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STRANDPLAIN AND DELTAIC DEPOSITIONAL MODELS FOR THE POINT LOOKOUT SANDSTONE, SAN JUAN BASIN AND FOUR CORNERS PLATFORM, NEW MEXICO AND COLORADO

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Abstract—The Point Lookout Sandstone of Late Cretaceous (Campanian) age is a regressive marine coastal sandbody that records variable influences of storm, wave and fluvial processes in the San Juan Basin area. Widespread linear strandplains and associated estuarine and inner-shelf deposits developed along storm- and, to a lesser extent, wave-dominated shorelines. The strandplain record is well preserved within high-frequency transgressive-regressive depositional cycles (parasequences and progradational parasequence sets) that have composite thicknesses of as much as 120 m. Fluvially derived sediment supplied to strandplain coastlines was either trapped within the intertidal estuarine system or was effectively reworked along depositional strike into marine shoreface deposits. Although linear strandplain deposits dominate Point Lookout facies on a basinwide scale, delta mouthbar sandstones are present locally and are especially well developed in the Durango area (Durango delta) of southwestern Colorado. The change from strandplain to deltaic deposits is characterized by a variable sandbody geometry, decrease in bed thickness, decrease in sorting, increase in organic matter, and a different suite of sedimentary structures. Eastward transition from strandplain to fluvial deltaic deposition in southwestern Colorado was accompanied by an abrupt basinward (northeast) shift in coastal-plain facies, a coincident thinning (to less than 30 m) of the Point Lookout, and a decrease in stratigraphic rise. Associated with these changes is a subtle, previously undocumented unconformity within the upper Point Lookout west of Durango. Whether this unconformity underlies or overlies the bulk of Durango delta deposits in the seaward direction is a subject of continuing study.

INTRODUCTION

The Point Lookout Sandstone records complex interactions of both fluvial and marine coastal processes along a generally northwest-southeast-trending shoreline during Late Cretaceous Campanian time in the San Juan Basin in New Mexico and Colorado. This extensive regressive sandstone unit is a major reservoir for oil, gas and potable water in the basin, and thorough understanding of its reservoir characteristics depends on recognition and interpretation of differences in deltaic and strandplain lithofacies.

Wave and storm processes dominated much of Point Lookout depositional history, producing widespread linear strandplain, barrier island, intertidal and back-beach deposits. Fluvial-derived sediment supplied to the coastline was either trapped within the intertidal estuarine system or was effectively reworked along depositional strike into marine shoreface deposits. The recent recognition, however, of marine deltaic deposits in the Point Lookout requires re-evaluation and refinement of the widely applied strandplain depositional model. Local outcrops near Cuba, New Mexico, and extensive exposures in the Durango, Colorado, area preserve significant fluvial influence within the marine depositional record.

In this paper we present lithologic and stratigraphic data that describe the character of both strandplain and deltaic facies observed in New Mexico and Colorado exposures. Three areas of detailed study include the oldest Point Lookout strandplains at the landward limit of the formation near Gallup, New Mexico, and stratigraphically higher strandplain and deltaic deposits south of Cuba, New Mexico, and west of Durango, Colorado (Fig. 1). Large parts of these study areas are within private lands, including the Navajo and Ute Mountain Ute Indian Reservations, and access must be granted by appropriate authorities.

STRATIGRAPHY

The Point Lookout Sandstone consists of strandline deposits that accumulated by northeastward progradation across the San Juan Basin and Four Corners Platform during Campanian time. This progradation corresponds to Kauffman's (1977) R_7 and Molenaar's (1983) R_4 regressions. Coastal sandstones of the Point Lookout intertongue with the underlying marine Mancos Shale and the overlying dominantly nonmarine Menefee Formation (Fig. 2).

The Point Lookout consists of individual progradational coastal sandstone bodies organized into a series of thick "benches" separated by "steps," or phases of stratigraphic rise (Hollenshead and Pritchard, 1961; Molenaar and Baird, 1989, 1991). The formation can be further subdivided into individual transgressive-regressive depositional cou-

