ABSTRACT: The Santonian Emery Sandstone Member of the Mancos Shale is a continental to shallow marine succession that prograded into the Cretaceous Western Interior Seaway of western North America. Sediment sourced from the uplifted Sevier Orogen to the west fed a shoreline in the adjacent subsiding north–south trending foredeep. These sandstones are now superbly exposed along a 120-km-long, strike-parallel, continuous outcrop in the cliffs of the Wasatch Plateau of central Utah. Shoreface parasequences are composed of coarsening-upward successions of hummocky cross-stratified and intensely bioturbated sandstones, indicating deposition at a storm-dominated shoreline. Two distinct depositional complexes record eastward and north-eastward shoreline progradation at the northern and southernmost extremities of the Plateau respectively. In the subsurface, Emery strata comprise a thick succession of coal-bearing, coastal-plain deposits. The Emery Sandstone records a period of long-term paralic progradation to aggradation, containing at least 17 parasequences arranged into three, 600 kyr, regressive–transgressive cycles that are recognizable in both complexes. Each cycle comprises only hightstand and transgressive systems tracts, and erosional sequence boundaries are absent. Absence of erosional sequence boundaries is attributed to high rates of subsidence in the foreland basin at this time. Santonian glacio-eustatic sea-level fluctuations are proposed to account for the high-frequency cyclicity, whilst longer-term aggradation may be a function of organic controls on shoreface stacking patterns by immobile raised coal mires lying landward of the shorefaces.

When placed in a temporal and spatial context, the Emery Sandstone provides a missing link in the understanding of long-term controls on Late Cretaceous depositional systems in the central Utah segment of the foreland basin, and allows inferences to be made regarding foreland basin dynamics. In particular, thrust tectonics is postulated to have played a major role in governing the architecture of Late Cretaceous strata in central Utah. Marked along-strike thickening of the Emery Sandstone in particular is attributed to long-lived elevated rates of subsidence in northern Utah and southern Wyoming during the Late Cretaceous that is adjacent to concentrated zones of thrust nappes. A north-dipping depositional slope is inferred from this subsidence distribution, aligned approximately parallel to the structural grain of the hinterland load. Northeastward progradational directions of successive Turonian, Santonian, and early Campanian regressive wedges in this part of the Western Interior Basin are attributed to the presence of this tectonically induced regional slope gradient. Sediments sourced to these Late Cretaceous shorefaces is likely to have been sourced through structural recesses within the thrust front, resulting in a spatial alignment of several successive regressive wedges and implicates an important, long-lived kinematic control on sediment supply. Of Late Cretaceous regressive wedges, only the Emery Sandstone does not temporally coincide with reported periods of active thrusting, suggesting that the regression was a consequence of factors other than uplift-related, elevated rates of sediment supply.

INTRODUCTION

The Wasatch Plateau of central Utah exposes regressive shallow marine clastic wedges deposited in the Cretaceous, Western Interior Basin (Young 1955; Kauffman 1977). Stacking of thrust sheets in the north–south trending Sevier Highalnds to the west generated an adjacent, asymmetrically subsiding retro-arc foreland basin that received sediment from the uplifted orogen (Armstrong 1968; Royse et al. 1975; Wiltshcko and Dorr 1983; DeCelles et al. 1995). During Phanerozoic sea-level highstand, a seaway extended from boreal Canada in the north to the Gulf of Mexico in the south (Fig. 1; McGookey et al. 1972; Kauffman 1977). Episodic fluctuations in sea-level and sediment supply caused shoreface successions to periodically prograde basinward and recede landward creating a series of clastic wedges encaisted by marine mudstones (Young 1955; McGookey et al. 1972; Kauffman 1977; Van Wagoner et al. 1990). These sediments record the interplay among eustasy, tectonics, and sediment supply during deposition, and are superbly exposed in a complex of canyons and cliffs stretching from the Wasatch Plateau in central Utah to the eastern Book Cliffs in western Colorado (Fig. 1).

The exceptional quality of the Wasatch Plateau outcrop has given rise to a plethora of stratigraphic studies and serves as a natural laboratory in which to apply sequence stratigraphic principles to clastic sedimentary successions (e.g., Gardner 1995a; Kamola and Van Wagoner 1995; Van Wagoner 1995; Dubiel 1999; Posamentier and Morris 2000). One such regressive wedge, the Santonian Emery Sandstone Member of the Mancos Shale, has however, remained largely unstudied in contrast to underlying and overlying units, leaving a major void in the understanding of long-term (i.e., greater than 10 My) behavioral patterns of depositional systems in this part of the foreland basin. The comprehensive documentation of regressive wedges in this sector of the foreland basin provides a unique insight into the long-term controls on the evolution of depositional systems, and resulting stratigraphic architecture. Therefore, whilst the Emery Sandstone has remained largely ignored, it does constitute a crucial link between older and younger regressive wedges, in an otherwise well-understood sedimentary basin.

Emery strata are exposed as a series of prominent cliffs in the middle to lower portions of the eastern escarpment of the Wasatch Plateau (Fig. 2). The outcrop forms a 120-km-long continuous exposure along the western flank of the San Rafael Anticline, extending northwards from Interstate Highway 70 in the south, to just north of the town of Price, before the outcrop turns eastwards and forms the western edge of the Book Cliffs. Spieker and Reeside (1925) named the Emery Sandstone for a series of prominent, beige and buff sandstones encased by gray siltstones of the Blue Gate Shale at the foot of the Wasatch Plateau near the town of Emery, Utah (Fig. 2). When traced northward along the Plateau, these sandstones correspond to a sand-rich succession near the town of Price, that subsequently became known as the Garley Canyon Sandstone Beds (Fouch et al. 1983). Regional correlations reveal that the Emery can be mapped westwards into continental and coal-bearing strata from drill holes on the Wasatch Plateau (Ryer 1984; Franczyk et al. 1992). It should be noted that the Emery Sandstone of the Wasatch Plateau should not be confused with the misnamed Emery Sandstone of the Henry Mountains area of southern Utah (Hunt et al. 1953), which has subsequently been renamed the Muley Canyon Member by Eaton (1990). This shallow marine to continental suc-
A) Paleogeographic setting of the western United States during the Cretaceous. Thrust-sheet loading of the Sevier Orogen and Phanerozoic sea-level highstand created the Western Interior marine foreland basin, which stretched from Arctic Canada to the Gulf Coast (modified from Kauffman 1984; Eaton and Nations 1991). B) Central Utah was a site of thrust-sheet stacking in the mountain belt to the west and sediments were deposited into the seaway in central and eastern Utah, where they are now exposed. C) Outcrop distribution and subsurface wells located along the Wasatch Plateau of Utah. Stratigraphic sections have been constructed along the Plateau (A–A′ and B–B′) and correspond to Figures 11 and 12. Sediment thickness for the Emery Sandstone derived from this study is given in meters and contoured in 50 meter increments.

