Stratigraphic and Sedimentological Evaluation of Organic-Rich Carbonates and Mudrocks from Shelf to Basin, Northern Germany*

Ursula Hammes[1], Hans-Martin Schulz[2], Maria Mutti[3], and Michael Krause[3]

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[1]Bureau of Economic Geology, University of Texas, Austin, TX (ursula.hammes@beg.utexas.edu)
[2]Geosciences Section Organic Geochemistry, GeoForschungsZentrum Potsdam, Potsdam, Germany
[3]Institut für Erd- und Umweltwissenschaften, Universität Potsdam, Potsdam, Germany.

Abstract

The Upper Permian Zechstein Formation in northeastern Germany has been a prolific conventional oil-producing formation primarily from shelf and slope carbonates that rimmed a basin extending from eastern England through the Netherlands and Germany to Poland. Main reservoirs to date are grainstones rimming islands created by pre-existing paleohighs, from platform-rimming shoals, and slope carbonates. Lagoonal evaporites formed the seal for these carbonate and underlying sandstone reservoirs. The objective of this investigation is to evaluate potential unconventional reservoirs in lagoonal, slope, basinal, and organic-rich, fine-grained and/or tight lithologies of this formation. Therefore, a comprehensive, basin-wide study was conducted that included sedimentology, sequence stratigraphy, and geochemistry. The Zechstein Formation is divided into seven 3rd-order sequences that are dominated by regressive and transgressive cycles of shelf origin. Sequence stratigraphic correlations from shelf to basin are crucial in establishing a framework that allow correlation of potential productive facies in fine-grained, organic-rich basinal siliceous and calcareous mudstones or interfingering tight carbonates and siltstones ranging from the lagoon to slope.

Most organic-rich shales worldwide are associated with 2nd- to 3rd-order eustatic transgressions. The basal Zechstein cycles, Z1 and Z2, contain organic-rich siliceous and calcareous mudstones and carbonates that form the transgressive deposits in the basin. Tight dolomitic layers, marlstones, and organic-rich limestones interfingering with organic-rich siliceous and calcareous mudrocks are candidates for forming a hybrid unconventional reservoir. A comprehensive database composed of core, wireline logs, and outcrop is used to analyze the organic-rich mudstones and carbonates. Maturities range from overmature (gas) in the basin to oil-generation on the slope with variable TOC contents. This sequence stratigraphic and sedimentologic evaluation of the transgressive facies in the Z1 and Z2 intervals, in conjunction

with chemostratigraphy, evaluates the potential for shale gas/oil and hybrid unconventional plays where interfingering organic-rich mudstones and carbonates might present new exploration possibilities and serve as analog to other hybrid plays, such as the Bakken or Pearsall Formations in the USA.

Selected References

Hartwig, A., and H.-M. Schulz, 2010, Applying classical shale gas evaluation concepts to Germany. -1: The basin and slope deposits of the Stassfurt carbonate (Ca2, Zechstein, Upper Permian) in Brandenburg: Chemie der Erde, v. 70/3, p. 77-91.

Kaiser, R., 2003, Facies and sequence stratigraphy: The Stassfurt carbonate (Ca2) at the Northern basin edge of the Southern Zechstein Basin (NE Germany): Proceedings of DGMK Spring Meeting, v. 1, p. 89-98.

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http://cpgeosystems.com/260moll.jpg

THE PERMIAN ZECHSTEIN FORMATION AS A POTENTIAL HYBRID UNCONVENTIONAL RESERVOIR: A SEQUENCE STRATIGRAPHIC AND SEDIMENTOLOGICAL EVALUATION OF ORGANIC-RICH CARBONATES AND MUDROCKS FROM SHELF TO BASIN, NORTHERN GERMANY

Ursula Hammes, Hans-Martin Schulz, Maria Mutti, and Michael Krause

Bureau of Economic Geology, Universität Potsdam, and Geoforschungszentrum Potsdam, Germany

Bureau of Economic Geology

Mudrock Systems Research Laboratory MSRL

GeoEn

Universität Potsdam

The University of Texas at Austin Jackson School of Geosciences

Issues

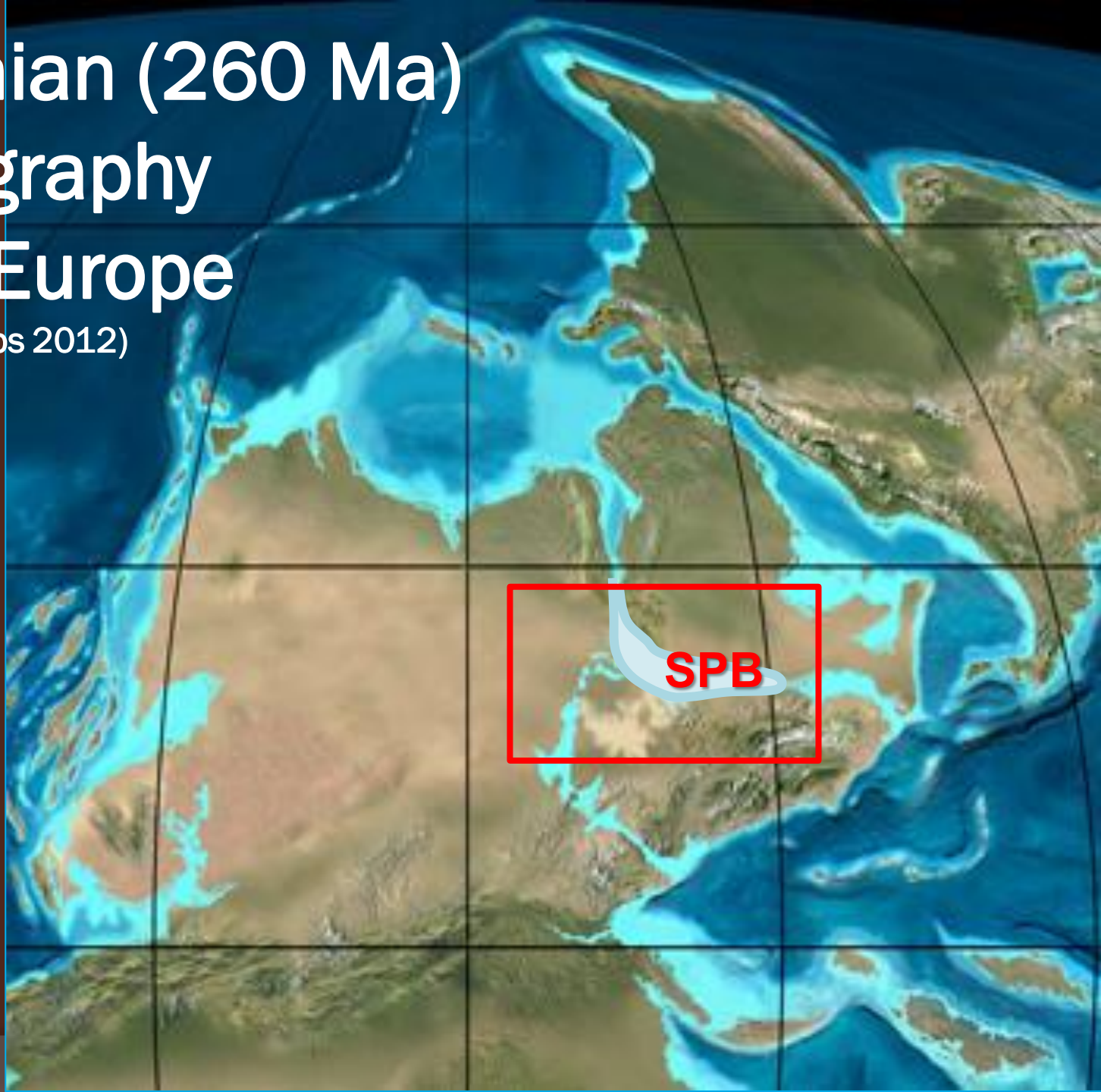
- Comprehensive facies and sequence stratigraphic model across lower (Z1 and Z2) Zechstein basin from Poland to UK missing.
- Most publications and research concentrated on localized studies of classic stratigraphy and geochemistry (e.g., Kupferschiefer).

Goals

- Evaluate Upper Permian Zechstein Z1 and Z2 mudrocks, shales, and carbonates for shale-gas/oil potential, hybrid, and conventional reservoirs.
- Establish facies and sequence stratigraphic model from shelf to basin – establish regional framework.

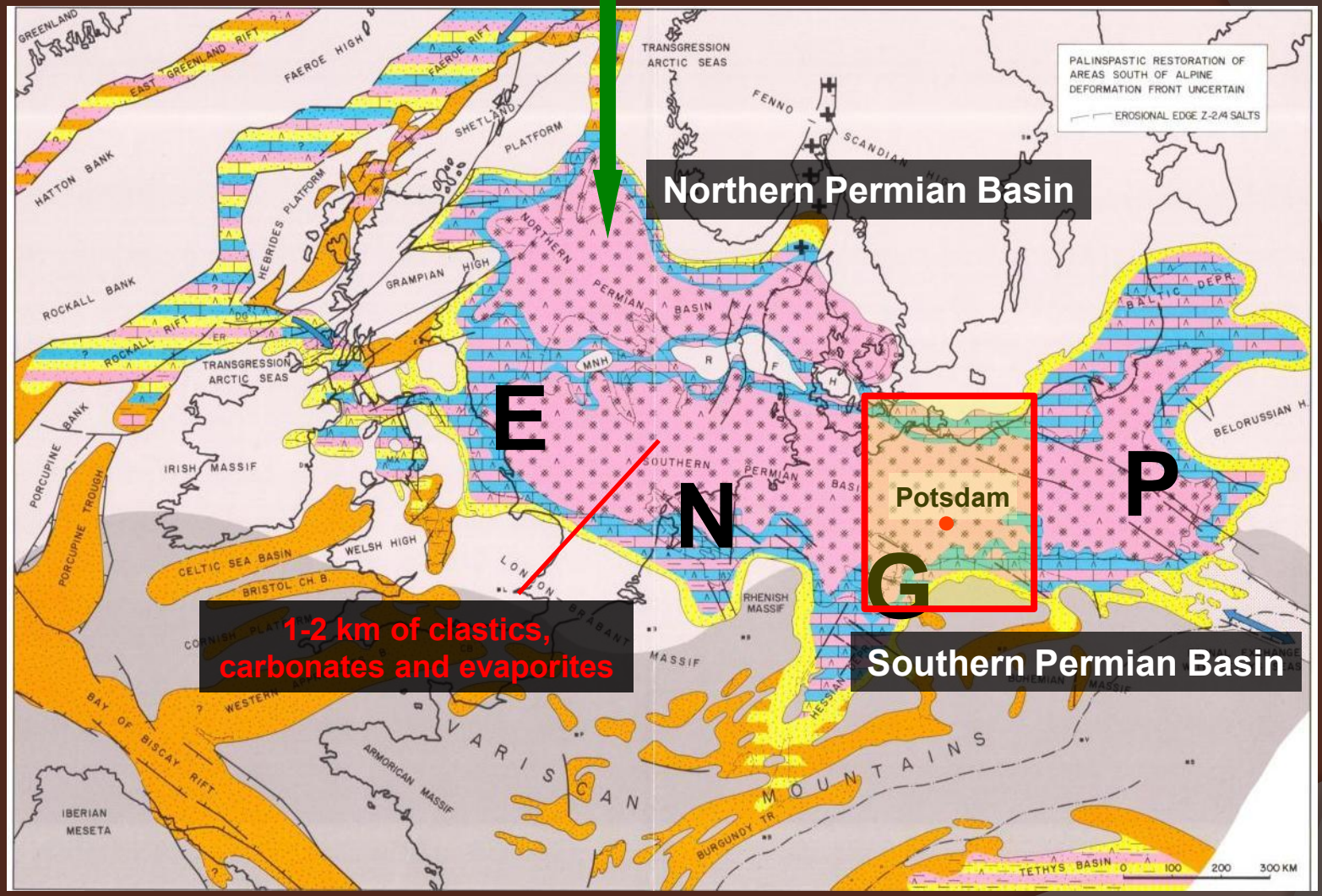
Late Permian (260 Ma) Paleogeography Northern Europe

(from Blakey Paleomaps 2012)



Paleogeography

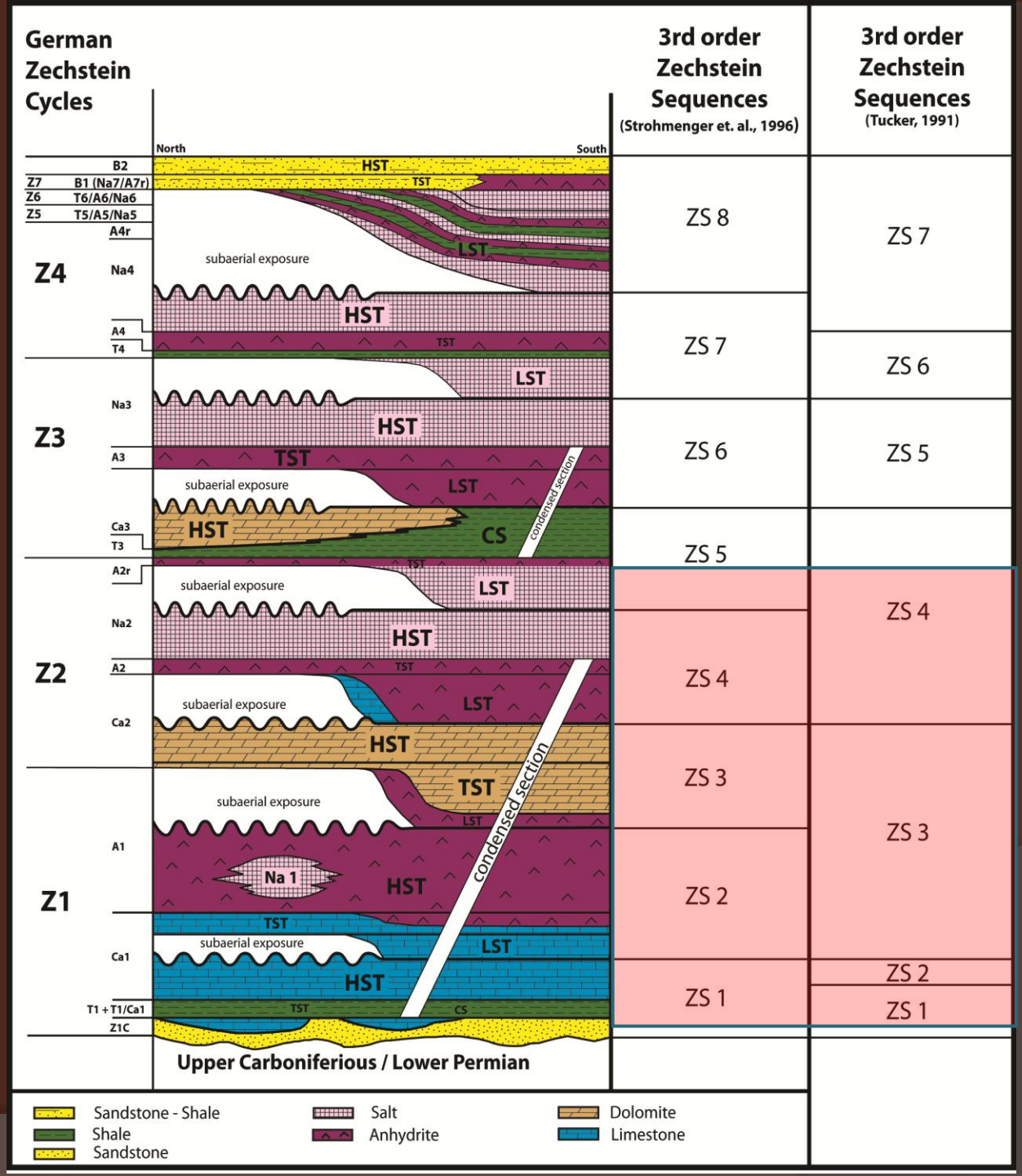
Transgression
(flooding of a sub-sea-level intracratonic basin)