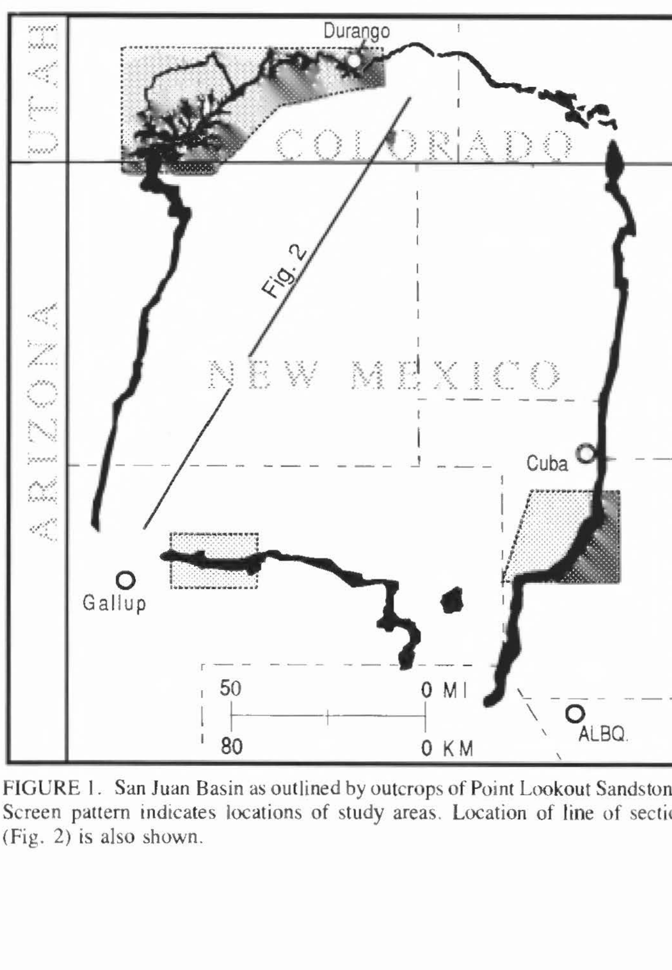

FIGURE 1. San Juan Basin as outlined by outcrops of Point Lookout Sandstone. Screen pattern indicates locations of study areas. Location of line of section (Fig. 2) is also shown.

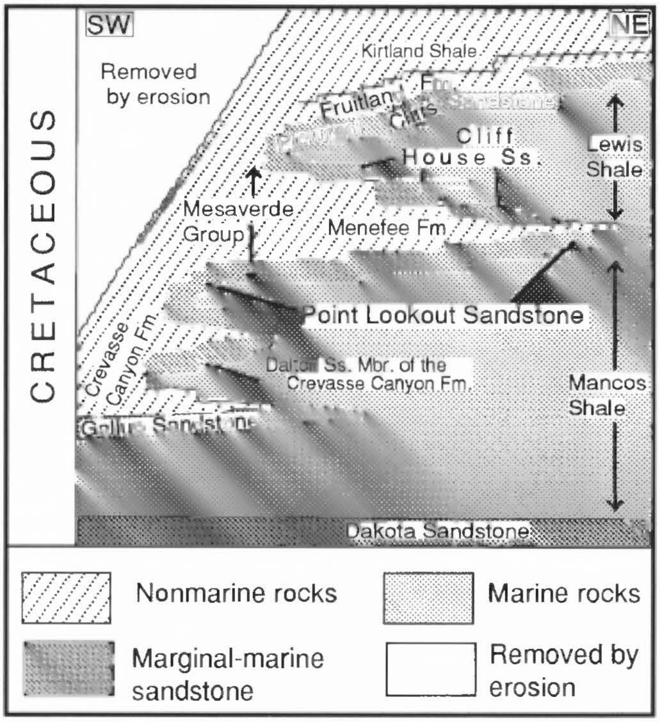

FIGURE 2. Generalized correlation chart of Cretaceous rocks in the San Juan Basin. Line of section extends approximately from Gallup northeast to Durango (Fig. 1). Modified from Molenaar (1983).

