Marine Ingressive Events Recorded in Epicontinental Sequences: Example from the Cretaceous Songliao Basin of NE China in Comparison with the Triassic Central Europe Basin of SW Germany*

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Abstract Songliao Basin is filled predominantly with continental facies sediments including alluvial fan, fluvial plain, fan delta, lacustrine delta, shore - shallow lacustrine, beach salty flat, semi - deep to deep lacustrine, subaqueous gravity flow, lacustrine swamp and pyroclastic sediments. However, some event units were formed during lake - marine linking periods of the Mid - Cretaceous in the basin, which include black shales with high values for salinity (Sr/Ba), alkalinity (Ca + Mg)/(Si + Al), reducibility (Ni + Zn)/Ga and sulfide sulfur as well as heavy isotopes. The Breitenholz - section to be represented for facies comparison with the Cretaceous evaporitic series in Northeast China is localized in Southwest Germany. Stratigraphically it belongs to the Crabfeld Formation of Keuper of the Germanic Triassic corresponding to Ladinian - Carnian of the international reference scale, and is generally called Lower Gipskeuper. The Germanic Triassic was deposited in the epicontinental (cratonic) central Europe Basin. It covered the area in between Great Britain, North Sea, Poland and Southern Germany. It is composed of cyclic deposits of multicolored mudstones, gypsum/anhydrite, and dolomite beds. The two cases of marine ingression - influenced sequences share some common features.

Key words Epicontimental sequences, Ingressive, Eacies comparison

1 Introduction

Songliao Basin has been being the largest oil and gas producing basin of China up to now. The present remnant area of the basin is about 260 000km^2. The giant Daqing oil field is located immediately up dip from the center of the basin, which contributes half of the country's annual oil output, about 60 million tons per year. Situated in northeastern China (42 ~ 49 north latitude, 120 ~ 128 east longitude), the Songliao Basin is a Ceno - Mesozoic sedimentary basin with the long axis direction of NNE (Fig. 1). Songliao Basin is filled predominantly with pyroclastic, alluvial fan, fluvial tile and lacustrine sediments of the Late Jurassic, Cretaceous and Tertiary ages. The whole sedimentary succession is mainly made of siliciclastic rocks of conglomerates, sandstones and pelites (including black shales). There are some ostracoda and/or estheria - bearing carbonate beds up to one meter thick each and some carbonate concretion units as thick as 30cm each. Both of them are generally inter - bedded with black shales. Evaporites being composed of anthydrite, barite and celestine are locally recognized in red beds. Based on the sedimentological study of outcrops and core sections within the basin, and also on the well logs as well as seismic reflection,

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the authors identified and classified ten types of sedimentary facies in the basin fillings, i. e. ①alluvial fan, ②fluvial plain, ③fan delta, ④lacustrine delta, ⑤shore – shallow lacustrine, ⑥beach salty flat, ⑦ semi – deep to deep lacustrine, ⑧subaqueous gravity flow, ⑨ lacustrine swamp, and ⑩ pyroclastic sediments.

2 Key Event Units Formed During Lake – marine Linking Periods of the Mid – Cretaceous, Songliao Basin of Northeast China

2.1 Black shales

There are two major black shale units in the sequence of Songliao Basin. They are lower Qingshankou Fm. (K_2qs^1, 100 ~ 97Ma, Albian) and lower Nenjiang Fm. (K_2nj^{1+2}, 84 ~ 80Ma, Santonian – Campanian). The thickness of K_2qs^1 is from 200m to 900m, averaged 608 ± 254m. Its vitrinite reflectance (Ro) of the shale is 0.46% to 1.5%, averaged 0.92 ±0.34%. The total organic carbon (TOC) is 1.075 ~3.0%, averaged 2.28 ± 0.82% and the chloroform bitumen "A" is 0.061 ~ 0.902%, averaged 0.424 ± 0.301%. Its total hydrocarbon (TH) is 0.0123 ~ 0.8235%, averaged 0.319 ± 0.284%. The thickness of K_2nj^{1+2} black shale is 100m ~ 700m, averaged 442 ± 238m with Ro = 0.34 ~ 0.9% (averaged 0.563 ± 0.173%). TOC = 1.075 ~ 2.886%, averaged 2.20 ± 0.8%. CB"A" = 0.022 ~ 0.454%, averaged 0.247 ± 0.136. TH = 0.0058 ~ 0.2605%, averaged 0.1537 ± 0.0836%. The total geological reserves generated from the two units are assessed approximately to be 30 billion tons contributing over half of the oil/gas reserves in Songliao Basin. The black shales contain five groups of minerals:

