Zbl. Geol. Paläont. Teil I	1998	Heft 11–12	1475–1495	Stuttgart, Februar 2000

High-resolution early Mesozoic Pangean climatic transect in lacustrine environments

EPICONTINENTAL
TRIASSIC
INTERNATIONAL
SYMPOSIUM
Halle/S. Germany
September 21 – 23, 1998

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with 8 figures

Abstract: Analysis of 6700 m of core from the Newark rift basin in New Jersey, USA provides a high-resolution astronomically calibrated magnetic polarity time scale for the Late Triassic and Early Jurassic spanning about 33 million years. This time scale, and its application elsewhere, allows a significant simplification of the pattern of climate-sensitive facies in the early Mesozoic basins of the central and north Atlantic margins. Coals and deep-water lacustrine deposits were produced at the paleoequator (Richmond-type sequences), while strikingly cyclical lacustrine and playa deposits were produced 10° to the north and south (Newark-type lacustrine sequences). At 10–30 °N, eolian dunes, playas sediments and evaporites were deposited (Fundy-type sequences). Farther north, shallow-water lacustrine red beds were deposited (Fleming Fjord-type sequences), while yet farther north (~40°), perennial-lake black mudstones and coals again dominated in the humid temperate zone (Kap Stewart-type sequences). Central Pangea drifted north about 10° during the Late Triassic, and the vertical sequence of climate-sensitive facies in individual basins changed as the basins passed through different climate zones. This simple zonal climate pattern explains most first-order changes in overall lacustrine sequences seen in the rift zone. Lake-level cycles of Milankovitch origin change in a predicable way with the latitudinal shifts in climate and lacustrine style. Roughly 10 ky precessional cycles dominate within a few degrees of the equator, while ~20 ky precessional cycles are dominant northward to about 30 °N where ~40 ky obliquity cycles become evident in lake-level records.

Introduction

Stratigraphic correlation provides the framework for understanding ancient Earth systems. If stratigraphic resolution is poor, so will be the understanding of the system. Advances in paleoclimatology, especially aspects related to orbital forcing, have shown the permeating and persistent nature of relatively high-frequency (~10– ~20 ky) climate cycles throughout geological time. Given the poor resolution thought to be typical of interbasinal correlations in the early Mesozoic, outdated paleogeographic control, and high frequency climate change, it is hardly surprising that the lacustrine and related strata, preserved in numerous rift basins and rift-related basins from Svalbard to the Gulf of Mexico, have been depicted as

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displaying a baffling array of climate-sensitive lithologies. The seemingly conflicting associations of facies have prompted several ad hoc explanations invoking non-zonal climatic processes such as monsoons, the effects of topography, and global climate change (e.g. Manspeizer 1982, Parrish 1992).

Cyclostratigraphic and paleomagnetic analyses of 6700 m of core from the Newark basin collected by the Newark Basin Coring Project (NBCP – Olsen et al. 1996a) provide a high-resolution, astronomically calibrated, magnetic polarity time scale for the Late Triassic and Early Jurassic spanning about 32 million years (Kent et al. 1995, Olsen and Kent 1999). This time scale allows global correlations at intra-Neogene-level of resolution. In this paper we summarize our attempts to extend high-resolution correlations along a N-S transect from about 30 °N paleolatitude to the paleoequator along the axis of what would later become the Central and North Atlantic Oceans (Fig. 1). We use these correlations to place the basin sequences into a simple climatic scheme.

