Unconventional pattern of reservoir facies distribution in epeiric successions: Lessons from an outcrop analog (Lower Keuper, Germany)

Michael Pöppelreiter and Thomas Aigner

ABSTRACT
This article presents (1) a process-oriented description of an outcrop analog for epeiric successions; (2) a discussion of fundamental characteristics of epeiric basin fills; and (3) a generic depositional model, which may be used for improved reservoir prediction in epeiric settings. The case study focuses on the upper Ladinian, mixed siliciclastic-carbonate Lower Keuper Formation. It is composed of storm-generated, tide-generated, and bioturbated facies. Paleogeographically the succession shows an unusual lateral energy zonation comprising a seaward low-energy zone close to wave base; an intermediate, reservoir-prone, high-energy zone within wave base; and a landward low-energy zone above wave base. Stratigraphically the Lower Keuper Formation is subdivided into meter-scale transgressive-regressive cycles, correlatable over distances of more than 500 km. Cycle boundaries are interpreted to be isochronous. Within the resulting chronostratigraphic framework, facies distributions have been mapped out in three dimensions, revealing that reservoir-prone facies are most extensive in shoreline-detached positions. Reservoir bodies are thin, have sheetlike geometries but extend for several tens of kilometers, and are stacked in an aggradational facies architecture. Additionally, the reservoir-prone facies is thicker developed in zones of stronger subsidence, a few kilometers wide, linked to underlying basement blocks.

Resulting unconventional reservoir prediction strategies for similar shallow-marine epeiric settings should target shoreline-detached high-energy facies belts that are preferentially developed within zones of stronger subsidence, controlled by basement tectonics.

AUTHORS
Michael Pöppelreiter ~ Institut und Museum für Geologie und Paläontologie, Universität Tübingen, Sigwartstrasse 10, 72076 Tübingen, Germany; current address: 3737 Bellaire Blvd., Houston, Texas, 77025; michael.poppelreiter@shell.com

Michael Pöppelreiter studied at the Mining University of Freiberg, Germany, the Postgraduate Research Institute of Sedimentology, United Kingdom, and the University of Tübingen, Germany. He received his Ph.D. from the University of Tübingen, Germany, in 1998. Since 1998 Michael has worked as a sedimentologist with Nederlandse Aardolie Maatschappij/Shell in Holland and currently is with Shell International Exploration and Production at Bellaire Technology Centre as a reservoir geologist. His research interests include tectonic control on reservoir facies distribution and integrated 3-D reservoir prediction in epeiric successions.

Thomas Aigner ~ Institut und Museum für Geologie und Paläontologie, Universität Tübingen, Sigwartstrasse 10, 72076 Tübingen, Germany; t.aigner@uni-tuebingen.de

Thomas Aigner studied geology at the universities of Stuttgart, Tübingen, Reading, and Miami and received his Ph.D. in 1985. From 1985 to 1990 he worked as a research geologist in the Shell Laboratories of Rijswijk, Holland, and Houston, Texas. Since 1991 he has been a professor of sedimentary geology at the University of Tübingen, Germany. His interests include genetic stratigraphy and applied sedimentology.
ACKNOWLEDGEMENTS

We wish to gratefully acknowledge the contributions of V. P. Wright, Cardiff University, United Kingdom, during fruitful discussions in the field. Especially we thank T. A. Cross, Colorado School of Mines, for his inspiration on the baselevel concept and lively discussions in the field. H. Brunner and A. Etzold from the Geological Survey of Baden-Württemberg, Germany, provided access to cores, and G. Beutler, University of Halle, Germany, and K.-P. Kelber, University of Würzburg, Germany, assisted with information, logistics, and discussions. Financial support from the Graduiertenförderung des Landes Baden-Württemberg is gratefully acknowledged. M. Thompson, NAM, kindly polished up the English language. AAPG reviewers O. J. Martinsen, E. F. McBride, K. W. Shanley, and R. Erickson significantly enhanced the quality of the original manuscript.

INTRODUCTION

Epeiric or epicontinental successions are widespread in the geological record (e.g., Tucker and Wright, 1990; Leighton and Kolata, 1991; Leighton, 1996) and host important hydrocarbon reservoirs, especially in the Middle East (M. A. Ziegler, 2001). Epeiric shelves are extensive areas with extremely low depositional slope (Tucker and Wright, 1990) and typically, but not exclusively, formed in cratonic basins (Aigner and Dott, 1990). This basin type is characterized by (1) low subsidence rates, on the order of 20–250 m/m.y. (Leighton, 1991); (2) extremely low depositional slope of 0.01–0.001° (Shaw, 1964; Irwin, 1965); and (3) overall low accommodation potential.

Well-known examples of epeiric deposits include parts of the Paleozoic and Mesozoic succession of central North America, such as the Williston basin and the Western Interior basin (e.g., Irwin, 1965; Laporte, 1969; Klein and Ryer, 1978; Pratt and James, 1986; Elders et al., 1994; Choi and Simo, 1998; Choi et al., 1999). The Triassic and Jurassic successions of central and western Europe, namely, the Paris basin and the German basin, comprise typical epeiric successions (e.g., Strasser, 1988; Aigner and Bachmann, 1992; Wetzel et al., 1993; Bourquin et al., 1996; Wetzel and Allia, 2000). Of particular importance for the petroleum industry are epeiric sequences in the late Paleozoic and Mesozoic of the Middle East, particularly in the Rub’Al Khali basin (e.g., Aigner and Dott, 1990; Al Silwadi et al., 1996; Al-Husseini, 1997; M. A. Ziegler, 2001). Reservoir prediction in epeiric successions is particularly difficult because individual reflectors on seismic sections in most cases do not show diagnostic signatures and geometries but only parallel reflectors. Moreover, epeiric successions are genetically poorly understood because of the absence of analogous present-day settings (e.g., Shaw, 1964; Matthews, 1974). One way toward more accurate reservoir prediction in epeiric successions is the detailed investigation of outcrop analogs. This approach was used in our case study of the Late Triassic Lower Keuper Formation to investigate generic patterns of reservoir facies distribution in shallow-marine, epeiric successions.