Group 1: Siliciclasts of quartz, albite, potash feldspar, plagioclase and muscovite. They are several to several tens of micrometers (μm) sub – angular, contributing 40 ~ 90% of the shales by weight.

Group 2: Authigenic sulfides and sulphades of pyrite (FeS_2), sphalerite (ZnS) and galena (PbS) as well as gypsum ($Ca[SO_4] \cdot 2H_2O$) and barite ($Ca[SO_4]$). They are commonly several micrometers, idiomorphic to hypidiomorphic crystals. Gypsum/barite nodules up to several tens of centimeters can be frequently observed in the sequcnces.

Group 3: Authigenic carbonate minerals of calcite, dolomite, siderite ($FeCO_3$) and rhodochrosite ($MnCO_3$). They are several to twenty micrometers, idiomorphic to hypidiomorphic shapes, commonly not very pure and with isomorphism.

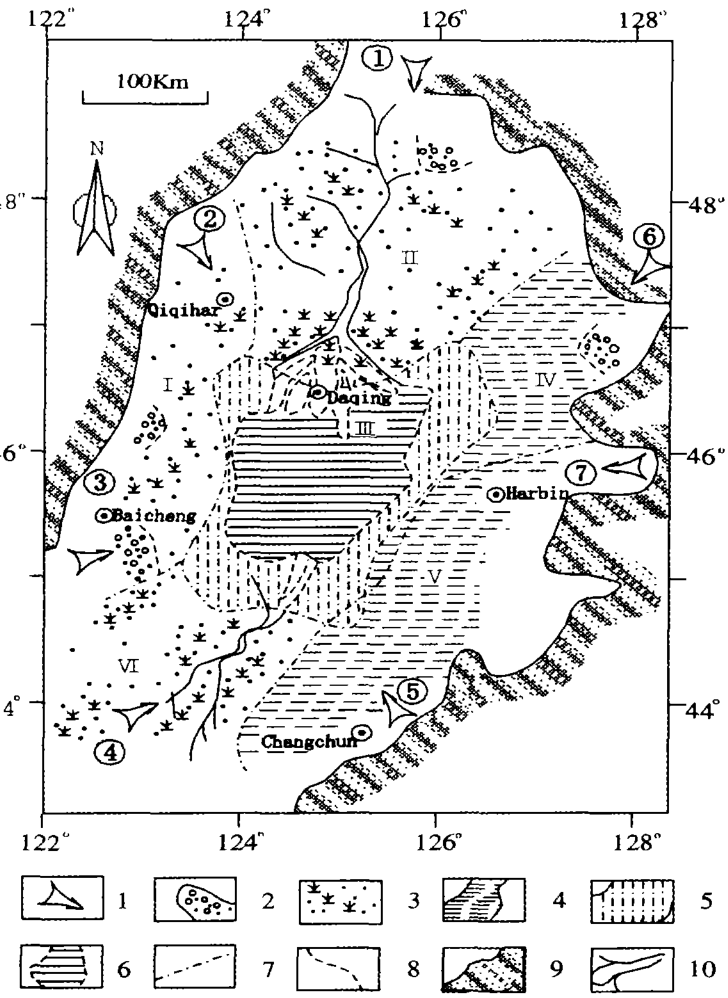
Group 4: Authigenic clay minerals of illite, chlorite, zeolite, smectite and kaolinite, which they are from less than 1μm to 3μm, scaly texture.

