Table 1.—Biofacies analysis from 27 samples within the Trout Creek Sandstone and Mt. Harris Fork Member.

<table>
<thead>
<tr>
<th>Location/Sample No.</th>
<th>Species</th>
<th>Observations</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locality 15/ Sample S-1, S-2, S-3, S-4</td>
<td><em>Aquilapollenites</em> spp.</td>
<td>Very abundant mineral (quartz) grains. Minor–moderate amounts of organic matter (terricans), including rare leaf cuticle and black (charcoal?) wood fragments. Rare spores and pollen, barren for palynomorphs.</td>
<td>Typical assemblage from a sand succession. Due to the higher-energy, oxidizing environment, little organic material is preserved. No clear evidence of marine influence.</td>
</tr>
<tr>
<td>Locality 15/ Sample S-5</td>
<td><em>Aquilapollenites</em> spp.</td>
<td>Common-abundant terrigenous organic matter, including large leaf-cuticle fragments. Common spores and pollen.</td>
<td>Deposition in a low-energy environment, close to the original source (or rapid burial) is indicated by the presence of large amounts of organic and fragile leaf cuticle material. No clear evidence of marine influence.</td>
</tr>
<tr>
<td>Locality 15/ Sample S-6</td>
<td><em>Aquilapollenites</em> spp.</td>
<td>Abundant terrigenous organic matter, including common leaf cuticle. Common spores and pollen; possible rare marine dinoflagellate cysts present, but preservation is too poor to definitely confirm this.</td>
<td>Deposition in a low-energy environment, close to the original source (or rapid burial) is indicated by the presence of large amounts of organic and fragile leaf cuticle material. No clear evidence of marine influence, but possible presence of cysts may point towards this.</td>
</tr>
<tr>
<td>Locality 15/ Sample S-9, S-10, S-11</td>
<td><em>Aquilapollenites</em> spp. <em>Perinдоidae</em> species.</td>
<td>Common organic matter, including leaf cuticle. Spores and pollen: rare to common. Marine dinoflagellate cysts: rare to common.</td>
<td>Fully marine succession, but a more nearshore environment, compared to S7 and S8, indicated by smaller numbers of dinoflagellate cysts and increased presence of leaf cuticle</td>
</tr>
<tr>
<td>Locality 15/ Sample S-12</td>
<td><em>Aquilapollenites</em> spp. <em>Perinдоidae</em> species.</td>
<td>Abundant mineral (quartz?) grains. Almost barren of organic matter, but some leaf cuticle is present. No recognizable palynomorphs.</td>
<td>Typical assemblage from a sand succession. Due to the higher-energy, oxidizing environment, little organic material is preserved. No clear evidence of marine influence.</td>
</tr>
<tr>
<td>Locality 11/ Sample S-1</td>
<td><em>Aquilapollenites</em> spp.</td>
<td>Moderate amounts of terrigenous organic material, including common leaf cuticle. Common pollen and spores. One fragment of a peridinioid marine dinoflagellate cyst noted.</td>
<td>Deposition in a low-energy environment, close to the original source (or rapid burial) is indicated by the presence of large amounts of organic and fragile leaf cuticle material. No definite evidence of marine influence, but possible presence of cysts may point towards this.</td>
</tr>
<tr>
<td>Locality 11/ Sample S-2, S-3</td>
<td><em>Aquilapollenites</em> spp.</td>
<td>Common-abundant organic matter, including leaf cuticle. Common and diverse spores and pollen. Rare marine dinoflagellate cysts present.</td>
<td>Deposition in a low-energy environment, close to the original source (or rapid burial) is indicated by the presence of large amounts of organic and fragile leaf cuticle material. The presence of rare marine dinoflagellate cysts points to a nearshore environment.</td>
</tr>
<tr>
<td>Locality 11/ Sample S-4</td>
<td><em>Aquilapollenites</em> spp.</td>
<td>Abundant mineral (quartz?) grains, minor amounts of organic matter present. Rare pollen and spores; possible poorly preserved marine dinoflagellate cysts also present.</td>
<td>Typical assemblage from a sand succession. Due to the higher-energy, oxidizing environment, little organic material is preserved. Poorly preserved cyst fragments may indicate a possible marine environment.</td>
</tr>
<tr>
<td>Locality 14/ Sample S-2</td>
<td><em>Circulodinium distinctum</em>, <em>Oligosphaeridium complex</em></td>
<td>Moderate amounts of organic matter. Common black to dark brown (charcoal?) woody fragments. Low numbers of spores and pollen; poorly preserved. Rare marine dinoflagellate cysts present, including both peridinioid and chorate species.</td>
<td>Fully open marine succession.</td>
</tr>
</tbody>
</table>
**Skolithos** and **Arenicolites** representing an Arenicolites ichnofacies. **Orphiomorpha nodosa** defines a Skolithos ichnofacies. This assemblage of ichnogenera has previously been attributed to lower-shoreface environments in other areas (e.g., Vossler and Pemberton, 1988; Frey and Howard, 1990; Pollard et al., 1993; MacEachern and Pemberton, 1992).

**Upper-Shoreface Facies Association (FA-US)**

Description.—

Deposits coarsen upward from fine- to medium-grained sandstones. Individual sandstone beds (between 10 and 35 cm thick)
are amalgamated into thicker deposits averaging 8.5 m in thickness. Stratigraphically lower beds possess trough (Fig. 8E) and tangential cross-stratification, while overlying beds possess low-angle planar and plane-parallel lamination (Fig. 7). Uppermost beds also contain small scour surfaces. Minor amounts of wave-ripple lamination, shale lags, shell lags, and massive bedding are observed. Bimodal current orientations are observed in thicker deposits.

Bioturbation is generally absent, although lowermost beds may contain *Ophiomorpha nodosa*, and there may be root traces at the top of the FA-US facies association. Rare *Diplocraterion* is also present. FA-US deposits occur stratigraphically above FA-LS deposits.

**Interpretation.**—

The coarser grain size, the range of sedimentary structures, in particular trough cross-stratification, and the stratigraphic position of FA-US above FA-LS deposits (Fig. 7) suggest deposition above fair-weather wave base, in an upper-shoreface depositional environment. Low-angle and plane-parallel lamination in the uppermost parts (1–2 m) of FA-US reflect swash and backwash currents in a beach and foreshore zone.

Rare *Ophiomorpha nodosa* and *Diplocraterion* of the *Skolithos* ichnofacies suggest an upper-shoreface setting (Pollard et al., 1993). Sparse bioturbation is related to consistently high-energy conditions above fair-weather wave base.

**Lagoon Facies Association (FA-L)**

**Description.**—

Deposits consist of thin coal beds, mudstones, siltstones, heteroliths, and very fine- to fine-grained sandstone beds (Fig. 9). FA-L deposits are up to 10.5 m thick. Individual sandstone beds, 15 to 40 cm thick, contain wave-ripple lamination (Figs. 8F, 8G), current-ripple and plane-parallel lamination, trough cross-stratification, and HCS. Convolute bedding and shale clasts are observed in sandstone beds. Double mud drapes are associated with current ripples; however, exposures are not adequate to allow identification of a rhythmic cyclicity. Heterolithic deposits commonly contain plane-parallel lamination (often mud-draped), current and wave-ripple lamination, and flaser and wavy bedding (Figs. 8H, 8I). Shell and plant fragments are observed.