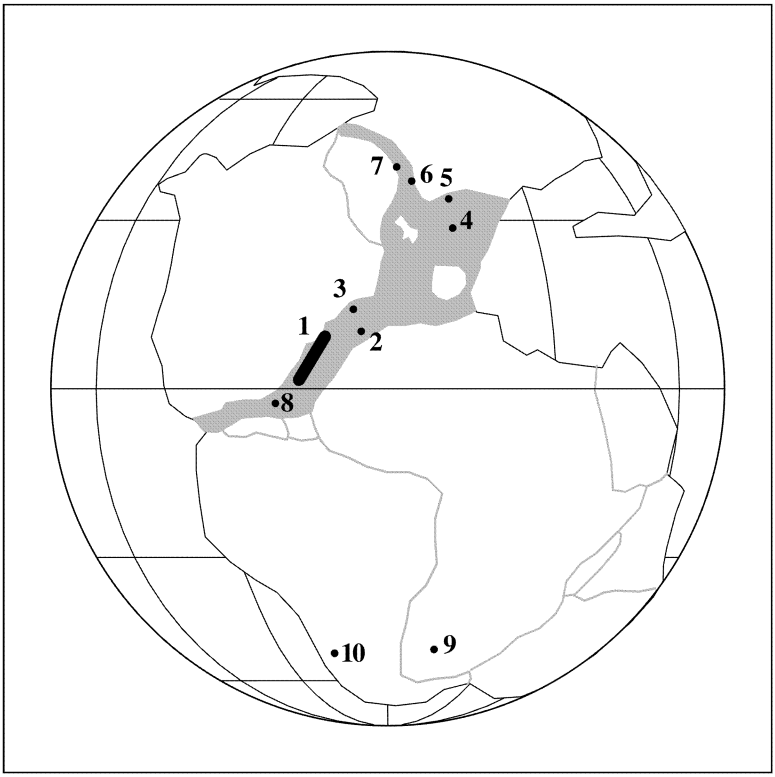


Fig. 1. Triassic-Early Jurassic zone of rifting (gray) in north-central Pangea. Reconstruction is modified from Olsen et al. 1996a and is for 210 my (Norian). Basins discussed in the text are: 1. Southern Newark Supergroup basins; 2. Argana basin; 3. Fundy basin; 4. Germanic basin; 5. Danish-Polish basin; 6. Haltenbanken; 7. Jameson Land basin; 8. South Georgia basin; 9. Karoo basin; 10. Ischigualasto basin.