Group 5: Heavy minerals of apatite($Ca_5[PO_4]_3(F, Cl, OH)$), cassiterite (SnO_2) and monazite ($(Ce, La)[PO_4]$). They are 5 ~ 10μm, and unregularly shaped.

Within the horizons of black shales, there are sharp increases of the geochemical indexes for salinity (Sr/Ba), alkalinity (Ca + Mg)/(Si + Al), reducibility (Ni + Zn)/Ga and sulfide sulfur. With the results of isotopic datings, we know that the two black shale units were formed within fairly short time intervals of 3Ma (K_2qs^1) and of 4Ma (K_2nj^{1+2}) respectively. The two periods when the black shales were deposited have coincidence both with the maximum lake level terms of Songliao Basin and with the worldwide sea level risings (Wang et al. 2001).

2.2 Carbonate units

Several kinds of authigenic carbonate units have been recognized by now. They include concretions (made of ankerite, dolomite and limestone), ostrocoda /estheria limestones, stromatolitic limestones and argillaceous concretions /limestones. The typical sections containing them have been measured by the authors. The authigenic carbonate units always interbed with black shales. Their isotopic compositions show transitional features between fresh and normal sea water.



1-Depositional systems; 2-Alluvial fan; 3-Fluvial plain; 4-Beach flat; 5-Shore facies; 6-Deep lacustrine facies; 7-Structural division/depositional system boundary; 8-Facies boundary; 9-Present basin boundary; 10 - Stream. Ⅰ-Ⅵ are structural divisions: Ⅰ-West slope; Ⅱ-North downdip; Ⅲ-Central downwarp; Ⅳ-NE uplift; Ⅴ-SE uplift; Ⅵ-SW uplift; ① ~ ⑦ are depositional systems: ①-North Beian - Nenjiang systems; ②-West Qiqihar systems; ③-West Yingtai - Baicheng systems; ④-SW Baokang - Tongyu systems; ⑤-SE Huaide - Jiutai systems; ⑥-NE Suihua - Qinggang systems; ⑦-East Binxian - Shangzhi systems.

Fig. 1 Songliao basin geographical Co - ordinate, structural division and depositional system

2.3 Sulphates and sulfides

Syn - sedimentary sulphates of gypsum, anhydrite, barite and celestine were recognized and described in the red beds of Quantou Fm. (K_1qt) and Yaojia Fm. (K_2yj). Their mineral association, micro - textures and geochemical characters are described in Wang et al. (1995). According to these features, the authors believed that they were syn - sedimentary deposits and their formation had got contributions from sea water. Sulfides composed mainly of pyrite (FeS_2) as well as pentlandite $(Fe,Ni)_9S_8$, sphalerite (ZnS) and galena (PbS) are commonly contained in the black shale sequence of the basin filling. The sulfides may primarily generate from sulphate reduction during early diagenesis. There are several kinds of mineral associations including sulfide - sulphate ones. The sulfur isotopic compositions of pyrite change from -31.3 to $+20.8‰$ (CDT of $\delta^{34}S$). The high positive values of $\delta^{34}S$ can be considered as the results of complete sulphate reduction in closed systems and can represent the sedimentary environment as sulphates do. Some of these values show the same changing trend with those of the according marine sulphates (Richardson and McSween, 1989). The pyrite with regular shape or spheroid can frequently appear in or even thinly bedded with black - shales. They must have some relations to sea water although they still remain to be further studied.