*Planolites* and *Palaeophycus* are common, root traces, *Rhizocorallium* and *Diplocraterion* are present, and *Arenicolites*, *Teichichnus*, *Ophiomorpha nodosa*, and *Asterosoma (?)* are rare. The degree of bioturbation varies from...
low (BI 1–2 in sandstones) to high (BI 4–5 in siltstones and mudstones). Deposits show a coarsening-upward trend accompanied by an upward increase in sand content. Several stacked, coarsening-upward FA-L successions are observed (Fig. 9).

**Interpretation.**

Infilling of a marine-influenced bay or lagoon is indicated by palynological data (e.g., Locality 12, samples S9–S11, and Locality 13, samples S2–S4; Table 1), the upwards transition from shale to heterolithics to wave-rippled sandstones, and the presence of marine trace fossils and shell material. Tidal indicators, double mud drapes, and flaser and wavy bedding, indicate significant variations in current flow velocities, suggesting a protected marginal-marine environment (e.g., Reineck and Wunderlich, 1968; Reineck and Singh, 1980; Visser, 1980; Nio and Yang, 1991). Although FA-L deposits may be interpreted as marine bay deposits, correlation to time-equivalent, high-energy upper-shoreface settings by Frey et al. (1978), Pollard (1981), Cornish (1986), and discussions therein). Trace fossils belonging to the ichnogenera associated with FA-TI (Ophiomorpha nodosa, Diplocraterion, and less commonly root traces, Diplocraterion (Fig. 8L), and Rhizocorallium. FA-TI often occurs in close proximity to lagoonal deposits.

**Tidal Inlet–Tidal Creek Facies Association (FA-TI)**

**Description.**

Sandy heterolithic deposits and very fine- to fine-grained sandstone beds (Fig. 10) range in thickness from centimeters to several meters. Erosionally based beds are predominantly trough and tangential cross-stratified. Bidirectional cross-stratification (Fig. 8J), low-angle planar cross-stratification, current-ripple laminated (sometimes occurring as backflow ripples in troughs), and plane-parallel laminae are present. Double mud drapes occur in current-rippled beds while lower bed boundaries are sometimes lined by shale clasts or shell debris (Fig. 8K). Wave ripples are observed at the tops of beds (Fig. 10) or in sandy heterolithic deposits. Ichnogenera commonly include Planolites and Ophiomorpha nodosa, and less commonly root traces, Diplocraterion (Fig. 8L), and Rhizocorallium. FA-TI often occurs in close proximity to lagoonal deposits.

**Interpretation.**

The observed suite of sedimentary structures and the erosional nature of bed contacts indicate traction-related deposition at the base of a highly erosive, unidirectional current dominated by turbulent flow conditions (e.g., Harms et al., 1982, and discussions therein). Trace fossils belonging to the Skolithos ichnofacies indicate a marine-influenced environment. Wave ripples result from the reworking of dune tops by subordinate oscillatory currents. The close association of FA-TI and FA-L facies associations and the presence of double mud drapes imply either a tidal-inlet or tidal-creek environment. The ichnogenera associated with FA-TI (Ophiomorpha nodosa, Diplocraterion, and Rhizocorallium) have been reported from tidally influenced settings by Frey et al. (1978), Pollard (1981), Cornish (1986), and Dam (1990). A lack of predominantly bidirectional paleocurrent directions is attributed to either the geographic separation of ebb and flood currents (e.g., Dalrymple et al., 1990; Dalrymple, 1992; Nio and Yang, 1991) or the dominance of one flow over the other at any given point in the tidal environment (e.g., Terwindt, 1971; Nio and Yang, 1991).

**Floodplain Facies Association (FA-FP)**

**Description.**

Interbedded heteroliths, siltstones, claystones, mudstones, coal beds (Fig. 8M), and very fine-grained sandstones (Fig. 11) are up to 10 m thick. Sandstone beds (up to a few centimeters thick) occur within heterolithic deposits up to 2.5 m thick. Sandstone beds are structureless, plane-parallel laminated, current-ripple laminated, or wave-ripple laminated. Siltstone deposits are either structureless or contain thin plane-parallel lamination. Some organic-rich shales grade into coal.

Root structures (BI 4–5) are the most common form of bioturbation in siltstones and sandstones (Fig. 8N). These traces occur in distinctive horizons ranging from a few centimeters to ca. 1 meter thick. Rare Planolites are observed. FA-FP either overlies FA-US deposits or occurs interbedded with other coastal-plain facies associations.

**Interpretation.**

FA-FP represents a variety of sub-environments in a floodplain setting. With the exception of wind-blown dust, sediment is introduced into this environment during stages of fluvial flooding. Mud is generally deposited from suspension fallout (Collinson, 1996), while sand is introduced by traction processes. Plane-parallel and current-ripple laminated sandstone beds are

![Fig. 10.—Log of tidal inlet and/or creek deposits (FA-TI) from Locality 5. Trough cross-stratification dominates, but wave ripples are also present. A marine influence is indicated by the presence of Ophiomorpha. See Figures 1 and 5 for location within the study area. See Figure 6 for a key to sedimentary structures in the log.](image-url)
section 11.—Log of floodplain deposits (FA-FP) from Locality 5. Various sub-environments are recognized, including swamp, distal crevasse-splay, lacustrine (?), and inundated or subaerially exposed overbank settings. See Figures 1 and 5 for position of Locality 5. See Figure 6 for a key to sedimentary structures in the log.

Distal crevasse-splay deposits, as described by Farrell (1987, 2001). Wave ripples reflect reworking of crevasse-splay deposits in a standing body of water (a temporary flood-generated water body or a permanent lake).

Thick mudstone deposits are tentatively associated with more permanent lakes where root horizons and paleosols reflect intermittent ablation of floodwaters and subaerial exposure of the floodplain. Coal beds indicate a swamp environment (e.g., Collinson, 1996). Thin coal beds (interbedded with sandstones and siltstones) reflect clastic discharge into the swamp (possibly associated with proximity to the fluvial system), while thick coal beds indicate deposition in a raised mire far removed from points of clastic input (e.g., McCabe, 1984).

**Fluvial-Channel Facies Association (FA-FC)**

Description.—

Conglomeratic beds (mudstone and sandstone intraclasts, Fig. 8O) are overlain by very fine- to medium-grained sandstone beds (Fig. 8P). Conglomerate beds (5 cm to 2.7 m thick) and sandstone beds (10 cm to 1.8 m thick) form erosionally based deposits up to 17 m thick. Sandstone beds possess trough cross-stratification and ripple lamination (Insert 1 in Fig. 12). Soft-sediment deformation and convolute bedding are relatively common. Tool marks, massive bedding, tangential and low-angle planar cross-stratification and plane-parallel lamination are observed. Large-scale inclined surfaces (Fig. 13) are observed at several locations.

Bioturbation is absent. Deposits occur as either small sandbodies (Fig. 13) or as larger, laterally extensive amalgamated belt-sandbodies (Figs. 12, 14) interbedded with crevasse-splay (below) and floodplain facies associations.