GEOLOGICAL SETTING

The Lower Keuper Formation was deposited in the cratonic German basin during the Late Triassic (Figure 1). The basement of this basin consists of crustal blocks formed during the Variscan orogeny. Differential subsidence of these blocks strongly influenced the paleogeography and facies distribution throughout the basin history (e.g., van der Baan, 1990; Frisch and Kockel, 1997). Maximum subsidence rates occurred along the Fennoscandian high in the north, where Lower Keuper deposits are more than 70 m thick. Minimum subsidence was recorded near the passive continental margin of the Tethys ocean in the south, where only 10 m of Lower
Figure 1. Stratigraphy of the German Triassic and paleogeography of the German basin during the Middle Triassic (modified from Brunner, 1973; P. A. Ziegler, 1990; Aigner and Bachmann, 1992).
Figure 2. The investigation area stretches northeast-southwest, coinciding with the depositional gradient of the Lower Keuper.
Figure 3. Detailed facies description of well Siegelsbach-6 (compare point 17 in Figure 2).
Reservoir Facies Distribution in Epeiric Successions (Lower Keuper, Germany)
Keuper beds were deposited (Figure 1). The semienclosed German basin was located about 30°N of the equator (P. A. Ziegler, 1990) and partly covered by a shallow marginal sea, which was intermittently connected to the adjacent Tethys ocean by narrow seaways (P. A. Ziegler, 1990). Periodic marine incursions flooded the basin from the south and triggered carbonate production. The main denudation area was the Fennoscandian high in the north (Patzelt, 1964; Würster, 1968), from which siliciclastic sediments were transported distances in excess of 1000 km toward the Tethys ocean (Figure 1). The Lower Keuper Formation represents a transitional period between the fully marine Muschelkalk carbonates below and predominantly terrestrial Keuper clastics above. Cyclically prograding siliciclastic deposits gradually replaced the carbonates as water depth decreased (Aigner and Bachmann, 1992).

**SEDIMENTARY FACIES**

**Description**

Twenty-five outcrops and 22 completely cored wells have been logged in detail (Figures 2, 3), thereby facilitating subdivision of the predominantly fine-grained sedimentary rocks into various lithofacies. Figures 4–9 and Tables 1 and 2 provide a summary of basic facies characteristics and an interpretation of depositional processes and sedimentary environments.

**Interpretation**

Storm-dominated carbonates (Figures 4, 5) consist predominantly of graded beds lying on a sharp erosive base. Furthermore, they show features such as low-angle lamination, microhummocks, and bidirectional current indicators (e.g., imbricated intraclasts). Graded, densely packed shell beds (coquinas) are also characteristic (Figure 5).

Storm-dominated siliciclastics (Figure 7) show similar features to storm-dominated carbonates but contain a higher percentage of microhummocks (Figure 8). Additionally, wave-ripple laminations and gutter casts are common.

More than 50% of original physical stratification has been destroyed in the bioturbated siliciclastic and carbonate facies, either by marine trace fossils, motling, or rooting (Figures 4d–e; 5e–f; 8d–e). In addition, relics of sedimentary structures indicate that storm reworking originally influenced these facies. The nature of bioturbation requires special attention because it has implications for interpretation of the primary depositional environment (e.g., low-energy shelf or restricted lagoon to coastal plain).

Siliciclastics interpreted as tide-dominated facies are composed of rhythmic intercalations of current-rippled sandstones and laminated shales at a centimeter scale. Diagnostic structures are wispy bedding, tidal bundling, argillaceous toesets, mud drapes on foresets, and reactivation surfaces (Pöppelreiter, 1998) (Figure 9).

**Figure 4.** (a) Carbonate bed with typical facies sequence (Dolomite 1, Kirchberg/Jagst [point 21 in Figure 2]): A = claystones with scour surfaces; B = sharp base covered by storm-reworked bone bed (facies 5A); C = calci-mudstones with scour surfaces (facies 1); D = erosive surface covered with intraclasts (facies 2); E = graded coquinas (facies 2); F = calci-mudstones with scour surfaces (facies 1). (b) Calci-mudstones with scour surfaces (facies 1). The completely dolomitized carbonate bed shows microhummocks, scour surfaces, and low-angle lamination. The bed consists of an intercalation of lighter, cleaner event beds draped by darker, marlifer layers. Camera cap for scale is about 5 cm in diameter. Dolomite 2, Ilsfeld (point 14 in Figure 2). (c) Calci-mudstones with scour surfaces (facies 1). The facies consists of small, slightly erosive scour surfaces covered by thin graded beds, which are succeeded by low-angle-laminated mudstones. The highly amalgamated facies is interpreted as tempestite. The facies is very common and constitutes the largest proportion of most carbonate beds. Alberti bed, Wilhelmsglück (point 20 in Figure 2). (d) Calci-mudstone with scour surfaces (facies 1). Interval with intense bioturbation due to marine trace fossils (*Rhizocorallium* burrows). Marine burrows occur only sporadically in the lower half of carbonate beds. Size and depth of penetration are small. In the middle part of a carbonate bed, size and frequency of burrows is high. In the upper part of carbonate beds, burrows disappear. Antrakonit bed, Bad Windsheim (point 30 in Figure 2). (e) Calci-mudstones with scour surfaces (facies 1). Interval is vigorously bioturbated by several generations of *Teichichnus* burrows. Intervals with intense bioturbation by marine ichnofabrics occur in the middle part of distal carbonate beds and represent maximum flooding intervals. Blue bed, Illingen (point 9 in Figure 2). (f) Calci-mudstones with scour surfaces (facies 1). Firm ground in the middle part of a carbonate bed erosively truncated and covered by centimeter-size rounded intraclasts. Firm grounds, clean carbonates (GR-minimum), maximum percentage of preserved calcite in mainly dolomitized beds, and marine body and trace fossils are interpreted as indicators for maximum flooding. Antrakonit bed, Ilsfeld (point 14 in Figure 2).
Reservoir Facies Distribution in Epeiric Successions (Lower Keuper, Germany)
The carbonate and siliciclastic facies were interpreted as a mix of storm-dominated, tide-dominated, and bioturbated deposits. The overall succession contains a low-diversity, brackish, opportunistic fauna with only a few marine species concentrated in carbonate beds.

The facies types described in this section represent distal-shelf to coastal-plain environments, formed in the bathymetric zones from sea level to below storm-wave base.

LATERAL FACIES SUCCESSIONS

Description

The Lower Keuper Formation contains long established and widely used lithostratigraphic marker beds (Figure 3), which are traceable for tens but mostly hundreds of kilometers, although biostratigraphic control is poor (Brunner, 1973). In particular, the distribution of certain carbonate beds is known to extend on a subbasin scale (Frank, 1931; Richter, 1936; Essigmann, 1979; Brunner and Bruder, 1981). Lateral facies changes of these marker beds were carefully documented using closely spaced outcrops and wells. Generally, facies changes are very subtle and occur over distances of tens of kilometers. The detailed documentation of lateral and vertical facies variations allowed the grouping of lithofacies into four lateral facies successions: (1) transgressive clastic complex, (2) transgressive carbonate system, (3) regressive carbonate system, and (4) regressive clastic complex (Figure 10).