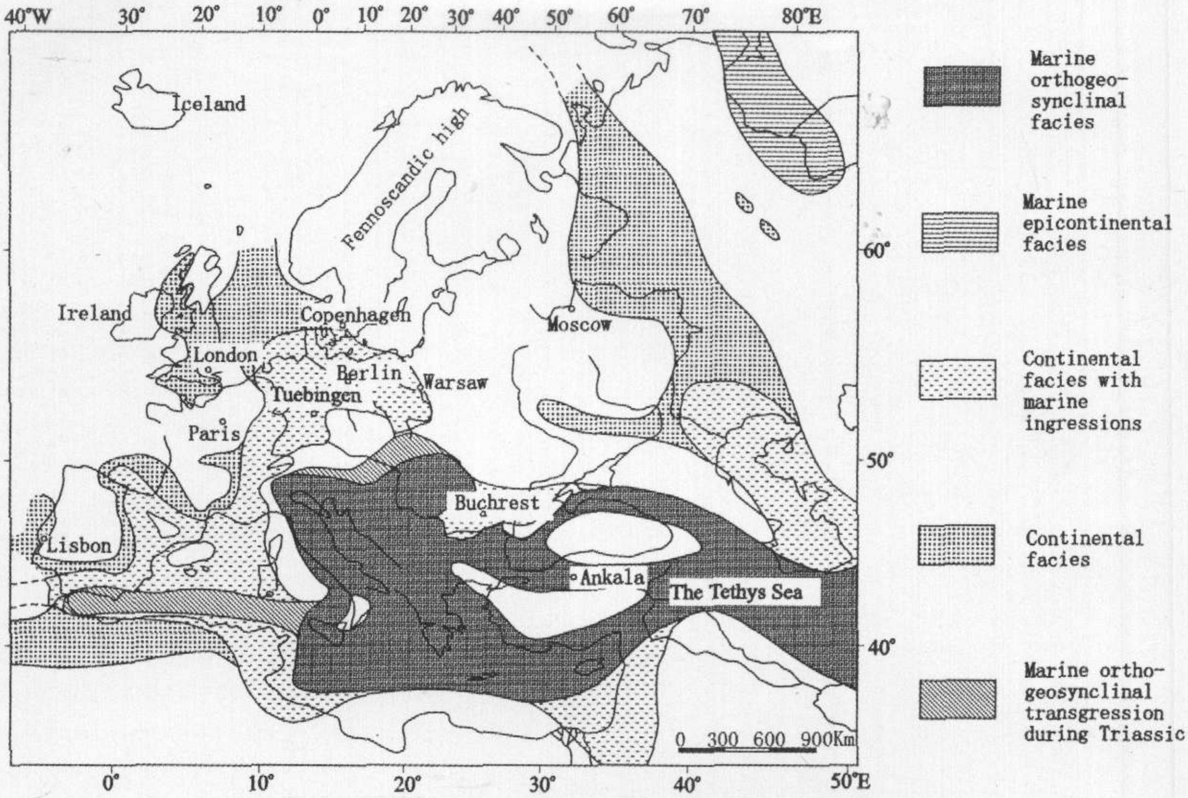


Fig. 2 Palaeogeography of the Triassic of the Central Europe Basin

3 Epicontinental Sequence with Marine Ingressions in the Triassic Central European Basin of Southwest Germany

The Breitenholz – section to be represented for facies comparison with the Cretaceous evaporitic series of Northeast China is localized in Southwest Germany. Stratigraphically it belongs to the Crabfeld Formation of Keuper of the Germanic Triassic corresponding to Ladinian – Carnian of the international reference scale, and is generally called Lower Gipskeuper.

In contrast to the Alpine Triassic of the Tethys the Germanic Triassic was deposited in the epicontinental (cratonic) central European Basin. It covered the area in between Great Britain, North Sea, Poland and Southern Germany. The basin was bordered to the north and northeast by the Fennoscandic – Baltic High, by the Gallic High to the west, and by the Bohemian – Vindilician High to the east and southeast (Fig. 2). Therefore the basin was almost landlocked with only a few narrow straits that opened and closed at different times, through which Triassic Tethys Sea water could come into the basin.

The Triassic deposits represent transgressive/ regressive cycles. The continental red beds of the lower Triassic Buntsandstein pass upwards into marine carbonates and evaporates of the Middle Triassic Muschelkalk, and then into continental Keuper redbeds with a few marine ingression from the Tethyan Sea (Fig. 2).