**Interpretation.—**

The absence of marine trace fossils, observed sedimentary structures, and the stratigraphic position of these deposits (Fig. 13) reflect a channelized fluvial environment. Large-scale inclined surfaces are lateral-accretion surfaces (indicating the progressive migration of point bars) which, along with the juxtaposition of sandbodies upon cohesive coal beds, indicates lateral channel migration across a broad floodplain. Large-scale, channel-belt geometries (Figs. 12, 14) support this interpretation.

**Overbank Sand Deposit Facies Association (FA-OB)**

Description.—

Fine- to very fine-grained sandstone beds, 10-30 cm thick, form deposits up to 5 m thick (Fig. 15). Current-ripple lamination (2-D and 3-D ripples) predominates (Fig. 8Q) while mud clasts, trough cross-stratification, plane-parallel lamination, structureless bedding, and convolute bedding are common structures. Climbing-ripple lamination and planar (tangential and sigmoidal) cross-stratification are observed. Bed tops may be bioturbated by roots (BI 2-5) or by Planolites (BI 5). Deposits are closely associated with fluvial-channel or floodplain facies associations, and beds are sometimes inclined away from fluvial channel deposits.

**Interpretation.—**

Deposits reflect a variety of proximal channel–overbank subenvironments including levee, crevasse-splay, and crevasse-channel settings. Where dipping beds overlie, or are overlain by, FA-FC facies association, and/or grade laterally into channel sandstones, a levee setting is inferred (see Reineck and Singh, 1980). Crevasse-channel deposits are erosionally based and typically contain cross-stratified sandstones (e.g., Flores et al., 1985; Mjøs et al., 1993; Farrell, 2001). Limited channel size and a close association with levees and crevasse splays indicate crevasse-channel deposits. Crevasse splays are deposited farther out in the floodbasin (e.g., Mjes et al., 1993) and possess ripple and climbing-ripple structures (McKee, 1965; Jopling and Walker, 1968; Reineck and Singh, 1980). Splays are seen to progressively advance into the basin where distal crevasse-splay sandstones are overlain by stacked, current-ripple cross-laminated sandstone bedsets. Crevasse-splay progradation is a product of repeated crevassing (Elliott, 1974; Farrell, 2001) and nearby fluvial-channel migration (Collinson, 1996).

**Mouth-Bar Facies Association (FA-MB)**

Description.—

Deposits coarsen upward from very fine- to fine-grained, tabular sandstone beds. This facies association is observed only at Locality 15 (Fig. 16), where it is 1.30 m thick. Current-ripple lamination and low-angle planar cross-stratification are common. Wave-ripple lamination and trough cross-stratification are observed. Bioturbation (BI 3) within one bed contains escape structure traces (Fig. 16).
Fig. 12.—Photo mosaic from the most proximal part of the study area. The mosaic is divided into three sections that form a continuous panel from top left to bottom right. The position of Locality 1 is indicated on the mosaic. The regressive surface of marine erosion is marked by arrows at the base of the Trout Creek Sandstone. Insert of Locality 2 shows channelized fluvial deposits in the Mt. Harris Fork Member. See Figure 2 for position of localities 1 and 2 and Figure 6 for a key to sedimentary structures in the log.
Interpretation.—

A coarsening-upward trend, tabular geometry, and interpreted sedimentary structures are analogous to mouth-bar deposits (e.g., Oomkens, 1970; Coleman and Wright, 1975; Elliott, 1986). Surrounding deposits are poorly exposed but are similar to underlying lagoonal sediments. Escape-structure traces indicate rapid introduction of sediment into the depositional environment (e.g., Bromley, 1996) and in this case reflects channel avulsion or crevassing. The resultant sandbody is termed a minor mouth-bar or bay-head delta (Elliott, 1974, 1986; Mjøs et al., 1993).

RECOGNIZING SHORELINE TRAJECTORY TRENDS IN THE ROCK RECORD

Although syndepositional and postdepositional compaction and tectonic movement make direct observation of shoreline trajectory trends difficult, interpretations of trajectories from outcrop and wireline data were based on the character of the bases and tops of shoreface tongues, the nature of facies-association successions (compressed or expanded) in the shoreface succession (e.g., see Walker and Plint, 1992, their Figure 16), and the thickness and nature of laterally adjacent coastal-plain facies associations. Regressive shoreline trajectory trends may be descending.
Fig. 14.—Photo mosaic from Locality 5. The mosaic is divided into two sections that form a continuous panel from top left to bottom right. Insert 1 shows nested channel deposits; Insert 2 shows channelized fluvial sandstones and floodplain deposits. See Figure 1 for position of Locality 5.
flat, or ascending (reflecting falling, stable, or rising relative sea level, respectively). Transgressive shoreline trajectory trends may be flat (non-accretionary) or ascending (accretionary).

Descending shoreline trajectories are defined by compressed shoreface tongues with abrupt upward transitions from offshore heterolithics to thickly amalgamated lower-shoreface or upper-shoreface sandstones (Fig. 17A; see also Plint, 1988; Plint and Norris, 1991; Walker and Plint, 1992; Plint, 1996; Posamentier and Morris, 2000). The tops of these marine shoreface tongues may contain rootlets signifying subaerial exposure. Adjacent coastal-plain facies associations are absent, and overlying floodplain deposits are genetically unrelated. Shoreface and foreshore successions may be incised by amalgamated fluvial channel-belt sandstones (Fig. 17A1). In a conventional sequence stratigraphic framework, a sequence boundary is placed at the base of the lower-shoreface deposits (cf. Van Wagoner et al., 1988; Posamentier and Allen, 1999).

Flat regressive shoreline trajectories are defined by shoreface tongues with gradational lower contacts and complete lower-shoreface successions (Fig. 17B). Sand-to-shale ratios increase gradually upward as sandstone beds become more amalgamated (e.g., gradationally based succession described by Walker and...
Fig. 17.—Schematic diagram of expected relationships between different shoreline trajectory trends, vertical shoreface profiles, and time-equivalent coastal-plain deposits. A descending regressive shoreline trajectory (DRST) is associated with a sharp-based, compressed shoreface package (A) and coastal-plain areas characterized by incised channels and bypass (A1), or nondepositional interfluvies. A flat regressive shoreline trajectory (FRST) is associated with a complete shoreface succession (B) and channel incision or bypass in time-equivalent coastal-plain areas (B1). An ascending regressive shoreline trajectory (ARST) is associated with an expanded shoreface succession (C) and the occurrence of thin coals, floodplain mudstones and sandstone, and some channel sandstones in the time-equivalent coastal-plain area (C1). A flat transgressive shoreline trajectory (FTST) is associated with a thin upper-shoreface succession (D) and possibly with a transgressive lag deposit (ravinement surface) separating coastal-plain deposits from shoreface and offshore deposits. An ascending transgressive shoreline trajectory (ATST) is associated with an expanded shoreface succession where lower shorefaces overlie upper-shoreface deposits (E). Time-equivalent coastal-plain areas are characterized by stacked bay-fill sediments that correlate landwards to floodplain successions with thick coals, mudstones, and isolated fluvial channels (E1). FA-OT = offshore-transition-zone facies association, FA-LS = lower-shoreface facies association, FA-US = upper-shoreface facies association, FS = foreshore deposits, FA-FC = fluvial-channel facies association, FA-FP = floodplain facies association, FA-L = lagoon facies association. See Figure 6 for a key to sedimentary structures in the log.
Plint, 1992, their Figure 16). Fluvial incision and/or channel-belt amalgamation (Fig. 17B1) and relatively thin fluvial plain successions are observed in adjacent coastal-plain areas. A type 2 sequence boundary (cf. Van Wagoner et al., 1990) may be associated with flat regressive shoreline trajectories.

