# Presaline sedimentation controlling the initial development of a giant salt deposit (Zechstein Cycle-1, Germany)

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A facies and sequence stratigraphic model is presented for the Hessian basin (Germany) including the rocksalt bearing Werra subbasin based on detailed lithofacies descriptions of Zechstein Cycle-1 carbonates and evaporites in the cores of more than 30 wells. Seven facies associations (FA) are described and two third-order depositional sequences (ZS1, ZS2) can be recognized. ZS2 is most important for the understanding of the initial development of the salt deposit. At the end of ZS1 a sea level drop led to the exposure of the marginal areas of the Hessian Zechstein basin. Lowstand aggradation of peritidal wedges characterize the shelf margin systems tract of ZS2. The transgressive systems tract of ZS2 comprises three shallowing-upward cycles which developed in a salina-sabkha environment. In the Werra subbasin maximum flooding during ZS2 is clearly indicated by laminated anhydrites and carbonates. Highstand conditions prevailed throughout the subsequent sulfate and finally sulfate/halite deposition.

In the Hessian basin sulfate precipitation started under shallow water conditions and evolved into deeper water, whereas rocksalt deposition took place in a deep water environment created by differential precipitation and subsidence/sea level rise. The deep water/deep basin setting of halite precipitation was caused by evaporite precipitation itself, not by a relief existing prior to the inset of evaporite sedimentation.

## 1. INTRODUCTION

The Hessian Zechstein basin (Germany) is a marginal basin of the Southern Permian Zechstein basin, which extended from Great Britain, via The Netherlands and Germany to Poland (Ziegler 1990). Subsidence induced by rifting (Smith 1980, Ziegler 1990) in combination with a second- and third-order sea level rise (Strohmenger et al. 1996) caused a marine transgression invading the Permian basin from the north. The marine Upper Permian Zechstein is characterized by evaporite cyclic sedimentation (Richter-Bernburg 1955). The progressive sedimentation of a complete evaporite cycle starts with clastic sediments followed by carbonates, sulfates, chlorides and finally potash salts. So far, eight more or less complete evaporite cyles are known (Subkommission Perm-Trias 1993) which are thought to represent a time span of about 7 My with the Zechstein Cycle-1 (or Werra-Cycle) covering a period of about 2 My (Menning 1995). Sequence stratigraphic concepts were presented by Tucker (1991) for the Zechstein of England and by Strohmenger et al. (1996) and Leyrer et al. (1999) for the Zechstein of Northern Germany, focussing especially on the gas-bearing Zechstein Cycle-2.

The investigated area within the Hessian Zechstein basin is located south of Kassel and is bound by the Rhenish Massif in the west, the Spessart mountains in the south and the border between Hesse and Thuringia in the east (Fig. 1).

According to Kulick et al. (1984), palaeohighs subdivided the Hessian Zechstein basin into different subbasins reflecting the former morphology of the terrestrial Lower Permian Rotliegendes. Therefore, the published evaporite depositional model for the Werra subbasin during Zechstein Cycle-1 (Richter-Bernburg 1985) corresponds to a deep water-deep basin model (see Warren 1989, Kendall 1992). According to it, evaporite sedimentation in the basin centre usually starts off deep. There, thin evaporites are deposited in deep water whereas shallow water evaporites build up thick sulfate wedges at the basin margins.

It is thought that Zechstein Cycle-1 carbonates and evaporites were deposited mainly under the control of sea level fluctuations (Peryt 1978, Smith 1980, Taylor 1980, Paul 1986, Tucker 1991, Strohmenger et al.