The lower Middle Keuper (Km1) comprising the Breitenholz – section reveals sediments of a playa lake system. It is composed of cyclic deposits of multicolored mudstones, gypsum/anhydrite, and dolomite beds. Halite occurs only locally in North Germany. In the upper most part of the Gipskeuper the fluvial system of the Schilfsandstein (Stuttgart Formation) passed through the Germanic Basin from Fennoscandic source areas.

The Breitenholz – section represents the middle part of the Gipskeuper of Southwest Germany in between two dolomite marling beds that give evidence of marine ingressions from the Tethys (Fig. 1). The sedimentary sequences of the section are as shown in Fig. 3. Sedimentology and facies model of the Triassic epicontinental sequence influenced by marine ingression events in the Central European Basin represented by the Breitenholz – section are as bellow. Across the Germanic Basin the Grabfeld Formation (Gipskeuper, km1) represents cyclic deposits of multicolored mudstones with beds of massive and nodular sulfates, and thin layers of dolomite as well (Aigner and Bachmann, 1992, 1989; Anadon et al., 1992; Einsele, 2000).

A further subdivision can be done by mudstone/dolomite/sulfate cycles and by using the dolomite beds as marking horizons. A few of the later ones contain marine bivalves, gastropods and vertebrate relics which invaded in the course of ingressions from the Tethys located in the south (Fig. 1). Halite predominantly concentrates on North Germany, extensive area of the flat playa basin reveal sulfate deposits. Thereby the nodular sulfate facies, more or less associated with halites, cover the basin center. Whereas the platy anhydrite facies characterizes the flanks of paleohighs.

The Breitenholz – section represented in this paper shows a 40 meters thick well exposed sequence of the middle part of the Crabfeld Formation of southwest Germany, in between two marine dolomite marked horizons, the "Bleiglanzbank" and the "Snpelhoper Plalle" (Wang et al. 2002). The lower portion of this sulfate – bearing sequence is dominated by massive, but laminated gypsum intercalated by thin dolomitic marlstones, mudstones and dolomite layers. In contrast, the upper portion shows an alternation of multicolored mudstones, thin – to medium – bedded dolomites and sulfates, and towards the top a significant increase of mudstones (Fig. 3).

Features like lithology, thickness, color, sedimentary structures and crystallinity give indications on salinity (Mg/Ca – ratio), water depth, energy – index, and redox – potential (cf. Wang et al. 1995). By recording the facies shifting from mudstones to dolomites and sulfates in connection with black shale facies and the bedding character, more than six cycles of varying salinity/evaporation can be recognized (Fig. 3).

In the following, the major facies types will be briefly described as mudstones, marlstones. The thickness of fine – grained rocks (mudstones and marlstones) ranges from millimeter to meter scale. In general, dark colors dominate the lower portion of the sequence, which occur mostly as thin layers intercalated within dolomites and sulfates. The fine – grained rocks of the upper portion are multicolored and exposed thickness up to several meters. Thus, the mudstones are associated with dolomites and sulfates in all environments. Even black shales are underlying and overlying the carbonate and sulfate rocks. Bedding planes may be parallel, wavy or irregular. All facies transitions occur from claystones to marlstones to marly dolomicrites.

Dolomites of the ingression event in the Breitenholz section show the following features. The light to dark grey dolomites not more than 15 centimeters thick are dolomicrites and dolomicrosparites (Fig. 3). The most important representatives of them ("Bochinfer Bank", "Bleifanzbank" and "Eufellhnfer Plalle") are deposits of marine ingression from the Tethys and contain marine bivalves, gastropods, and vertebrate relics (facies type I). In addition to the major ones, there are more thin dolomite layers to be interpreted in the same way. They are often associated with black shales and structureless sulfates, and useful as marker horizon. Facies type – II of the dolomites is laminated, either by algalmats or by thin sulfate intercalations