Ascending regressive shoreline trajectories are defined by shoreface tongues with gradational lower contacts and thicker foreshore/shoreface successions (Fig. 17C). Laterally adjacent lower coastal-plain floodplain and isolated tidal or fluvial channel facies associations are observed (Fig. 17C1). These paralic deposits are vertically juxtaposed onto adjacent foreshore deposits. Initial flooding surfaces are associated with the most proximal extent of ascending regressive trajectories. Traditionally these deposits are attributed to highstand, lowstand wedge, or regressive systems tracts.

Non-accretionary transgressive trajectories are defined by the omission, or compression, of nearshore facies associations, as shown by abnormally thin shoreface successions (Fig. 17CD) capped by a ravinement surface (Demarest and Kraft, 1987; Nummedal and Swift, 1987). Accretionary transgressive trajectories are defined by retrogradational successions that change laterally from coastal-plain stacked bay-fill and thick floodplain facies associations (Fig. 17E1), to shoreface, and then offshore deposits (e.g., Demarest and Kraft, 1987). Maximum flooding surfaces are associated with the most landward extent of accretionary and/or non-accretionary transgressive trajectories. Traditionally these deposits are attributed to a transgressive systems tract.

**STRATIGRAPHIC ARCHITECTURE AND SHORELINE TRAJECTORY TRENDS**

The Trout Creek Sandstone–Mt. Harris Fork clastic wedge contains seven regressive–transgressive (R/T) sequences (R/T 1–7, Fig. 5), each averaging approximately 285,000 years. These are interpreted as fourth-order sequences. The lower part of each R/T sequence comprises a shoreface tongue that formed predominantly during stages of falling and stable relative sea level. Intervening, thick continental successions are largely formed during transgression (thinner paralic deposits also form during regressive events). Marine shale between shoreface sandstones bounds the distal portions of R/T sequences. Associated shoreline trajectory trends are described in detail below.

**R/T 1 Regressive Architecture**

The regressive part of R/T 1 consists of a 50-km-long shoreface tongue (Tongue 1, Fig. 5). In the most proximal part of the study area, Tongue 1 is the lower marine shoreface succession (ca. 20 m thick) 25 m above the top of the underlying Iles Formation shoreface sandstone (localities 1 and 5). In this proximal area, gutter casts (Fig. 8B) near the base of Tongue 1 indicate an erosional surface (Fig. 12) that marks a dramatic upward increase in the sand-to-shale ratio and bed amalgamation (Fig. 18). To the north (along strike) of these proximal exposures, wells show abrupt increases in gamma-ray and induction values at this horizon (e.g., Well 2, Fig. 5). The upper surface of the tongue is defined by an abrupt transition into overlying coastal-plain facies associations, and the uppermost few centimeters of the foreshore–shoreface succession is bioturbated by rootlets. Ten kilometers farther basinward, the thickness from the underlying Iles Formation shoreface to the top of Tongue 1 increases from 40 m (Locality 1) to 53 m (localities 9 and 10). At Locality 10, two parasequences are visible in the Tongue 1

**R/T 1 Transgressive Architecture**

The most proximal occurrence of R/T 1 transgressive deposits is reflected by a 10–15 m thick lower-delta-plain succession...
consisting of floodplain (possibly marine influenced) and tidal-creek facies associations. These coastal-plain facies associations overlie shoreface deposits and onlap regressive Tongue 1 deposits near Locality 1 (Fig. 5). Time-equivalent depositional environments to the southeast indicate that these are transgressive floodplain and tidal-creek facies associations and do not represent a lowstand alluvial onlap wedge. These marine-influenced delta-plain deposits are correlated 17 km (between localities 1 and 11, Fig. 5) to a 24-m-thick stacked lagoonal succession extending from Locality 11 to Well 8 (Fig. 5). At Locality 13 the same stratigraphic succession consists of a 5-m-thick, poorly exposed section interpreted to contain offshore shales (based upon the presence of an overlying shoreface tongue and a high gamma-ray, high-induction log response in Well 10). In wells 8 and 9 (Fig. 5), blocky log motifs are tentatively interpreted as a barrier- sandstone complex. This defines the most landward position of the R/T 1 transgressive shoreline.

R/T 1 Shoreline Trajectory Trends

In proximal parts of the study area (e.g., localities 1 and 5), falling relative sea level is indicated by a comparatively thin (upper plus lower) shoreface succession and a sharp contact with underlying transition-zone deposits. The contact between the lower shoreface and the offshore transition zone is a distinct surface (Fig. 18) containing gutter casts and amalgamation of overlying shoreface deposits. This surface is a regressive surface of marine erosion, formed when falling relative sea level superposed thick, homogeneous sandstones upon offshore deposits (Plint, 1988, 1991, 1996; Plint and Nummedal, 2000). Bypass and a lack of coastal-plain deposits (i.e., a sequence boundary) are expected to be caused by the fall of relative sea level associated with proximal Tongue 1 shoreface deposits. A descending shoreline trajectory is associated with these deposits (Fig. 20).

At Locality 10 (Fig. 2), parasequences in shoreface deposits suggest an expanded shoreface profile, and increased accommodation in front of the prograding shoreface, that is not concordant with conditions of falling relative sea level. The increase in water depth necessary to obtain this gradual lower contact probably results from the southeast-dipping gradient of the shelf, and not necessarily from sea-level rise. The upper Tongue 1 contact is sharp, with foreshore deposits overlain by a coal bed (Fig. 6) that correlates to the initial flooding of R/T1 regressive deposits in a basinward direction (Fig. 5). Overlying coastal-plain facies associations are therefore genetically unrelated to regressive Tongue 1 deposits. Time-equivalent areas, behind the Tongue 1 shoreface succession observed at Locality 10, also appear to lack coastal-plain facies associations (Fig. 5). The lack of coastal-plain facies associations directly behind the prograding shoreface and the presence of a gradational lower contact imply that the shoreline migration path flattened (Fig. 20), reflecting progradation during stable relative sea level.

Following these conditions of stable relative sea level, a renewed fall of sea level (similar to the proximal area described above) is indicated basinward of Locality 10 by sharp-based lower- shoreface successions and abrupt upward facies-association transitions evident from both wireline log responses and exposures at localities 11 and 12. Relative sea-level fall occurred between wells 4 and 6 (Fig. 5). A descending shoreline trajectory is associated with this part of the Tongue 1 progradation (Fig. 20). Beyond Well 6, the gradational lower contact of Tongue 1 (observed at Locality 13) and an inferred lack of time-equivalent paralic deposits (Fig. 5) reflect stable relative sea level and a flat shoreline trajectory (Fig. 20). At the most basinward extent of Tongue 1, the shoreline trajectory rose as the shoreface aggraded, prior to transgression. This short-lived rise of relative sea level resulted in the formation of accommodation behind the shoreline, and the deposition of a thin, regressive coastal-plain wedge that laps onto the Tongue 1 shoreface succession in a landward direction (Fig. 5). An ascending, regressive shoreline trajectory is therefore associated with this distal part of the R/T 1 progradation (Fig. 20).