The transgressive clastic complex consists distally of repeated millimeter-thick storm-ripped bone beds containing quartz grains and glauconite that represent omission surfaces (facies 5A). The bone beds pass proximally into sheetlike, storm-ripped sandstone beds (facies 7), which cover erosive surfaces. These sandstones give way more proximal to destratified sandy shales (facies 12). Even farther proximally the destratified beds are intercalated with thin but extensive coaly claystone layers (facies 10) locally replaced by incised tide-ripped sandstone deposits (facies 8, 9). The base of these tide-dominated beds is typically erosive.

A transgressive carbonate complex covers the transgressive clastic complex. It consists distally of calcitc dolostones composed of centimeter-thick graded beds (facies 1) and bioturbated horizons, dominated by fully marine trace fossils (e.g., Rhizocorallium and Tectichnus).

These predominantly muddy storm-dominated carbonates contain a brackish to marine fauna. Proximally they pass into muddy dolostones, which are comprised of amalgamated millimeter-scale graded beds that contain a brackish fossil association (facies 1). Farther proximally they give way to bioturbated marly dolostones or mottled marly clays.

A regressive carbonate complex succeeds the transgressive carbonates. Proximally it consists of marly bioturbated carbonates (facies 4), similar to the transgressive bioturbated carbonates. Distally these

Figure 5. (a) Graded coquinas (facies 2). Interval contains shells and centimeter-scale intraclasts, which consist of intensely bioturbated calcic-mudstones. Such reworking horizons, commonly intercalated with shell bed, typically occur in the middle part of carbonate beds. In this example, the interval occurs on top of calcic-mudstones with scour surfaces (facies 1) and below graded coquinas. Lower dolomites, Eschenau (point 22 in Figure 2). (b) Graded coquinas (facies 2). Slab (sample from carbonate bed of Figure 5a) showing intensely bored intraclasts. They represent a reworked firm ground as shown in Figure 4e. Note multiple generations of firmground and hardground borers. The dark clasts at the lower left side of the picture are covered by borings on all sides. Lower dolomites, Eschenau (point 22 in Figure 2). (c) Graded coquinas (facies 2). Outcrop photo showing a graded coquina composed of densely packed bivalve shells intercalated with scoured mudstones. Shell layers can occur as amalgamated sheets or individual, centimeter-scale graded shell layers intercalated with calcic-mudstones. Blue bed, Kirchberg/Jagst (point 21 in Figure 2). (d) Graded coquinas (facies 2). The shell bed shows a sharp, slightly erosive base, normal grading, and shells oriented mainly convex up. Densely packed shell layers at the base grade upward into calcic-mudstones with scour surfaces. These shell beds are interpreted as tempestites. Blue bed, Kirchberg/Jagst (point 21 in Figure 2). (e) Bioturbated mudstones and marlstones (facies 3). The mudstone is vigorously bioturbated by Planolites-like traces, penetrating the sediment mainly horizontally. Some preserved scour surfaces and graded beds (upper half of picture) point to storm reworking. Landward, all carbonate beds pass gradually into this low-energy facies before they pinch out. Alberti bed, Siblingen (point 1 in Figure 2). (f) Bioturbated mudstones and marlstones (facies 3). The carbonate bed shows mottling, pseudo brecciated fabric, angular and subrounded floating grains, and undifferentiated ichnofabrics. These bioturbated, marly, low-energy carbonates constitute the landward-located low-energy zone of the Lower Keuper epeiric ramp. Dolomite 1, Deiderode (point 44 in Figure 2).
marly beds pass into storm-dominated dolostones with a brackish fauna. Characteristically these muddy carbonates consist of amalgamated graded beds. Farther distally they pass into calcitic dolostones with a marine fauna. In contrast to the mud-dominated transgressive carbonates, regressive carbonates contain considerable amounts of shell fragments (facies 2) and ooids (facies 3).

A regressive clastic complex covers the regressive carbonates. Distally the regressive clastic complex consists of dark, slightly marly claystones with scour surfaces (facies 6). Proximally these pass into graded storm-dominated siltstones and sandstones (facies 7). Farther proximally the sandstones give way to graded, silty sandstones and siltstones. These are commonly oscillation rippled, moderately bioturbated, and contain amalgamated graded beds (facies 7). Centimeter-scale scattered rootlets are commonly found in these beds and point to very immature water-logged paleosols formed during short intervals of exposure. Even farther proximally these regressive clastics pass into a bypass or erosion surface.

**Interpretation**

The observed lateral facies successions were deposited in the bathymetric interval between storm-wave base and sea level. The stratigraphy is composed of strongly amalgamated, more or less homogeneous facies sheets, and facies changes are very subtle. There is no indication of any significant morphological differentiation along the depositional gradient into shoals, bars, or lagoons. These observations point to an extensive area of low accommodation space with negligible depositional slope characterized by continuous reworking and redistribution of sediment. The lateral facies successions (Figure 11) reflect an unusual energy zonation for a storm-dominated shelf, which consists of three zones: (1) a seaward-located low- to medium-energy zone, (2) a middle-shelf high-energy zone, and (3) a nearshore low-energy zone.

The low- to medium-energy zone occupies the paleogeographically distal part of the shelf several tens to hundreds of kilometers from the shoreline. Sedimentological attributes such as maximum set-height of graded beds, most complete preservation of sedimentary structures, and preservation of bioturbated horizons several centimeters thick are characteristic for this zone and testify to maximum accommodation potential close to storm-wave base. The medium-energy zone contains muddy nonreservoir rocks.

Landward the medium-energy zone passes into a high-energy zone. This zone occupies the middle part of the epeiric shelf. It extends for several tens of kilometers and occurs tens of kilometers away from the actual shoreline. Characteristically the high-energy zone is composed exclusively of physically stratified sedimentary rocks. Potential reservoir facies such as bioclastic carbonates and storm-reworid sandstones occur in this zone.