The Emery Sandstone is distinct from other depositional units within this segment of the Western Interior because its deposition coincides with a period of unusually high accommodation. Roberts and Kirschbaum (1995) produced several sediment-thickness maps for Turonian to Campanian stages of the Late Cretaceous. They noted that for a 5 Myr period during the Coniacian–Santonian, sediment accumulation in the Cretaceous foredeep was double that of equivalent duration intervals in the Turonian and Campanian. Thus in contrast to the numerous other regressive wedges in the central Utah salient, the Emery Sandstone provides an opportunity to examine a period of shoreline regression and its resulting stratigraphic architecture within a high-accommodation setting.

This manuscript documents the depositional and stratigraphic architecture of the Emery Sandstone along the eastern Wasatch Plateau, and integrates these findings with published data to provide an improved synthesis of middle-Late Cretaceous paleogeography. Attempts have been made to tie shallow marine successions in outcrop with nonmarine equivalents in the subsurface where the Emery provides a potential coalbed methane play (Tabet and Quick 2003). The Emery Sandstone can then be placed in stratigraphic context with other underlying and overlying, well-documented regressive successions within this portion of the basin, providing some unique insights into the long-term dynamic structural controls on foreland basin deposition. In particular, this paper examines the role of spatial variations in supracrustal loading, timing of thrust sheet stacking and its effect on sediment supply and depositional style, and the geometry of thrusted terranes in the routing and distribution of sediment. The role of nonmarine environments in the development of regional Santonian shoreface stacking patterns is also discussed in light of documented time-equivalent stratigraphic units with important implications for future commercial exploitation of coalbed methane reserves.

**STRATIGRAPHY**

The Emery Sandstone lies stratigraphically above the Turonian Ferron Sandstone Member of the Mancos Shale and beneath the lower Campanian Star Point Sandstone and Blackhawk Formation of the Mesaverde Group (Fig. 2). These successions have been studied in considerable detail, and
Their relationships to relative sea-level changes are well documented (e.g., Ryer 1984; Gardner 1995a; Kamola and Van Wagoner 1995; O’Byrne and Flint 1995; Taylor and Lovell 1995; Van Wagoner 1995; Posamentier and Morris 2000). The upper and lower parts of the marine Blue Gate Shale Member of the Mancos Shale stratigraphically separate the Emery Sandstone from these regressive units. Ryer (1984) described the Emery Sandstone as a 250-m-thick, eastward-thinning, regressive wedge encased by marine shales and consisting of delta-front sandstones deposited during a period of shoreline regression. Others have described these sandstones as a series of transgressive-regressive cycles, consisting dominantly of either offshore to tidal-flat facies (Matheny and Picard 1985) or an aggradational stack of storm-dominated shoreface sandstones deposited when the ratio of sediment supply to accommodation creation was close to unity (Chan 1990).

A number of studies have speculated upon the significance of the Emery Sandstone in context with other surrounding stratal units, but in the absence of a detailed analysis of the Emery succession itself (Fouch et al. 1983; Chan et al. 1991; Cole and Young 1991; Franczyk et al. 1992; Schwans 1995; Shanley and McCabe 1995). Scoured surfaces in marine siltstones and sandstones of the Prairie Canyon Member lying basinward of the Emery outcrops were perceived to be the products of prodeltaic plume discharge and have been speculatively correlated with the Emery shoreface succession (Fig. 3; Kellogg 1977; Fouch et al. 1983; Swift et al. 1987; Chan et al. 1991; Cole and Young 1991; Franczyk et al. 1992). However, recent mapping of these mud-rich sandstones demonstrates that they are younger than the Emery Sandstone, and therefore are unlikely to have a genetic depositional relationship (Cole et al. 1997; Hampson et al. 1999).

In a regional stratigraphic synthesis, Shanley and McCabe (1995) implied that the Emery Sandstone contains an erosional sequence boundary that corresponds to a relative sea-level fall at the top of shoreface and continental sediments of the John Henry Member in the Kaiparowits Plateau of southern Utah. In contrast, Chan (1990) concluded that the Emery Sandstone represents a balance between the rate of relative sea-level change and sediment supply, and the aggradational stack of shoreface parasequences recorded the deposition of shelf-margin systems tract strata (Chan 1990). Schwans (1995) related the deposition of the Emery Sandstone to a coeval angular unconformity in up-dip areas in the western Wasatch Plateau. The angular unconformity was ascribed to progressive tilting, associated with proposed tectonism in the Sevier hinterland. The correlations of Santonian strata made by Schwans (1995) were achieved by subsurface well-log correlations, yet the Emery Sandstone exposed on the eastern flank of the Wasatch Plateau remained unstudied.

The age of the Emery Sandstone is constrained by recovered lower middle to upper late Santonian macrofossils associated with the *Cliocosphites vermiformis* ammonite biozone in the Garley Canyon Sandstone Beds and *Desmoscaphites bassleri* found at the top of the Emery Sandstone (Cobban 1976; Fouch et al. 1983). The Santonian–Campanian boundary probably lies within overlying siltstones because *Baculites aquilaeansis* was found 91 m from the top of the Blue Gate Shale and has affinities with earliest Campanian *Scaphites hippocrepis* (Cobban 1976). According to the timescale and biostratigraphic framework of Obradovich (1993) and Kauffman et al. (1993), the duration of Emery Sandstone deposition may have been as long as 1.8 Myr. (85.7–83.9 Ma). The Emery Sandstone is probably time equivalent to progradational to aggradational shoreface and coal-bearing coastal-plain deposits of the John Henry Member of the Straight Cliffs Formation of southern Utah (Peterson and Ryder 1975; Peterson et al.
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Figu 3. Previous stratigraphic interpretations of the Emery Sandstone after A) Fouch et al. (1983); B) Chan et al. (1991); C) Cole et al. (1997); D) Shanley and McCabe (1995). (A and B) A common conception is that the Emery contains a significant stratigraphic surface that may be related to deposition of the Prairie Canyon Member. C) This relationship was later resolved by Cole et al. (1997), who determined the Prairie Canyon Member to be younger than the Emery Sandstone. D) Shanley and McCabe (1995) suggested that an erosional surface lay within the Emery Sandstone that corresponds to a period of erosion in southern Utah.

DATASET AND METHODOLOGY

Over 1800 m of outcrop has been logged along the length of the Wasatch Plateau. A total of 13 measured sections give an average spacing along the Plateau length of 9 km. The thickness of the Emery ranges from 223 m in Quitchupah Creek (Section 2; refer to Fig. 1 for location) in the southern part of the Plateau to 170 m in Haley Canyon (Section 10) in the north near Price. In the subsurface the succession thickens to 570 m in the Cockrell #1 well, 30 km to the west of Price, Utah, compared to 300 m in Phillips US “D” #1 well 23 km west of Section 1 at Interstate Highway 70. The best exposed strata are located in the southernmost Wasatch Plateau, south of the town of Emery, and to the west of Price. Access to outcrops is possible via well-maintained canyon tracks. Stratigraphic correlations have been achieved through a combination of physical tracing-out of stratal surfaces and visual correlations from photographic montages.