- **Late Permian (*Zechstein*)**

(Ziegler 1990)

Zechstein Stratigraphy



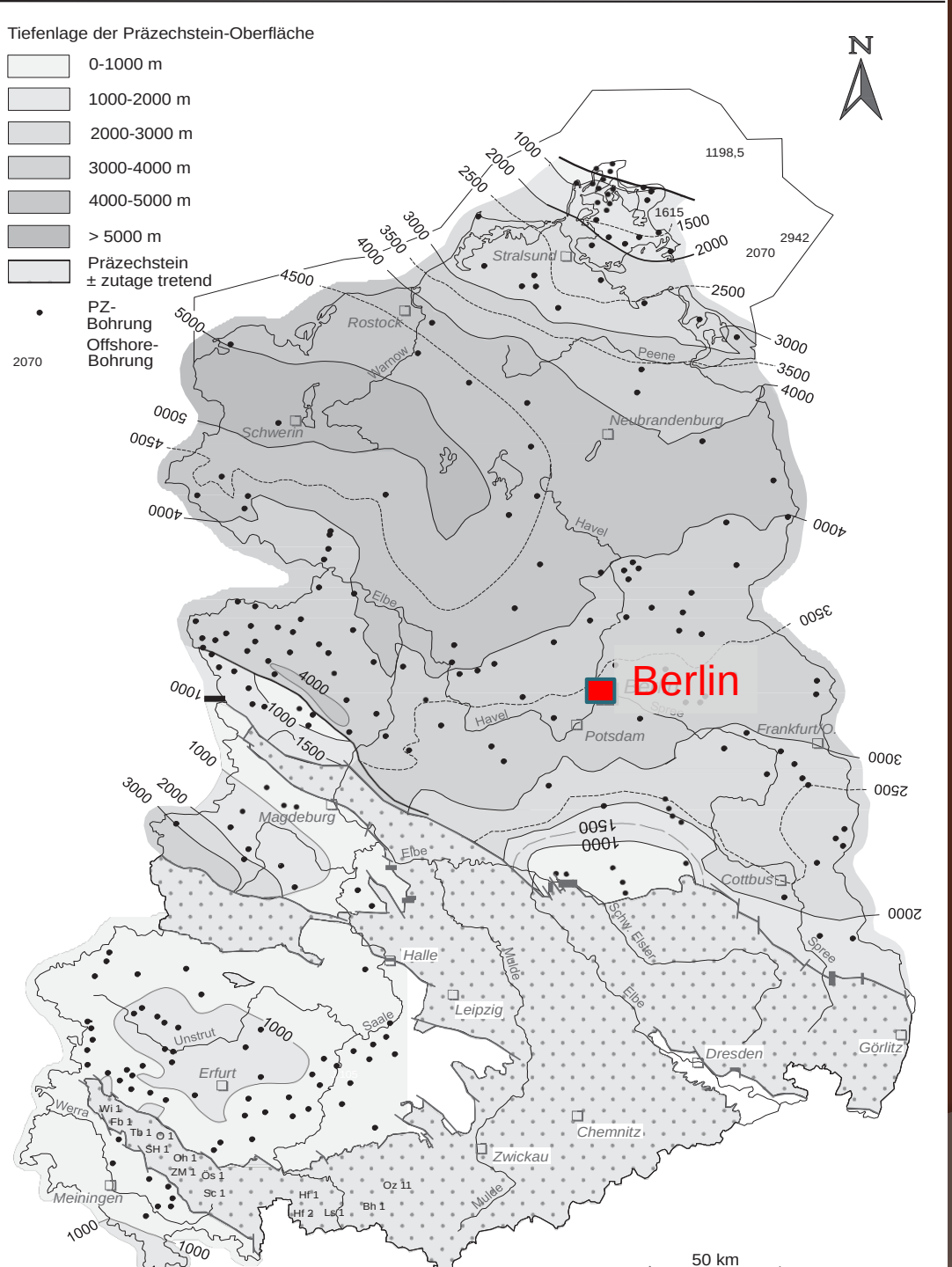
(from Kaiser et al., 2003)

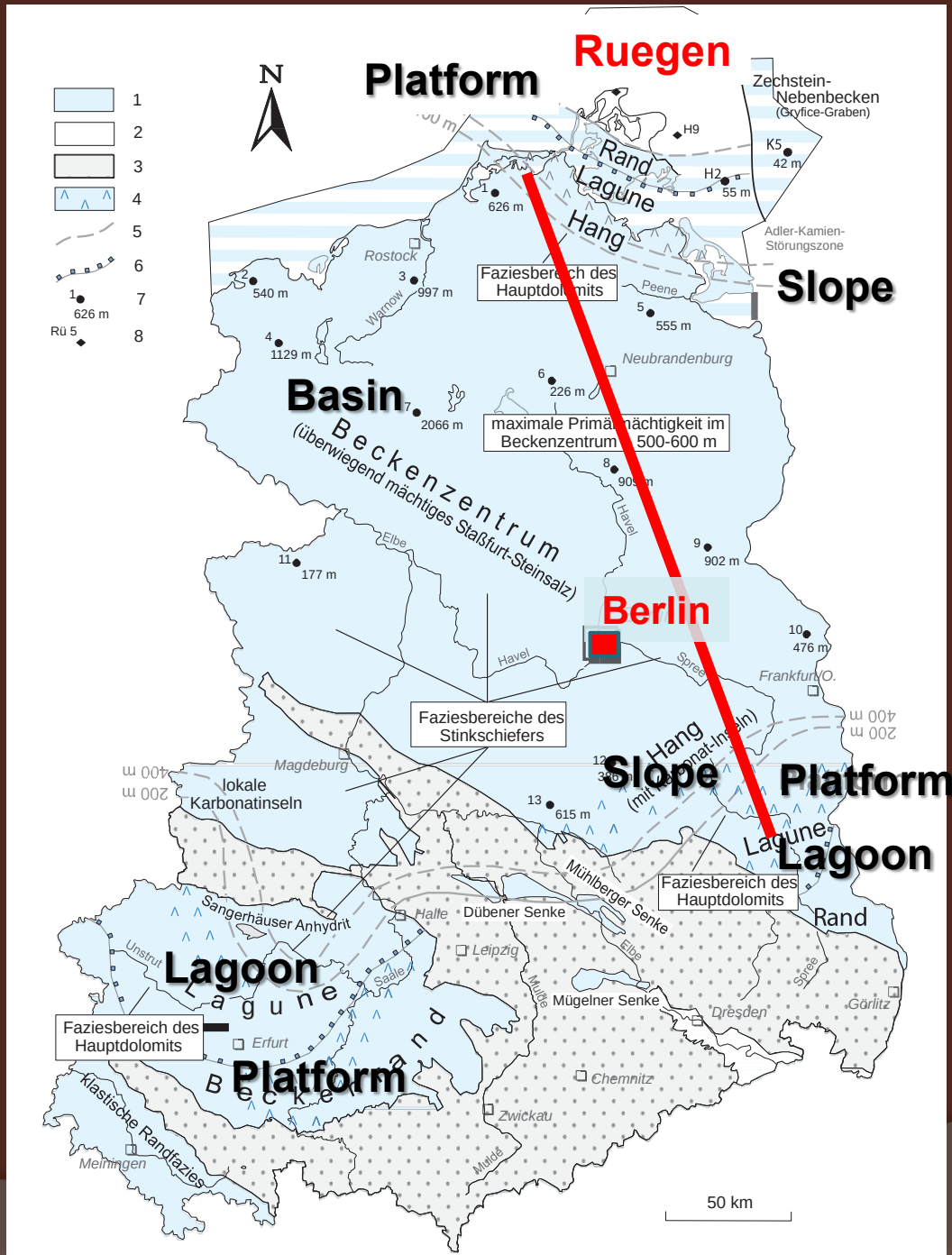
Zechstein Study Area – northern Germany

- Brandenburg
- Mecklenburg-Vorpommern

Base Zechstein

(from Franke, 2012)



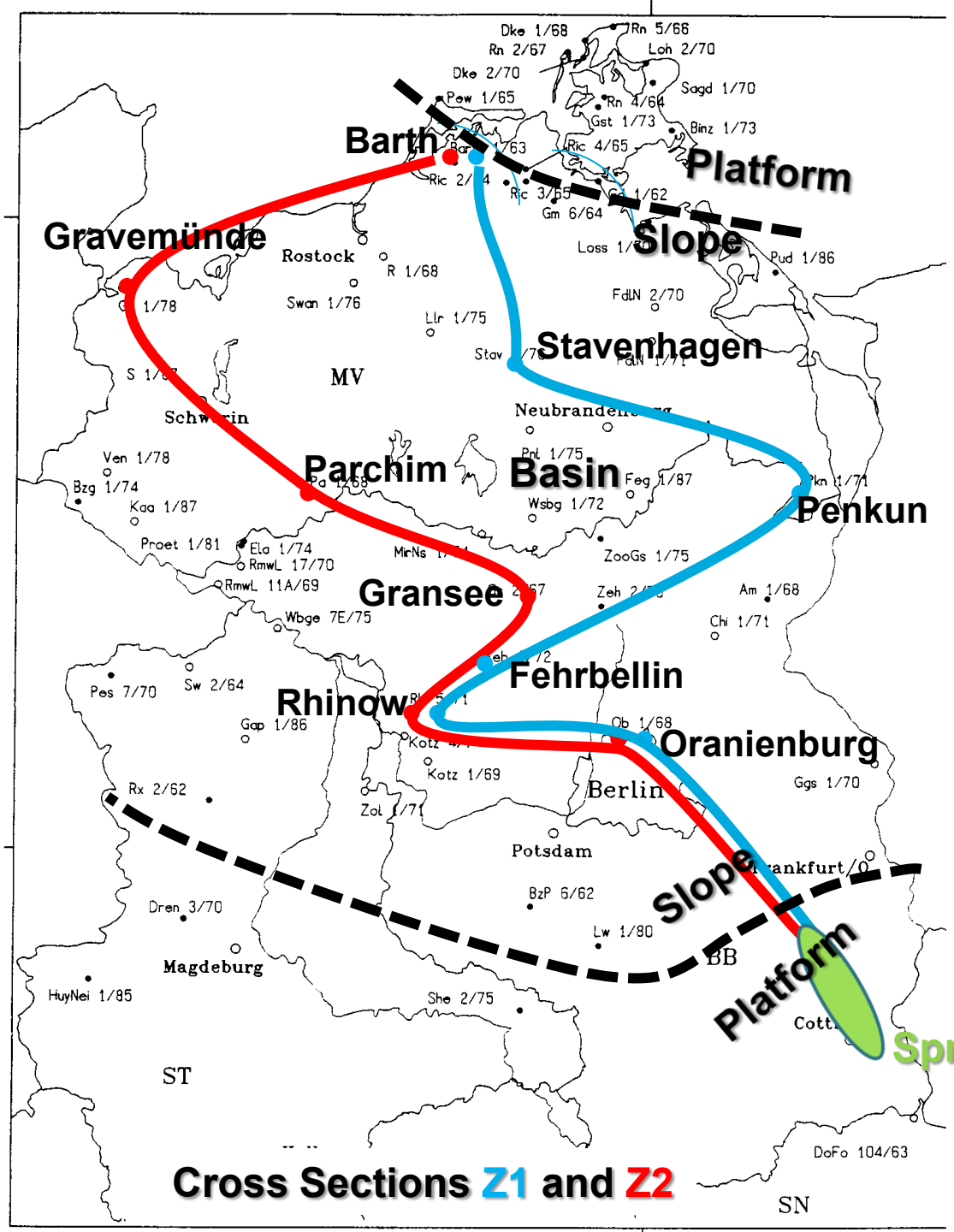


Z2 Paleogeo-morphology

(from Franke, 2012)

Database

- Cores and logs from German State offices in Brandenburg and Mecklenburg-Vorpommern (Research wells from Hoth et al. (1993))



Spremberg Structure

- Zechstein Z2 cores sampled and described
- Zechstein Z1 cores sampled and described

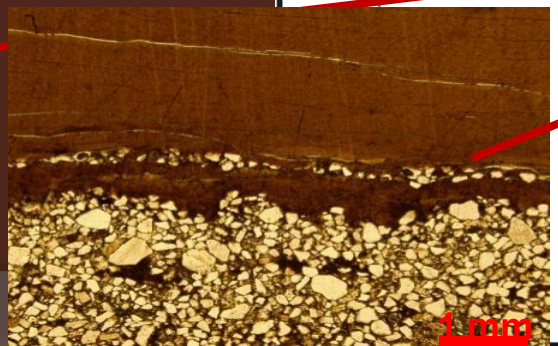
Zechstein Facies and Sequences Z1

(from bottom to top)