The high-energy zone passes landward gradually into a low-energy zone. This zone extends for tens of

**Figure 6.** (a) Calci-mudstones with scour surfaces (facies 1) and bioturbated mudstones and marlstone (facies 4). Lime-mudstone with ostracod shells and peloids. This kind of muddy deposit constitutes the vast majority of all Lower Keuper carbonates. The mud is a microspar with crystal sizes of 5–15 μm, which can consist of multiple-zoned subeuhedral crystals. Blue bed, Kirchberg/Ilagst (point 21 in Figure 2). (b) Calci-mudstones with scour surfaces (facies 1) and bioturbated mudstones and marlstone (facies 4). Photomicrograph (crossed nicols) shows a peloidal bioclastic packstone. Such beds constitute thin lag deposits on scour surfaces in calci-mudstones (facies 1). Peloids, ostracod shells, and bivalve shells are the most common components, cemented by an isopachous fringe and a later blocky equant spar. Blue bed, Ilsfeld (point 14 in Figure 2). (c) Calci-mudstones with scour surfaces (facies 1) Photomicrograph showing skeletal packstone to grainstone mainly composed of ostracod and lingulid brachiopod shells. This facies forms lag deposits on millimeter-scale scour surfaces. The ostracods are mainly disarticulated but unfragmented. The fossil content suggests a brackish water composition. Anoplophora dolomite, Ilsfeld (point 14 in Figure 2). (d) Graded coquinas (facies 2). Photomicrograph (crossed nicols) showing a skeletal packstone. This microfacies typically occurs in graded coquina sheets. Bioclastic phosphate grains, peloids, ostracod shells, and quartz grains occur besides bivalve shells. Bivalve shells commonly show remains of preserved calcite causing conspicuous calcitic layers within dolomitized carbonate beds. Blue bed, Ilsfeld (point 14 in Figure 2). (e) Graded coquinas (facies 2). Photomicrograph (crossed nicols) showing skeletal wackestone to packstone mainly containing bivalve shells. Commonly, shells are very densely packed and oriented. Photo showing unfragmented, nested bivalve shells in a muddy matrix. Blue bed, Kirchberg/Ilagst (point 21 in Figure 2). (f) Oolitic sheets (facies 3). Photomicrograph (crossed nicols) showing an oolitic grainstone. The well-rounded, moderately sorted ooids occur exclusively in the uppermost carbonate bed, the “Grenzdolomit.” The ooids form commonly around skeletal fragments or peloids. Isopachous fringes and blocky equant spar cement them. Border dolomite, Gemmingen (point 15 in Figure 2).
Reservoir Facies Distribution in Epeiric Successions (Lower Keuper, Germany)
kilocameters and forms the gentle transition from shallow-marine to coastal-plain environments. Carbonate and siliciclastic facies of this zone are fine grained, vigorously bioturbated, poorly sorted, and constitute essentially nonreservoir facies.

A similar facies and energy zonation was described by Irwin (1965) in his classical study of Mississippian carbonates in the Williston basin, from Devonian carbonates of the Helderberg Group (Laporte, 1969), and Tertiary carbonates of the Murray basin (Lukasik et al., 2000). Irwin (1965) attributed this zonation to the very low depositional slope, unique at epeiric shelves, which would lead to wave-energy dissipation far offshore.

The energy zonation of the epeiric storm-dominated shelf is in contrast to modern storm-dominated shelves with steeper slope gradients (e.g., the East Coast of the United States, the coast of southern Australia, or the West Coast of Mexico [Nummedal, 1991]). Maximum wave energy on modern storm-dominated shelves directly strikes the coastline and creates high-energy shoreface and beach complexes. This difference is significant for reservoir prediction because high-energy reservoir rocks on epeiric shelves appear tens of kilometers away from the coastline (Figure 11) in a paleogeographic position occupied by offshore shales in modern shelves.

**VERTICAL FACIES SUCCESSIONS (CYCLES)**

**Approach**

The building blocks of the Lower Keuper Formation are small-scale cycles, similar to the classical transgressive-regressive cycles from the Carboniferous of the Appalachian basin (e.g., Matthews, 1974; Cecil, 1990). We described and interpreted these cycles in terms of accommodation vs. supply variations as suggested by Homewood et al. (1992, 2000), Cross et al. (1993), and Cross and Lessenger (1997). Cycles record sediment and time of increasing and decreasing accommodation/supply (A/S) ratio. They consist of a transgressive and a regressive hemicycle separated by turnaround points. Turnaround points are the zones of maximum transgression and regression representing maximum and minimum A/S ratio, respectively (Homewood et al., 2000). We have chosen to discriminate A/S cycles as opposed to systems tracts (Brown and Fisher, 1977), parasequences (Van Wagoner et al., 1990), or punctuated aggradational cycles (Goodwin and Anderson, 1985) for the following reasons:

1. Lack of depositional geometries hampers the identification of systems tracts (e.g., Van Wagoner et al., 1988), defined by geometric relationships as characteristic for passive continental margins.

**Figure 7.** (a) Marly claystones with scour surfaces (facies 6). Outcrop photo showing dark-gray claystones, which appear horizontally laminated and contain brackish fossils as well as pyritized *Planolites*-like traces. Note intercalated, lenticular fine-sandstone bed, indicating storm reworking. Esterien beds 2, Schmalfelden (point 26 in Figure 2). (b) Marly claystones with scour surfaces (facies 6). Hand specimen showing claystone, which consists of slightly erosive, centimeter-wide scour surfaces filled with millimeter-thick graded laminae. These thin lag deposits, filling scours, consist of phosphatic particles and shell debris (mainly conchostracan and ostracod shells). The claystones are interpreted as distal, muddy tempestites. Esterien beds 2, Illingen (point 16 in Figure 2). (c) Graded siltstones and sandstones (facies 7). Slab showing graded sandstone-claystone intercalations. The facies consists of normally graded, low-angle-laminated sandstone layers with sharp erosive base. These sandstone-siltstone rhythmtes are interpreted as distal tempestites reflecting variable intensity of storms. Main sandstone, Illingen (point 9 in Figure 2). (d) Graded siltstones and sandstones (facies 7). Slab showing normally graded fine sandstone. The sandstone exhibits a sharp erosive base covered by few intraclasts and microhummocks. Microhummocks show a characteristic pinching and swelling of individual laminae and numerous reactivation surfaces. Main quartzite layers, Rügenheim (point 36 in Figure 2). (e) Graded siltstones and sandstones (facies 7). Hand specimen showing gutter cast at the base of a graded sandstone. Low-angle-laminated sandstones commonly show erosive base with gutter casts. Gutter casts can contain imbricated bivalve shells and tool marks, which are excellent paleocurrent indicators. Main quartzite layers, Rügenheim (point 36 in Figure 2). (f) Graded siltstones and sandstones (facies 7). Outcrop photo showing graded fine sandstone with microhummocks. Graded fine sandstones with microhummocks are interpreted as proximal tempestites. Note the occurrence of rootlets directly on top of the sandstones. The rooted interval is a regional exposure surface. Main sandstone, Erfurt-Melchendorf (point 41 in Figure 2).
2. Sequence boundaries (e.g., Van Wagoner et al., 1990) are difficult to demonstrate in the investigated succession and can be confused with other unconformity surfaces (e.g., Bhattacharya, 1993).
3. The controlling factors for the cyclicity cannot be unambiguously discriminated in the Lower Keuper. Hence, the delineation of A/S ratio variations provides a pragmatic way to delineate stratigraphic cycles.
4. Changing cycle pattern along the depositional slope rules out the definition of only one cycle type (e.g., shallowing-upward cycles) (e.g., Goldhammer et al., 1987; Pratt and James, 1986).
5. A/S cycles can confidently be traced along the depositional gradient through different lithologies and depositional environments, a prerequisite for basinwide correlations.