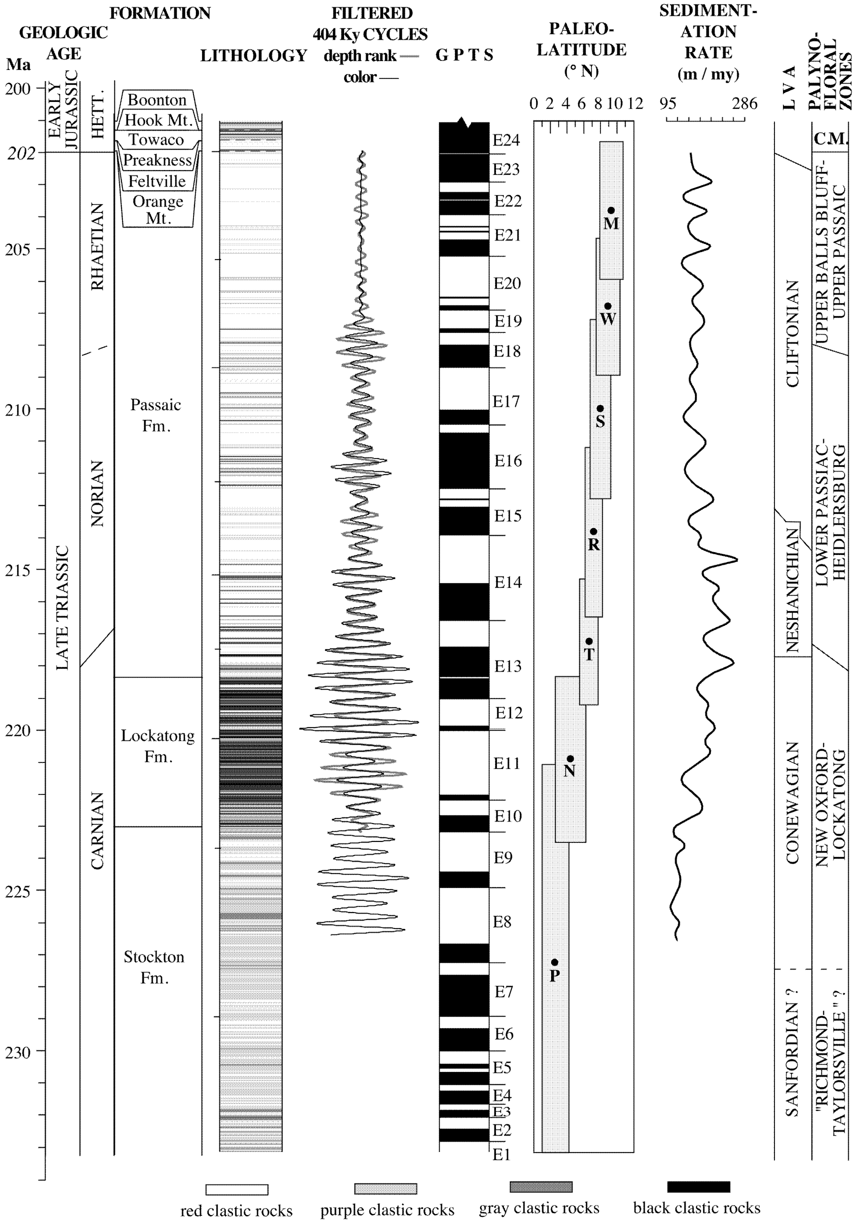
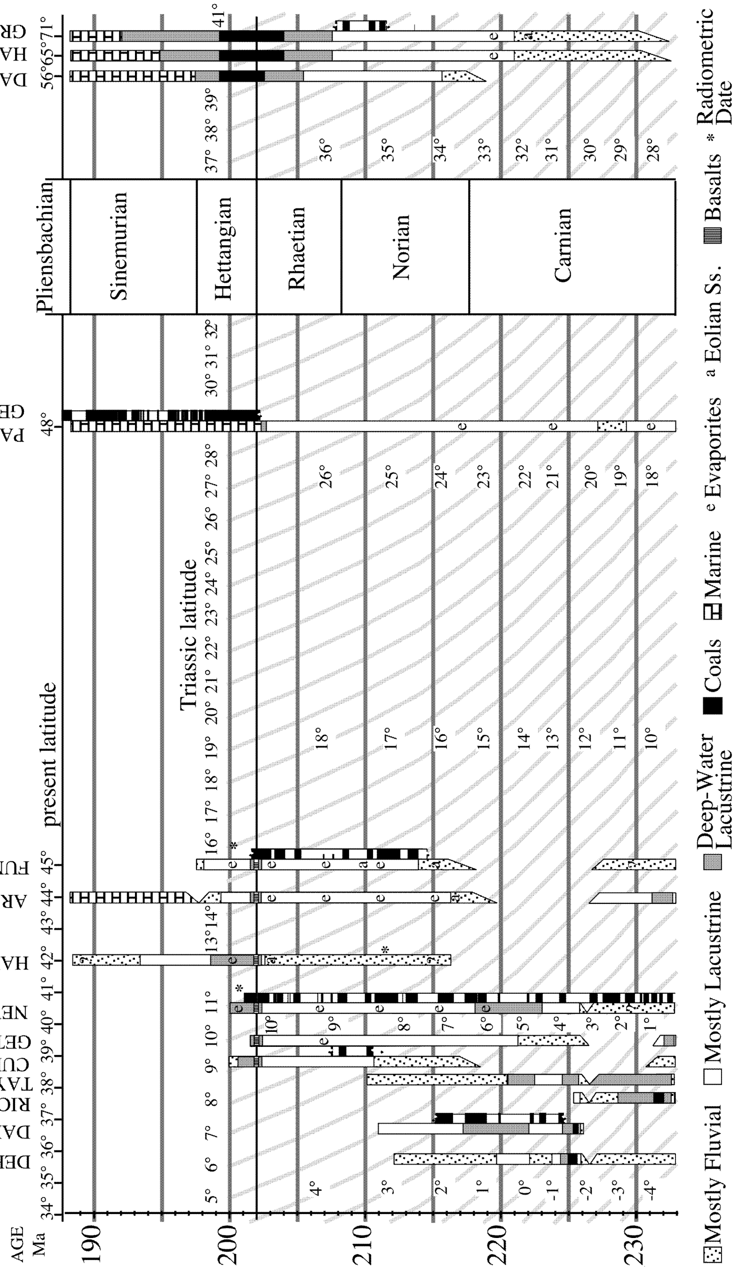


Fig. 2. Newark basin time scale, modified from Olsen and Kent (1999). Asterisks in lithology column indicate basalt flow horizons (dashed lines in lithology column) shown here represent zero duration (e.g. Olsen et al. 1996b). Magnetic polarity and paleolatitudes from Kent et al. (1995). Italicized date (*202*) under GEOLOGIC AGE is the absolute age tie point based on radiometric dates of lave flows.