OUTCROP FACIES ASSOCIATIONS

In outcrop, two facies associations are present that collectively form repeated coarsening-upward cycles. Facies association A is the dominant lithofacies type and consists of coarsening-upward successions of siltstones, with interbedded, fine-grained, bioturbated, and hummocky cross-stratified sandstones. Facies association B is volumetrically minor, but consists of intensely bioturbated, medium-grained sandstone. Tidal-flat facies reported by Matheny and Picard (1985), and delta-front facies of Ryer (1984) have not been identified. Levels of bioturbation have been quantified using the standardized scheme of Taylor and Goldring (1993), whereby a scale of 0 to 6 reflects increasing intensity of burrowing.

Facies Association A: Coarsening-Upward Siltstones, and Fine-Grained, Bioturbated and Hummocky Cross-Stratified Sandstones

Description.—The bases of the prominent benches in the Emery Sandstone are chiefly composed of monotonous, thinly laminated, light- to dark-gray, silty mudstone and more commonly, muddy siltstone (Fig. 4A). This poorly exposed but well represented facies is bioturbated by *Paleophycus*, *Planolites*, and *Teichichnus* burrows with bioturbation indices in the range of 3 to 4. The siltstones are crudely bedded on the centimeter to decimeter scale, and defined by very subtle grain-size variations. Rare sedimentary structures include wavy laminae and irregular, fine, low-angle laminae. Thin, centimeter-thick, bentonitic ash layers form isolated orangey-white
Fig. 4.—Characteristics of facies association A. A) Gray concretionary siltstones form the base of upward-coarsening successions that are intercalated with hummocky cross-stratified sandstones (HCS). 1.2 m Jacob’s staff for scale. B) Fine-grained, HCS, and bioturbated sandstones amalgamate to form thick sandstone bodies. A single HCS bed is encased in bioturbated sandstones (arrow). C) Intensely bioturbated, fine-grained sandstones with complete reworking by *Thalassinoides* networks. Ten-centimeter graticules on Jacob’s staff for scale. D) HCS sandstones with meter-scale wavelengths. 1.5 m Jacob’s staff for scale. E) HCS beds commonly display wave-ripple caps. F) Fine-grained, wave-rippled sandstone and siltstone intercalations.
**Fig. 5.** Example measured section of a single parasequence from Section 3 (Link Canyon) summarizing the key facies, facies associations, and interpreted key surfaces. For key see Figure 6.
bands within the dominantly siltstone succession. These poorly developed layers commonly weather to produce thin, clay-rich bands. Small botryoidal concretions, cored by carbonate fragments, lie embedded in the shales where they weather against recessive siltstones (Fig. 4A). In the central Wasatch Plateau, the Emery section is dominated by these siltstones with only a few thin sandstone ribs projecting from the weathered slopes.

The bulk of the Emery Sandstone is composed of partially amalgamated, tan-colored, bioturbated or hummocky cross-stratified (HCS), well-sorted, fine- to very fine-grained sandstones arranged in upward-coarsening and -thickening bedsets (Fig. 4B). Eastwards, these sandstones grade into gray siltstones described above. Bioturbated sandstones are characterized by poorly defined bedding surfaces and internal sedimentary structures that have commonly been destroyed as a result of intense sediment reworking by burrowing organisms (Fig. 4C). Bioturbation indices range from 4 to 6, and in examples where burrowing intensity is fractionally lower, relict low-angle and hummocky cross stratification is occasionally preserved. The dominant burrows are *Thalassinoides* and *Asterosoma*, but high-diversity assemblages are also present with accessory occurrences of *Paleophycus*, *Rosselia*, *Planolites*, *Skolithos*, and less common *Arenicolites* and *Teichichnus*. The intense biogenic reworking results in a friable, poorly cemented, and weathered deposit. Consequently bed thicknesses can be difficult to estimate, because beds appear to amalgamate, producing homogenized sandstone packages up to 5 m in thickness.

In contrast, HCS sandstones occur as individual, tan-colored beds that form sharp-based, lenticular to sheet-like bodies extending from tens to hundreds of meters and varying in thickness from less than 10 cm to up to 2 m (Fig. 4D). In the most sand-rich sections at the northernmost and southernmost limits of the Wasatch Plateau, pristine HCS beds commonly grade upward into thin, symmetrical-ripple-laminated caps (Fig. 4E) providing rare paleocurrent information. These ripples show oscillatory currents were east–west (82.5°) in the northern part of the study area and northeast–southwest (46.5°) in the southern part. Deformed HCS and convolute laminae with good examples of water-escape structures are common. Inoceramid debris and pinnacea (*Pinna* sp.) bivalve shell fragments form widely distributed, and thin bioclastic lags. Bioturbation intensity is noticeably lower in these HCS beds than in the bioturbated beds, with a bioturbation index ranging from 1 to 3, and sedimentary structures are generally well preserved. Trace faunas occur as isolated *Ophiomorpha*, *Skolithos*, and *Paleophycus*.

Bioturbated and HCS Sandstone beds are commonly intercalated with
decimeter-thick, parallel-laminated and symmetrical ripple-laminated siltstone with very fine-grained sandstone (Fig. 4F). The sandstones of these heterolithic units display well-preserved symmetrical ripples with wavelengths of a few centimeters and draped by thin, comminuted coal streaks and/or pyritized woody fragments (Fig. 4F). The finer, organic fraction is penetrated by large sand-filled *Thalassinoides* burrows.

**Interpretation.**—Blue-gray siltstones are pervasive throughout the stratigraphy of the Wasatch Plateau, forming badland topography on weathered slopes. Fine grain size, coupled with few sedimentary structures and fully marine ichnofacies, is indicative of an offshore-shell setting that received only suspended sediment. Bentonite clays are the products of volcanic ash fallout from the volcanic arc to the west. Unfortunately, they are not easily traced through the succession, limiting their use for chronostratigraphic correlation.

The interbedded sandstones are interpreted to have been deposited in an offshore-transition zone to lower shoreface setting. During storms, large-scale oscillatory shoaling waves redistributed sediment from the foreshore and upper shoreface into lower shoreface areas as sheet-like, HCS sandstones (Dott and Bourgeois 1982; Harms et al. 1982; Southard et al. 1990). The rapid deposition of sand resulted in water escape and soft-sediment deformation, manifest as contorted and recumbent laminae (Dott and Bourgeois 1982). As storms waned, oscillatory motions diminished, resulting in lower-flow-regime reworking of the upper surfaces of the HCS beds, generating thin caps of symmetrical ripple cross-lamination (Cheel and Leckie 1993). With continued waning energy, suspension fallout of organic debris draped the ripple crests. These symmetrical ripple crests provide crude indications of paleoshoreline orientation, the long axis aligning parallel or subparallel to the general trend of the coastline (Leckie and Walker 1982; Shanley et al. 1992; Hettinger et al. 1994). On this basis, shoreline orientations in the southern part of the study area were N–S. Fair-weather periods are reflected as continued periods of hemipelagic deposition and biological reworking of sediment.