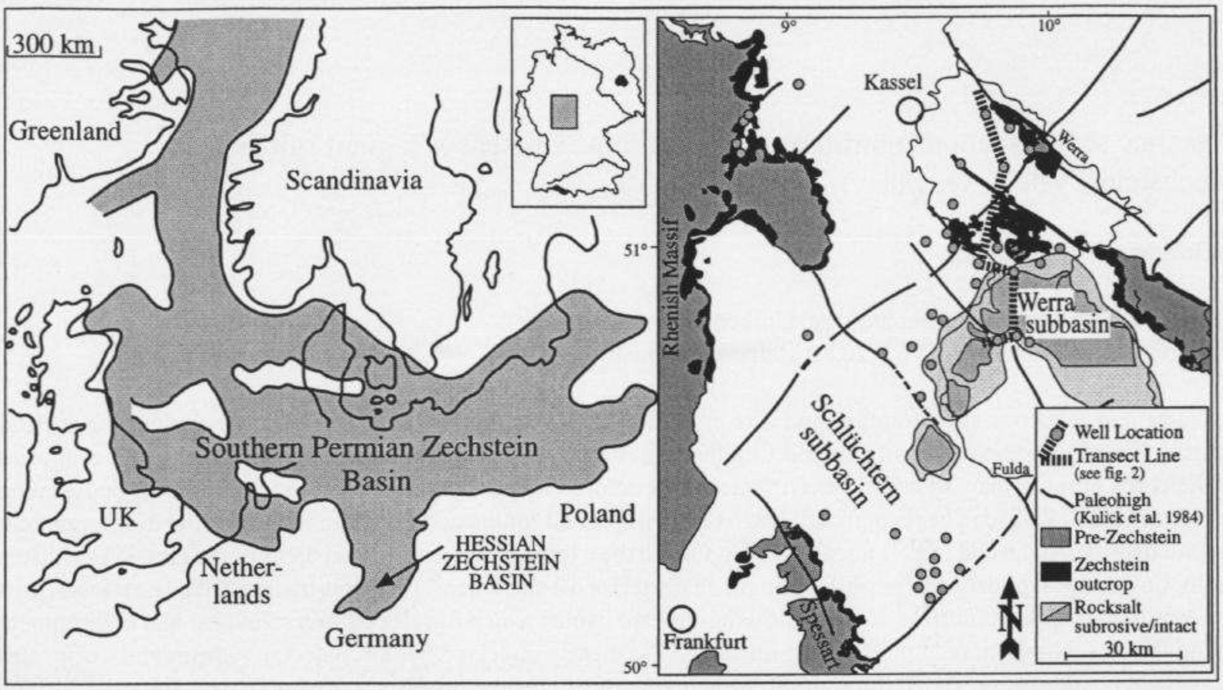


Figure 1: Palaeogeography of the Southern Permian Zechstein basin (after Smith 1980) and of the Hessian Zechstein basin (after Kulick et al. 1984).

1996). Changes in currents and/or climatic factors were proposed by Richter-Bernburg (1985) to explain the cyclicity within the sulfate succession. Regional differences and temporal changes in total subsidence of the Zechstein substrate have to be considered as well to explain regional facies distribution (Ziegler 1989).

This paper deals with the carbonate and evaporite sediments underlying the huge, up to 300 m thick rocksalt accumulations of the Werra-Halite (Na1). Detailed facies analysis based on lithofacies descriptions in cores of more than 30 wells allowed to establish a facies and sequence stratigraphic model. Cycle stacking patterns of genetically related depositional facies within facies associations and their interpretation in sequence stratigraphic terms are very important for the understanding of the initial development of this giant salt deposit.

## 2. FACIES ANALYSIS

Genetically related lithofacies types were grouped into 7 facies associations (FA), which are comparable to depositional environments. FA1 to FA4 belong to the known lithostratigraphic unit of the Zechsteinkalk (Ca1). FA5 to FA7 are found within the so called "Anhydritknotenschiefer" (A1Ca) and in the Lower Werra-Anhydrite (A1).

***FA1 Clastic dominated basin facies***

Siltstones and silty mudstones with thin bioclastic intercalations build up a 30 to 40 m thick succession in a separate subbasin (Schlüchtern subbasin) south of the Werra subbasin.

***FA2 Algal-reef mound- and back-reef facies***

Boundstones with thrombolithic and laminar textures characterize the algal-reef mound facies. The dominant reef building organism is *Archaeolithoporella*. Bryozoa play only a minor role. The back-reef facies is dominated by algal laminated oncoid-wacke- to packstones with few gastropodes and dasycladacean algae. FA2 is developed at the southern margin of the Schlüchtern subbasin close to the Spessart.