AGE Ma
190
200
210
220
230
DEEP RIVER
DAN RIVER
RICHMOND
TAYLORSVILLE
CULPEPER
GETTYSBURG
NEWARK
HARTFORD
ARGANA
FUNDY
PARIS & GERMANIC
DANISH - POLISH
HALTENBANKEN
GREENLAND
present latitude
Triassic latitude
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
Carnian
34° 35° 36° 37° 38° 39° 40° 41° 42° 43° 44° 45°
48°
56° 65° 71°
5° 6° 7° 8° 9° 10° 11° 13° 14° 16° 17° 18° 19° 20° 21° 22° 23° 24° 25° 26° 27° 28°
30° 31° 32°
37° 38° 39° 41°
4° 3° 2° 1° 0° -1° -2° -3° -4°
10° 9° 8° 7° 6° 5° 4° 3° 2° 1°
18° 17° 16° 15° 14° 13° 12° 11° 10°
26° 25° 24° 23° 22° 21° 20° 19° 18°
36° 35° 34° 33° 32° 31° 30° 29° 28°
▨ Mostly Fluvial
☐ Mostly Lacustrine
▨ Deep-Water Lacustrine
■ Coals
⊞ Marine
e Evaporites
a Eolian Ss.
▥ Basalts
* Radiometric Date

Newark basin time scale

Based on the NBCP cores, the Newark basin time scale spans about 33 million years, of which about 25 million years are calibrated by lake level sequences under Milankovitch climate cycle control (Fig. 2, Olsen et al. 1996a, Olsen and Kent 1996, Olsen 1997). We delineate roughly 58 major magnetic polarity intervals with a mean duration of 0.5 my (Kent et al. 1995, Kent and Olsen, this volume 1999). A roughly 20 my-level of resolution is permitted by the detailed cyclostratigraphy in the younger 22 million years of the time scale, while the older part is calibrated to only the 400 ky-level. Radiometric dates from feeders to the interbedded lava flows in the most recent million years of the record place the entire Newark basin time scale within absolute years with an estimated error of about ±1 my. Within the Newark basin this time scale has been extensively tested (Kent et al. 1995, Olsen et al. 1996a, Olsen and Kent 1996, Kent and Olsen 1999a, 1999b) by comparison of magnetic polarity stratigraphy and cyclostratigraphy over distances in excess of 180 km. We have also tested the constancy of the paleolatitudinal estimates and polarity stratigraphy by detailed comparisons with the Dan River basin section some 500 km away (Kent and Olsen 1997). The close correspondence of both the apparent pole positions and polarity stratigraphy of these two basins makes it very unlikely that tectonic rotations have biased the Newark basin paleomagnetic record.

Extension of the Newark basin time scale to other basins

Thus far we have been able to produce at least preliminary magnetic polarity stratigraphies for significant portions of several major basins over a roughly 30° swath of paleolatitudes (Fig. 3). From south to north, these basins include: the Dan River basin of Virginia and North Carolina (Kent and Olsen 1997), the Taylorsville basin of Virginia (LeTourneau et al. 1998), the Culpeper basin of Virginia, the Argana basin of Morocco, the Fundy basin of Maritime Canada, and the Jameson Land basin of East Greenland (Kent and Clemmensen 1996, Clemmensen et al. 1998). Along with biostratigraphy, particularly that based on palynomorphs and tetrapods (Cornet 1993, Fowell et al. 1994), these correlations allow rigorous comparisons of climate-sensitive lithologies along 30° of paleolatitude (Fig. 3). The paleomagnetic data are preliminary and the subject of ongoing projects (with

Fig. 3. Matrix showing relationship between main climate-sensitive lithologies, age, geography and paleomagnetic polarity stratigraphy (black and white bars) for the basins discussed in text. Curved gray lines are lines of equal paleolatitude based on the Newark basin section (Newark basin polarity scale from Kent et al 1995. Other basin sections are based on the following: Culpeper and Fundy are based on our more recent work in progress; Dan River (Kent and Olsen 1997); Paris basin (Yang et al. 1996); Jameson Land (Kent and Clemmensen 1996).

the exception of the Newark and Dan River basins), and therefore the paleomagnetic stratigraphies are given in outline form only. We have also included other basin sections in Figure 3 that we believe are correlated finely enough by biostratigraphy to allow at least first-order comparisons.