The abundant and diverse shallow marine ichnofaunas suggest prime conditions for burrowing organisms. Variations in bioturbation intensity of storm-dominated, lower-shoreface bedforms has been discussed by Dott and Bourgeois (1982), who considered an inverse relationship between storm magnitude and/or duration between successive storm events and the degree of biological mixing of the substrate. Diversity of biofacies is regarded as an indicator of oxygenation in the water column and can be related to styles and depth of burrow tiering (e.g., Bottjer et al. 1986; Savrda et al. 1991). Oxygen supply is likely to be enhanced during storm surges and turbulence of the water column, thus allowing deep bioturbation to prevail (Bromley 1996). Thus, the intensely burrowed beds and the predominance of *Thalassinoides* in the Emery may simply reflect a well-oxygenated lower shoreface related to storm-induced turbulent mixing. However, Howell et al. (1996) questioned the plausibility of very thick (i.e., greater than 20 cm) intensely bioturbated, lower-shoreface sandstone beds from the central North Sea Fulmar Formation as being representative of inter-storm periods. They proposed that the homogenized sandstone bodies were the amalgamated products of low-magnitude, high-frequency storm events, depositing numerous, decimeter-thick beds with sufficient intervening time for complete biogenic reworking. This model may also account for thick bioturbated beds in the Emery Sandstone.

The gradual upward transition from shelf siltstones through individual sandstones into amalgamated sandstone bodies, combined with upward coarsening of bedsets and a predominance of storm-generated structures, is interpreted as the seaward progradation of a storm-dominated shoreface parasequence (Fig. 5; Scott 1992; Walker and Plint 1992). In the northern part of the study area, the most continuous dip-parallel exposures afford the tracing of these parasequences to their down-dip terminations into the Mancos Shale (Fig. 6). Proximal shoreface facies are not exposed in outcrop. Repetitive parasequences form the many buff-colored ledges in the slopes of the eastern Wasatch Plateau. The base of blue-gray siltstones that sharply overlie the progradational shoreface units define flooding surfaces and are interpreted as parasequence boundaries (Posamentier et al. 1988; Posamentier and Vail 1988; Van Wagoner et al. 1988). These key surfaces can be traced along the Wasatch Plateau for great distances, forming the basis for the correlation of time-equivalent strata.
Fig. 8.—Cored logs from the Cockrell #1 well characterized by cross-beded, fluvial channel sands, to carbonaceous, crevasse-channel and crevasse-splay sandstones to coals and fine-grained, overbank facies. Facies indicate deposition in a coastal-plain setting. Letters correspond to core photographs in Figure 7.
**Facies Association A: Crossbedded, Medium-Grained Sandstone**

**Description.**—At the crest of one of the Emery parasequences are irregularly distributed, flat-based or low-relief, erosional features, fine- to medium-grained, poorly-sorted sandstone beds. These beds are distinctly coarser than their subjacent lower shoreface facies, and form a thin, irregular, laggy deposit that is highly variable in thickness and composition between the three localities at which it is present. At Link Canyon (Section 3) it consists of an inversely graded, fine to medium-grained, arenaceous, 1.2-m-thick sandstone unit, containing large inoceramid shells up to 10 cm in length and abundant Arenicolites, Thalassinoides, Ophiomorpha, and Skolithos ichnogenera. This unit is overlain by a weakly trough cross-bedded 30-cm bed. Foresets dip at angle of repose towards the south (185° in length and abundant inoceramid shells up to 10 cm) and are locally disturbed by Thalassinoides, Ophiomorpha, Skolithos, and Planolites. Abundant, disarticulated shelly detritus is also a distinctive feature of this unit. At Interstate Highway 70 (Section 1) this facies association is also located at the same stratigraphic level but is no thicker than 60 cm. Here it also contains abundant, fragmented bioclasts and is intensely bioturbated by Rosselia and Asterosoma. Bioturbation indices are high at both of these localities and seldom drop below 5. At Muddy Creek (Section 4), the same stratigraphic horizon is recognized by a sharp-based, 20-cm-thick bed that displays an abrupt increase in component grain size and a diverse array of clast types. Most notably there is an increase in chert grains amongst medium-grained, subrounded to rounded, opaque and pink quartz grains that constitute the bulk composition. This exotic array of clasts separates this facies association from the more common arenites of previously described facies. Ichnofauna at this locality are low diversity and dominated by large pellet-lined Ophiomorpha nodosa. At all localities, the top surface of these facies is a sharp contact with offshore siltstones of facies association A.

**Interpretation.**—Irregularly distributed, coarse-grained, bioturbated beds capping shoreface parasequences are typical of reworked transgressive lags that develop as a result of wave ravinement during landward migration of the shoreline (e.g., Bhattacharya and Walker 1992). However, unlike many previously described transgressive lags (e.g., Suter and Berryhill 1985; Demarest and Kraft 1987) the coarse beds at the top of the Emery parasequences are relatively thin and their basal surfaces are only mildly erosional. In addition, their association with lower-shoreface deposits suggests that these sandstones are not the products of in situ (fair-weather) wave ravinement. Indeed, the coexistence of Rosselia and Asterosoma at Section 1 suggests a period of continued deposition at the top of the lower shoreface (e.g., Pemberton et al. 2001). Nonetheless, their position at the crests of coarsening-upward parasequences suggests an intrinsic relationship to rising relative sea level. Rather than being the products of in situ reworking, these sandstones are interpreted to have been transported offshore during transgressive ravinement of proximal shoreface sectors, perhaps during storms. The minor basal erosion is considered a consequence of gentle scour associated with basinward sediment transport and the migration of three-dimensional dune forms across the sea floor, the uneven distribution of this facies probably reflecting an irregular nature to such offshore transport. The southward, shoreline-parallel paleoflow recorded by the trough cross-stratification may be a product of geostrophic flows generated by pressure gradients at the shoreface during intense storms (Duke 1990), although this interpretation remains speculative in the absence of more substantial paleocurrent data. The ubiquitous sharp contacts at the tops of these beds with siltstones of facies association A defines a landward shift in facies and a return to offshore deposition, and are interpreted as parasequence flooding surfaces.

**SUBSURFACE FACIES**

Four intervals from the Cockrell #1 core have been logged in detail, revealing a wide range of nonmarine facies lying between 1000 and 1600 m depth below the surface of the Wasatch Plateau (Figs. 7, 8). The well penetrated 570 m of time-equivalent nonmarine strata to the shoreface units in outcrop west of Price. The succession constitutes coals, organic mudstones, and siltstones with interbedded, variable-thickness sandstones.