**Description of Small-Scale Cycles**

Stratigraphic cycles were identified by detailed sedimentological investigation of vertical facies successions and their bounding surfaces. Three basic cycle types were distinguished: (1) carbonate-claystone cycles (Figure 12), (2) carbonate-sandstone cycles (Figure 13), and (3) sandstone-carbonate-sandstone cycles (Figure 14). Carbonate-claystone cycles occur on the distal to middle shelf, carbonate-sandstone cycles typically occupy the middle to proximal shelf, and sandstone-carbonate-sandstone cycles appear in the proximal shelf to nearshore environment. Laterally the cycles pass into each other because of gradual changes in facies composition, vertical facies succession, and cycle symmetry (Figure 15), similar to observations by Einsele and Bayer (1991) and Elders et al. (1994).

The nature of these cycles can best be exemplified with sandstone-carbonate-sandstone cycles, which consist of lower transgressive clastics, intermediate transgressive-regressive carbonates, and upper regressive clastics. Coaly claystones or tidal sandstones occur at the cycle base covering weakly rooted clastics. Destratified clastics with a brackish fauna occur above and, in turn, are succeeded by storm-deposited sandstones with a sharp erosive surface.

The sandstones pass upward into storm-deposited carbonates. The lower parts of the carbonates show an upward decrease in mud content and a change in body and trace fossils from brackish to marine. Maximum flooding is recorded in the middle of carbonate beds by the highest diversity of marine body and trace fossils, cleanest carbonates, highest percentage of preserved calcite in otherwise completely dolomitized beds, maximum set thickness of graded beds, and preservation of thick bioturbated intervals in overall strongly amalgamated sediments.

The upper part of the carbonates shows a dirtying-upward trend (i.e., upward increase in siliciclastic mud content) and an increase of brackish-water fossils. Storm-deposited carbonates give way to storm-deposited sandstones. These show a coarsening-upward trend, which, as the cycle progresses, reverts to fining-upward and increasing signatures of wave reworking. The cycle cap consists of fine-grained, rooted clastics with brackish or freshwater fossils.

**Figure 8.** (a) Graded siltstones and sandstones (facies 7). Core slab showing graded rhythmites. Low-angle-laminated very fine sandstones are interbedded with low-angle-laminated argillaceous siltstones. Features like sharp erosive base, low-angle lamination, and normal grading point to storm reworking. Main sandstone, Morsleben (point 45 in Figure 2). (b) Graded siltstones and sandstones (facies 7). The facies consists of an intercalation of slightly erosive, poorly graded sandstone beds and oscillation-rippled sandstone beds. The sandstones are interlayered with scoured dark-gray claystones. Overall, they show a fining-upward trend and are interpreted as transition between proximal shelf and the nearshore zone. Main sandstone, Siegelsbach (point 17 in Figure 2). (c) Graded siltstones and sandstones (facies 7). Core slab showing oscillation-rippled fine-sandstone. Oscillation-rippled sandstones are typically intercalated with low-angle-laminated sandstone at the proximal epeiric shelf. Overall, however, rippled sandstones are not very widespread. Upper sandstone, Erfurt-Melchendorf (point 41 in Figure 2). (d) Destratified clastics (facies 9). Specimen showing completely destratified silty sandstone. Destratification is due to intense bioturbation. Bioturbated clastics occur in the low-energy, shallow subaqueous zone of the epeiric shelf. Sandstones have very poor reservoir characteristics because of poor sorting and a high percentage of detrital clay. Sandy plant shales, Erfurt-Melchendorf (point 41 in Figure 2). (e) Rooted clastics (facies 11). Core slab showing rooted, fine to medium sandstones. Stratification of this originally storm-deposited sandstone is completely obliterated by coaly rootlets of horsetails. The rooted interval is a regional exposure surface indicating a major downward shift of facies. Main sandstone, Morsleben (point 45 in Figure 2). (f) Coaly claystones (facies 10). Outcrop photo showing thin layers of coaly claystones, which form on top of rooted clastics and are covered by storm-reworked transgressive sandstones. Coaly claystones are composed of plant debris and commonly contain brackish bivalves and abundant pyrite. Upper gray marls, Ilsfeld (point 14 in Figure 2).
Reservoir Facies Distribution in Epeiric Successions (Lower Keuper, Germany)
Interpretation

Small-scale cycles represent migration of depositional environments through time caused by increase and decrease of the A/S ratio. During initial transgression the partially exposed shelf was flooded. Plant debris was preserved and accumulated as thin but extensive coaly layers during periods of increasing accommodation (Flint et al., 1995). Embayed coastlines locally focused tidal currents, leading to incision of tidal channels. Further increasing accommodation initiated deposition of bioturbated clastics in the proximal low-energy zone of the shallow subaqueous shelf. Transgressive storm-deposited sands above indicate deposition within the high-energy zone of the pericline shelf. During maximum accommodation, carbonate production commenced in increasingly marine seawater and deeper water depth. Decreasing accommodation caused progradation of clastics, leading to clastic poisoning of the carbonate factory. The upper clastic section reflects decreasing accommodation, causing the return of the low-energy zone and, finally, short periods of subaerial exposure.