- Underlain by conglomerate or Weissliegendes sandstone.
- Kupferschiefer (black, clay-rich, massive mudstone, partly calcareous, bituminous shale)
- Massive, laminated and bioturbated calcareous mudstones (Zechsteinkalk).
- Carbonate facies composed of wackestone, grain- and packstones
- Werra Anhydrite: nodular, massive, and chicken-wire anhydrite facies

Core box = 1m

Z1 Basin: Oranienburg

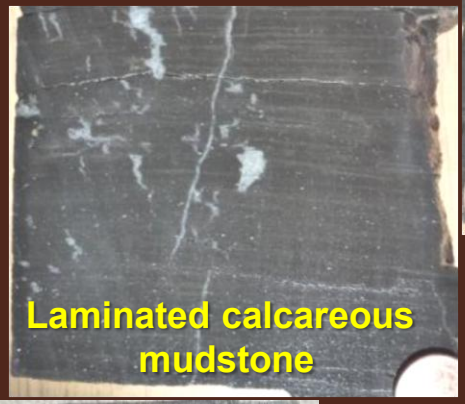


Z1 Third-order basinal sequence

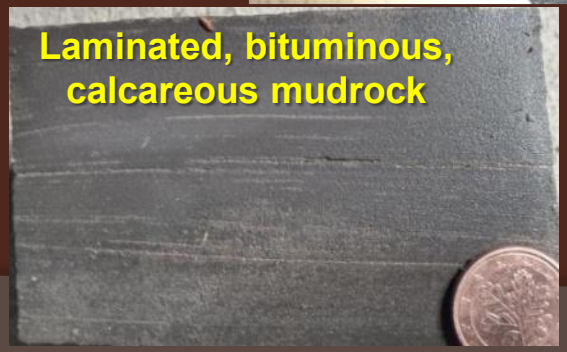
Massive Anhydrite (Werra)

Crinkle-laminated Calcareous (dolomitic) mudstone

Thrombolite intraclast packstone



Laminated calcareous mudstone



Laminated, bituminous, calcareous mudrock

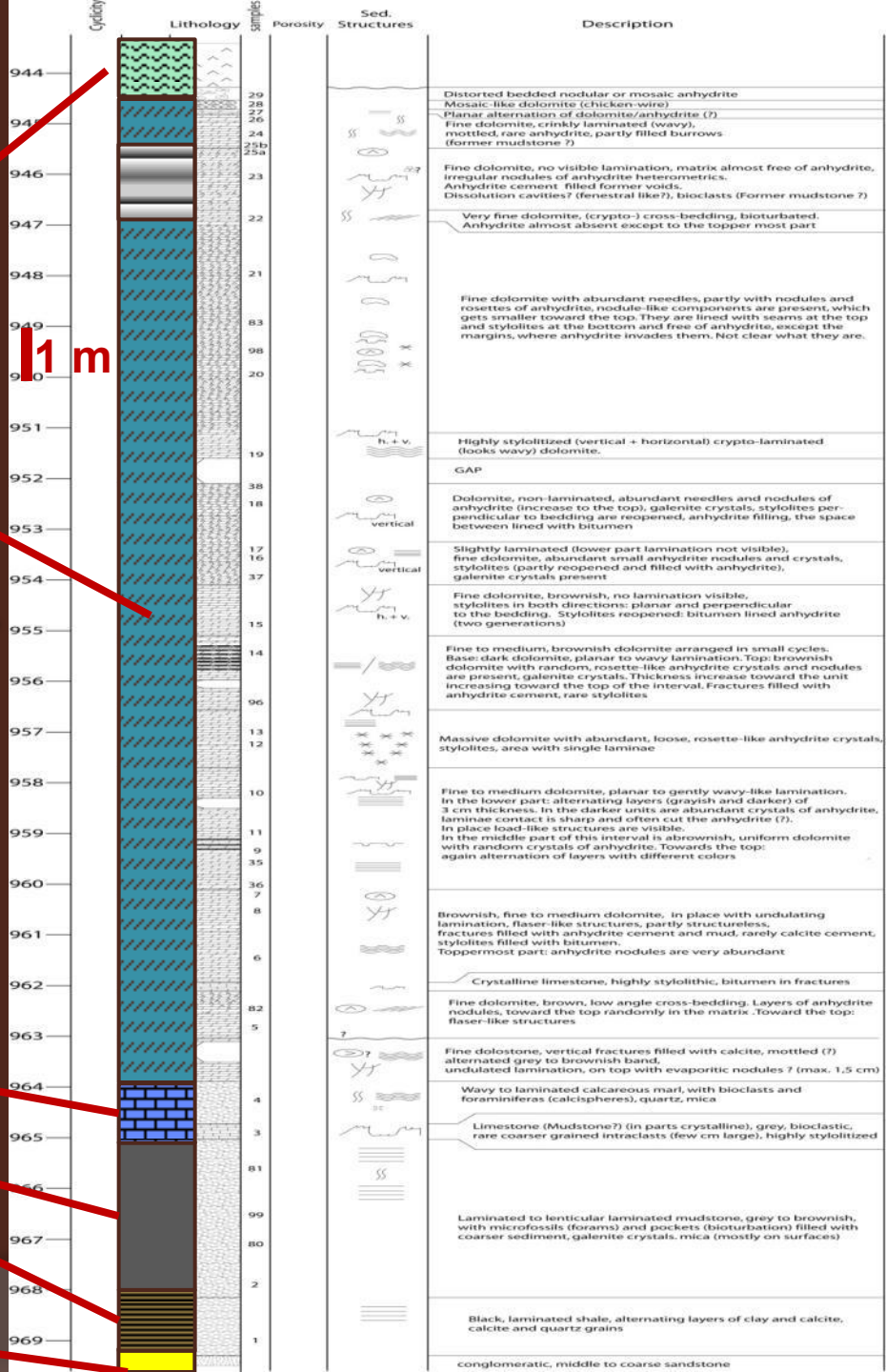
Shallowing-upward

Platform/Lagoon: Spremberg

(core descriptions courtesy of Michael Krause U Potsdam)

Note: thickness double as in basin!

- Anhydrite
- Dolomite
- Limestone
- Lime Mudstone
- Shale
- Sandstone



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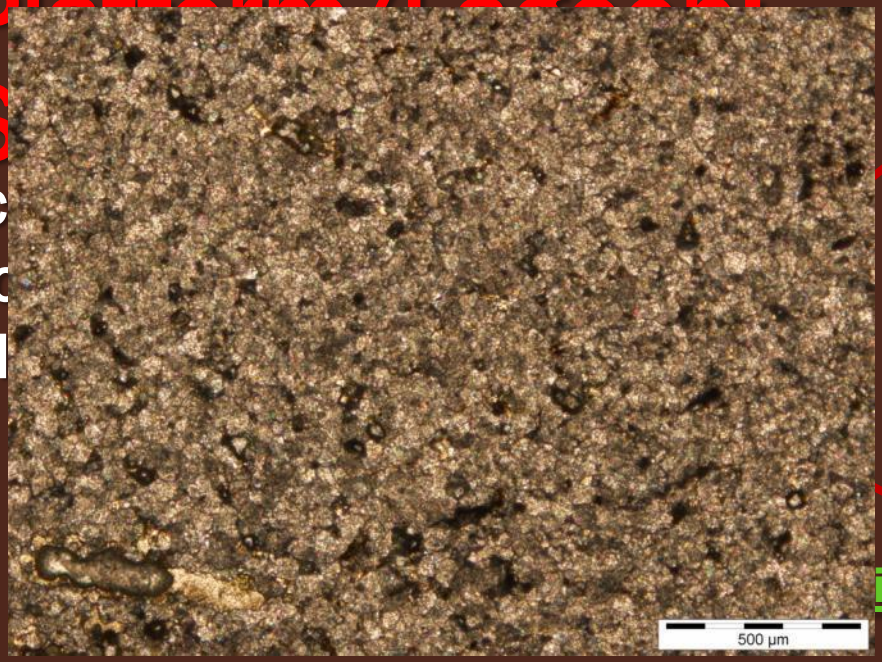

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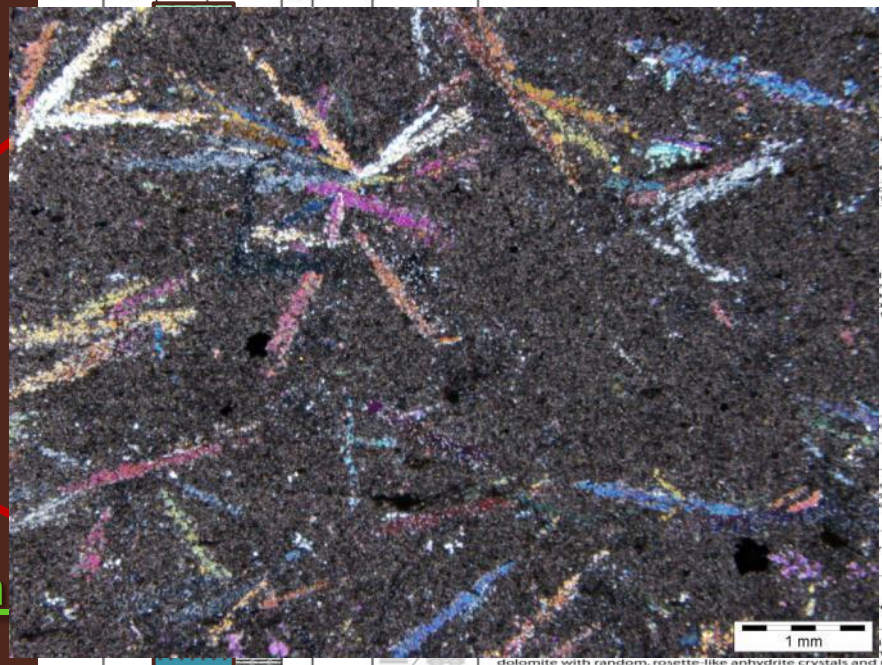
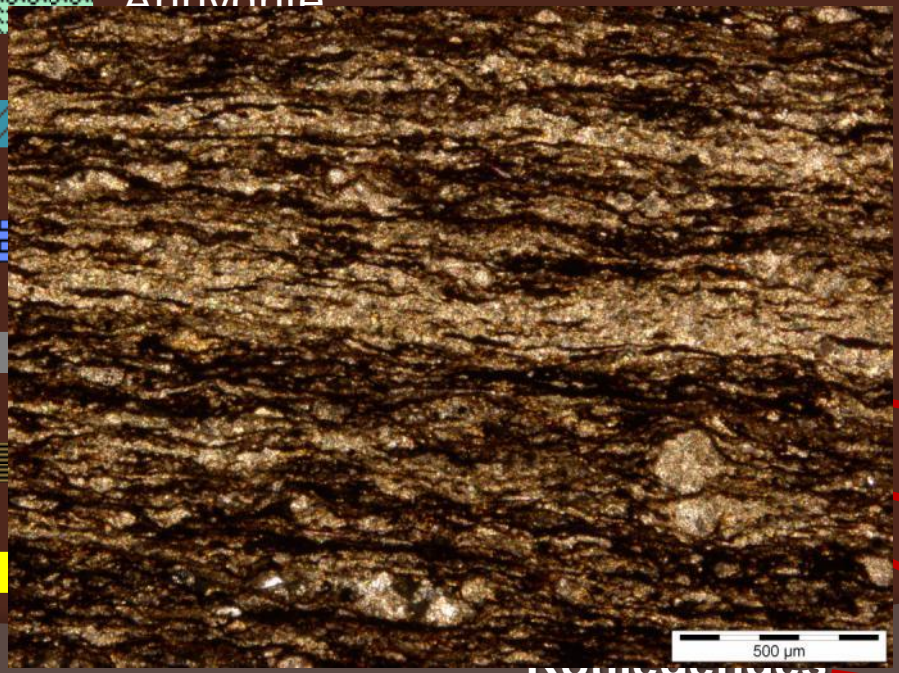