The following R/T 1 transgression led to rapid flooding of the coastal plain in distal areas and a pronounced landward shift of the shoreline. However, as the rate of relative sea-level rise decreased (or sediment supply increased) the shoreface aggraded and significant accommodation was created behind the shoreline. A thick transgressive succession of lagoonal deposits and proximally located tidal channel and floodplain facies associations was deposited in the coastal-plain area (Fig. 5). This resulted in an R/T 1 transgressive shoreline trajectory that was initially non-accretionary (flat) but became significantly more accretionary (ascending) at its most landward extent (Fig. 20).

R/T 2 Regressive Architecture

Proximal R/T 2 regressive deposits occur at Locality 13 (Fig. 5), where a 9.5-m-thick, sharp-based, Tongue 2 upper-shoreface facies association is exposed (Fig. 19). Rootlets bioturbate the top
Fig. 20.—Schematic diagram of varying shoreline trajectories (arrowed lines) within different tongues identified in Figure 5. DRST = descending regressive shoreline trajectory, FRST = flat regressive shoreline trajectory, ARST = ascending regressive shoreline trajectory, FTST = flat transgressive shoreline trajectory, ATST = ascending transgressive shoreline trajectory, RSME = regressive surface of marine erosion, u. sf. = upper shoreface, l. sf. = lower shoreface, mfs = maximum flooding surface, R/T = regressive–transgressive cycle. (Vertical and horizontal scales are approximate.)
of the Tongue 2 succession, and shoreface facies associations are
overlain abruptly by coastal-plain facies associations. The land-
ward limit of this shoreface succession occurs between Locality
13 and Well 8 (Fig. 5). The thickness of Tongue 2 increases to ca.
19 m in Well 11, approximately 15 km to the southeast of Locality
13. Here, the contact between offshore shale and lower-shoreface
deposits is more transitional than in proximal areas. The upper
boundary, between foreshore–shoreface deposits and overlying
coastal-plain facies associations, appears to remain sharp.
Basinwards, Tongue 2 pinches out in marine shales, between
localities 15 and 16 (Fig. 5).

In proximal areas (between localities 1 and 5, Fig. 5), amalgam-
gated channel-belt deposits, occurring above R/T 1 transgres-
sive deposits, are tentatively correlated ca. 20 km basinward to
the Tongue 2 shoreface progradation. Significant amounts of
coastal-plain bypass (between Locality 9 and Well 8, Fig. 5) are
probably related to this regressive shoreface development. In
distal areas (Well 11), intermediate wireline log responses (be-
tween low gamma–low resistivity shoreface sandstones and high
gamma–high resistivity offshore shales) suggest that ca. 8 m of
cosaltal-plain deposits occur above Tongue 2 foreshore to upper-
shoreface deposits. These lower-delta-plain deposits are overlain
by high-gamma-ray, offshore shale deposits and represent a thin
alluvial onlap wedge formed during regression and distal aggra-
dation of Tongue 2.

R/T 2 Transgressive Architecture

The most distal occurrence of R/T 2 transgressive deposits
occurs at Locality 13, where a shale-rich offshore succession,
inferred from wireline logs in Well 11, overlies coastal-plain depos-
its occurring behind an aggrading R/T 2 regressive shoreface (Fig.
5). Approximately 15 km landward, this offshore succession corre-
lates to tidally influenced channels, floodplain, and overbank-sand
facies associations (Locality 13) in a lower-delta-plain setting.
These deposits are overlain by a poorly exposed succession consist-
ing of shale-rich or heterolithic lithologies (Well 10). This shale-
rich, lagoonal succession occurs landward of an aggrading barrier
complex inferred between localities 13 and 15 (Fig. 5). Ravinement
of the shoreface is interpreted between Well 11 and the most
landward extent of the R/T2 transgressive shoreface (Fig. 5).

This lagoonal succession occurs in the middle to upper part of
the R/T 2 transgressive succession and can be traced landwards for
a distance of approximately 15 km before terminating near
Locality 11. Here, a 13-m-thick succession of wave-ripple-lami-
nated bedsets and lenticular-bedded heterolithic deposits (con-
taining marine dinoflagellate cysts) is observed. Coal beds and
paleosols (indicated by rootlet burrows) suggest intermittent
subaerial exposure and shallow water depths.

In a proximal direction (between localities 1 and 10), this lagoonal facies association corresponds to the upper part of the R/
T 2 transgressive succession and consists of floodplain, fluvi-
channel, and overbank sandstone facies associations lacking signs
of marine influence. These delta-plain facies associations overlie
R/T 2 regressive channel-belt deposits (e.g., Locality 1, Fig. 5) and
represent an upper-delta-plain setting. Floodplain deposits and
coal beds are generally thinner, with fewer intermittent sandstone
beds, than in underlying R/T 1 lower-delta-plain deposits. Gener-
ally, transgressive fluvial sandbodies are thinner and more later-
ally discontinuous than regressive fluvial sandbodies.

R/T 2 Shoreline Trajectory Trends

At Locality 13, thin (9.5 m), sharp-based, regressive Tongue 2
deposits indicate limited accommodation in front of the shoreface
and deposition during falling relative sea level. Correspond-
ingly, a descending, forced-regressive shoreline trajectory is
associated with R/T 2 in proximal parts of Tongue 2 (Fig. 20),
and the sharp base represents a regressive surface of marine
erosion (RSME). A coal bed in time-equivalent coastal-plain areas
(e.g., just below the 60 m marker at Locality 5, Fig. 5) represents the transgressive–regressive turnaround point. This
is eroded by an extensive fluvial channel belt (localities 1 and 5)
that correlates to the descending, regressive R/T 2 shoreface
trajectory (Fig. 20). The amalgamated nature of these channel
deposits suggests limited accommodation in the coastal-plain
area, a situation potentially coincident with a descending shore-
line trajectory and possible valley incision (indicating a candi-
date sequence boundary). The apparent absence of this amalgam-
gated channel complex between wells 3 and 8, in southeastern
regions, is attributed to lateral variability of the position of
the channel complexes in a strike direction.

Normal progradation is inferred from the gradual upward
decrease in gamma-ray and induction log values in Well 11 (Fig.
5). This is probably a result of coastline progradation beyond
the most basinward extent of the underlying Tongue 1 progradation.
A lack of Tongue 2 outcrop exposures in this area prohibits
the examination of time-equivalent coastal-plain areas, and it is
therefore difficult to determine whether the shoreline trajectory
at Well 11 is flat or accretionary. However, following the sea-level
fall related to proximal Tongue 2 areas it is likely that sea level
stabilized and remained stable for a period of time, prior to its
subsequent rise. A flat trajectory is therefore tentatively attrib-
uted to these deposits (Fig. 20). Beyond Locality 15, a thin alluvial
wedge onlap, inferred from wireline log responses in Well 11
(Fig. 5), implies aggradation of the shoreface and a higher-angle,
ascending-regressive shoreline trajectory (Fig. 20).