General climatic pattern

With the Newark basin time scale and paleolatitudinal data in hand, the overall pattern of climate-sensitive facies in the Triassic and Early Jurassic is greatly simplified (Olsen 1997). Most clear is a more or less symmetrical arrangement of facies around the paleoequator during Carnian time. Coals and deep-water lacustrine deposits were produced in the Deep River, Dan River, Richmond, and Taylorsville basins (summarized in Olsen 1977) around the paleoequator, while strikingly cyclical perennial lacustrine and playa deposits and bioturbated red beds were produced 10° to the north and south (Kent and Olsen 1997). Broadly contemporaneous deposits at 30 °N paleolatitude in Greenland (Clemmensen 1980, Clemmensen et al. 1998) and the Haltenbanken area of offshore Norway (Hollander 1984, Hagevang and Ronnevivk 1986, Withjack et al. 1990) are comprised of red mudstones, eolian sand dunes, and evaporite beds, while further north in the Barents Sea, deltaic coals and black mudstone again dominate (Van Veen et al. 1992). This conforms to a simple zonal pattern, with a narrow equatorial humid zone and an arid belt mostly south of 30°, passing northward into hot house humid temperate climates. Basins in the Triassic southern hemisphere show the same pattern, although their stratigraphy is much less tightly calibrated in time. For example, Carnian age red beds are present in the South Georgia basin (Moy and Traverse 1986), while Carnian age gray mudstones (Argentina) and coals (Karoo basin, southern Africa) are present farther south. Although non-zonal elements such as orography and an enhanced monsoon may have been important elements of the Earth's climate system during the Carnian, such are not required by the observations.

As Pangea drifted northward, the vertical sequence of climate-sensitive facies within individual basins changed as the basins passed from one climate zone to another. Thus, in each basin within the Newark Supergroup of North America (North Carolina to Nova Scotia) and in Morocco, the transition from Carnian through Norian age strata is characterized by apparent drying with shallow water cyclical lacustrine strata predominating in the southern basins, specifically the Newark, Gettysburg, Culpeper, Taylorsville, and Dan River basins (Olsen 1977). Conversely, in northern and eastern Germany, England, Poland, Sweden, the Haltenbanken area and Greenland, the vertical Late Triassic sequence within individual basins is from red beds and evaporites upward into black lacustrine, paludal, and paralic shales (Norling et al. 1993, Bilan W 1991, Hollander 1984, Hagevang and Ronnevivk 1986, Withjack et al. 1990, Clemmensen 1980). This vertical pattern within basins fits the same basic geographic pattern seen in Carnian data except that the pattern shifts south in present geographic coordinates and, hence, is consistent with a northward drift of central Pangea.

A similar pattern, with lower level of resolution, is seen in individual basins in the Triassic southern hemisphere. Examples include younger Triassic and Early Jurassic strata in the Ischigualasto and Karroo basins of Argentina and southern Africa, respectively. In both basins the sections become dominated by red beds and then eolian dune sands upward, again consistent with a northward drift of that part of Pangea.

However, within this broad pattern, there are some apparent anomalies. In particular, the Schilfsandstein of the Germanic basin appears to have been deposited in notably more humid conditions than stratigraphically surrounding deposits (Simms and Ruffell 1990). No physical arid indicators, such as evaporites or eolianites, are known and occasional thin coal beds and abundant plant fragments are present. Visscher et al. (1994) attribute this apparent anomalous humid interval to ground water conditions in an essentially arid overall environment. However, we note that strata correlated with the Schilfsandstein on the basis of vertebrates and palynomorphs in eastern North America also appear to have been deposited under slightly more humid conditions. However, the significance of this anomaly, along with the supposed Carnian "pluvial event" of Simms and Ruffell (1990), will be difficult to assess until more precise correlative techniques (e.g. magnetostratigraphy) are more broadly available for this part of the Late Triassic.

