[PS]The Impact of Dedolomitization on Reservoir Quality of the Upper Permian Zechstein-2-Carbonate, NW Germany*

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Abstract

The Upper Permian Zechstein 2 Carbonate (Ca2), one of the most prolific gas reservoirs in northwestern Germany, shows fair to excellent reservoir quality where dolomite and decreased reservoir quality where calcite. The majority of calcite is related to an intermediate burial dedolomitization phase. Dedolomitization, the replacement of dolomite by calcite, is accompanied by calcite cementation and represents the most intense porosity- and permeability-destroying stage during the diagenetic history of the Ca2. Most of the gas fields within the German Zechstein fairway are located in the mainly dolomitized platform environment. The remaining fields are in the mainly dedolomitized slope environment. Significant exceptions to this generalization occur along the slope, where porous dolomitic zones enhance reservoir quality in otherwise tighter dedolomitized carbonates. Dedolomitized zones also decrease reservoir quality in platform-lithofacies-types carbonates.

The spatial distribution of the gas-bearing dolomite zones is challenging to predict between wells. Detailed petrography and areal mapping of the dolomite/calcite ratio of wells indicates that most of the dolomitic zones within the slope occur along the upper slope. The middle and lower slope show dolomite contents of ca. 10% and are thus lower reservoir quality than the upper slope. On the platform a regional pattern is observed, with intertidal lithofacies types consisting mainly of dolomite, whereas more open marine shallow subtidal lithofacies types show a higher degree of dedolomitization. The occurrence of dedolomite present within platform lithofacies types is essentially limited to the lowstand wedge (LSW), which overlies upper slope carbonates basinward of the late transgressive and highstand Ca2 platform carbonates. Porosity-permeability cross-plots, coded for mineralogy and lithofacies, indicate a strong dependency of reservoir quality on the stratigraphic architecture of the Ca2.

The dedolomitizing fluids may originate from the overlying (A2) and/or underlying (A1) anhydrite layer. Calcium-rich pore fluids, released during the transformation of gypsum to anhydrite, and pressure solution of anhydrite might have entered the Ca2 via a conductive fracture network, preferentially dedolomitizing lithofacies types with initially high reservoir quality.

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The Impact of Dedolomitization on Reservoir Quality of the Upper Permian Zechstein-2-Carbonate, NW Germany (Part I)

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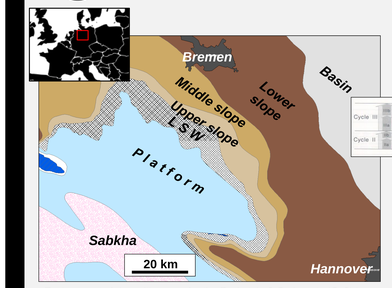
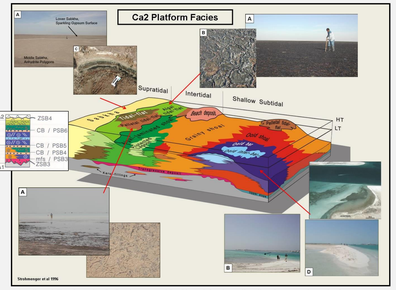
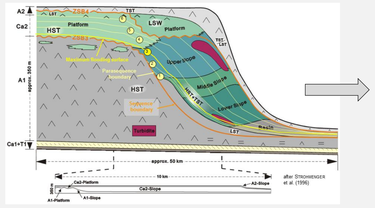
1 Geologic Setting



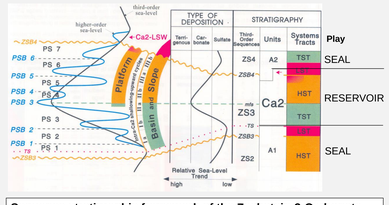
Environment of deposition map for the Zechstein-2-Carbonate (Ca2) in NW Germany (Strohmenger et al., 1996).



Idealized Zechstein-2-Carbonate (Ca2) subfacies distribution on the platform (Strohmenger et al., 1996). Recent Middle East carbonate environment can serve as a modern analogue for the Ca2 depositional model.