At Locality 13, marine-influenced coastal-plain deposits (con-
sisting of fluvial and tidal channel-fill sandstones and flood-
plain facies associations), above Tongue 2 shoreface deposits,
are correlated to a distal transgression of Tongue 2 between
localities 13 and 15 (Fig. 5). This 24-m-thick, transgressive lower-
delta-plain succession implies an accretionary, transgressive
shoreline trajectory between localities 13 and 15 (Fig. 20). Much
of the transgressive shoreface was removed by erosion (ravine-
ment). However, as the R/T 2 transgressive shoreline retreated
to its most landward position, aggradation of an inferred barrier
complex resulted in the formation of a high-angle, accretionary
transgressive shoreline trajectory between wells 10 and 11 (Fig.
20). This highly aggrading shoreline trajectory is correlated
landward to lagoonal deposits (occurring above R/T 2 trans-
gressive, channel-fill and floodplain facies associations at Lo-
cality 13), and to more proximally located floodplain and flu-
vial-channel (isolated meander belts) facies associations (Figs.
5, 20).

R/T 3 Regressive Architecture

R/T 3 regressive shoreface deposits are not observed in
outcrops, but the presence of an 18-m-thick progradational R/
T 3 shoreface (Tongue 3), below the Locality 15 outcrop,
is interpreted from wireline log responses in Well 11 (Fig. 5). The
respective landward and seaward terminations of the tongue
occur between Well 11 and Locality 13, and localities 15 and 16.
This implies a progradational length of approximately 10–15
km (Fig. 5). Sonic and induction log motifs in Well 11 suggest
that the base of Tongue 3 is a gradual transition from offshore-
shale to lower-shoreface facies associations, and the top of
Tongue 3 is characterized by an abrupt transition from fore-
shore–shoreface deposits to overlying shale deposits.
Coastal-plain R/T 3 regressive deposits are largely represented by thick (up to ca. 20 m), amalgamated, fluvial channel-belt deposits occurring above previously described R/T 2 transgressive deposits in proximal areas (e.g., Locality 9, Fig. 5). Levee, crevasse-splay, and thin floodplain deposits are associated with these regressive fluvial sandbodies. These amalgamated fluvial sandstones dominate a stratigraphic succession (from Locality 5 to Well 4, and from Locality 11 to Locality 13, Fig. 5) that correlates basinward to the Tongue 3 progradation in Well 11 (Fig. 5).

**R/T 3 Transgressive Architecture**

In proximal and distal areas (between wells 1 and 5, and wells 9 and 11, Fig. 5), R/T 3 regressive deposits are overlain by floodplain-dominated coastal-plain facies associations (ca. 8–10 m thick) containing isolated fluvial channel deposits and overbank sandstones. These transgressive deposits are correlated basinward to offshore shale deposits occurring above Tongue 3 in Well 11 (Fig. 5). In proximal areas, initial R/T 3 transgressive, coastal-plain facies associations are overlain by a lagoonal succession that varies in thickness from ca. 5 m (Locality 12) to ca. 20 m (Locality 9) and extends over 10 km in a dip direction (Fig. 5).

Basinwards, these lagoonal deposits pinch out between Locality 12 and Well 6. In distal areas, a transgressive ravinement surface is interpreted to separate R/T 3 transgressive coastal-plain facies associations from overlying shale deposits (Fig. 5). Overlying, “backstepping” foreshore deposits (FA-US) are observed at Locality 12 (Fig. 5), where they are ca. 2.5 m thick and consist of plane-parallel-laminated sandstones (Fig. 8R). As with underlying lagoonal deposits, these foreshore deposits pinch out between Locality 12 and Well 6 in a basinward direction.

Thick lagoonal deposits at Locality 9 are correlated landward to a ca. 15-m-thick tidally influenced channelized sandbody, containing **Ophiomorpha nodosa**, at Locality 5 (Fig. 5). Basinwards, these lagoonal deposits equate to an inferred barrier complex, between wells 3 and 4, which is superseded basinward by an offshore shale succession 20 to 25 m thick (Fig. 5). This shale succession can be followed to the southeast (using wireline log responses) for a minimum distance of 35 km and is tentatively correlated to shale occurring directly above Tongue 3 in Well 11 (Fig. 5).

**R/T 4 Transgressive Architecture**

R/T 4 transgressive deposits in distal areas (Locality 16) consist of approximately 4 m of offshore shale overlying regressive Tongue 4 deposits (Fig. 5). Landwards, these shale deposits correlate to an inferred barrier complex between localities 15 and 16 (Fig. 5). Approximately 4 m of lagoonal deposits (Locality 15, Fig. 5) occur behind this transgressive barrier complex. Landward correlation of R/T 4 transgressive deposits is restricted by a lack of well or outcrop data, but these transgressive deposits onlap the underlying regressive Tongue 4 succession between localities 13 and 15 (Fig. 5).

**R/T 4 Shoreline Trajectory Trends**

The gradual change from shale to sand at the lower-shoreface interface, as indicated by Well 11 wireline log responses (Fig. 5), reflects either a flat or an ascending shoreline trajectory related to the progradation of Tongue 3 (Fig. 20). This represents either stable or rising relative sea level during normal regression of the shoreline. Time-equivalent coastal-plain facies associations (amalgamated fluvial channel-belt sandstones) imply low accommodation rates associated with a flat shoreline trajectory.

In Well 11, the abrupt transition from R/T 3 regressive shoreface deposits to overlying offshore shale implies rapid flooding of the shoreface and a non-accretionary (Hat) R/T 3 transgressive shoreline trajectory in distal areas (Fig. 20). However, the occurrence of R/T 3 transgressive deposits in coastal-plain areas landward of Well 11 suggests that the transgressive shoreline trajectory became accretionary between wells 10 and 11 (Fig. 20). Between wells 4 and 10 thin transgressive deposits indicate a low-angle, accretionary transgressive trajectory which became progressively steeper and more accretionary in a landward direction. Significant aggradation of shoreface and lagoonal deposits landward of Well 4 (Fig. 5) implies the presence of a highly aggradational, transgressive shoreline trajectory in proximal areas (Fig. 20).

**R/T 4 Regressive Architecture**

In proximal areas, between Well 4 and Locality 12, the base of the regressive, R/T 4 shoreface (Tongue 4) is characterized by a transition from offshore shale to overlying lower-shoreface deposits. The transition into overlying coastal-plain facies associations is not observed here. Landward of Locality 12, the R/T 4 regressive shoreface correlates to fine-grained, floodplain or lacustrine delta-plains deposits (Locality 9) overlying R/T 3 transgressive lagoonal and tidal-channel facies associations (Fig. 5).

Basinwards of Locality 12, the R/T 4 shoreface is correlated to Locality 15 (Well 11) where Tongue 4 consists of lower-shoreface and upper-shoreface facies associations. Wireline log responses in Well 11 indicate a gradational lower boundary to underlying shale deposits, while the tongue is abruptly overlain by a ca. 4-m-thick lower-delta-plain succession composed of floodplain (including coal), overbank sandstone, and lagoon facies associations (Locality 15, Fig. 5). This lower coastal-plain succession represents a thin alluvial wedge onlap.