In the Newark Supergroup and in Morocco, there is an additional major, but short lived, departure from the pattern seen in the Carnian and Norian age beds. In strata of latest Rhaetian and earliest Jurassic age, more humid cyclical deposits appear more or less concurrently with an enormous extrusion of flood basalts. Because this apparent reversal in the paleoclimatic trend is not accompanied by a drift of Pangea to the south, it must reflect a true climate change. This kind of climate change might be expected from a spread of the ocean closer to the region, as occured in the Early Jurassic flooding of western Europe, perhaps generated by massive flood basalt eruptions (Olsen et al. 1997). A true climate change for this time interval may also be indicated by the stratigraphically abrupt transition into coal-bearing sequences in the Danish-Polish and East Greenland-Haltenbanken areas (e.g. Clemmensen et al. 1998) during a time of slow northward drift. However, because we lack cyclostratigraphic and magnetostratigraphic data in this geographic area through the Triassic-Jurassic transition, we do not know if this transition was broadly synchronous over the area or consistent with a very sharp geographic gradient between climatic zones.

Lacustrine styles and orbital forcing

Within the 30° of latitude spanned by the sequences discussed above there are profound changes in both the overall stratigraphic architectural style and the component sedimentary cycles of lacustrine strata. Olsen (1990) described three styles of lacustrine sequences in Eastern North America which, from the equator northward, are termed the Richmond, Newark, and Fundy type lacustrine sequences (Fig. 4). Farther north, the Fleming Fjord and Kap Stewart style lacustrine sequences (Fig. 4) can be added.

Richmond style lacustrine sequences are characterized by indicators of long term submergence and relatively muted climatic cycles (Figs. 4a, Fig. 6a). During relatively deeper water phases of the section, thick black shale sequences are interbedded with sandstones in the basin center, while much coarser strata interfinger along the basin margins. Black mudstones and carbonates are frequently microlaminated and contain a characteristic taphocoenesis of articulated fish with an absence of bioturbation. Based on industry drilling logs and seismic data Cornet and Olsen (1990) suggested that there appears to be significant relief on fluvial and deltaic structures within and adjacent to the black shale sequences. Cores and outcrops indicate the presence of abundant turbidites, sublacustrine channels, and fan deltas far into the basin. Shallower water phases of the basin sections have more prominent cyclicity, but the drier parts of the cycles tend to be sandy with intense bioturbation. Significant coal bearing intervals can be present in the shallower water intervals (e.g. the "productive coal measures"). Richmond style lacustrine sequences have been found in the Richmond, Taylorsville, Briery Creek, and Scottsburg basins of Virginia.

Newark-style lacustrine sequences are the most common type in eastern North America (Figs. 4b, 5) and have a very extensive descriptive literature (Smoot and Olsen 1994 and Olsen 1977), being characterized by very pronounced cyclicity caused by alternating intervals of submergence and desiccation at time scales of 20 ky. Basin center facies tend to be fine-grained with low-stand intervals dominated by red or gray mud-cracked massive mudstone and rooted mudstone. Deeper water intervals consist of black to red shales, with black shales frequently being microlaminated with the same basic taphoceoensis as in the Richmond-style sequences. Coarse clastic rocks are more restricted to the margins of the basin than in Richmond-type sequences. Deeper-water parts of the basin sequences can be mostly gray, but each sedimentary cycle has evidence of desiccation, even though the cycles may have a very prominent black shale. Shallower water phases of the basin sections tend to be mostly red clastics with less bioturbation than Richmond-style sequences. Coals are rarely present, but some are present in the more southern basins. Evaporites can be fairly abundant, although no pure bedded evaporites have been identified. The evaporite-bearing beds are almost always in the shallower-water parts of cycles, usually with dessication cracks and sometimes reptile tracks. The overall stratigraphic architecture tends to be characterized by virtually no evidence of significant topography. Newark-type sequences have been