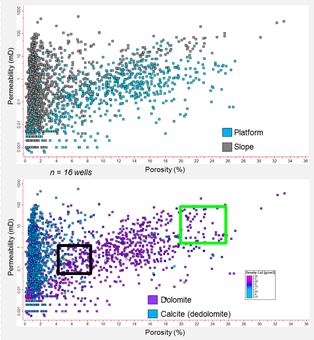


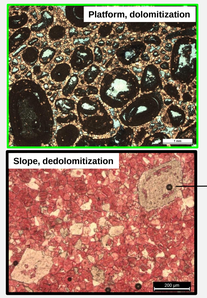
Sequence stratigraphic framework of the Zechstein-2-Carbonate (Ca2) in NW Germany (Strohmenger et al., 1996):
- Ca2 play types: platform, slope
- Ca2 thickness 20-ca. 270 m depending on EOD and local syntectonic induced differential subsidence
- Formation of Ca2 during TST & HST of the 3rd Zechstein sequence and LST of the 4th sequence with sedimentation of a lowstand wedge (LSW)
- 4 marine floodings / parasequence boundaries detectable on the platform

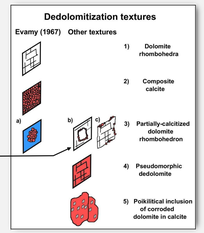


Sequence stratigraphic framework of the Zechstein-2-Carbonate (Ca2) in NW Germany (Strohmenger et al., 1996):
PLATFORM
Dominantly HST, TST thin/absent, four parasequences, only peritidal facies
SLOPE
Lower + Middle slope dominantly TST, Middle + Upper slope HST
LSW
Recognized by abrupt basinward shift of platform tidal flat facies (<20m) and shoal bars, if thickness > 20 m

2 Research Objective







OBSERVATIONS FOR Ca2:
- **Good Reservoir Quality correlates to Dolomite**
- **Poor Reservoir Quality correlates to Calcite**
- **Most of this calcite formed by dedolomitization**

RESEARCH OBJECTIVE / BUSINESS DRIVER
- **Spatial distribution of dedolomite?**
  - **Characteristics of dedolomite?**
  - **Correlation to Stratigraphy (EOD, Facies)?**
- **Paleo-hydrogeology during dedolomitization?**

→ Patterns, Mechanisms, Rules to build concepts?

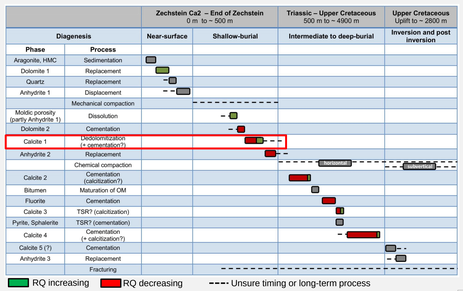
$$CaMg(CO_3)_2 + Ca^{2+} + SO_4^{2-} = Mg^{2+} + SO_4^{2-} + 2CaCO_3\downarrow$$
Dolomite | Calciumsulphat dissolution | Mg in solution due to sulphate | Calcite precipitation

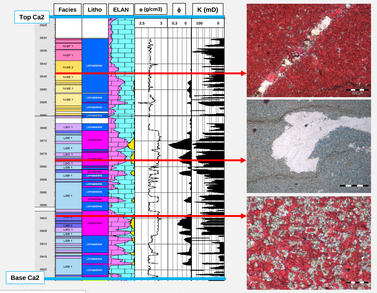
DEDOLOMITIZATION – DEFINITION
Dedolomite forms by the replacement of dolomite with calcite which is driven by the infiltration of Ca-rich water. This process has been described in the literature as either increasing, preserving or decreasing porosity of the initial dolostone (*Ayora et al., 1998*).

The replacement of dolomite by calcite either through mole per mole calcite replacement of the dolomite or by the dissolution of dolomite followed by in situ calcite precipitation (*Literature review by Nader et al., 2008*).

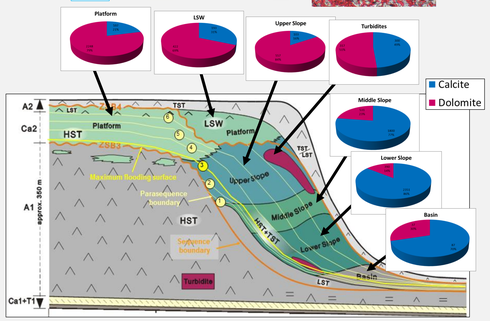
Only if dissolution/precipitation took place concurrently, the use of 'dedolomitization' is appropriate. If dolomite is dissolved and calcite precipitated at a later stage, the term dedolomite should not be used (*Nader et al., 2008*).