Anhydrite

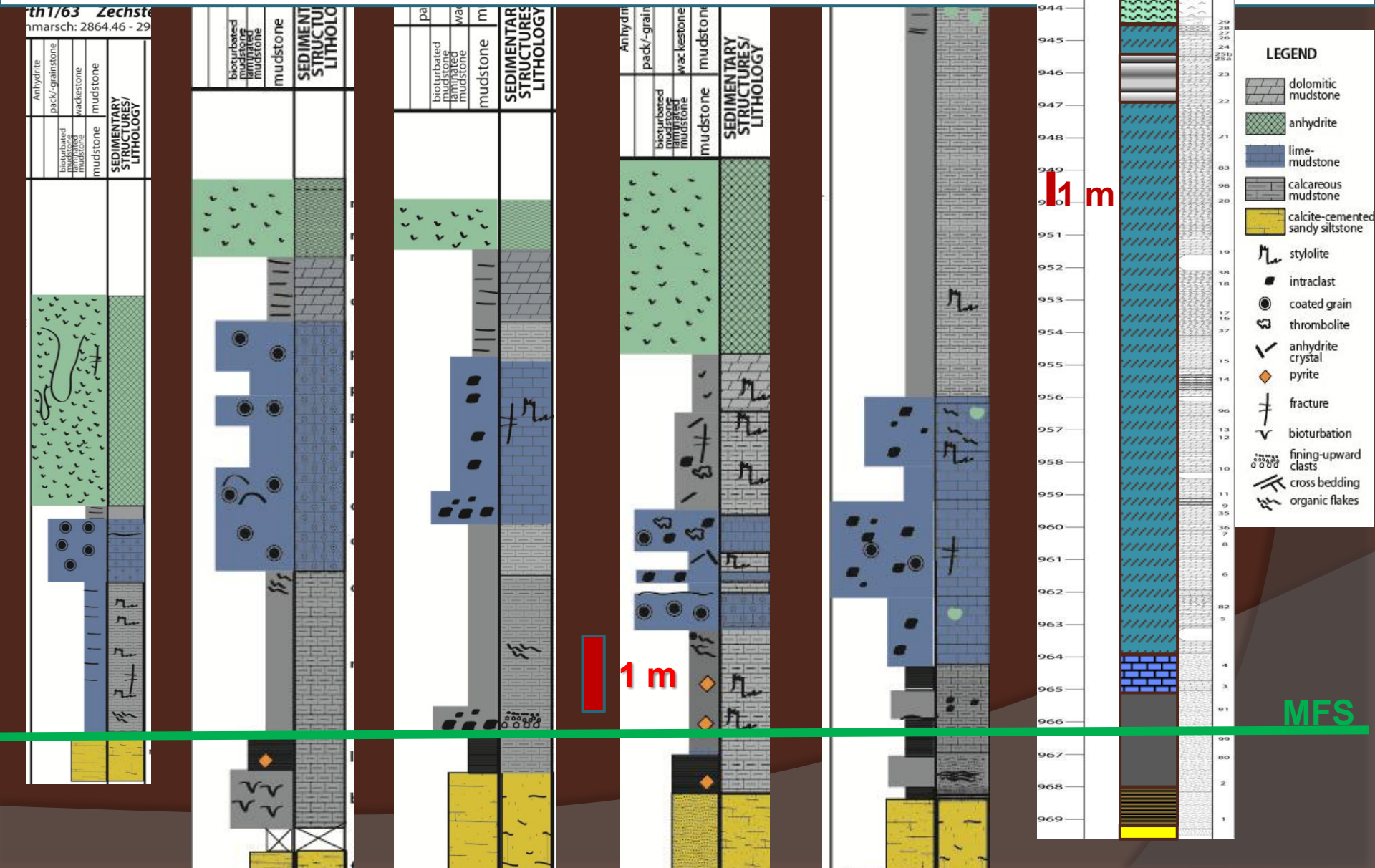


Rotliegendes

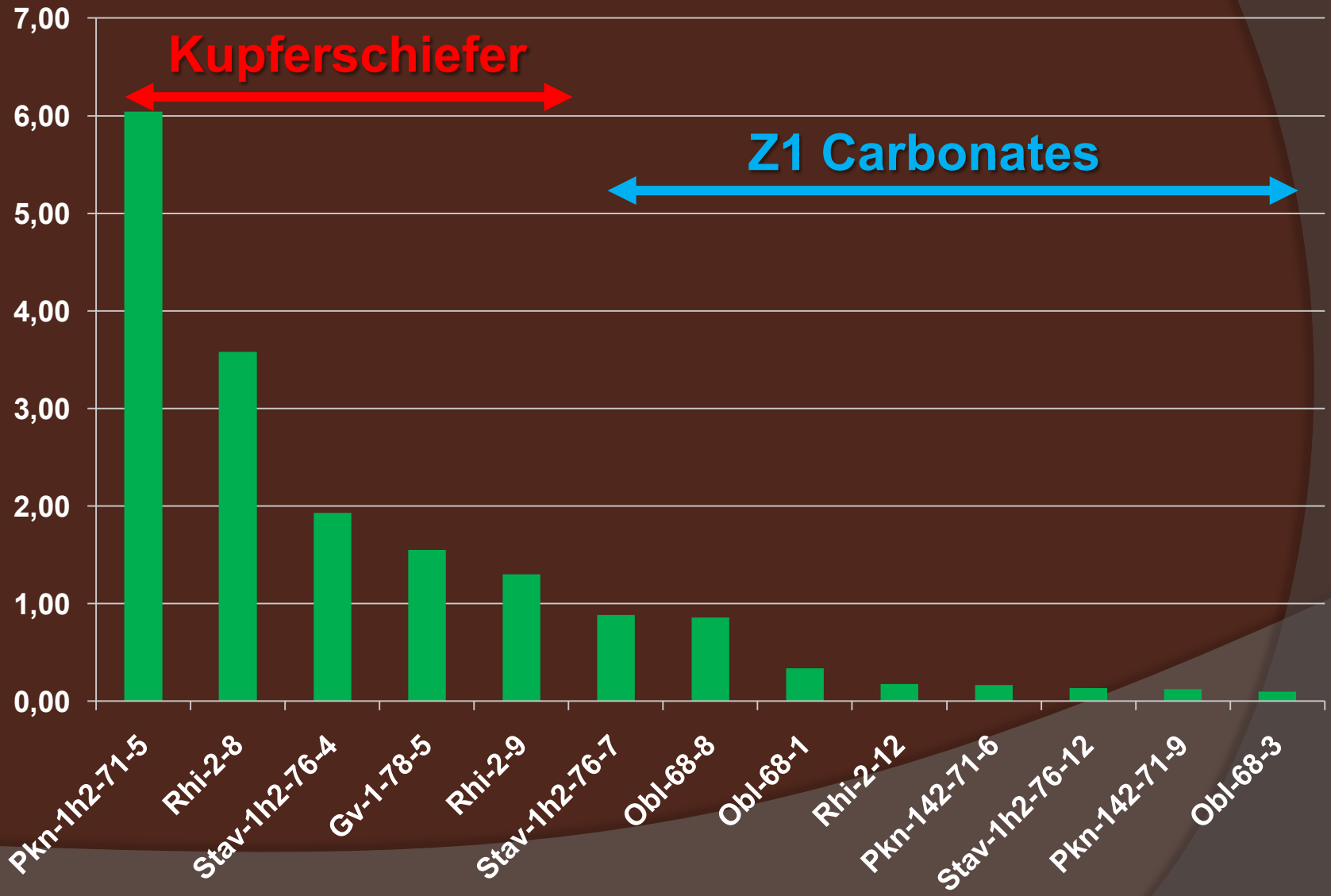
Z1 correlation

N SLOPE | **BASIN** | **S PLATFORM**

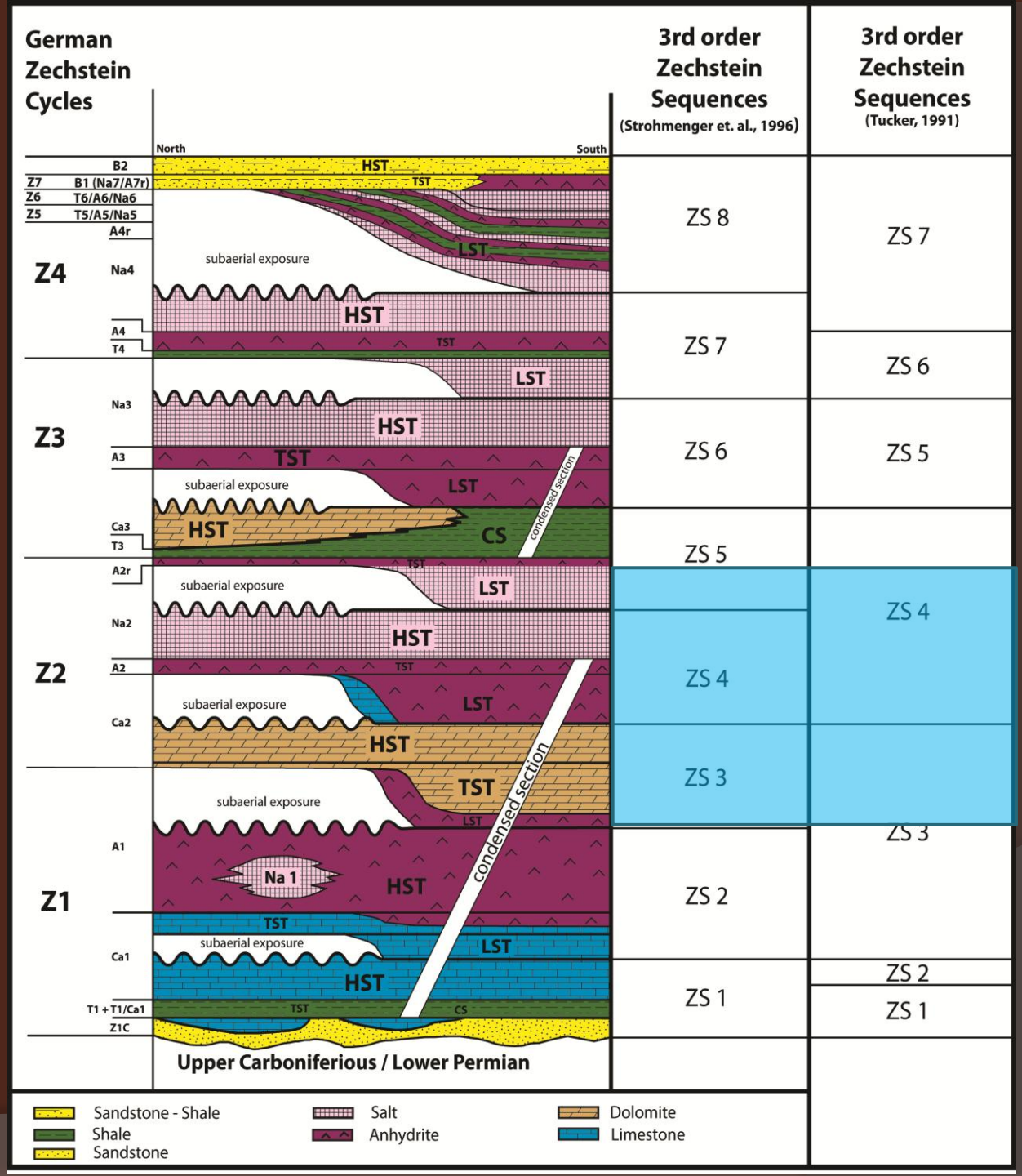
Barth | **Stavenhagen** | **Penkun** | **Rhinow** | **Oranienburg** | **Spremberg CuSp H8/71**



TOC ZECHSTEIN Z1



Zechstein Stratigraphy

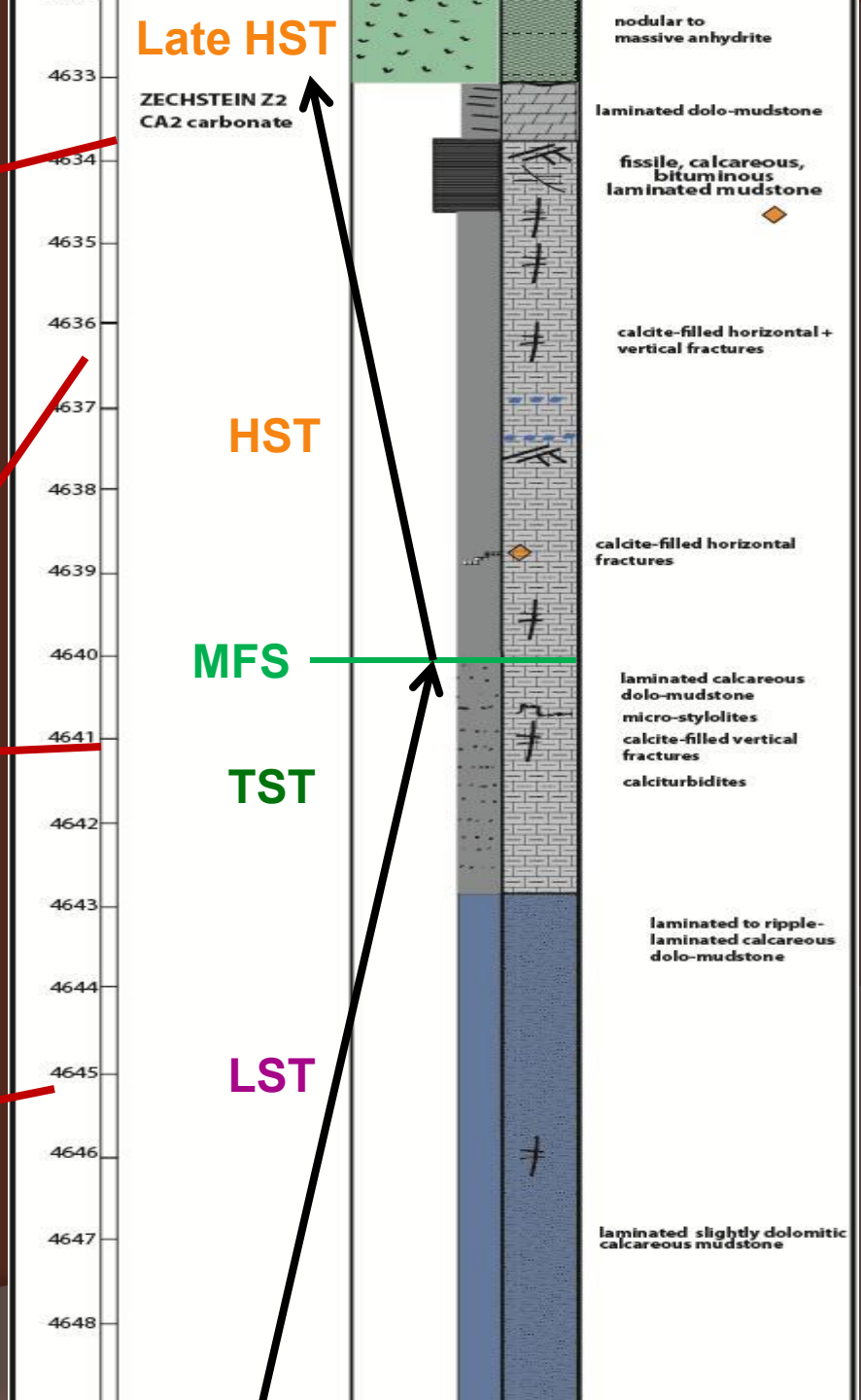


(from Kaiser et al., 2003)