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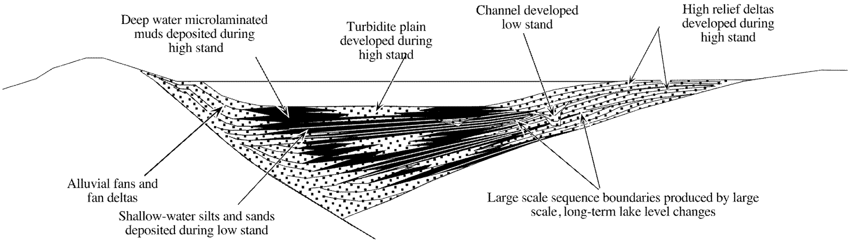
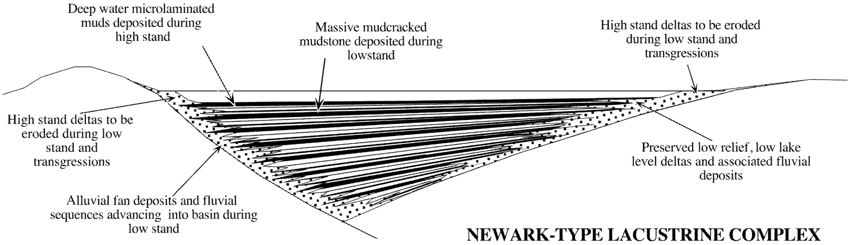
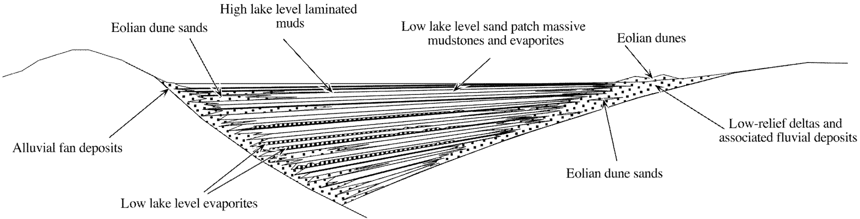
Fig. 4. Cartoons of the five types of lacustrine complexes in the Triassic-Jurassic rifting zone. The upper three are modified from Olsen (1990); the Fleming Fjord-type complex is based on Clemmensen (1980) and Seegis (1993); and the Kap Stewart-type complex is based on Dam and Surlyk (1992).



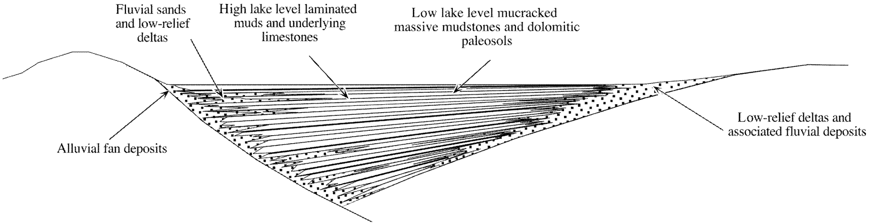
RICHMOND-TYPE LACUSTRINE COMPLEX
(± 2° N & S Latitude)



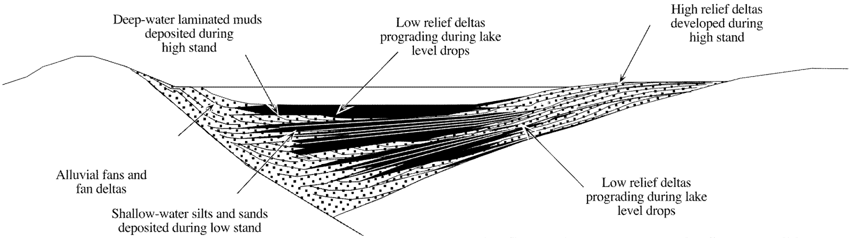
NEWARK-TYPE LACUSTRINE COMPLEX
(2°- 12° N Latitude)



FUNDY-TYPE LACUSTRINE COMPLEX
(10°- 33° N Latitude)



FLEMING FJORD-TYPE LACUSTRINE COMPLEX
(24° - 38° N Latitude)



KAP STEWART-TYPE LACUSTRINE COMPLEX
(> 35° N Latitude)