***FA3 Low energy shallow water carbonates***

Bioturbated silty mudstones, homogeneous mudstones and oncoid wackestones associated with small columnar stromatolites and inversely graded pisoid layers are found throughout the entire Hessian basin north of the Schlüchtern subbasin.

***FA4 High energy shallow water carbonates***

At the western margin of the Hessian basin cross-bedded ooid-grainstones are developed on top of a mudstone succession.

***FA5 Peritidal facies***

Shallow subtidal, intertidal and supratidal environments characterize the peritidal facies association. In the central part of the Hessian basin (Werra and Schlüchtern subbasin) subtidal deposits prevail. Laminated, bituminous carbonates with displacive, early diagenetic, small gypsum crystals indicate low energy stagnant conditions of a slightly deeper lagoonal area. Intercalations of dolomudstones within the laminites are attritbuted to a periodic breakup of the water stratification. The dolomudstones were deposited in a low energy shallow subtidal lagoonal environment. Cryptalgal laminites which were intensively replaced by sulfates during early diagenesis represent intertidal deposits and occur to the west of the Werra and Schlüchtern basins. Separated and coalesced sulfate nodules within dolomudstones (chicken-wire anhydrite) are interpreted as supratidal sabkha deposits. They occur west of the algal laminite belt.

***FA6 Salina and sabkha facies***

Mosaic anhydrite and upright elongated nodular to mosaic anhydrite are interpreted as former primary selenite gypsum forming in shallow subaqueous salinas (Warren & Kendall 1985). In the Werra subbasin salina-type sediments reach only a thickness of 10 m. To the west of the Werra subbasin a remarkable increase in thickness (up to 50 m in the interval discussed) indicates more favourable physico-chemical conditions for sulfate precipitation. Within the salina-type anhydrites three intercalations of sabkha-type chicken-wire anhydrites occur. Each succession from salina to sabkha sediments is interpreted as a shallowing-upward cycle.

***FA7 Deep water laminites***

Finely laminated sulfates ("Linien-Anhydrite") and carbonates with a slightly elevated organic carbon content (up to 1 %) are mainly found in the Werra subbasin. In general, laminated evaporites are deposited in low energy deep water environments (Richter-Bernburg 1985, Kendall 1992).

## 3. SEQUENCE STRATIGRAPHY

In the Hessian basin two complete third-order depositional sequences are recognized within the basal Zechstein Cycle-1 succession (Fig. 2).

### 3.1. Zechstein sequence 1 (ZS1)

According to Strohmenger et al. (1996) reworked sandstones of the "Weissliegendes" and/or the "Zechstein-Konglomerat" overly Zechstein sequence boundary 1 (ZSB1) and are interpreted as transgressive systems tract (TST) deposits of Zechstein sequence 1 (ZS1). The Copper Shale is regarded as a condensed section (CS). Zechstein Cycle-1 carbonates represent predominantly highstand systems tract (HST) deposits. Within the carbonates (FA1 to 4) two shallowing-upward cycles (fourth- to fifth order) are developed throughout the whole basin. They are interpreted as parasequences (PS1, PS2).

The uppermost parts of the algal-reef mound facies (FA2) and of the ooid-grainstones (FA4) at the southern and western basin margins show karstification. Stable carbon and oxygen isotope data of the ooid-grainstones reveal cementation under meteoric influence (Becker & Zeeh in press). This indicates exposure of Zechstein Cycle-1 carbonates at the marginal parts of the Hessian Zechstein basin at the end of ZS1 and gives evidence for Zechstein sequence boundary 2 (ZSB2).