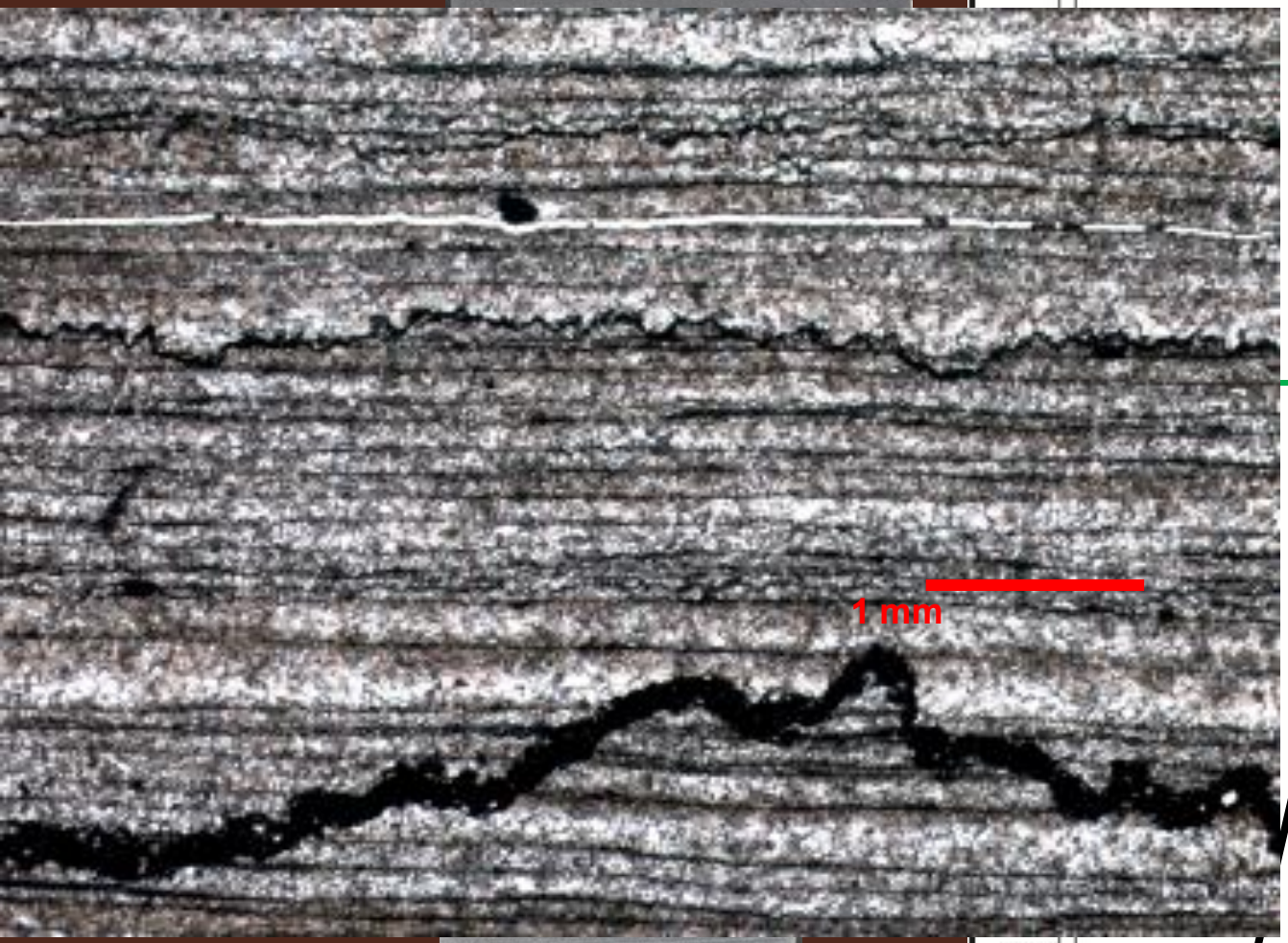
Zechstein Facies and Sequences Z2
(from bottom to top)

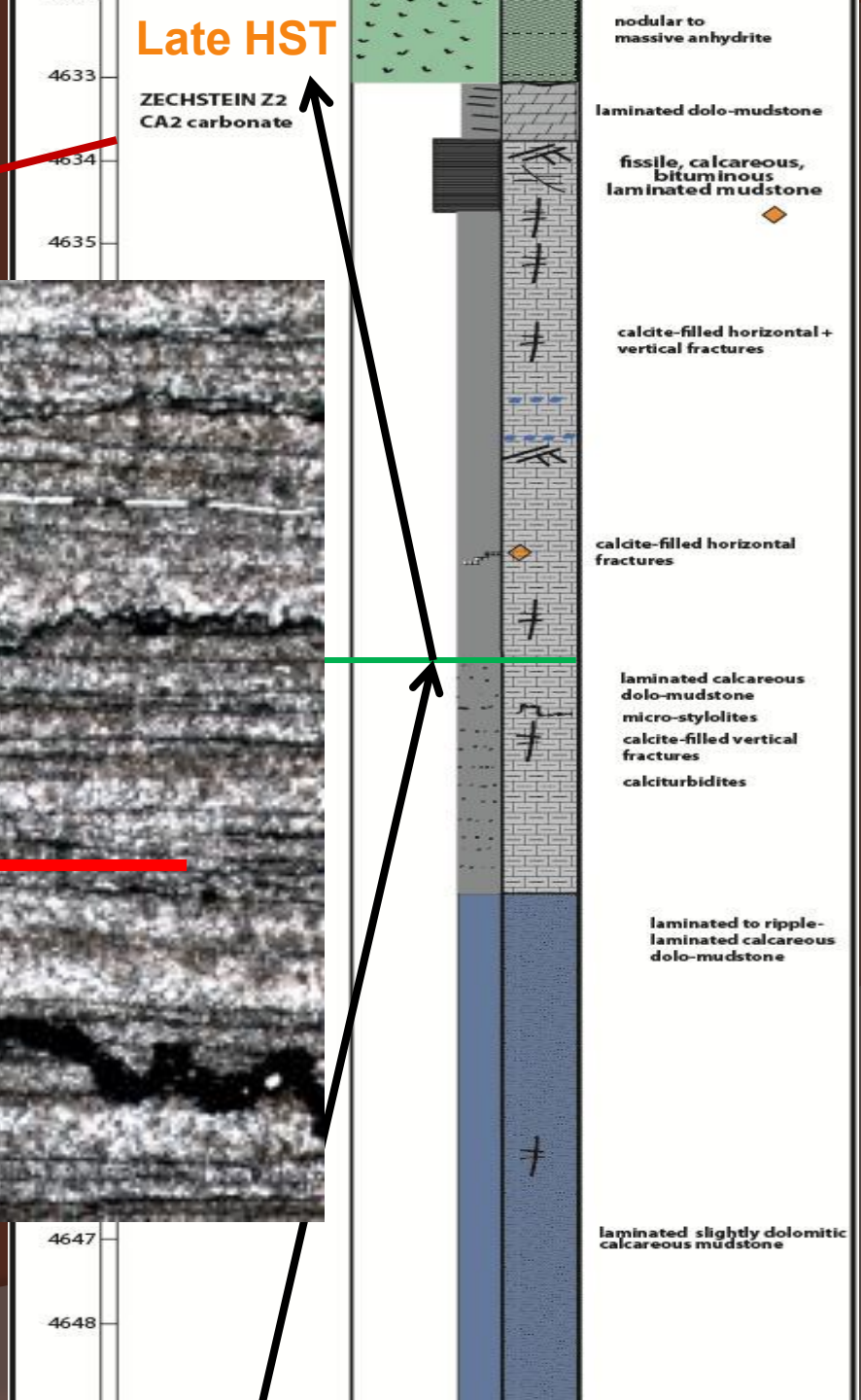
- Underlain by Werra Anhydrite
- Shales are calcareous, laminated mudstones (Stinkschiefer)
- Limestones characterized by laminated, slightly dolomitic, calcareous mudstones with crinkle-laminated beds (Stassfurt carbonate, Stinkkalk)
- Basal Anhydrite, nodular, massive, and chicken-wire anhydrite facies.