**Facies Association C: Interbedded Sandstones, Siltstones, Mudstones, and Coals**

**Description.**—Sandstone facies are diverse, with variable grain sizes, sedimentary structures, and bedding surfaces. Individual sandstone beds are fine to medium-grained, flat-based to erosional based, and are either well-sorted and cross-bedded, or carbonaceous and massively bedded. In the former, units commonly fine upward from medium- to fine-grained sand and range from 3 to 7 m in thickness. Foresets of decimeter-scale cross-beds are dominantly planar, but a few examples have slight asymmetric bases indicating trough cross-beding (Fig. 7A). Soft-sediment deformation structures are commonly interpersed with pristine cross bedding. The carbonaceous sandstones may also reach significant thickness, but they tend to be more variable than their cross-bedded counterparts. Soft-sediment
deformation and rip-up clasts are ubiquitous (Fig. 7B). A 6-m-thick, erosionally based, massive sandstone was recovered and contains concentrated leaf debris and an isolated, thin, cross-bedded interval. Other carbonaceous sandstones range from 0.2- to 1-m-thick, are flat-based rather than erosionally based, normally and inversely graded, massive to wavy bedded, and contain abundant organic debris and coal flasers (Fig. 7C, D).

Interbedded with sandstones are dark-gray organic mudstones and siltstones (Fig. 7E). These sections are wavy-laminated, may contain very thin, fine-grained, sand laminae, and coal flasers, and reach a maximum thickness of 3 m. The core recovered a single incomplete coal bed at least 0.5 m thick in addition to a number of other thinner coals. These coals range in quality from low-grade fusains to clean vitrains. Early subsurface wells penetrated several coalbeds 3–6 m thick (Edson et al. 1954), and, more recently, coals as thick as 3.3 m have been reported from a well near Castle Dale in the central Wasatch Plateau, occurring as six separate beds and reaching a cumulative thickness of over 10 m (Roberts and Kirschbaum 1995). Present coal estimates suggest that a cumulative thickness of as much as 40 m in 17 beds may be present in the northern Wasatch Plateau (Tabet and Quick 2003).

**Interpretation.**—The erosionally-based, fining-upward, cross-bedded sandstones are considered to be the fills of fluvial channels (Allen 1964). Decreasing flow velocities towards the higher parts of the barform and a systematic decrease in grain size and bedform definition upward reflect the lateral migration of the channel macroform across the flood plain (Allen 1970a, 1970b; Bridge 1975, 1977). Bedload transport of sediment and the migration of straight- and sinuous-crested dune forms over the bar gave rise to cross-bed sets. Rapid rates of sedimentation during high flood stages resulted in loading of the bar and soft-sediment deformation associated with water escape.

Carbonaceous sandstones and organic fines represent adjacent overbank environments. Thick carbonaceous sandstones are attributed to crevasse channel deposits that received sand-grade sediment during flood-induced breaching of fluvial channel levees. Similarly, thinner sandstones were deposited as distal equivalents to the crevasse channels on crevasse-splay lobes and in the most distal parts are interbedded with organic floodplain fines (Farrell 1987). The organic overbank fines most likely reflect high water tables within the flood plain, occurring as peat swamps or lakes that received wind-blown sediment and sediment from suspension during episodic flooding.

Anoxic delta-top environments are indicated by coals, the thicker examples of which are probably the products of raised mires whilst the thinner counterparts may have been deposited in smaller lakes or low-lying mires (McCabe 1991). The widespread occurrence of thick coals provides a sensitive monitor of balanced rates of peat growth and accommodation generation (McCabe and Parrish 1992; Bohacs and Suter 1997). Although the continuity of these coals is difficult to determine with any level of certainty...
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A

--- Depositional Strike

14.4 km 18.3 km 3.8 km 8.9 km 12.5 km 28.1 km

--- Depositional Dip

4.7 km 12.0 km 9.0 km

Phillips J. Hiram Moore
U.S. "D" 1 Old Woman #1

1 2 3 4 5 6 7 8 10 11

--- Flooding Surface (Parasequence Boundary)

Offshore siltstones
Shoreface sandstones
Nonmarine sandstones and mudstones (Facies association C)

upper Blue Gate Shale

MFS

TST3

HST3

TST2

HST2

"Garley Canyon Beds"

PS17
PS16
PS15
PS14
PS13
PS12
PS11
PS10
PS9
PS8
PS7
PS6
PS5
PS4
PS3
PS2
PS1

Southern Complex

Northern Complex

153 km Total Horizontal Distance
given the wide spacing of drill holes available, it is clear that coal-forming environments were prominent, long-lived features of the Santonian coastal plains in central Utah.

**DEPOSITIONAL MODEL**

Upward-coarsening successions comprising facies association A are particularly prevalent in the northern and southern parts of the Wasatch Plateau. Central parts of the plateau are significantly muddier where sheet sandstones of facies association A are replaced by a monotonous succession of offshore siltstones. In a regional context, the Wasatch Plateau is aligned approximately parallel to depositional strike, and thus the apparent pinching and swelling of sandy facies along the outcrop belt is interpreted to be representative of a curvilinear trend to the shoreline, defining two depositional promontories. In subsurface drill-hole data to the west, progradational shoreface parasequences occur as upward-coarsening, serrated, gamma-ray log responses. In more proximal (westernmost) positions, these well-log motifs are replaced by sandy sections, consisting of blocky, fining, and coarsening-upward log motifs interspersed with muddier intervals that correspond to coastal-plain deposits of facies association C (Fig. 8).

A dominance of bidirectional current indicators in shoreface facies in outcrop and a general absence of typical prodeltaic facies (e.g., climbing-ripped sandstone and mudstone interbeds, suppressed intensity and diversity of ichnofauna, etc.), suggests that these sandstones accumulated along long linear strandplains. Lateral transitions in mud-to-sand content that might be expected to occur across the mouths of wave-modified deltas (e.g., Bhattacharya and Giosan 2003) are not apparent in the laterally continuous lower-shoreface facies of the Emery Sandstone that extend for many tens of kilometers along the plateau. Despite delta-front facies being absent, rivers draining the Sevier Orogen must have carried sediment to the Emery shoreline, because such facies are represented in the subsurface (Fig. 8). We infer that in the southern part of the Wasatch Plateau a number of small rivers, rather than a single large system, transported sediment northeastwards to the northwest-trending shoreline. Similarly, in the northern part of the plateau, a number of smaller rivers are inferred to have carried sediment eastwards to a coeval north-trending coastline. The lateral continuity of the shoreface facies suggests that the coastline likely received sediment from symmetrical wave-dominated deltas attached to long strandplains (Bhattacharya and Giosan 2003). Given these considerations, the paleogeography of the Emery Sandstone may bear a close similarity to the modern Nayarit Coast of Mexico (Fig. 9; Curry et al. 1969; McCubbin 1982; Walker and Plint 1992). Depositional promontories of this deltaic, wave-dominated strandplain appear to be related to a combination of delta-front fluvial deposition and efficient alongshore transport of sand to produce long strandplains extending many tens of kilometers away from the delta mouths (Bhattacharya and Giosan 2003). Thus the general lobate expression of the Emery shoreline and the broad sandy promontories in southern and northern parts of the Wasatch Plateau most likely represent the clustering of small rivers that dissected the strandplain. Landward of the Emery shorefaces, the coastal plain is interpreted to have been dominated by subaqueous organic-rich environments, most notably large, raised peat mires capable of producing thick coal seams.