### 3.2. Zechstein sequence 2 (ZS2)

The peritidal facies association (FA5) was formed under relative lowstand conditions. It represents an aggradation of peritidal wedges and is regarded as a shelf margin systems tract (SMST) of Zechstein sequence 2 (ZS2) (Fig. 2). Two shallowing-upward cycles are recognized and interpreted as fourth- to fifth order parasequences (PS1, PS2). PS1 is not developed in the southernmost parts of the Werra subbasin. Here, exposure lasted until PS2. In the northern part of the Werra subbasin the base of PS2 is indicated by the transgressive onlap of shallow lagoonal dolomudstones on intertidal cryptalgal laminites and supratidal sabkha deposits of PS1.

High sedimentation rates of evaporites compared to rates of sea level change within a basin lead to its rapid infill up to the water level (Warren 1989). As a consequence shallowing-upward cycles start with shallow subaqueous salina deposits overlain by thin supratidal sabkha horizons (FA6). During the transgressive systems tract (TST) of the second Zechstein sequence (ZS2) three of these cycles are recognized and interpreted as parasequences (PS3 to PS5). The stacking pattern of the parasequences indicate transgressive backstepping (Fig. 2).

Finally, laminated bituminous sulfates and carbonates (FA7) were deposited in slightly deeper water and mark the maximum flooding in the area (maximum flooding surface, mfs). During the highstand systems tract (HST) a simultaneous deposition of sulfates and