Medium-Scale and Large-Scale Cycles

The small-scale cycles are stacked into medium-scale cycles, which in turn are part of a large-scale cycle. Medium-scale cycles reflect facies changes, which have more regional importance and, thus, aid in larger scale correlation. The entire Lower Keuper constitutes one medium-scale cycle with a lower regressive hemicycle and an upper transgressive hemicycle (Figure 16).

Small-scale cycles 1–6, in the lower part of the Lower Keuper, show an overall regressive trend. Marine body and trace fossils in carbonate beds decrease upward. Carbonate content also decreases upward, as evidenced by a dirtying-upward gamma-ray signature and a decreasing carbonate/clastic ratio. Grain size in siliciclastic deposits increases upward, and fossil association in siliciclastic beds shifts from brackish to freshwater forms. The amount of rootlets gradually increases, and limnic and terrestrial palynomorphs gradually replace marine ones.

A prominent exposure surface is present at the top of small-scale cycle 6, exhibiting intensely root-bioturbated storm to wave-reef deposited sandstones. This exposure surface reflects the most significant basinward shift in facies observed in the Lower Keuper. It represents the turnaround point of the medium-scale regressive hemicycle to the medium-scale transgressive hemicycle and has been interpreted as a sequence boundary (Aigner and Bachmann, 1992).

The upper part of the Lower Keuper, composed of small-scale cycles 7–11, displays an overall transgressive trend. Carbonate beds show an upward decrease in siliciclastic mud reflected by decreasing gamma-ray readings. The carbonate/clastic ratio of subsequent small-scale cycles continuously increases. Carbonates show a clear upward increase in the amount of marine body and trace fossils. Siliciclastic beds, however, show an overall fining-upward trend. The relative amount of marine palynomorphs increases upward, whereas the amount of rootlets diminishes. The small-scale cycles show an upward increase in

Figure 9. (a) Current-rippled sandstones (facies 8). Outcrop photo showing regular thickness variations of trough cross-bedded foresets of sandstones, representing tidal bundles. The bed is composed of thick, sand-dominated spring bundles and thin mud-dominated neap bundles. Main sandstone, Fallteich, Crailsheim (point 24 in Figure 2). (b) Current-rippled sandstones (facies 8). Outcrop photo showing trough cross-bedded megaripples. Current-rippled sandstones consists here entirely of planar to trough cross-bedded sandwaves and megaripples. Megaripples occur preferentially at the transitions from sandwaves to more argillaceous ripple-bedded intervals. Main sandstone, Ilsfeld (point 14 in Figure 2). (c) Current-rippled sandstones (facies 8). Outcrop photo showing argillaceous toesets of sandwaves. These toesets are a characteristic feature of tide-dominated sediments. In contrast to fluvial channels where coarsest material occurs at the channel base, tidal channels commonly show mud-dominated toesets, which represent slack water periods. Main sandstone, Fallteich, Crailsheim (point 24 in Figure 2). (d) Current-rippled sandstones (facies 8). Core slab shows wispy bedded fine sandstone. This facies typically exhibits a regular interbedding of current-rippled beds and argillaceous beds. Facies reflects regular interchange of bed load and suspension load transport, a typical feature of tide-dominated sedimentation. Haupt-sandstein, Siegelsbach (point 17 in Figure 2). (e) Current-rippled sandstones (facies 8). Outcrop photo showing wave-rippled toesets. This close-up photo of toesets pictured in Figure 9c shows that current-rippled foresets pass into oscillation-rippled, mud-draped toesets. Soft sediment deformation, for example, ball and pillow structures, are also common. Main sandstone, Fallteich, Crailsheim (point 24 in Figure 2). (f) Current-rippled sandstones (facies 8). Outcrop photo showing current ripples at the base of sandwave foresets. The current ripples consist of well-developed lee sides whereas the stoss side is depressed, leading to a distinctive lunette ripple form, the so-called rib and furrow structures. Main sandstone, Fallteich, Crailsheim (point 24 in Figure 2).
### Table 1. Characteristic Attributes of Carbonate and Bonebed Lithofacies Types

<table>
<thead>
<tr>
<th>Facies group</th>
<th>No.</th>
<th>Facies type / sketch</th>
<th>Lithology, sedimentary structures</th>
<th>Dimensions</th>
<th>Fossils / trace fossils</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBONATES</td>
<td>1</td>
<td>calci - mudstones with scour surfaces</td>
<td>- light to medium gray dolo-(lime) mudstones to wackestones - graded beds resting on scour surfaces - low-angle lamination - microhummocks - vigorously bioturbated intervals with firm grounds</td>
<td>thickness: decimeter; width: tens of kilometers</td>
<td>- brackish bivalves - marine bivalves -stromatolites - rugioids</td>
<td>- storm-dominated - brackish to marine - intermediate to distal shelf</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>graded coquinas</td>
<td>- light to medium gray dolo-(lime) packstones - normally graded shell sheets resting on sharp erosive base - oriented shells, e.g., imbricated shells - sorted shells - intraclasts</td>
<td>thickness: decimeters; width: hundreds of meters</td>
<td>- marine bivalves - brackish bivalves - ostracods - <em>Phycocorallium</em></td>
<td>- storm-dominated - marine to brackish - distal to intermediate shelf</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>oolitic sheets</td>
<td>- light gray lime-(dolo) grainstones to packstones - normally graded beds resting on sharp erosive base - intraclasts</td>
<td>thickness: decimeters; width: hundreds of meters to few kilometers</td>
<td>- marine bivalves - brackish bivalves - ostracods - gastropods</td>
<td>- storm-dominated - marine to brackish - intermediate shelf</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>bioturbated marlstones and mudstones</td>
<td>- medium gray marly dolo-mudstones to marlstones - more than 50% bioturbation - relic graded beds</td>
<td>thickness: decimeters; width: tens of kilometers</td>
<td>- ostracods - lingulid brachiopods - brackish bivalves - <em>conchostracans</em> - <em>Planolites</em></td>
<td>- bioturbated, weak storm-agitation - brackish - intermediate to proximal shelf</td>
</tr>
<tr>
<td>BONE BEDS</td>
<td>5A</td>
<td>A: storm-reworked bone beds</td>
<td>A: regionally occurring bone beds - occur at bounding surfaces between clastic and carbonate beds - composed of mm-scale fragile vertebrate remains e.g., fish teeth, scales</td>
<td>thickness: centimeters to few kilometers; width: tens of kilometers</td>
<td>A: remains of marine and brackish vertebrates such as fish and amphibians</td>
<td>A: - storm-dominated - marine to brackish - intermediate shelf</td>
</tr>
<tr>
<td></td>
<td>5B</td>
<td>B: tide-reworked bone beds</td>
<td>B: locally occurring bone beds - brownish gray</td>
<td>thickness: centimeters to few meters; width: tens of meters</td>
<td>B: remains of marine to freshwater vertebrates</td>
<td>A: - tide-dominated - marine to fresh water - proximal shelf to coastal plain</td>
</tr>
</tbody>
</table>
Table 2. Characteristic Attributes of Siliciclastic Lithofacies Types