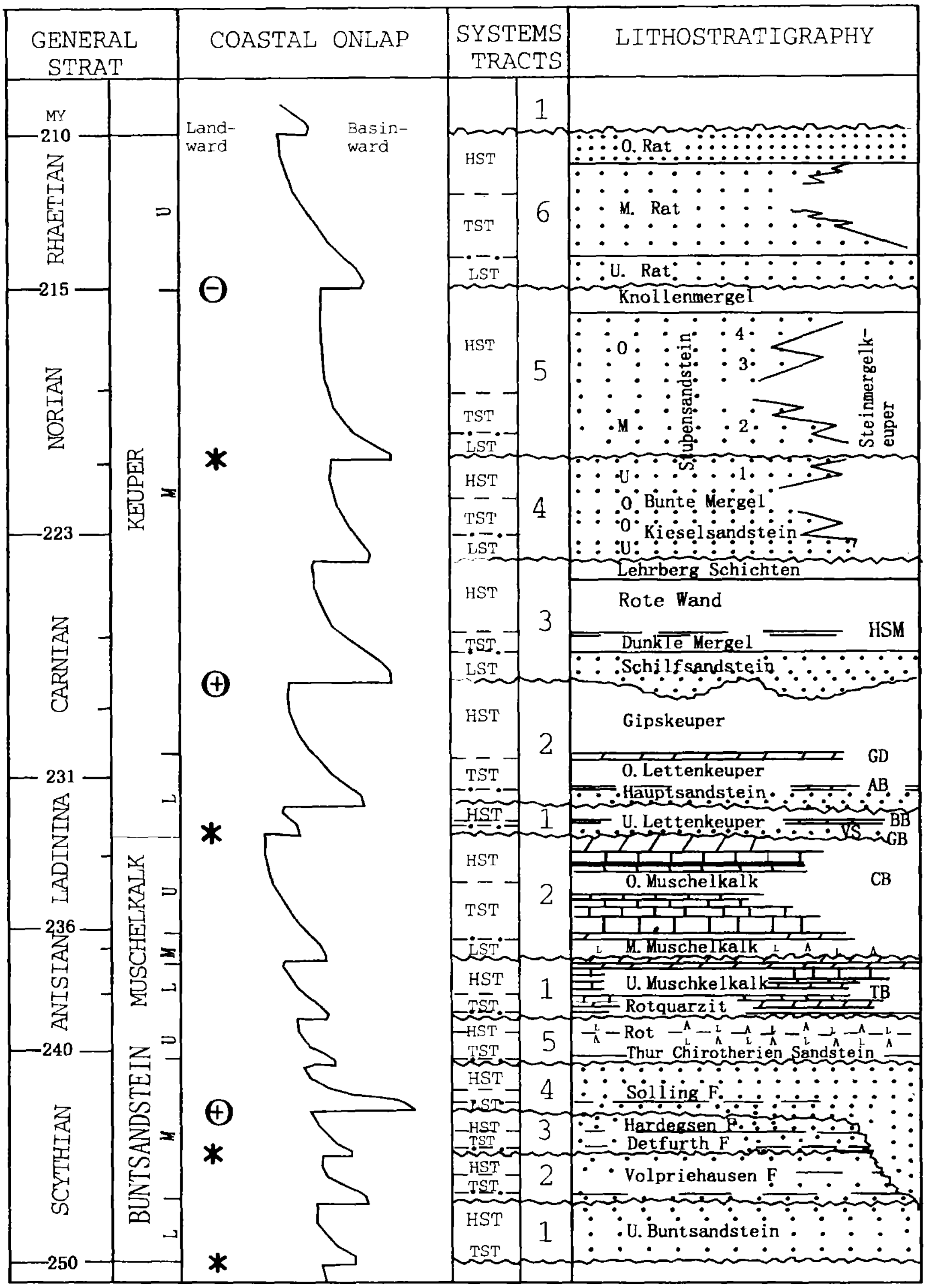


Fig. 3 Sequence stratigraphic framework of the German Triassic with regional coastal onlap curve (After Aignen and Bachmann, 1992)