**PARASEQUENCE SETS AND SYSTEMS TRACTS**

Upward-coarsening parasequences stack to produce a vertical succession over 200 m thick in the most proximal outcrop sections. A total of 17 parasequences have been identified, labeled 1 through 17 from oldest to youngest. Much of the Emery Sandstone is marked by minor facies-tract offsets across flooding surfaces, producing a thick stack of shoreface sandstones in outcrop (Fig. 10). With only a restricted quantity of core and well-log data available, outcrop-to-subsurface correlations remain tentative. However, where possible, flooding surfaces identified in outcrop have been tied to coals in the nonmarine realm, because such lithologies in the subsurface often reflect rising watertables associated with relative sea-level rise (Bohacs and Suter 1997).

Figure 11 is a correlation of the Emery shoreface parasequences along the length of the plateau. The thickness of the Emery Sandstone in the subsurface is greater to the north where it thickens from over 350 m in Phillips US "D" # 1 well in the southwestern part of the Wasatch Plateau to over 500 m in the Cockrell # 1 core. The wholesale architecture of the Emery Sandstone is represented by initial progradation of the shoreline, followed by overall long-term aggradation. Such a thick succession of aggraded shorefaces is consistent with the interpretation that the Emery Sandstone represents a time of balance between sediment supply and accommodation (Chan 1990). Significantly however, major basinward facies tract dislocations and erosional surfaces are absent within the Emery strata. Supposed upon the long-term aggradation are a series of higher-frequency regressive-transgressive cycles that are characterized by a sequential evolution from highstand to transgressive systems tracts. These cycles occur as subtle changes in shoreface stacking pattern and are present in both northern and southern parts of the Wasatch Plateau (Figs. 11, 12). The means of separating the two systems tracts is through the recognition of flooding surfaces that are of demonstrably greater magnitude than the parasequence boundaries that separate individual highstand parasequences. Falling-stage and lowstand systems tracts are absent, and thus the means of partitioning each cycle must be achieved through the recognition of major flooding events. In this way, these cycles are distinct from conventional Exxon sequences (sensu Vail et al. 1977; Van Wagoner et al. 1988), because correlations cannot be made through the identification and tracing of subaerial exposure surfaces or surfaces of erosion. Three regressive-transgressive cycles are identified.

**Cycle 1**

Cycle 1 is perhaps the most stratigraphically significant of the three cycles, because it is the highstand systems tract of this cycle that constitutes the oldest shoreface units of the Emery Sandstone in outcrop. In the subsurface, a gentle cleaning upward of the gamma ray log, over at least 30 m, identifies the outbuilding of the shoreline. This unusually thick parasequence appears to be entirely conformable in the central and eastern Wasatch Plateau, reflecting normal progradation of the shoreline. Other anomalously thick parasequences have been described from the Campanian Blackhawk Formation in the Book Cliffs that record the filling of accommodation space following a major flooding event (Reynolds 1999; Hampson and Storms 2003). This initial parasequence is overlain by a thinner but equally sand-rich parasequence, defining a progradational parasequence set (parasequences 1 and 2). In outcrop, this parasequence consists of a few thin sandstone ribs that project from the Mancos Shale in the northern part of the study area but is more clearly defined by lower-shoreface sandstones in the south. An abrupt flooding event at the top of this parasequence forced the shoreline landward and offshore siltstone deposition resumed along the eastern edge of the Wasatch Plateau.

**Cycle 2**

In outcrop, the lowermost part of this cycle is dominated by gray siltstones in the northern part of the study area and by sandier, thin shoreface parasequences in the south. The true architecture of the highstand systems tract of this cycle is represented in gamma-ray logs where successive upward cleaning and thickening motifs record the deposition of a progradational parasequence set (parasequences 3 and 4). The youngest parasequences in this cycle (parasequences 5 and 6) are well exposed in both the northern and southern parts of the plateau and continue the progradational stacking pattern defined in the subsurface. These parasequences correspond to the Garley Canyon beds of Fouch et al. (1983). Their lateral continuity
Fig. 12.—Stratigraphic correlation parallel to depositional dip through Haley Canyon immediately to the west of Price. The section highlights the minimal offsets of facies tracts across parasequence boundary flooding surfaces. The parasequences can be traced to their down-dip depositional pinchouts in the area north of Price. Note the similarity of stacking patterns with respect to that in the southern part of the Wasatch Plateau in Figure 11.
allows the tracing of the capping flooding surface along the entire length of the plateau, and has been used for the stratigraphic datum in Figure 11. This abrupt flooding event is all that constitutes the transgressive systems tract of cycle 2.

**Cycle 3**

The lower two thirds of cycle 3 comprises aggradational to progradational stacking of shoreface parasequences. Early aggradation (parasequences 8 to 12) is represented by a repetitive succession of sandstone benches in the hillside, interpreted as early highstand systems tract deposits that preceede strong progradation associated with late highstand systems tract deposition (parasequences 13 and 14). At the top of parasequence 14 lies an upward-thinning succession of parasequences (parasequences 15 to 17) that record the successive landward migration of the shoreline as rising relative sea level began to outpace sediment supply. This backstepping pattern constitutes a thin transgressive systems tract capping the Emery Sandstone Member prior to prolonged deposition of shelf siltstones of the Blue Gate Shale over the eastern Wasatch Plateau area. Accordingly, the flooding surface capping parasequence 17 represents the maximum flooding surface of the Emery regressive wedge and corresponds to the top of the transgressive systems tract and the base of a subsequent highstand systems tract as documented by Schwans (1995).

**DISCUSSION**

The Emery Sandstone provides an unusual record of long-term aggradational parasequence stacking, unbroken by erosional sequence boundaries. The sequence stratigraphic and paleogeographic significance of these deposits is analyzed through a discussion on: the role of organic accumulation in the aggradational stacking of shoreface strata; the origin of stratigraphic cycles; and the tectonic effects on long-term stratigraphic architecture, sediment thickness patterns, shoreface orientations, loci of sediment input points and depositional process dominance at the shoreline, in contrast with younger and older fluvial-dominated regressive wedges.