At Locality 16, 10.2 km basinward of Locality 15, Tongue 4 (minimum 11 m thick) consists entirely of lower-shoreface deposits overlain by offshore shale deposits (Fig. 5). The lower part of the tongue is obscured by debris at this locality. The large, dip-oriented extent of Tongue 4, compared to other shoreface tongues, suggests that it either consists of several regressive tongues or is a single tongue, extending basinward by more than 60 km, with a flat or descending trajectory (see below).
wells (e.g., wells 6 and 8, Fig. 5), show a sharp change in resistivity and gamma-ray values similar to that associated with the forced-regressive progradation (candidate sequence boundary) of Tongue 1. This implies the presence of a regressive surface of marine erosion (as with Tongue 1) and a descending shoreline trajectory in these areas (Fig. 20).

As with Tongue 2, stable relative sea level, following sea-level fall, is indicated by a gradational lower Tongue 4 boundary (seen in Well 11 wireline log responses, Fig. 5). A flat shoreline trajectory is interpreted at Locality 15 (Fig. 20). Time-equivalent coastal-plain facies associations are poorly exposed and are not used to infer regressive shoreline trajectory trends. However, the thin alluvial wedge onlap at Locality 15 implies aggradation of the shoreline (lowstand-wedge systems tract) prior to transgression, and the presence of an ascending regressive shoreline trajectory in distal areas (Fig. 20). The presence of R/T 4 coastal-plain deposits (Locality 15) and the interpretation of a barrier complex (between localities 15 and 16) suggest that the transgressive trajectory became more accretionary in a landward direction (Fig. 20).

R/T 5, 6, and 7 Regressive Architecture

Regressive, R/T 5 shoreface deposits (Tongue 5) are observed only at Locality 16, in distal parts of the study area. Tongue 5 is 10 m thick and consists of a thin (4 m thick), sharp-based, lower-shoreface facies association overlain by upper-shoreface deposits. Landwards, Tongue 5 terminates between localities 15 and 16, as time-equivalent coastal-plain deposits at Locality 15 consist of 7 m of floodplain (coals and mudstones) and overbank-sandstone facies associations (Fig. 5). Farther landward, this R/T 5 regressive succession thins and onlaps the underlying Tongue 4 between wells 10 and 11 (Fig. 5). The basinward termination of Tongue 5 is not observed in the study area.

Regressive, R/T 6 coastal-plain facies associations consist of either lower-delta-plain, overbank sand deposits and coal (Locality 15), or a 6-m-thick fluvial channel deposit (Locality 16, Fig. 5). R/T 6 shoreface deposits (Tongue 6) are not observed in outcrop or well data and are interpreted to occur southeast of the study area. Landward correlation of the R/T 6 regressive succession is hampered by limited data coverage.

Lower-shoreface deposits (minimum 5 m thick) in the uppermost part of Locality 16 constitute the only observation of regressive, R/T 7 shoreface deposits (Tongue 7). The basinward termination of this tongue is not observed in the study area. Landwards, Tongue 7 pinches out between localities 15 and 16 (Fig. 5). Time-equivalent coastal-plain facies associations (maximum 9 m thick) at Locality 15 are poorly exposed, although a 1-m-thick coal bed is identified.

R/T 5, 6, and 7 Transgressive Architecture

At Locality 15, 24 m of stacked lagoon deposits (Fig. 9) overlie R/T5 regressive coastal-plain deposits (described above) and indicate transgression of the R/T 5 regressive succession. Time-equivalent facies associations at Locality 16 (10 km basinward) consist of a poorly exposed, paralic (?) succession above Tongue 5 (Fig. 5). Landward of Locality 15, correlation of R/T 5 transgressive deposits is hampered by a lack of outcrop exposures.

Regressive R/T 6 deposits are overlain by approximately 25 m of stacked lagoon deposits (Locality 15) which reflects transgression of the shoreline. A transgressive barrier complex is interpreted to occur seaward of this lagoon facies association (Fig. 5). Basinwards (Locality 16), these transgressive coastalplain and shoreface deposits correspond to a c. 13-m-thick, poorly exposed succession occurring above the previously described regressive R/T 6 channel belt. The existence of an overlying regressive shoreface tongue (Tongue 7, described above) and observations from underlying tongues suggest that part of this poorly exposed succession contains transgressive, offshore shale deposits (Fig. 5).

The only exposure of R/T 7 transgressive deposits occurs at the top of Locality 15, where a 25-m-thick, coastal-plain succession, containing tidal-channel and lagoonal facies associations, indicates flooding and transgression of the R/T 7 shoreline. The contact between a 1.5-m-thick coal seam, at the top of this succession, and overlying shale deposits is interpreted to represent the pre—Twenty Mile Sandstone flooding surface that bounds the top of the Trout Creek Sandstone–Mt. Harris Fork clastic wedge (Fig. 5).

R/T 5, 6, and 7 Shoreline Trajectory Trends

Due to limited dip-oriented exposures and the occurrence of these R/T 5, 6, and 7 deposits in the most paleo-seaward parts of the study area, it is difficult to determine the nature of shoreline trajectories over the full length of R/T 5, 6, and 7 regressive-transgressive wedges. However, shoreline trajectories can be directly inferred for proximal R/T 5, 6, and 7 deposits observed at Locality 16. Additionally, observations of the relationships between previously described, underlying shoreface tongues and equivalent coastal-plain facies associations enable shoreline trajectory trends to be indirectly inferred for R/T 5, 6, and 7 deposits that occur southeast of the study area.

The presence of regressive, coastal-plain deposits behind Tongue 5 (Locality 15) suggests shoreface aggradation, and the creation of accommodation behind the shoreline, in proximal Tongue 5 areas. This indicates that an ascending regressive trajectory is associated with the initial Tongue 5 progradation (Fig. 20). At Locality 16, a sharp contact between marine shales and overlying amalgamated shoreface sandstones implies progradation of Tongue 5 during falling relative sea level and a resultant descending shoreline trajectory (Fig. 20). The occurrence of a thick succession of transgressive R/T 5 coastal-plain deposits above the R/T 5 regressive succession indicates the presence of an ascending, transgressive shoreline trajectory located southeast of the study area.

Regressive, R/T 6 coastal-plain deposits, above R/T 5 lagoonal deposits (localities 15 and 16), indicate that at least part of the R/T 6 progradation occurred during rising relative sea level, and that these deposits are associated with an ascending, regressive shoreline trajectory located farther to the southeast. Due to poor exposures within the upper parts of Locality 16, the nature of the R/T 6 transgressive trajectory is difficult to determine at this location. However, a thick succession of R/T 6 transgressive, lagoonal deposits, at Locality 15, indicates that the R/T 6 transgressive shoreline trajectory was highly accretionary (Fig. 20).