*-Additional sequence boundary; ⊕-More pronounced; ⊖-Less pronounced sequence boundaries as compared with the EXXON chart (Haq et al., 1987, 1988). LST = Lowstand Systems Tract; TST = Transgressive Systems Tract; HST = Highstand Systems Tract.

and/or sulfate pseudomorphs. Facies type – Ⅲ shows significant irregular bedding (cross bedding – like), emerrional sulfate pseudomorphs, and mud cracks, locally with teepee structures (Fig. 4). Sulfates of the ingression event in the Breitenholz section show the following features. The sulfates include both gypsum and anhydrite. Due to late diagenesis and weathering, it is hard to recognize the primary minerals. All facies types show a variety of low to high crystallinity. Similar to the dolomite facies subdivision, the following facies types appear.

Facies type – Ⅰ is white, massive, nodular or poorly bedded, coarse crystallized anhydrite.

Facies type – Ⅱ shows parallel, wavy and irregular lamination coursed by intercalated mudstone films. Mud cracks occasionally occur.

Facies type – Ⅲ Nodular sulfates are embedded as isolated nodular or irregular layers within mudstones of all colors.

Facies type – Ⅳ Alternating layers of anhydrite and mudstones form teepee structures overlain by according breccias (Fig. 4).

Based on lithology and sedimentary structures, a depositional model was proposed. Controlled by marine ingressions (high water) and the low water level in the playa system, three sedimentary environments can be distinguished:

(**A**) Subaquatic enviroment (shallow marine to playa)