**Santonian Paleogeography of Central and Southern Utah: Implications for Shoreface Stacking Patterns**

The long-term balance between accommodation creation and sediment supply is worthy of further discussion, not least because thick successions of aggradational paralic strata are relatively rare in published literature. McCabe and Shanley (1992) demonstrated that aggradational stacking patterns in the Santonian John Henry Member of southern Utah was intricately controlled by the immobility of raised peat mires lying landward of storm-dominated shorefaces that prevented relative sea-level rises from inundating the coastal plain (Fig. 13). In a subsequent paper, Shanley and McCabe (1995) suggested that an erosional surface at the top of the John Henry Member could be correlated to a postulated sequence boundary within the Emery Sandstone. We find no evidence for this sequence boundary and instead propose that the Emery Sandstone is time equivalent to the main body of the aggradational John Henry Member.

This correlation is corroborated by ammonite biostratigraphy. Peterson (1969) collected a single fragment of the middle Santonian ammonite, *Cliosphacites vermiformis*, within marine mudstones that project to shoreface sandstones lying in the middle part of the John Henry Member (Cobban et al. 2000). The same fauna was also identified by Cobban (1976) from the middle and lower parts of the Emery Sandstone. The mutual occurrence of this ammonite in both the Wasatch and Kaiparowits plateaus in these strata suggests that the period of aggradational stacking was penecontemporaneous in both areas and that the Emery Sandstone cannot be correlated to an erosional sequence boundary in the Kaiparowits Plateau. Consequently, correlating the Emery Sandstone with the aggradational, coal-bearing interval of the John Henry Member might suggest that the organic controls responsible for this architecture in the Kaiparowits Plateau extended northwards into the Wasatch Plateau and exerted the same influence on the stacking of Emery parasequences. Hence shore-parallel, raised mires lying up-dip of the Emery shorefaces may have contributed to the long-term aggradational shoreface stacking pattern. Given the large quantities of coal already estimated in the subsurface of the Wasatch Plateau (e.g., Tabet and Quick 2003) this model can be applied as an additional means to estimate positions, thicknesses, and geometries of coals associated with aggradationally stacked shorefaces.

**Origin of Regressive–Transgressive Cycles**

Multi-frequency stratigraphic cyclicity as a function of sediment supply, subsidence, and eustatic variables in Western Interior Cretaceous deposits have been frequently cited (e.g., Gardner 1995b; Kamola and Huntoon 1995; Houston et al. 2000). Compelling evidence from subsurface seismic surveys indicates that the Campanian regression of the Blackhawk Formation of the Book Cliffs (lasting approximately 3.5 Myr, Fouch et al. 1983) coincides with significant tectonic movement along the Charleston–Nebo thrust (Horton et al. 2004). Kamola and Huntoon (1995) and Houston et al. (2000) ascribed tectonic controls on sediment supply as the primary cause of higher-frequency, 500–600 kyr regressive members in these strata, which they attributed to hinterland thrust motion. The effects of eustasy as a driving mechanism for these contrasting duration cycles were considered insignificant (Kamola and Huntoon 1995; Houston et al. 2000; Horton et al. 2004). The constrained age of the Emery Sandstone to 85.7–83.9 Ma indicates an upper limit of individual parasequence duration approximating to 100 kyr and a regressive–transgressive cyclicity representing some 600 kyr, comparable to Blackhawk member-scale frequencies.

The model of Kamola and Huntoon (1995) and Houston et al. (2000) may have applicability to the Emery Sandstone wedge; however a number of studies have concluded that a global glacio-eustatic signature can be deciphered in the Late Cretaceous, and notably, that a high-frequency Santonian component was responsible for a number of eustatic sea-level falls (Hag et al. 1988; Hancock 1993; Sahagian et al. 1996; Miller et al. 2003). Proposed age dates for the initiation of the Canyon Range, Pavant and Nebo thrust sheets range from 90 to 97 Ma (Cross 1986; Heller et al. 1986; Talling et al. 1994). Active thrusting may have continued into the Santonian along various salients (DeCelles 1994; Talling et al. 1994), but Villien and Klugfield (1986) suggested that during the Coniacian to early Santonian the Sevier Orogen in central Utah was in a period of relative inactivity. Hence in the case of the Emery Sandstone tectonic pulses cannot account for depositional cyclicity alone. Moreover, the alongstrike uniformity of shoreface stacking patterns favors a regional, and arguably eustatic mechanism.

Many of the member-scale cycles documented from the Blackhawk For-
Fig. 14.—Paleogeographic reconstructions for the Late Cretaceous of central Utah, summarizing long-term shoreline trends. A) The Turonian upper Ferron Sandstone prograded northeast along southern Castle Valley and coincides with the decay of an older deltaic succession (lower Ferron Sandstone) farther to the north (modified from Gardner 1995a). B) Similarly in the southern Wasatch Plateau, Santonian shorefaces belonging to the Emery Sandstone are interpreted to have prograded in a northeastward direction from an area to the southwest. The northern shorefaces of the Emery Sandstone are considered to have been oriented closer to N-S. C) Brief southward progradation of the Panther Tongue in the earliest Campanian punctuated the northeastward prograding trend. D) The trend returned during the deposition of the Storrs Member of the Star Point Formation. The long-term continuity of shoreline progradation direction implies a long-term control, perceived in this case to be along-strike differential subsidence. Positions of the thrust trace are transcribed from Willis (2000), and no palinspastic reconstruction is applied. PX and PV correspond to Paxton and Pavant thrusts, respectively. Black fills indicate the presence of major coal-forming environments in the coastal plain.

Controls on Sediment Thickness, Shoreface Orientations, Sediment Transport Pathways and Shoreface Depositional Styles

Comparing well logs of similar facies composition from the northern and southern parts of the Wasatch Plateau, a north-dipping paleoslope of 0.1° has been crudely calculated, on the basis of differences in compacted lithological thickness. This northward-dipping basin bathymetry lying parallel to the axis of the crustal load is consistent with a southward-diminishing and long-lived high-subsidence setting for northern Utah, as suggested by Roberts and Kirschbaum (1995). This thinning is also consistent with a 700-m-thick, unnamed, stacked shoreface succession along the northern flank of the Uinta Basin of northern Utah (Molenaar and Wilson 1992), and to the time-equivalent, 200-m-thick John Henry Member of the Straight Cliffs Formation in southern Utah (Shanley and McCabe 1991; Hettinger 1993). The inferred elevated rates of flexural subsidence correspond to, or are slightly later than, a period of thrust-sheet propagation focused in northeast Utah and southwest Wyoming that resulted in over 30 km of horizontal shortening between 89 and 84 Ma (DeCelles 1994).

High rates of subsidence inferred in northern Utah may account for the northwesterly skew of Emery shorefaces in the southern part of the Wasatch Plateau. Similar paleoslopes are envisaged in the progradation of older and younger strata and may suggest a long-term control on sedimentation patterns (Fig. 14A–D). The Ferron Sandstone (Fig. 14A) is a middle to late Turonian, northeastward-prograding shallow marine and continental succession that crops out in southern Castle Valley (Hale 1972; Ryer 1981; Gardner 1995a). Its northeastward sediment distribution pattern was attributed to structural uplift in the area of the present-day San Rafael Anticline.
Fig. 15.—Possible sediment pathways in central Utah during the Turonian to earliest Campanian interval. Structural recesses or reentrants in the trace of the thrust front coincide with inferred sediment source areas providing a primary control on the delivery of sediment to Late Cretaceous shorelines. Structural map modified from Willis (2000).