<table>
<thead>
<tr>
<th>Facies group No.</th>
<th>Facies type / sketch</th>
<th>Lithology, sedimentary structures</th>
<th>Dimensions</th>
<th>Fossils / trace fossils</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>marly claystones with scour surfaces</td>
<td>- dark gray to black claystones - scour surfaces with thin graded beds - pyrite rich</td>
<td>- thickness: decimeter to few meters - width: 10s of kilometers</td>
<td>- conchostracans - lingulid brachiopods - ostracods - brackish bivalves - plant debris - Planolites</td>
<td>- storm-dominated - brackish - intermediate shelf</td>
</tr>
<tr>
<td>7</td>
<td>graded siltstones and sandstones</td>
<td>- light gray siltstones and sandstones - normally graded beds on sharp erosive base - low-angle lamination - microhummocks - oscillation ripples - gutter casts, intraclasts</td>
<td>- thickness: decimeter to few meters - width: 10s of kilometers</td>
<td>- brackish bivalves - plant debris - Planolites - Phycodes</td>
<td>- storm-dominated - brackish - intermediate to proximal shelf</td>
</tr>
<tr>
<td>8</td>
<td>current-rippled sandstones</td>
<td>- light gray to greenish sandstones - occurrence in erosive channels: megaripples and sandwaves in sand-dominated channels and lateral accretion in mud-dominated channels - argillaceous tosels, wispy bedding, mud drapes, reactivation surfaces, rib and furrow structures, lateral transition of current to oscillation ripples</td>
<td>- thickness: decimeter to few meters - width: 10s to 100s meters</td>
<td>- brackish bivalves - plant debris and fossil wood - Rhabdocorallium (Glossifungites)</td>
<td>- tide-dominated - brackish to marine - nearshore</td>
</tr>
<tr>
<td>9</td>
<td>destratified clastics</td>
<td>- greenish to red claystones - mottled - strong bioturbation, commonly, complete destratification</td>
<td>- thickness: decimeter to few meters - width: 10s of kilometers</td>
<td>- brackish bivalves - vertebrate skeletons - biauritated - brackish - nearshore</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>coaly claystones</td>
<td>- dark gray to black silty claystones - pyrite rich - millimeter to centimeter thick accumulations of plant debris</td>
<td>- thickness: centimeter to few decimeter - width: 100s meters to few kilometers</td>
<td>- brackish bivalves - plant debris</td>
<td>- fresh water to brackish - coastal plain</td>
</tr>
<tr>
<td>11</td>
<td>rooted clastics</td>
<td>- dark gray to black coaly rootlets - pyrite rich - rootlets can penetrate all clastic faces few centimeters to few meters deep</td>
<td>- thickness: centimeter to few decimeter thick - width: 10s meters to few kilometers</td>
<td>- roots - plant debris</td>
<td>- fresh water - coastal plain</td>
</tr>
</tbody>
</table>
Figure 10. Schematic diagram showing the lateral facies successions observed in the Lower Keuper Formation by following single beds or groups of beds along the depositional gradient. (Note: Facies relationships are illustrated here; no time connotations are implied.)
symmetry, with thicker preserved deposits recording the transgressive phases. The strongest marine influence was recorded in the uppermost carbonate bed (cycle 11). It contains fully marine bivalves and nautiloids over large parts of the basin. The carbonate bed is a maximum flooding zone and represents the turnaround point from a medium-scale transgressive hemicycle to a medium-scale regressive hemicycle.

The large-scale cyclicity is apparent from a comparison of the Lower Keuper depositional environments within the stratigraphic context. Fully marine carbonates occur below the Lower Keuper deposits, whereas marginal marine to terrestrial siliciclastic beds appear above, clearly indicating a large-scale regressive trend (Figures 1, 16, 17).

STRATIGRAPHIC CORRELATION

Small-scale cycles are laterally continuous and can be correlated over large distances, although cycle pattern, facies composition, and cycle symmetry change. Our correlation approach is a synthesis of lithostratigraphic correlation using the prominent marker beds and sequence stratigraphic correlation based on cycles and their stacking pattern. Marker beds, specifically carbonate layers, represent sequence stratigraphic timelines in large parts of the basin and link closely with a sequence-stratigraphic interpretation. Correlation of turnaround points in cycles supported by stacking made it possible to correlate the 11 small-scale cycles over a distance of more than 500 km (Figure 18). The following patterns become apparent on regional stratigraphic cross sections:

1. Individual, decimeter-thick facies units extend in sheets for several tens of kilometers. Reservoir-prone facies (e.g., storm-dominated sandstones) can extend for nearly 200 km along the depositional gradient.
2. Individual facies are organized in aggradational rather than progradational facies architecture. This applies to facies deposited during transgressive and regressive intervals.

Facies Maps

Facies and isopach maps were compiled for individual small-scale hemicycles following the sequence stratigraphic subdivision (Figure 19). Maps with the main tectonic lineaments (e.g., boundaries of individual crustal blocks of the basement) were plotted on these facies maps. Facies maps (Figure 20) showed the following patterns:

1. Facies zonation: Facies units are thickest developed above basement blocks with stronger subsidence. In these zones, the thickness of facies increases by a factor of 2–4. These zones of stronger subsidence are particularly important for increased thicknesses of potential reservoir rocks. Shelf sandstones occur in areas of stronger subsiding crustal blocks (Figure...
Figure 12. Outcrop photo showing three stacked carbonate-claystone cycles. Example is from lower dolomites/Dolomite 2, Wilhelmsgluck quarry (point 20 in Figure 2).
Figure 13. Outcrop photo illustrating a carbonate-sandstone cycle. Example is from main sandstone, Pleidelsheim quarry (point 13 in Figure 2).
Figure 14. Outcrop photo of a sandstone-carbonate-sandstone cycle. Example is from Antrakonit bed, Zwingelhausen quarry (point 10 in Figure 2).
and shale out at the boundary to slower subsiding blocks.