Z2 Basin Parchim

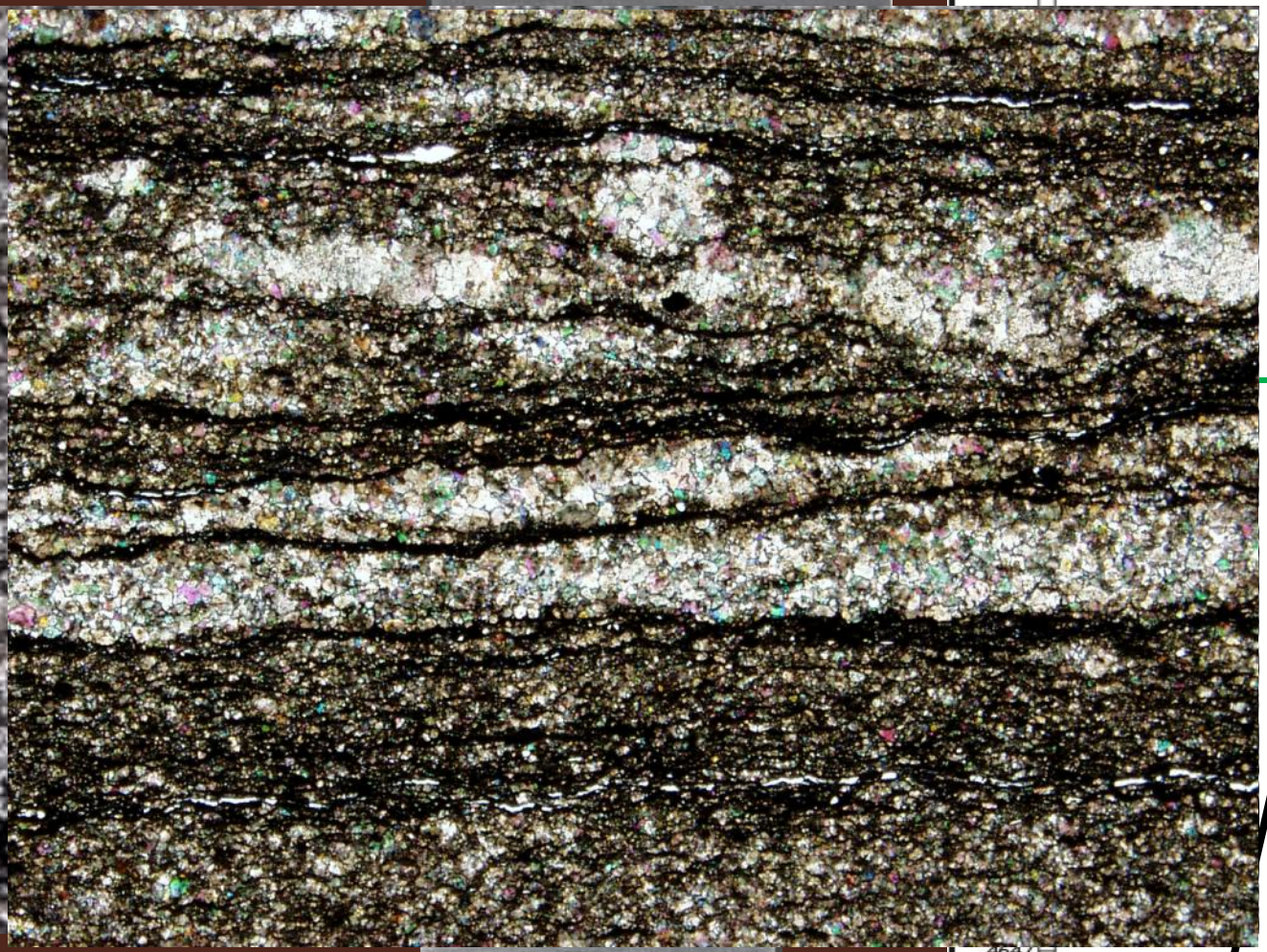


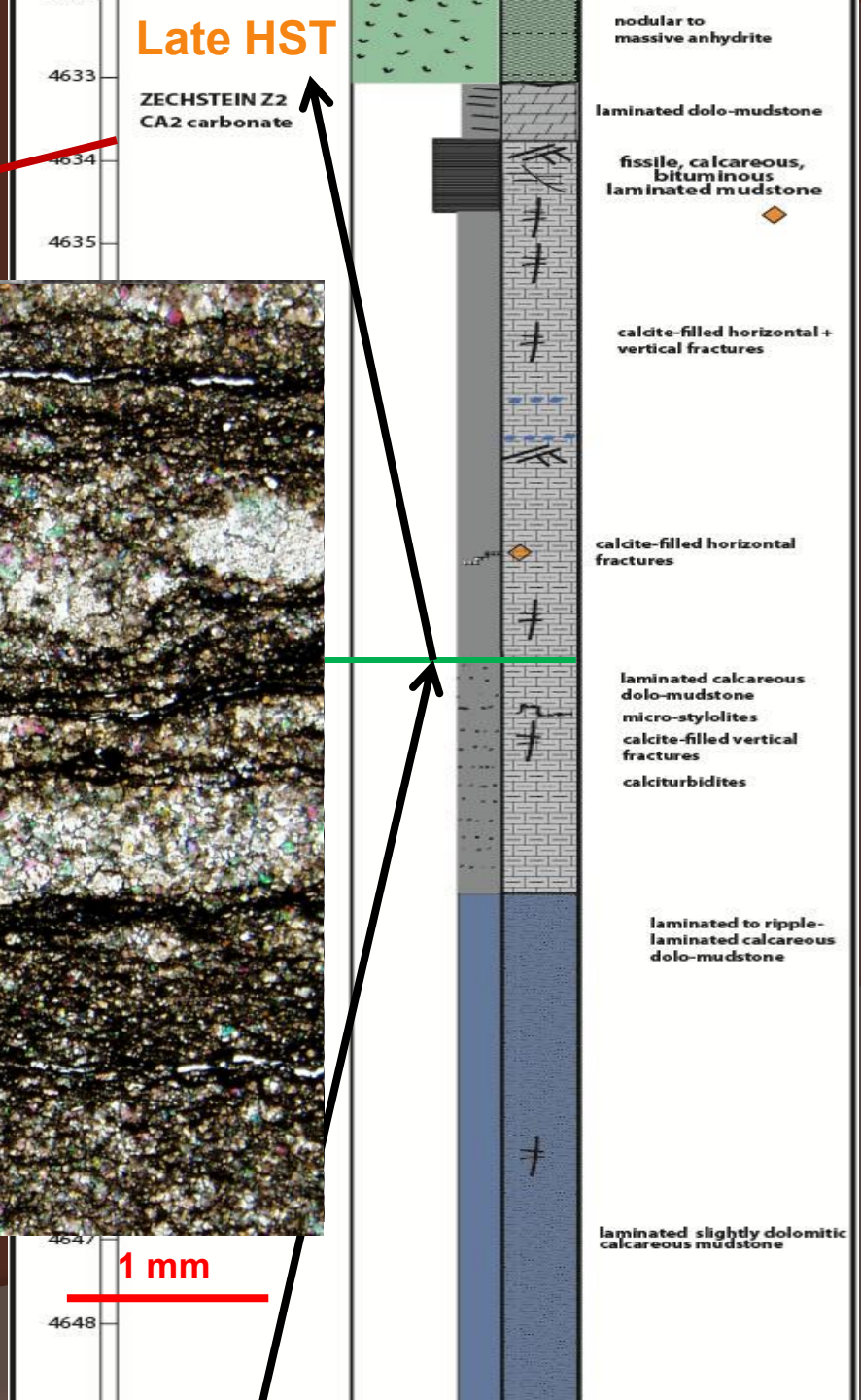
Z2 Basin Parchim



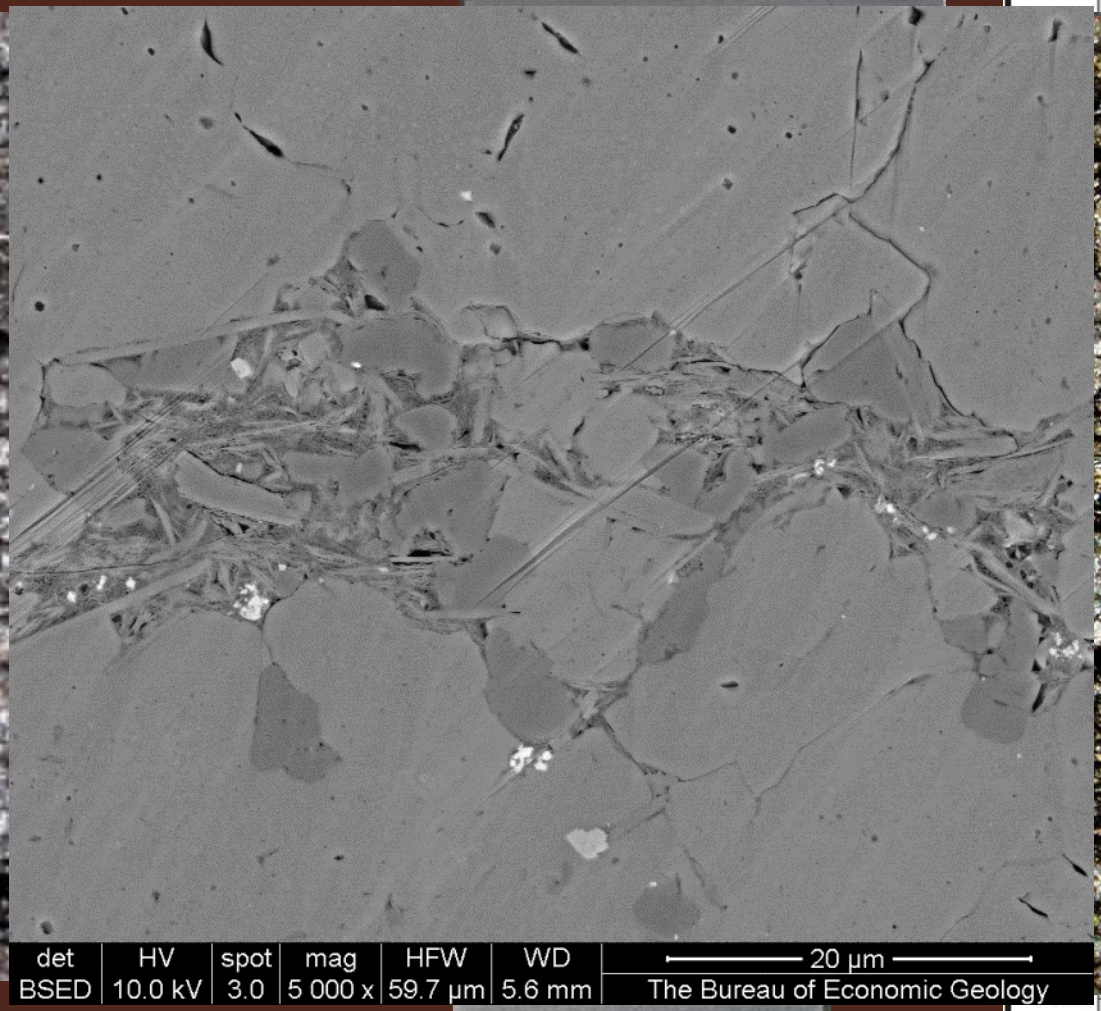


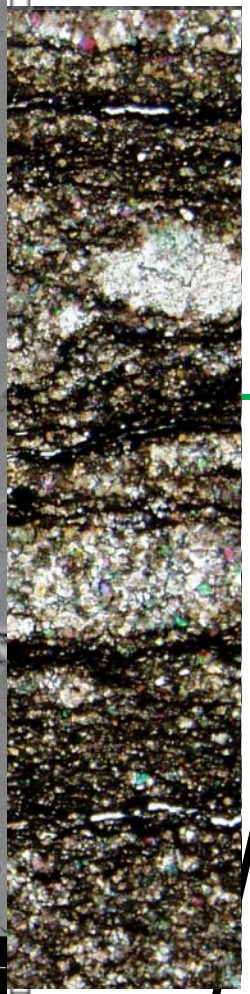
Z2 Basin Parchim

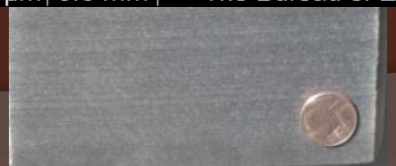




Z2 Basin Parchim







Z2 Third-order basinal/slope sequence

Grainstone blocks in laminated mudstone slope facies

Crinkle-laminated calcareous, dolomitic mudstone

Chicken-wire Anhydrite (Basal)

Crinkle-laminated mudstone

Laminated calcareous Mudstone with micro-stylolites

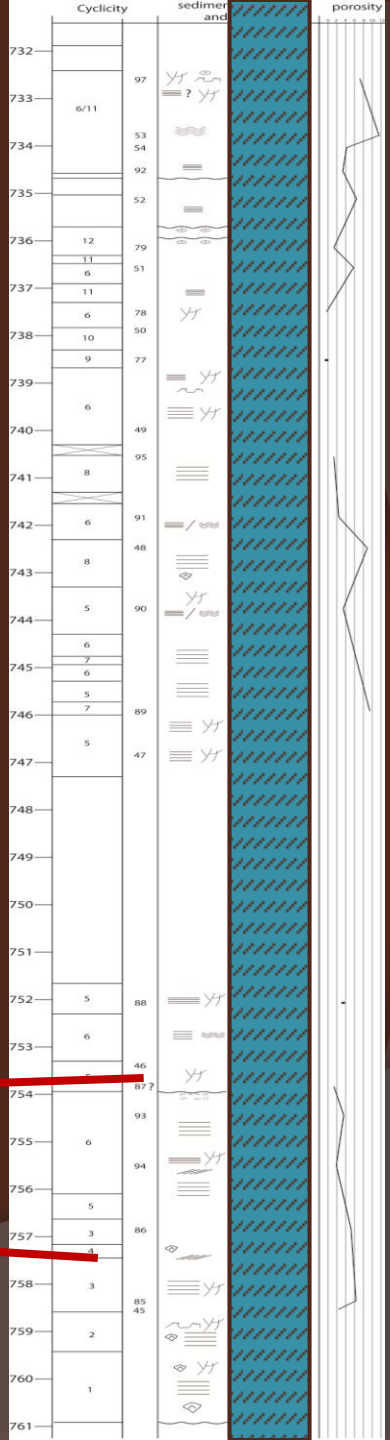
Laminated, bituminous Calcareous mudstone

Deepening-upward

Shallowing-upward

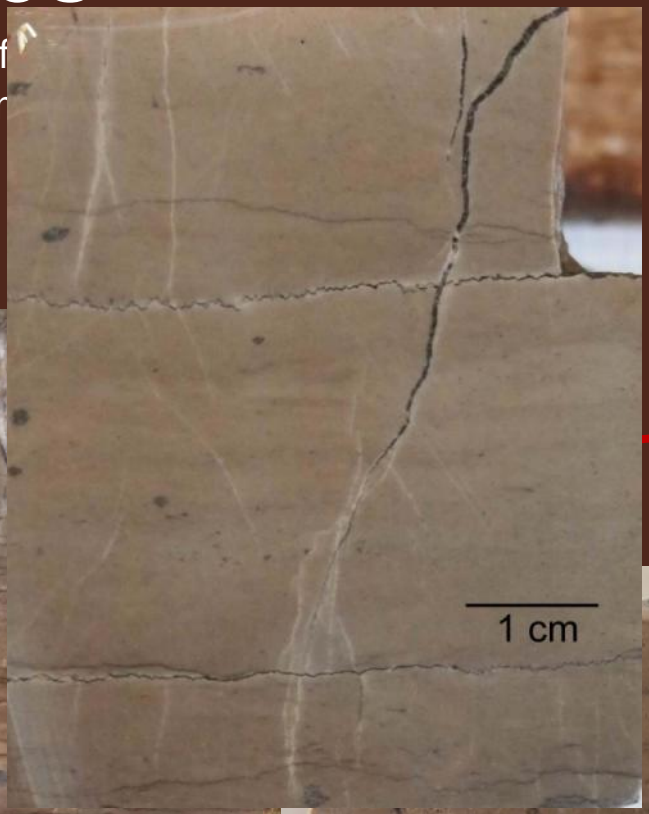
Z2 Platform Facies

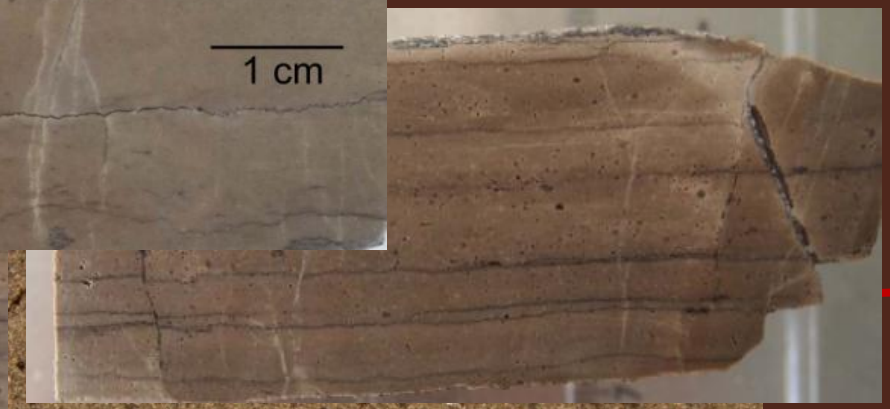
(courtesy of M. Krause, U. Potsdam)

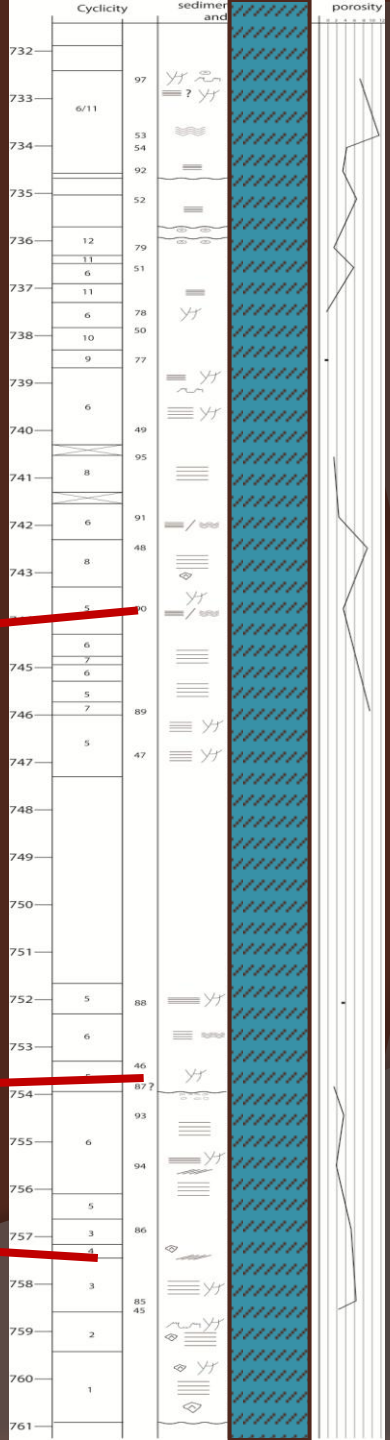


Z2 Platform Facies

(courtesy of U. Potsdam)