At Locality 16, the base of Tongue 7 is poorly exposed, and cannot be used to indicate the shoreline trajectory trend for these regressive R/T 7 deposits. The presence of regressive coastal-plain deposits, in the uppermost parts of Locality 15, indicates the generation of accommodation behind the shoreline, and is tentatively used to infer the existence of an accretionary shoreline trajectory associated with the R/T 7 progradation (Fig. 20). As with underlying R/T 5 and 6 deposits, thick R/T 7 transgressive, lagoonal deposits indicate that the transgression was associated with an accretionary transgressive shoreline trajectory farther to the southeast.
DISCUSSION AND SUMMARY

Influences on Fourth-Order Shoreline Trajectories

Shoreline trajectory trends are inferred to reflect sediment supply rates, basin physiography, and changes of relative sea level (Helland-Hansen and Øjlberg, 1994; Helland-Hansen and Martinsen, 1996). Flat and descending shoreline trajectories (tongues 1, 2, and 4, Fig. 20), formed during falling, or stable, relative sea level and resulted in significant phases of shoreface progradation. Relative-sea-level fall is the dominant influence on descending shoreline trajectories, while the interplay between sediment supply rates and the rate of relative-sea-level change is important for flat shoreline trajectories. From the short-lived, terminal stages of progradation related to the Tongue 1 and 2 regressions, and from the short length of the Tongue 3 progradation, rates of sea-level rise are inferred to be more important for individual shoreline trajectories during rising relative sea level. This can be attributed to the effects of autoretreat (Muto and Steel, 1997) where sediment is predominantly trapped in the overextended coastal plain area during sea-level rise, and the shoreface is subsequently drowned. This is indicated by the occurrence of flat, transgressive trajectories (in more distal areas) that give way to ascending (accretionary) trajectories landward. The overall progradational nature of tongues 1 to 6 indicates that sediment supply has an important influence on the progradation of the clastic wedge over time.

The shelf gradient influences progradation rates and tongue lengths, particularly during stable and rising relative sea level (Muto and Steel, 2002). During stages of stable relative sea level, the low shelf gradients below tongues 1 and 4 encouraged higher rates of shoreline advance than would have occurred if the shelf had a higher gradient.

Lateral Variability of Facies Associations

The northwest–southeast orientation of the outcrop belt allows an investigation into varying shoreline trajectories and facies-association distributions along the depositional profile. However, the largely 2-D orientation of outcrops renders a lateral (strike-oriented) investigation of these parameters impossible. Well data allow the overall geometry of the system to be identified and general shelf-to-sand relationships can be identified from wireline logs, but detailed recognition of facies associations (especially in coastal-plain environments) is more difficult. Some general inferences of lateral variations can be made based on the fact that the system is wave dominated and not river dominated and shows varying amounts of tidal influence. Most lateral variations within this system are related to the position of fluvial channels in the coastal plain and the position of distributary channels and tidal inlets at the shoreface during regression and transgression, respectively. We assume that, given the wave-dominated nature of the system, lagoonal environments are laterally extensive, and general trends in coastal-plain facies association architecture, i.e., fluvial-channel amalgamation density and coal formation, are similar along depositional strike within any given stratigraphic interval.

At one position (Locality 14, Fig. 2) along strike from localities 13 and 15, at least two tongues are exposed. While most of the lowermost tongue is dominated by wave processes and resembles shoreface deposits observed elsewhere in the study area, the uppermost part of this tongue and all of the overlying tongue is dominated by large channels containing tidally dominated, tangential and trough cross-stratified bedsets. This tidal dominance is not evident in time-equivalent, wave-dominated shoreface facies associations to the southwest. These tidal channel deposits are attributed to deposition in either a tidal inlet or an estuary.

Barriers versus Strandplains

Barrier-island and strandplain deposits possess similar facies association characteristics in vertical profile, and differentiation of these environments may be difficult in ancient examples. However, certain inferences are made based upon associated shoreline trajectories and the nature of shoreface and time-equivalent paralic deposits. Where extensive fluvial channel complexes feed a rapidly prograding coastline, especially one undergoing forced regression, the resultant flat or descending regressive shoreline trajectory reflects the progradation of a strandplain. Accommodation space in time-equivalent coastal-plain areas is either very low (and thus, infilled with fluvial channel deposits), or negative (i.e., erosion of coastal-plain areas). Shoreface and coastal-plain environments are tentatively interpreted to be dominated by strandplain and fluvial channel–floodplain deposits, respectively, during normal regression, although barriers and small lagoons may potentially develop as the shoreface aggrades (high-angle ascending shoreline trajectory) prior to transgression.

Alternatively, barrier systems are inferred to front lagoonal facies associations when the shoreline retreats and subsequently aggrades. Well-developed barrier systems are therefore preferentially developed during stages of transgression and the turn-around from transgression to regression, whereas strandplains are preferentially formed during stages of regression. These conclusions are supported by studies of recent depositional systems along the coast of Brazil (Dominguez et al., 1987; Dominguez and Wanless, 1991; Martin et al., 1996), and the Nayarit coast of Mexico (Curray et al., 1969) where strandplain development is related to stages of falling relative sea level, and barrier/lagoon formation is associated with stages of relative-sea-level rise and transgression of the coast.

Predictive Trends

A relationship between shoreline trajectories and paralic depositional environments can be used to predict the relative thickness of time-equivalent shoreface deposits provided that there was no significant change in subsidence (i.e., across an active fault) between coastal-plain and shoreface locations (Bullimore, 2004). Within coastal-plain deposits of the Mt. Harris Fork Member several interesting facies-association trends can be correlated laterally, within given stratigraphic intervals, along the depositional profile. Thin coastal-plain successions, dominated by amalgamated fluvial channel deposits, indicate periods of predominantly falling or stable relative sea level (descending or flat shoreline trajectory) where laterally extensive, regressive shoreface tongues are deposited.

Thick paralic successions, consisting of stacked lagoonal deposits and thick floodplain successions (where fluvial channel systems appear to be less frequent and of a more isolated nature) are associated with ascending, transgressive shoreline migration paths, and laterally restricted, barrier complexes inferred to occur at the shoreline. These relationships have significant implications for the prediction of sand-rich reservoirs in a petroleum exploration context where it is important to determine the geometries and extent of potential reservoir sandbodies.
CONCLUSIONS

1. Progradation of the third-order Trout Creek Sandstone–Mt. Harris Fork Member clastic wedge was punctuated by seven fourth-order transgressions.

2. Individual fourth-order shoreface tongues prograded several tens of kilometers into the basin and are largely characterized by flat or descending shoreline trajectory trends reflecting conditions of stable or falling relative sea level. Normal regression occurred over short distances prior to transgression of the tongues.

3. Time-equivalent coastal-plain facies are characterized by either sediment bypass or amalgamated channel-belt complexes formed during periods of relative-sea-level fall or stillstand. Thin alluvial onlap wedges correlate to normal regression during sea-level lowstand.

4. Transgressive shoreline trajectory trends became progressively more accretionary as the transgression proceeded. Time-equivalent coastal-plain deposits are characterized by thick successions of lagoonal deposits, tidal-channel sandstones, isolated fluvial sandstones, coals, floodplain shales, and overbank deposits.

5. Barrier-island complexes are inferred to separate protected paralic environments from a wave-dominated shoreface during transgression while strandplains are interpreted to be preferentially associated with shoreface progradation.

ACKNOWLEDGMENTS

S.B. would like to thank Jeff Crabaugh and Ron Steel for introducing him to the study area. Nils Janbu and particularly Mark Ryan are thanked for their assistance and discussions in the field. Land access was kindly provided by John Raftopoulos. VISTA and Statoil ASA are thanked for their financial support of this study. Bruce Tocher gratefully performed micropaleontological analyses of the rock samples, and Lars Reistad drafted outcrop profiles.

REFERENCES