In light of regional subsidence distributions, a tectonic slope could have played a similar role in dictating the broad shoreface architecture. The earliest Campanian Panther Tongue of the Star Point Sandstone (Fig. 14C) represents a short-lived departure from the long-term, northeastward sediment distribution pattern. However, sediment distribution patterns during deposition of this unit were towards the southwest (Newman and Chan 1991), and parallel to the structural grain of the Sevier orogenic belt, suggesting that sediment transport orientations were controlled by the geometry and position of the foredeep, and therefore, regional slope gradients. The Storrs Member of the Star Point Sandstone, which overlies the Panther Tongue, is also of early Campanian age (Fig. 14D) and consists of shallow marine and continental deposits that stepped progressively basinward from southwest to northeast along the length of the Wasatch Plateau (Flores et al. 1984; Dubiel 1999). Northeast-stepping shorefaces of this interval merge with the southeastward prograding shorefaces belonging to the lowermost part of the Blackhawk Formation (Kamola and Van Wagoner 1995) in the subsurface of the western and southwestern parts of the Wasatch Plateau (D. Tabet, written communication 2003). Schwans (1995) concluded that local thickness changes in the Emery Sandstone Member were controlled by the position of lineament offsets in
the thrust trace, giving localized areas of increased subsidence. From this study, it is also likely that at a regional scale the thickness contrasts and sediment distribution patterns along strike are governed by foreland basin subsidence heterogeneity and spatial non-uniformity of thrusting events in the orogen.

A common trend amongst Late Cretaceous regressive wedges in central Utah is the locations of the sediment input points. As discussed, the Emery rivers draining the Sevier highlands are inferred to have been concentrated in the southernmost and northernmost extremities of the Wasatch Plateau. These sediment-transport pathways coincide spatially with the location of sediment input points related to the deposition of the Turonian lower and upper Ferron Sandstone Members (Cotter 1975; Ryer and McPhillips 1983; Ryer 1984; Ryer and Lovekin 1986; Gardner 1995a). The longevity of these zones of sediment input is exhibited by the southward progradation of the Panther Tongue Member in the northern part of the Wasatch Plateau (Newman and Chan 1991) and the northeasterward and southeasternward progradation of the earliest Campanian Storrs Member (Flores et al. 1984; Dubiel 1999). The long-term existence of these northern and southern sediment input points in central Utah shows a close correspondence with major structural offsets or recesses in the trace of the thrust front (Fig. 15). Thus, although the shoreline orientation appears to be controlled by the distribution of subsidence, the spatial position of the regressive wedges appears to be controlled by the distribution of major thrusts.

Although the points of sediment entry into the basin during Emery deposition may correspond with that of overlying and underlying strata, some fundamental differences in depositional style exist between these regressive events. The upper Ferron and Panther Tongue members have a strongly progradational architecture and are characterized by river-dominated deltaic coastlines, relatively unmodulated by wave or storm activity (Newman and Chan 1991; Gardner 1995a). Parasequences are reported to comprise coarsening-upward successions composed of delta-front and distributary-channel sandstones (Newman and Chan 1991; Gardner 1995a). In contrast, the comparatively gentle Emery regression produced a succession of laterally continuous parasequences ornamented by beds deposited by storm events and reworking of the shoreline with little evidence of deltaic influence.

The contrasting depositional style of the Emery Sandstone with respect to the upper Ferron and Panther Tongue members could be attributed to changes in rates of sediment supply or the depositional response to a reduced wave fetch. Quantifying wave fetch is tenuous without better control on the eastward extent of the seaway for each of the respective regressions. However, it is considered unlikely that variations in wave fetch played a role, because in each regression described above, the basinward extent of their shorelines is constrained to a 15 km zone between the eastern edge of the Wasatch Plateau and the western margin of the San Rafael Anticline. Presumably any loss of wave fetch would be similar in each regression. Dominance of riverine processes occurring at the onset of upper Ferron and Panther Tongue regressions may instead reflect elevated rates of sediment supply either as a consequence of relative sea-level fall, as in the case of the Panther Tongue (Posamentier and Morris 2000), or from hinterland tectonics, as in the case of the Ferron Sandstone (Gardner 1995a). As discussed, the Santonian in central Utah is reported to have been a period of relative tectonic quiescence (Villien and Klighfeld 1986), and major sequence bounding unconformities pertaining to relative sea-level falls are not identified in the Emery Sandstone. We propose that the wave-dominated shorelines of the Emery Sandstone are thus a reflection of low sedimentation rates relative to that of the Ferron and Panther Tongue regressions, perhaps controlled by subsidence-suppressed eustatic sea-level falls.

CONCLUSIONS

1. The Emery Sandstone Member comprises 17 upward-coarsening, storm-dominated parasequences composed of HCS and heavily bioturbated sandstones exposed in outcrops along the eastern edge of the Wasatch Plateau. Shoreline progradation was confined to two spatially disjunct depositional complexes at the northern and southern extremities of the Wasatch Plateau. The southern, NW–SE oriented shoreline prograded towards the NE concomitantly with eastward regression of a N–S trending coastline in the north. Shorelines are interpreted to have consisted of linear strandplains dissected by numerous small rivers.

2. The broad-scale architecture of the Emery regression is progradational to aggradational. Prolonged aggradation indicates a fine balance between sediment supply and accommodation creation that may have been regulated by the presence of raised peat mires lying landward of the shoreline. Wave dominance at the shoreline is proposed to reflect modest rates of sediment supply during a period of high accommodation.

3. Superposed on the overall aggradational trend are three higher-frequency regressive–transgressive cycles that lack sequence boundaries. The cyclicity in this wedge is considered to reflect subsidence-suppressed eustatic sea-level falls during a period of tectonic quiescence in the westward thrust belt. High rates of subsidence coupled with hinterland tectonic quiescence may reflect a delay between crustal loading and viscous response of the lithosphere.

4. An improved long-term (> 10 Myr) understanding of the Emery Sandstone allows a number of inferences to be made regarding foreland basin evolution. The architecture of successive regressive wedges in central Utah was controlled by the geometries of the bounding thrust belt. Concentrated thrust complexes in northern Utah are attributed to the inferred generation of a northward-dipping depositional slope. This slope is considered the primary control on the progradation direction of successive shoreline regressions during the Late Cretaceous. Inferred sediment conduits that fed the Emery Sandstone shorelines are reflected in equivalent depocenter positions of older and younger clastic wedges. These geographic points of sediment delivery appear to coincide with offsets or embayments in the trace of the thrust belt. Consequently, the geometry of the thrust belt is considered to be a first-order control in the supply of sediment to Late Cretaceous shorefaces.

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