3 OVERVIEW Ca2 Reservoir Quality

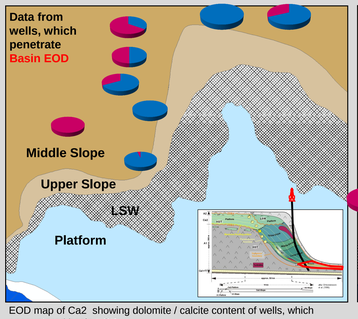




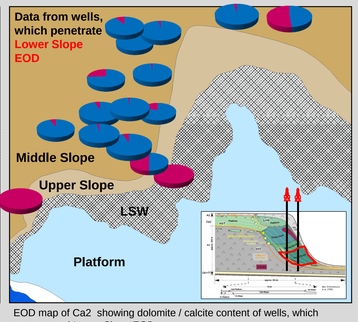
OVERVIEW ON OBSERVATIONS
- Dedolomitization identified as most important RQ decreasing process
- In all EODs most of calcite is a dedolomite
- Dedolomitization is most likely a shallow to intermediate burial process
- Lower-Middle slope shows higher degree of dedolomitization compared to platform EOD
- Basinal Ca2 facies „preserved" some dolomite



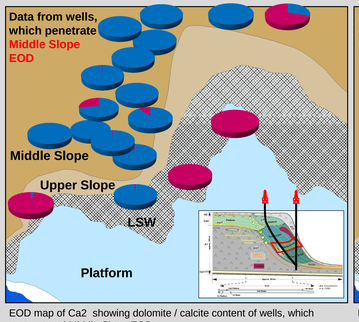
4 Spatial distribution of dolomite and calcite (= dedolomite)



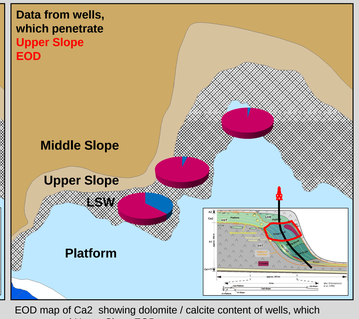
EOD map of Ca2 showing dolomite / calcite content of wells, which encountered basin EOD



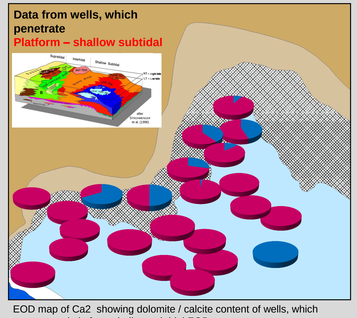
EOD map of Ca2 showing dolomite / calcite content of wells, which encountered Lower Slope EOD



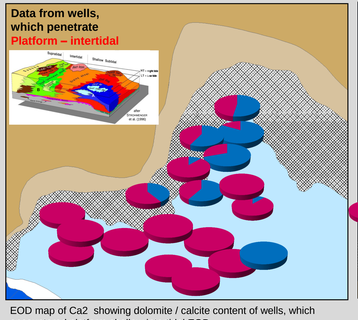
EOD map of Ca2 showing dolomite / calcite content of wells, which encountered Middle Slope EOD



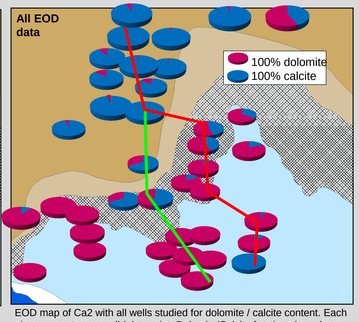
EOD map of Ca2 showing dolomite / calcite content of wells, which encountered Upper Slope EOD



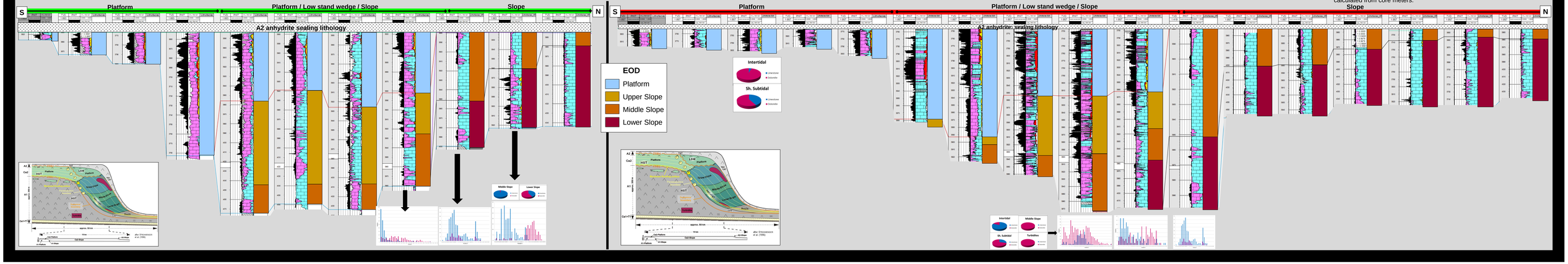
EOD map of Ca2 showing dolomite / calcite content of wells, which encountered platform shallow subtidal EOD