Directed by marine ingressions from the Tethys

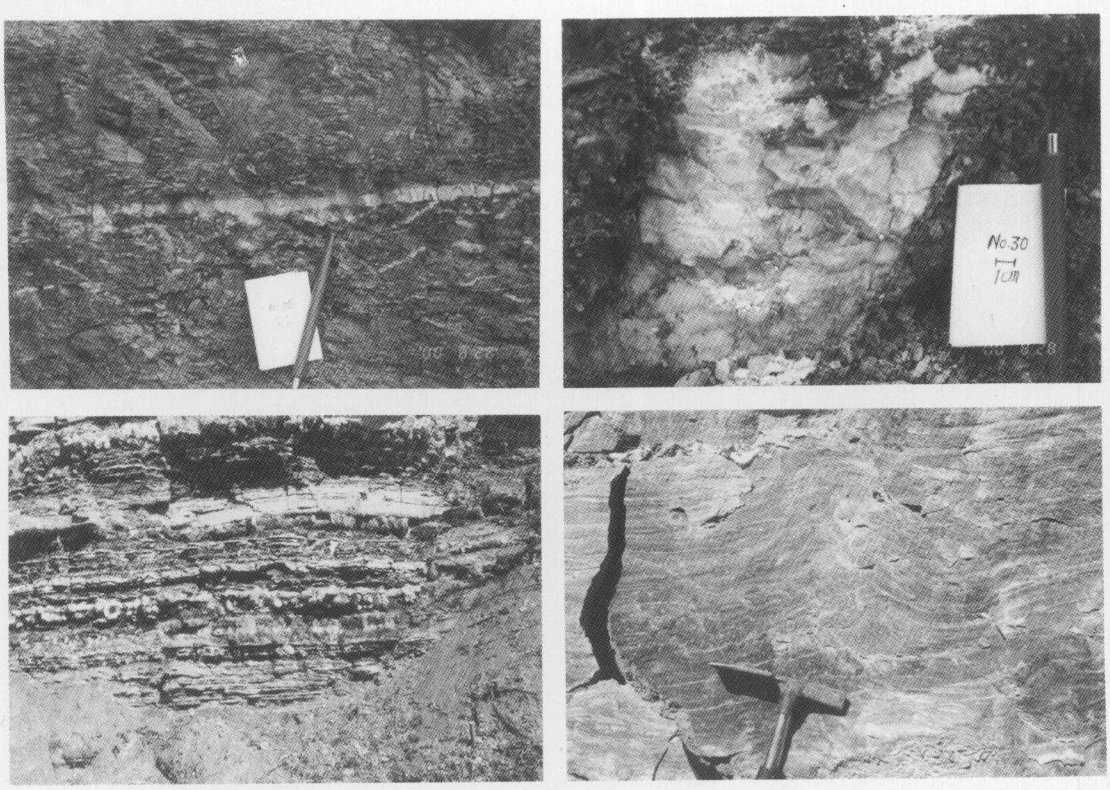


Fig. 4 Sedimentary sequences of the evaporates – bearing Breitenholz section of the Upper Triassic near Tuebingen in Southwest Germany

Lower left: interbedded multicolored mudstones, gypsum/anhydrite, and dolomite beds. Upper left: laminated gypsum/anhydrite intercalated in red mudstone. Upper right: gypsum/anhydrite nodules intercalated in black shale. Lower right: teepee structure of syn – deformed laminated gypsum/anhydrite beds. Photos were taken by Wang Pu-Jun during April – August of 2000. Length of the pen is 14cm.

located in the south subaquatic thin dolomicrites and sulfates are associated with black shales. The dolomites contain bivalves, gastropods and vertebrate relics and the exposed thickness up to only a few decimeters. The sulfates are also thin to medium bedded, coarse crystallized and mostly white and without any intercalated black shales (Fig. 4). It is obvious that the primary sulfate mineral was anhydrite which was hydrated to gypsum in an early diagenetic stage. Obviously a brine body existed from which anhydrite precipitated under low redox – potential conditions.

(**B**) Transitional environment ("intertidal")

Basinward, the lower part of the transitional zone is characterized by alternating thin to medium bedded mudstones and sulfates revealing irregular and wavy lamination (Fig. 4). Sabhka – ward two facies types exist. First, thin to medium bedded alternations of regular and parallel laminated sulfates and mudstones. Second, laminated dolomites without or with sulfate layers and sulfate pseudomorphs (Fig. 4).

(**C**) Sabkha environment ("supratidal")

There is a typical association of laminated and irregular bedded sulfates and dolomites, mud cracks, teepee structures and sulfate breccias (Fig. 4). The recognition of the teepees was according to the appearance of them as shown in Fig. 4, and also combined with load casts within sulfate/mudstone alternations.

Nodular sulfates are a product of early diagenetic origin throughout all three sedimentary environments.

References

Aigner T. and Bachmann G H. 1989, Dynamic stratigraphy of an evaporite – to – red bed sequence. Gipskeuper (Triassic), southwest German Basin. Sediment Geol, **62**: 5 ~ 25

Aigner T. and Bachmann GH. 1992, Sequence stratigraphic framework of the German Triassic, Sediment Geol, **80**: 115 ~ 135

Anadon P., Rossell L. and Talbot, M. R. 1992, Carbonate replacement of lacustrine gypsum deposits in two Neogene continental basins, eastern Spain, Sedim. Geol., **78**: 201 ~ 216

Einsele G. 2000, Sedimentary Basins, Second completely revised and enlarged edition, Berlin Heidelberg: Sringer – Verlag, 90 ~ 91

Richardson S. M. and McSween JR H. Y. 1989, Geochemistry – Pathways and Processes, Printice Hall, New Jersey

Wang Pujun, Liu Wanzhu, Shan Xuanlong et al. 2001, Depositional events: introduction example application. Changchun: Jilin Science & Technology Press

Wang Pujun, Ren Yanguang and Wang Dongpo, 1995, Evaporite origin and its palaeoenvironmental significance of Quantou Formation, Songliao Cretaceous nearshore continental basin NE China, ACTA Sedimentologica Sinica, **13** (supp.): 62 ~ 63

Wang Pujun, Schneider Werner, Mattern Frank and Bian Weihua, 2002, The characteristics of epicontinental basin ingression sequence: comparison between the Triassic of the Central Europe Basin and the Cretaceous of Songliao Basin of China, Mineralogy and Petrology, **21** (2): 1 ~ 8