2. Paleogeography: The spatial extent of maximum transgressions, indicated by marine fossils in carbonates, and the direction of maximum regression, testified to by the coarsest grained clastics, coincide with zones of strongest subsidence.

3. Subsidence pattern: Facies boundaries and thickness trends of subsequent stratigraphic cycles are very similar, indicating long-term uniform differential subsidence.

4. Diagenesis: Carbonate beds composed partly of primary calcite are concentrated in zones of strongest subsidence. In contrast, completely dolomitized carbonates occur in slower subsiding areas.

Facies boundaries and isopach trends of Lower Keuper deposits correlate, within a few hundreds of meters, with boundaries of differentially subsiding blocks of the crystalline basement (Figure 19).

**Interpretation**

Facies boundaries and thickness trends of subsequent cycles show nearly identical patterns. These patterns coincide with the extension of well-known crustal blocks of the crystalline basement (Krimmel, 1980; Aigner, 1985; Dittrich, 1989). Thus, tectonically induced differential subsidence is interpreted to have imposed a significant control on facies distribution, energy zonation, paleogeography, and early diagenesis in the basin. The influence of differential subsidence of basement blocks has been noticed in epeiric successions in numerous studies (e.g., from the Paris basin by Bourquin et al. [1997], Gaumet et al. [1997], and Goggin et al. [1997]; from the German basin by van der Baan [1990] and Wetzel et al. [1993]; and was even noticed to effect facies distribution in modern day settings [e.g., Lomando, 1999]). This is because slowly subsiding epeiric shelves undergo continuous reworking and redeposition of supplied sediment. Wave base effectively shaves off sediment (Cross and Lessenger, 1997) from the shelf and redistributes the material to areas of higher accommodation (e.g., zones of stronger subsidence). The interplay between depositional processes such as storms and differential subsidence results in accumulation of maximum sediment volumes in zones of stronger subsidence. This process is called here “sediment volume funneling.” Sediment volume funneling is especially important for the prediction of reservoir rocks. An understanding of the regional subsidence pattern can improve identification of exploration prospects and help prediction of decreasing risk of no reservoir development.
Figure 16. Outcrop photo showing the hierarchical cyclicity of the Lower Keuper. Small-scale cycles are stacked into a lower regressive hemicycle (darker rock colors) and an upper transgressive hemicycle (lighter rock colors). Example is from a section of the Ilsfeld quarry (point 14 in Figure 2).
Figure 17. Stacking pattern of Lower Keuper cycles, from a section of the Pleidelsheim quarry (point 13 in Figure 2). Note that a hierarchical cyclicity can be recognized in a variety of different sedimentological attributes. A/S = accommodation/supply.
Figure 18. Correlation of Lower Keuper cycles in the South German subbasin.
**GENERIC MODEL FOR EPEIRIC SUCCESSIONS**

Cratonic basins are characterized by long-term minimum subsidence, minimum accommodation potential, and minimum depositional-slope gradient. These features cause unique facies distribution patterns in epeiric successions.

1. Minimum and uniformly distributed accommodation space in cratonic basins does not promote gradual and continuous facies progradation. Instead, facies sheets extending over thousands to ten thousands of square kilometers tend to develop. These are commonly arranged in aggradational facies architecture (thickness/width ratio on the order of 1:200,000), commonly referred to as layer-cake stratification.

2. The minimum morphological gradient causes even minor changes in relative sea level to shift both shoreline and wave base over vast areas (e.g., Matthews, 1974) (Figure 19). This may result in abrupt and discontinuous shifts of facies zones from one cycle to the next. Moreover, these shifts result in continuous redistribution and reshaping of sediments. Slow subsidence, low morphological gradient, and water depth within wave base result in low preservation potential of morphological features. Thus, epeiric successions commonly consist of amalgamated facies sheets.

3. The low slope gradient in shallow-marine epeiric successions, deposited above storm-wave base, causes the development of a specific epeiric energy zonation, as originally highlighted by Irwin (1965) and Shaw (1964). The most significant feature of this energy zonation is the occurrence of shoreline-detached high-energy reservoir facies, documented also by Laporte (1969) and Lukasik et al. (2000).

4. The subsidence pattern of cratonic basins seems to be linked, in many cases, to subtle differential movements of the crystalline basement (e.g., Krimmel, 1980; Cloetingh, 1986; Frisch and Kockel, 1997; McBride, 1998). Zones of higher subsidence act as traps for sediment accumulation. This process may be referred to as sediment volume funneling.

**IMPLICATIONS FOR RESERVOIR PREDICTION IN EPEIRIC BASINS**

The analysis of the epeiric Lower Keuper on a basin-wide scale revealed a facies architecture and reservoir facies distribution very different from modern shelves. This may highlight the need for unconventional geological models for hydrocarbon reservoir prediction in some epeiric basins, such as in the Middle East.

The predictive reservoir model for epeiric layer-cake stratified successions should focus on the following:
Reservoir Facies Distribution in Epeiric Successions (Lower Keuper, Germany)

1. Identification and correlation of sedimentary cycles from core-calibrated well logs. These cycles are contemporaneous units, which help reconstruct temporally and spatially linked depositional systems. The common aggradational facies architecture, with thin sheet reservoir geometries extending for tens of kilometers, makes cycle correlation a key element in recognizing the three-dimensional arrangement of reservoir facies.

2. Mapping of large-scale tectonic units from isopach maps, gravity maps, fault maps, or seismic attribute maps. Major tectonic zones of the crystalline basement are commonly active for several tens to hundreds of million years and have a significant influence on reservoir facies distribution. Hence, isopach maps of large-scale stratigraphic units may reveal thickness trends within thin but vertically stacked reservoir units. These thickness trends correspond in many cases to facies trends. Tectonically controlled accommodation potential is likely to influence both reservoir thickness and its geographic position. Isopach and facies maps also may be used more rigorously in detailed seismic interpretation.

3. Mapping of the high-energy reservoir-prone facies. Based on the generic depositional model, the reservoir facies is most likely to occur in very broad, shoreline-detached belts. The distribution of landward and seaward shifts of these wide facies belts can be predicted from the cycle stacking pattern.

4. The application of the generic model for epeiric
successions may help to understand even minor anomalies of seismic amplitude in a genetic context and link them to reservoir facies. The model may give a better understanding and prediction for likely extension, thickness, and spatial distribution of reservoir facies in epeiric basins.

REFERENCES CITED