EOD map of Ca2 showing dolomite / calcite content of wells, which encountered platform shallow intertidal EOD



EOD map of Ca2 with all wells studied for dolomite / calcite content. Each pie represents one well / datapoint. Dolomite/Calcite fractions have been calculated from core meters.



The Impact of Dedolomitization on Reservoir Quality of the Upper Permian Zechstein-2-Carbonate, NW Germany (Part II)

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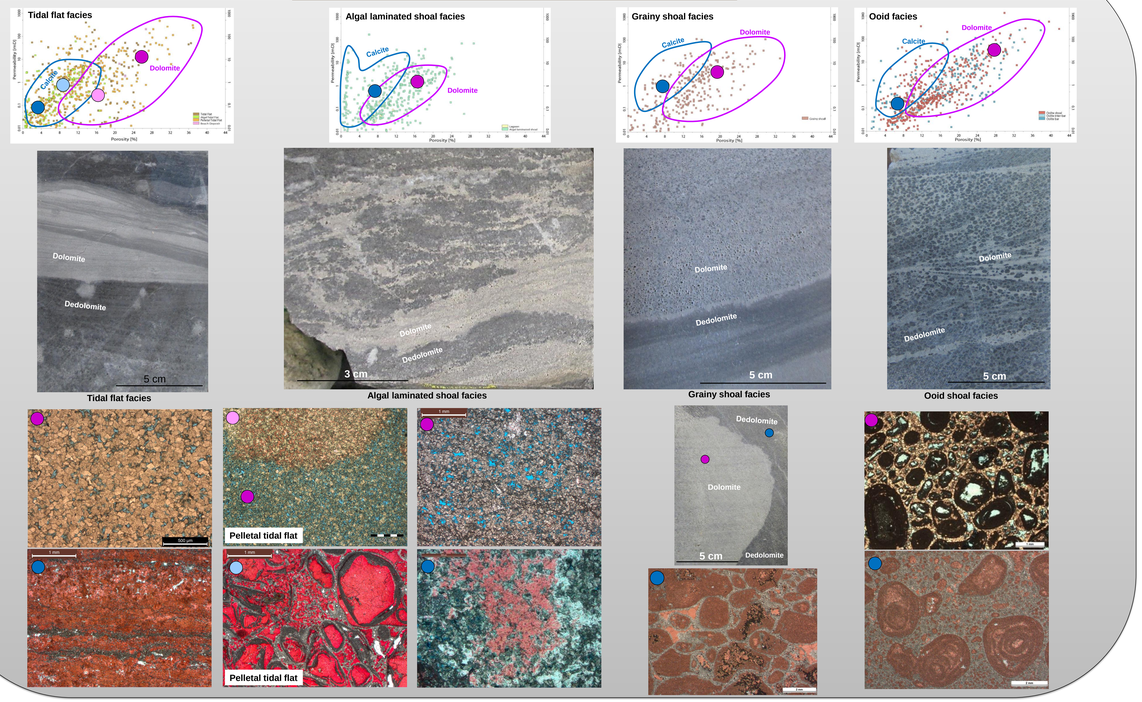
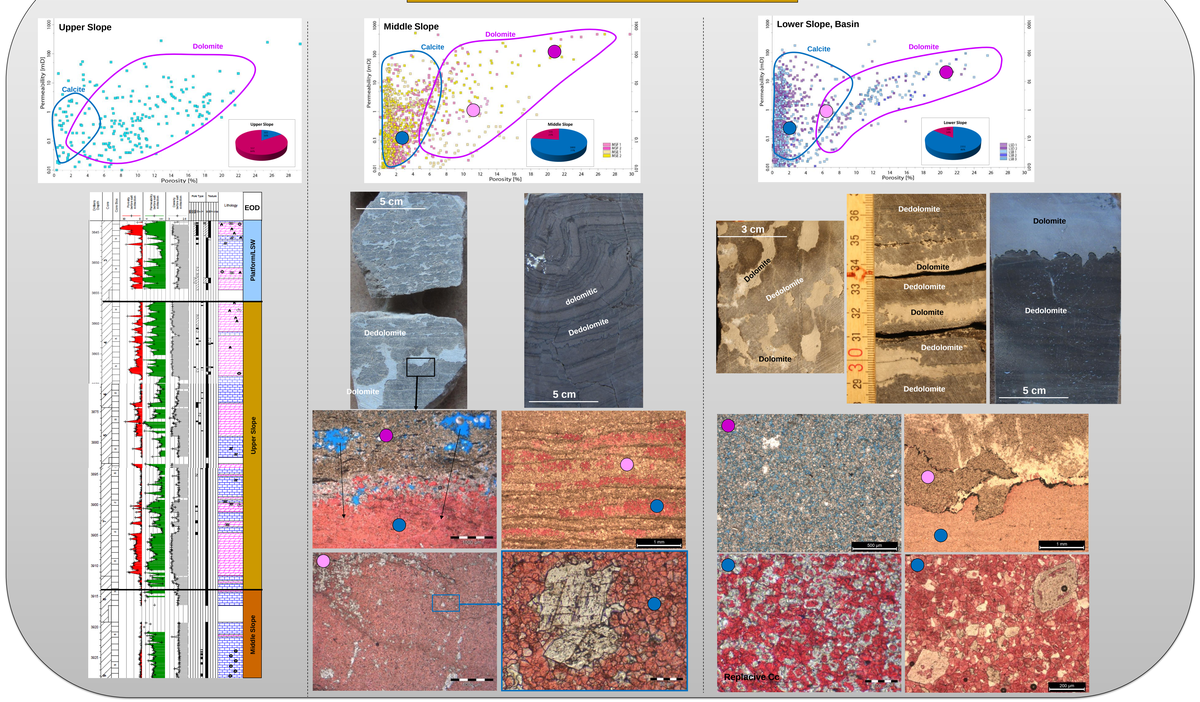
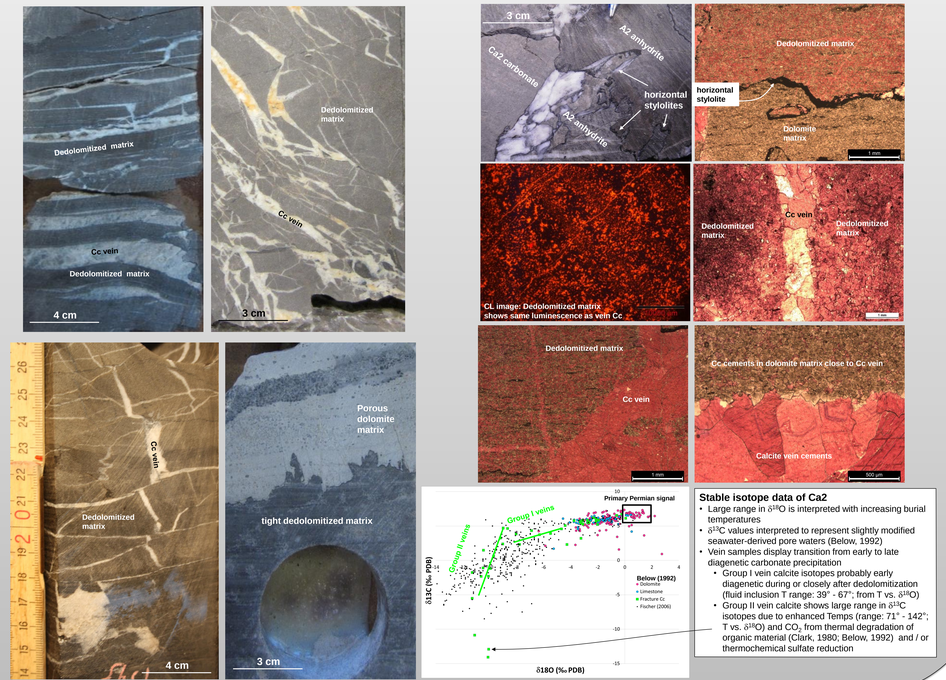
Matrix dedolomitization – Platform