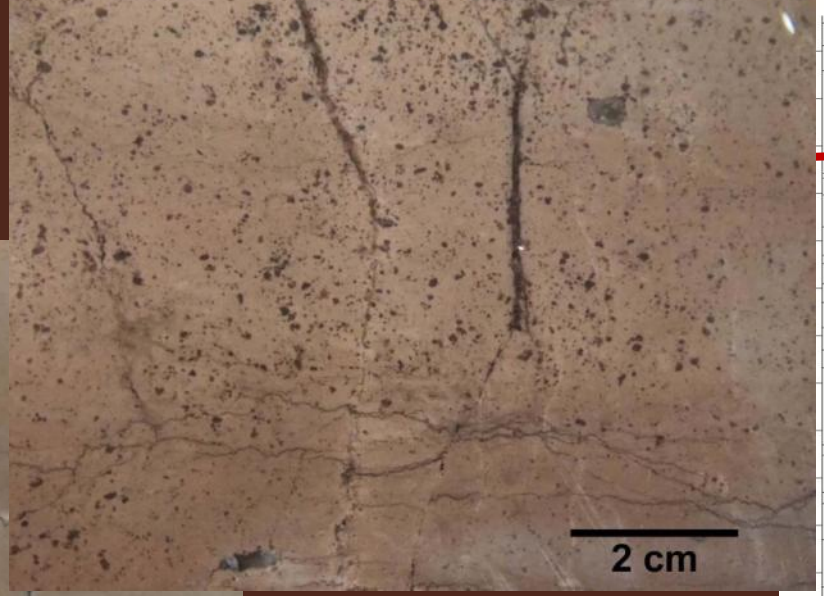


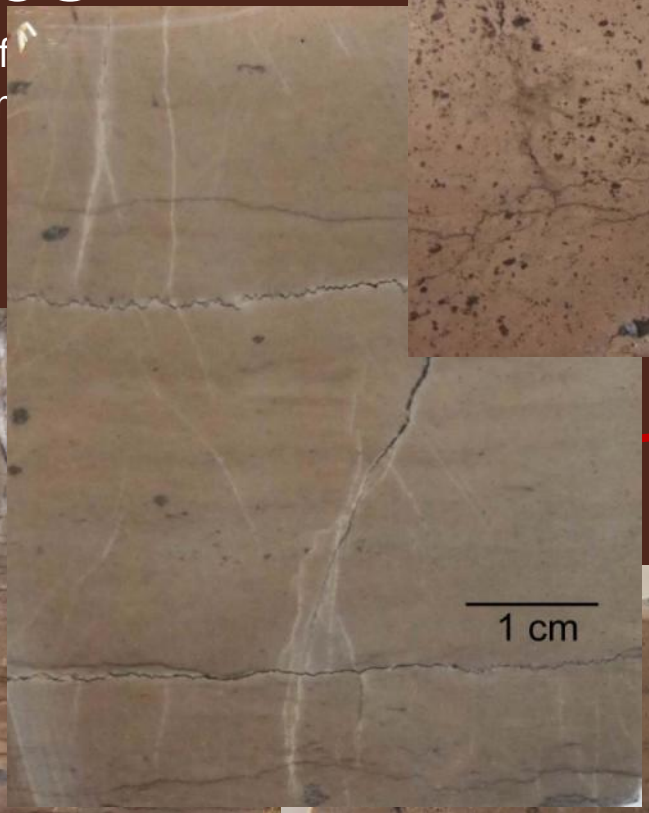


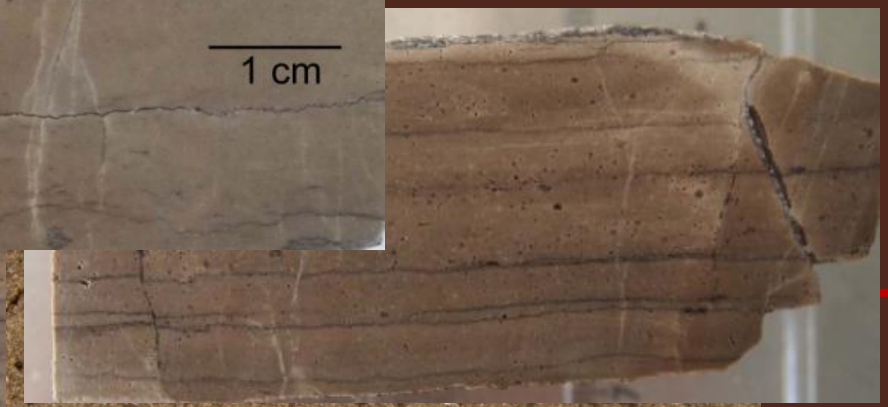


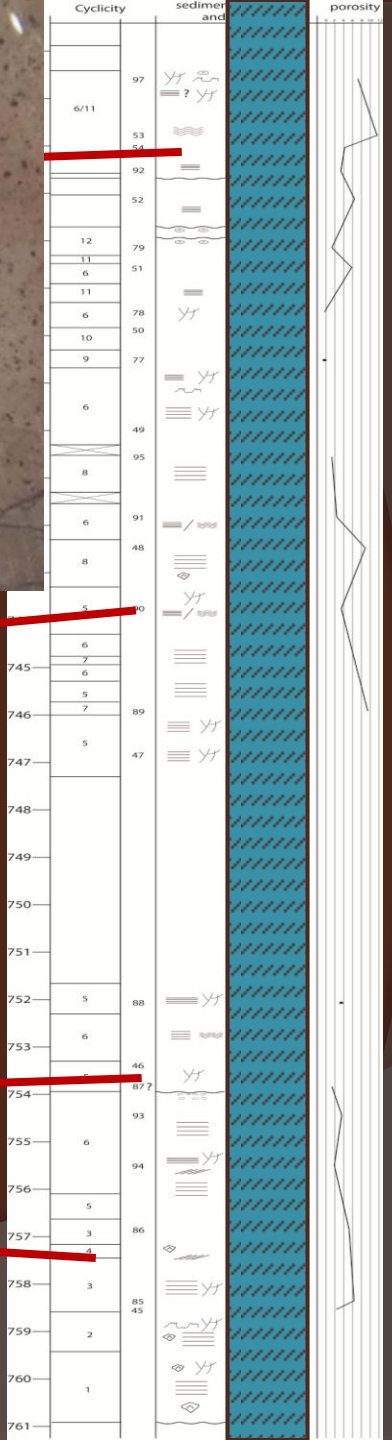
Z2 Platform Facies

(courtesy of U. Potsdam)