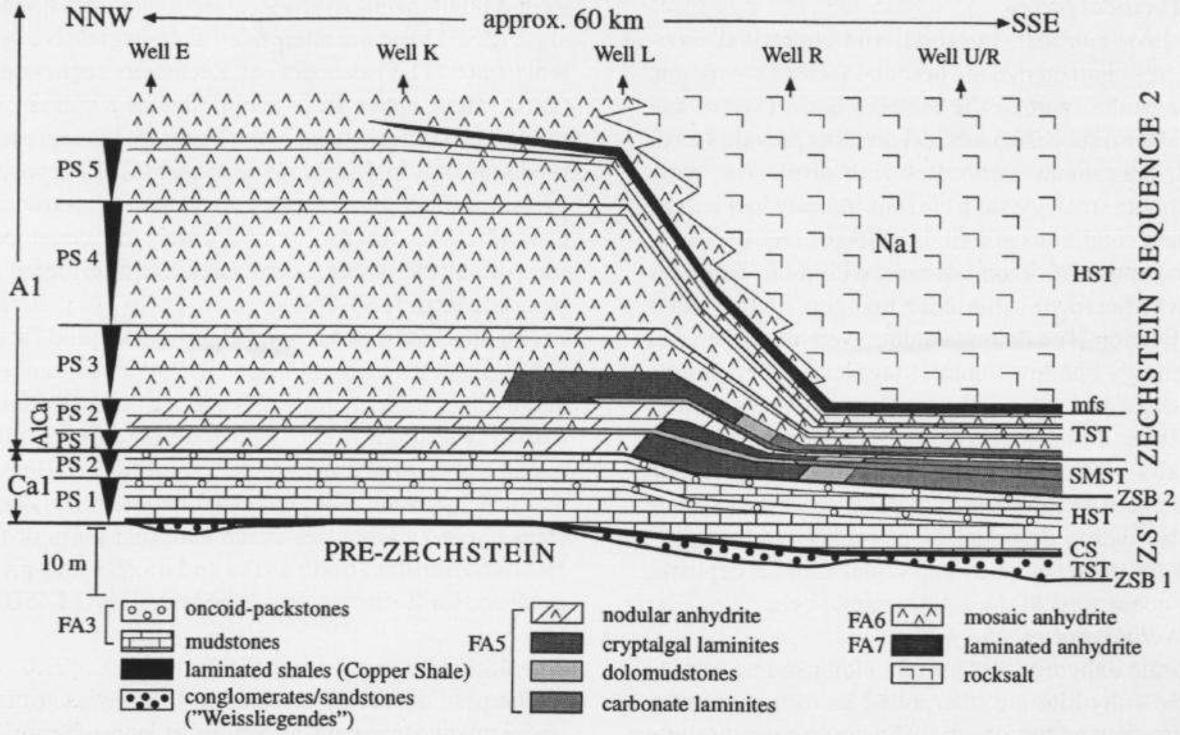


**Figure 2: Sequence stratigraphic model of Zechstein Cycle-1 carbonates and evaporites (see text for abbreviations).**

chlorides took place. Thick prograding wedges of shallow water sulfates developed around the Werra subbasin and to its west. Rocksalt deposition was restricted more or less to the Werra subbasin. Within the anhydrite succession some dm-thick intervals of thenardite and mirabilite possibly allow a correlation with the rocksalt. A more detailed investigation of the HST succession in the cores is prevented by the leaching and subrosion of sulfates and/or rock-salt having caused intensive brecciation. Red siltstones are found on top of the brecciated interval and indicate lowstand systems tract (LST) conditions of the third Zechstein sequence.

## 4. DISCUSSION

The parasequences PS1 to PS5 of the evaporites of Zechstein sequence 2 do not correspond to the known cycles in the Zechstein Cycle-1 evaporites described by Taylor (1980) and Richter-Bernburg (1985) from the Southern Permian basin. There, four to five intercalations of bituminous anhydrite and carbonate laminites into mosaic and/or displacive anhydrites indicate progressive rises in sea level. Water depths of approximately 150 to 300 m are assumed (Taylor 1980). The same problem of correlation is present for the marginal Leba subbasin in Poland, where deepening-upward cycles can not be recognized clearly, the succession therefore being difficult to correlate with the one of the Southern Permian basin. A possible reason may be a different brine composition and evolution in marginal areas compared to the main basin (Peryt 1994).

Low relief peritidal conditions existed throughout the Hessian basin during the early evaporite sedimentation. This indicates clearly, that in the Werra subbasin sulfate and rocksalt deposits did not infill a deep morphological structure existing prior to the beginning of evaporite precipitation. Therefore, other factors than a simple infill caused by cyclic evaporation-precipitation have to be responsible for the accumulation of huge sulfate and rocksalt deposits.

Water depth mainly controls sulfate precipitation: the best physico-chemical conditions are found in shallow water (centimeters to a few meters). As a consequence, minor differences in water depth lead to slightly different evaporite sedimentation rates and different evaporite thicknesses. Hence, increasing bathymetric differences may finally favour the development of characteristic sulfate facies types with distinctive sedimentation rates (Richter-Bernburg 1985).

To accumulate huge sulfate and rocksalt deposits several factors are important: (1) an autocyclic control (see above) on the high sulfate sedimentation rates (meters to 10 of meters per 1000 years, see Sonnefeld 1984), (2) a continuous influx of preconcentrated brine leading to a water level rise within the basin and thus creating accommodation space, (3) a brine residence time long enough to reach halite saturation, (4) furthermore, differential subsidence (tectonic and compactional) has to be taken into account (Ziegler 1989, Wächter & Dietrich 1992).

It is proposed therefore, that a continuous influx of preconcentrated brine from outside the Hessian basin existed during a third-order sea level highstand. Sedimentation started with sulfate precipitation, preferentially in areas marginal to the later "basin". This high sulfate sedimentation during time of increased accommodation caused a topographic structure to develop. It was infilled subsequently with rock salt, due to the long residence time of the brine, reaching halite saturation in areas away from the marginal influx. According to this model, the evaporite sedimentation rates compensated the relative sea level rise. Differential precipitation of evaporitic minerals were the main reason for the development of a relief, which was itself responsible for the rocksalt precipitation in central parts of the Werra subbasin.

## 5. RESULTS

Evaporite sedimentation in the Hessian basin started under shallow water conditions and evolved into deeper water, whereas rocksalt deposition took place in a deep water environment created by differential precipitation and subsidence/sea level rise. The deep water/deep basin setting of halite precipitation in the Werra subbasin was caused by evaporite precipitation itself, not by a relief existing prior to the inset of evaporite deposition. Therefore, the conventional deep water-deep basin model can be ruled out for this giant salt accumulation. A new model of "self-organization" is proposed instead. The setting is intermediate to shallow water/shallow basin and deep water/deep basin, the latter setting being caused by evaporite precipitation mechanisms themselves.

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