Matrix dedolomitization - Slope



Structurally-controlled dedolomitization – Platform and Slope



Stable isotope data of Ca2

- Large range in $\delta^{18}O$ is interpreted with increasing burial temperatures
- $\delta^{13}C$ values interpreted to represent slightly modified seawater-derived pore waters (Below, 1992)
- Vein samples display transition from early to late diagenetic carbonate precipitation
  - Group I vein calcite isotopes probably early diagenetic during or closely after dedolomitization (fluid inclusion T range: 39° - 67°; from T vs. $\delta^{18}O$)
  - Group II vein calcite shows large range in $\delta^{13}C$ isotopes due to enhanced Temps (range: 71° - 142°; T vs. $\delta^{18}O$) and CO_2 from thermal degradation of organic material (Clark, 1980; Below, 1992) and / or thermochemical sulfate reduction

CONCLUSIONS & CONCEPTS

CONCLUSIONS

SUMMARY OF OBSERVATIONS

1. Reservoir quality correlates to mineralogy: Dolomite (high porosity and permeability) vs. Calcite / Dedolomite (low poro-perm)
2. Almost all calcite is present as dedolomite and cements. Primary limestone is virtually absent.
3. Dedolomitization can be texturally partial or pervasive, fabric-selective or completely fabric-destructive
4. Dedolomite proportion gradually increases from platform to basin EOD
   - Often, dedolomite is observed to follow initially better reservoir quality depositional lithofacies types

INTERPRETATION

Distribution of dedolomite essentially controlled by environment of deposition, platform and slope lithofacies types

- Hydrogeologically, flow of dedolomitizing waters preferentially followed the initially more permeable lithofacies types, which locally led to an inversion of reservoir quality, especially in **middle and lower slope** sub-facies types; i.e. pore throat and pore cementation and replacement of dolomite by calcite
- → **Platform EOD:** locally intertidal lithofacies types show lower proportions of dedolomite than higher-energy lithofacies types in the Northern Zechstein platform, but overall grain-dominated lithofacies has the best RQ (opposite at Southern Zechstein platform)
- → **Upper Slope:** Quantitatively lowest degree of dedolomitization compared to Lower and Middle Slope EODs
- → **Middle Slope:** High poro-perm dolomite preferentially consists of facies types defined by the occurrence of soft-sediment deformational structures (MSE 2 and MSF 2 after Strohmenger et al., 1996). Dedolomitization appears to have happened equally in both, within regularly-spaced mm- to cm-bedded mudstones (MSE1 and MSF 1 after Strohmenger et al., 1996) and the re-worked lithofacies types.
- → **Lower Slope:** High poro-perm dolomite preferentially consists of facies types defined by the occurrence of soft-sediment deformational structures (LSD 2 after Strohmenger et al., 1996). Dedolomitization appears to have happened equally in both, within regularly-spaced mm-bedded mudstones (LSD1 after Strohmenger et al., 1996) and the re-worked lithofacies types.
- Fractures, locally acted as conduits for matrix-dedolomitizing fluids, which is supported by core observations where a higher degree of matrix dedolomitization in the vicinity of Cc-cemented veins was observed.

HYPOTHESES ON THE ORIGIN OF DEDOLOMITE

A. BASIN- SLOPE-DERIVED DEDOLOMITIZING FLUID

- **CO_2:** CO_2 is needed to dissolve dolomite – derives from thermal degradation of organic material in basinal mudstones: Reason for overall higher amount of dedolomite in slope vs. platform setting (hypothesis of Clark, 1980; partially of Below, 1992)
- **Anhydrite:** Often, total dedolomitization on a volume for volume basis has been observed → an external source for Ca2+ is needed: In these cases, Ca2+ may originate from dewatering (gypsum-to-anhydrite dehydration) and pressure solution of the sandwiching anhydrites (A1, A2). Dedolomites show a very high Sr-content compared to the dolomite (Huttel ,1987). It is more likely that this Sr comes from the anhydrite layers above and below rather than from the original seawater or even from deeper-basinal fluids.
  - → Model assumes that CO_2 was generated in basinal and lower slope organic-rich(er) mudstones. This CO_2 went into solution, migrating updip towards more proximal EODs, preferentially following lithofacies types with initially highest permeability/accessability in slope EODs. The dolomite dissolution potential was then almost lost as the CO_2-bearing fluids arrived on the platform.

B. FAULT-DERIVED DEDOLOMITIZING FLUID

- Model suggests that larger-scale fault systems and related fractures controlled distribution of nonporous dedolomite by acting as conduits for calcitizing fluids originating from the A1 anhydrite (Love et al., 1997).
- In this case, the distribution of dedolomite within the slope EODs would be not facies-dependent but rather that the same facies is subjected to different degrees of dedolomitization, depending on the proximity to these fault systems.