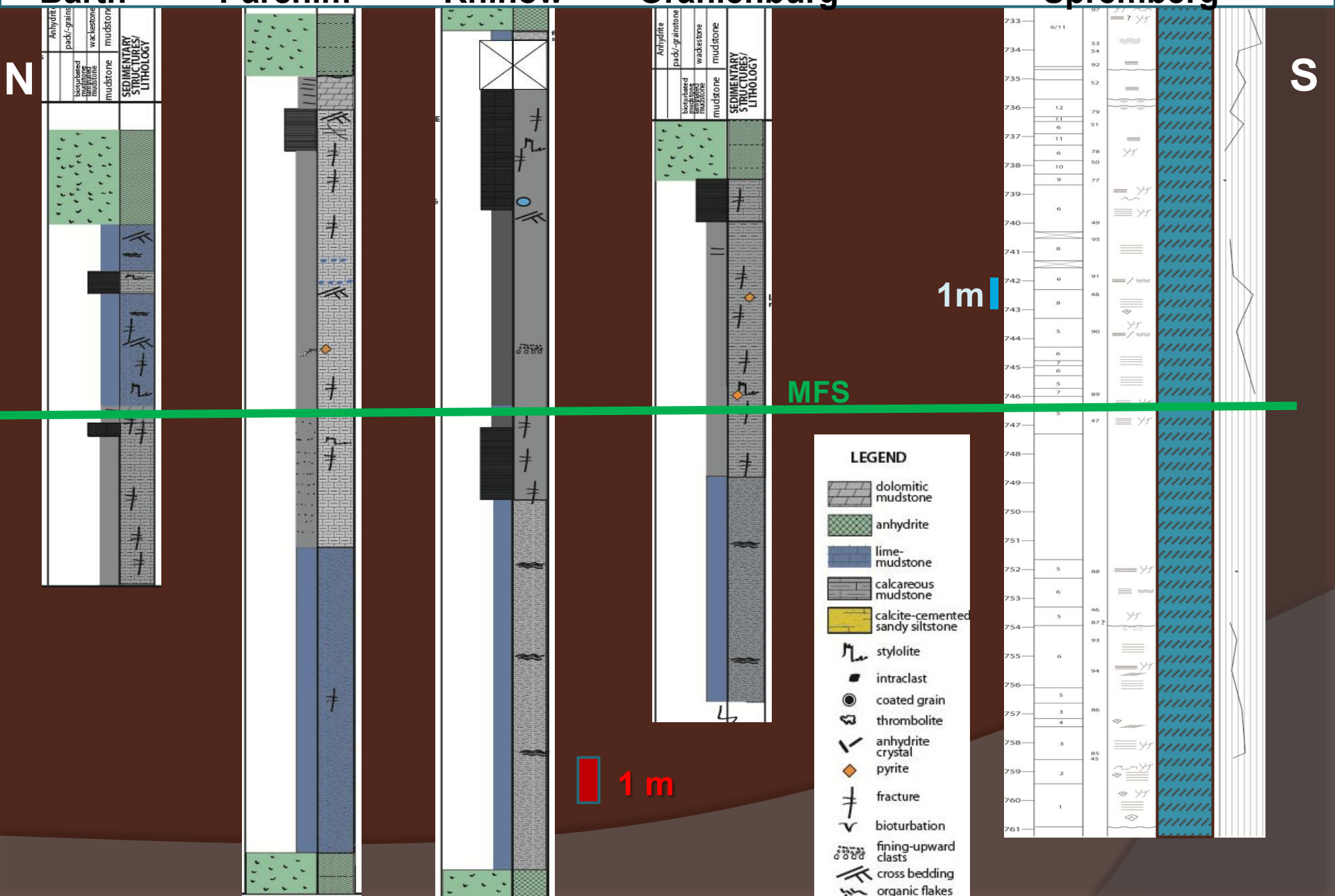




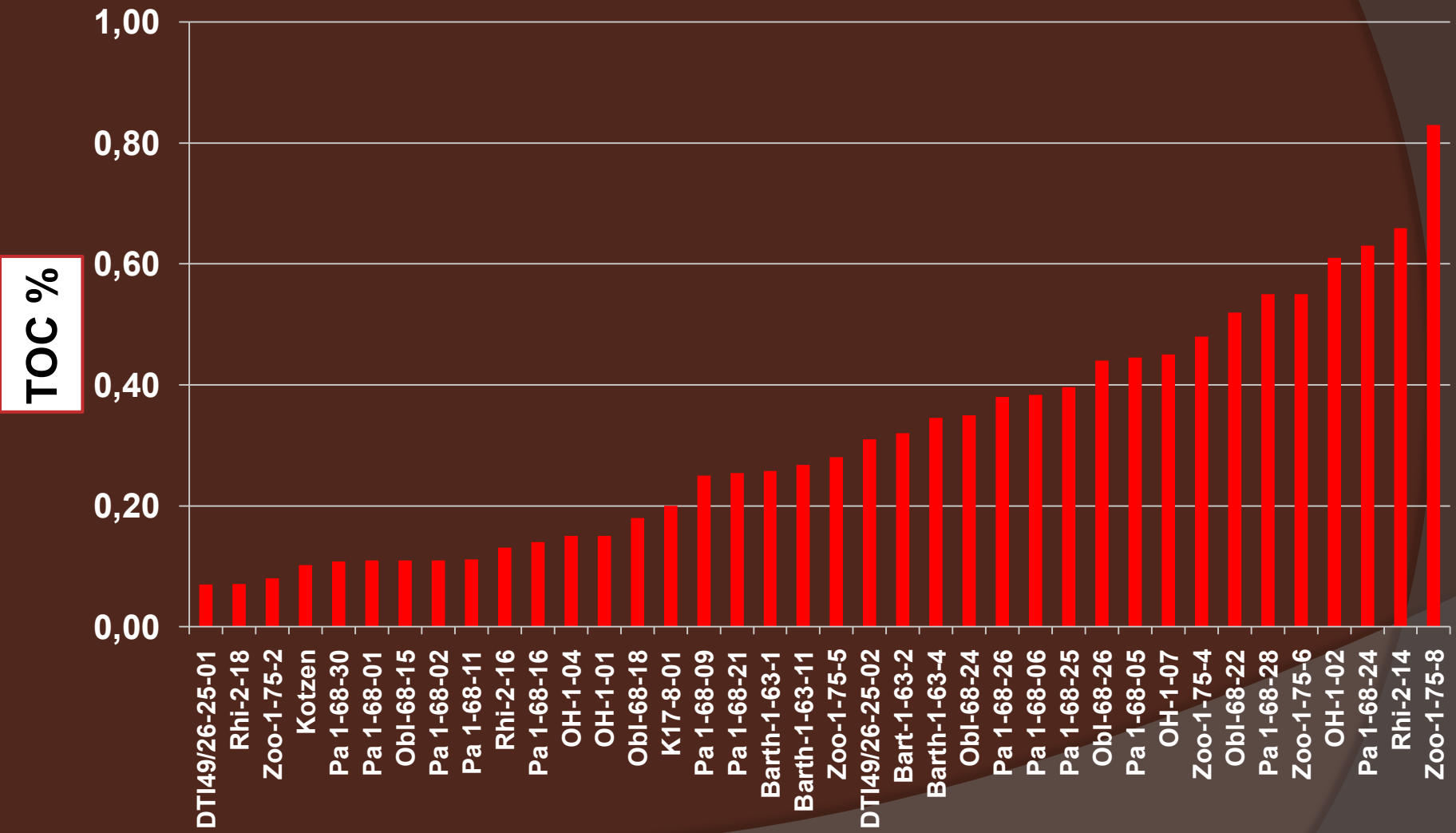




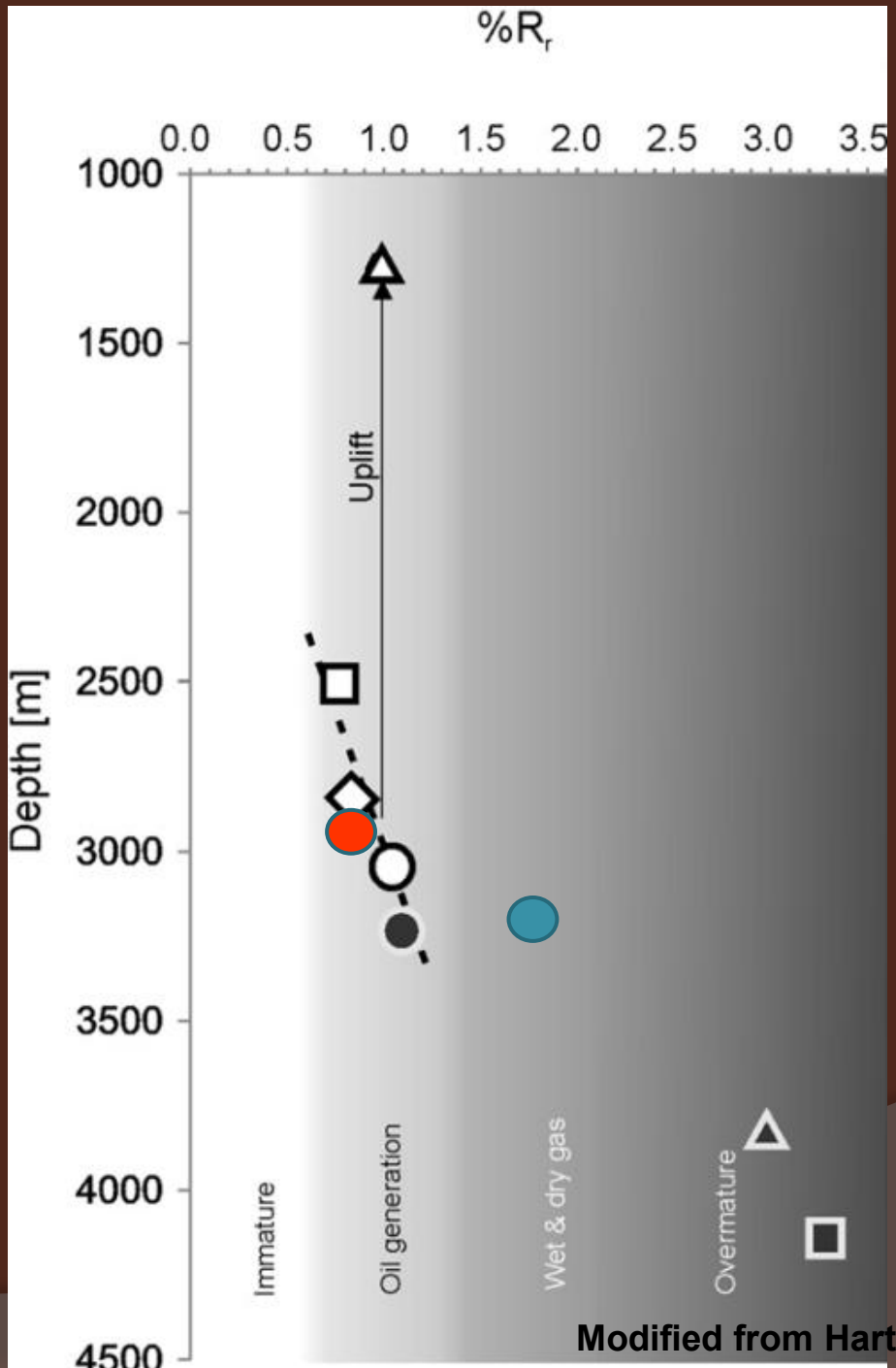
Zechstein Z2 – N to S Platform



TOC Z2 Germany and Holland



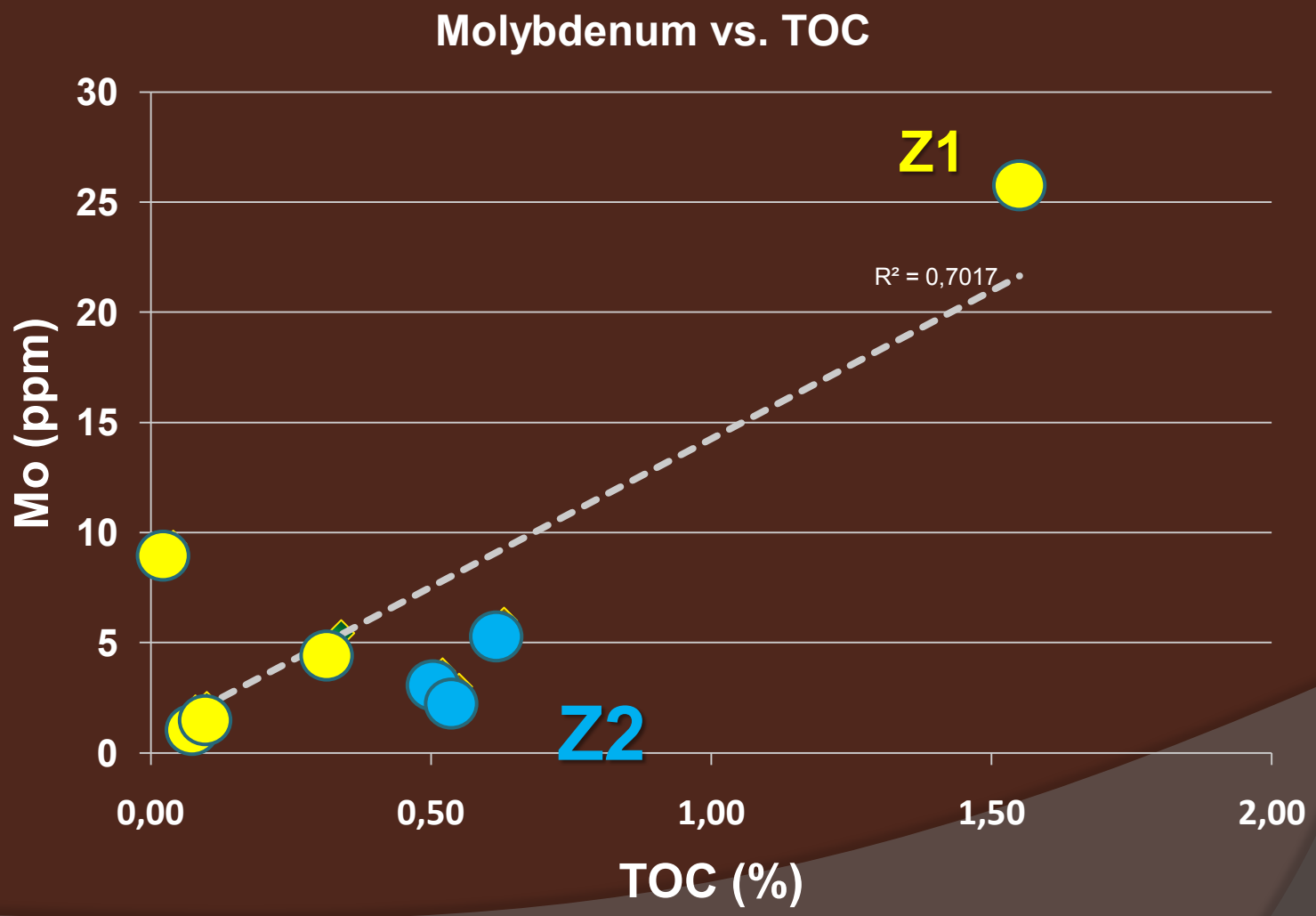
Maturity



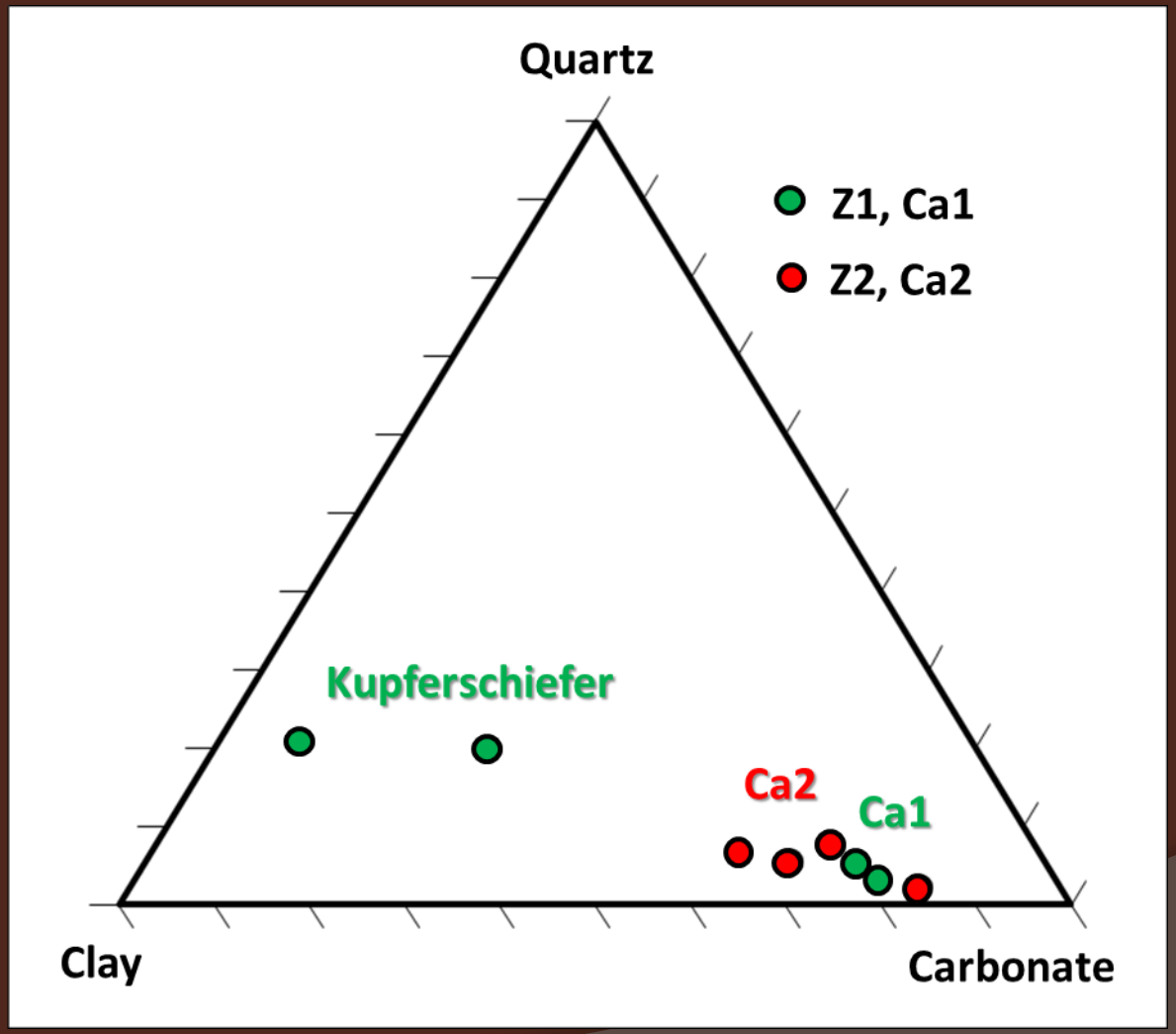
Modified from Hartwig and Schulz (2010)

Geochemistry

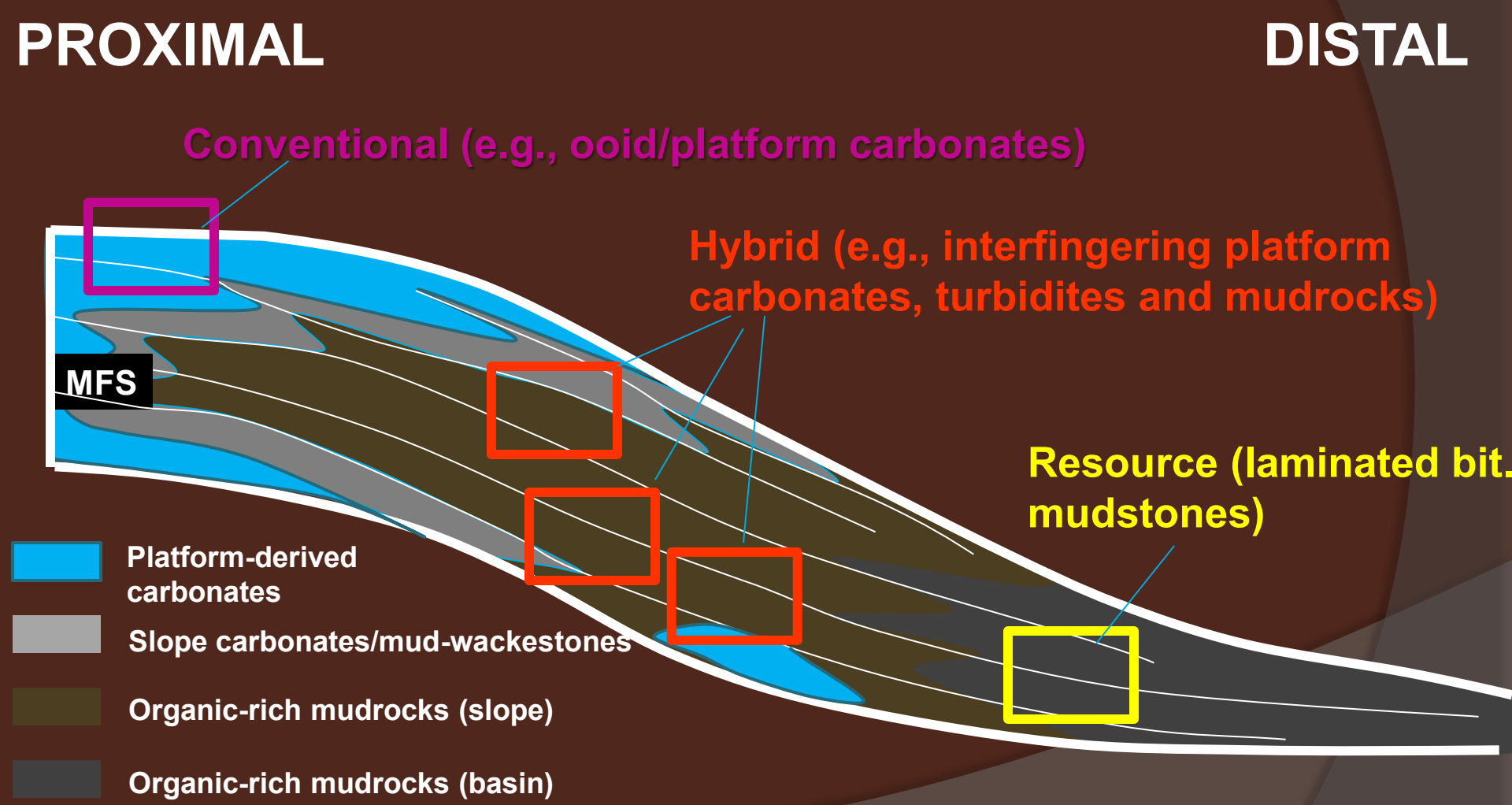
Mo versus TOC relationship



Geochemistry - XRD



Conventional, hybrid, or resource play?



Conclusions

- Bituminous, laminated, calcareous mudstones and mudrocks are present in the Zechstein Z1 and Z2 basins.
- Z1 mudrocks show high TOC and maturities ranging from oil to gas window.
- Z2 mudrocks show low TOC and maturities ranging from oil to gas window.
- Interfingering organic-rich mudstones and grain/packstones and dolomites might present new exploration possibilities and serve as analog to other hybrid plays.
- Further evaluation and expansion of the study area is necessary to assess the full potential of the Zechstein unconventional reservoirs.