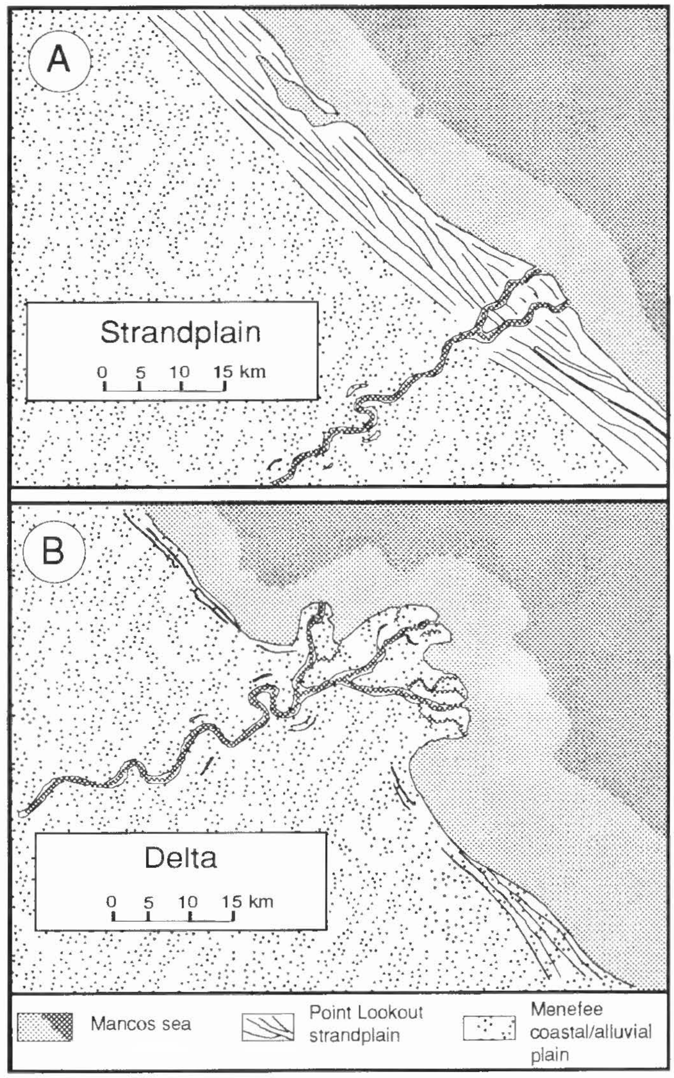

FIGURE 3. Two schematic models for Point Lookout deposition in the San Juan Basin. A, Strandplain–barrier island model characteristic of outcrops in the northwestern and southwestern parts of the basin. B, Deltaic model characteristic of outcrops in the southeastern and north-central parts of the basin.

plets, or parasequences (van Wagoner et al., 1988), that typically compose progradational parasequence sets. Recent observations (Zech and Wright, 1989) in southwestern Colorado of a sharp basinward shift in coastal facies and a coincident increase in deltaic strata suggest the possibility that late-stage progradation followed development of a previously unrecognized regional unconformity within the upper Point Lookout (for latest interpretation, see Crandall, 1992a, b).

Transgressive deposits are increasingly recognized as significant components of the predominantly regressive Point Lookout depositional record and may, in fact, comprise a much larger proportion of the sedimentary rock record in general. In contrast to the classic parasequence model (van Wagoner, 1985; van Wagoner et al., 1988), in which transgression is thought to be marked only by a sharp marine flooding or ravinement surface, Point Lookout parasequences contain various scales of transgressive shelf and estuarine deposits (Devine, 1980, 1991; Wright et al., 1989; Katzman et al., 1990; Katzman, 1991). Failure to recognize and properly interpret transgressive facies within the formation may result in an oversimplified view of lithologic heterogeneity and stratigraphic complexity.

Transgressive deposits, marine flooding surfaces and foreshore sandstones at their landward limits help distinguish individual parasequences which, in turn, help to constrain local paleoshoreline trends (Wright, 1986). Using such criteria to define mappable subunits, Point Lookout strandplain-barrier coastlines have been shown to be very straight over distances of miles to tens of miles (Zech, 1982; Katzman, 1991; Devine, 1991), whereas deltaic coastlines display considerable irregularity over comparable distances (Wright, 1986; Crandall, 1992a). Regionally, both deltaic and strandplain coastlines follow the northwest-southeast-trending shoreline orientation long recognized in this part of the Western Interior Seaway (Sears et al., 1941; McGookey et al., 1972).

STRANDPLAIN–BARRIER ISLAND SYSTEMS

Regressive strandplain and barrier island deposits (Fig. 3A) dominate the Point Lookout depositional record basinwide. Vertically repeated shoreface parasequences produce classic coarsening-upward profiles (Figs. 4A, 5) capped by foreshore or tidal deposits. Highly resistant shoreface sandstone forms the prominent cliffs on many of the mesas, buttes and steep-walled canyons, particularly in the northwestern and southwestern parts of the San Juan Basin. The lithology of these strandplain-barrier deposits has been reported by many authors; the following brief summary is derived from work by Zech (1982), Wright (1986), Devine (1980, 1991) and Katzman (1991). For additional details, see Katzman and Wright Dunbar (this volume).

The gradational basal contact of the Point Lookout Sandstone is typically marked by vertical transition from offshore mudrock deposits of the underlying Mancos Shale to interbedded mudrock and inner-shelf sandstone deposits. Thin (<1 m), inner-shelf sandstone beds are lenticular, hummocky cross-stratified (HCS) to waverippled, very fine grained and increase upward in thickness and number. Sandstone beds are sharp based and show abundant offshore-directed scour and tool marks. The base of the lower shoreface is defined (sensu Reineck and Singh, 1975) at the lowest fully amalgamated HCS sandstone unit. Middle to upper shoreface deposits in most outcrops are marked by a virtual absence of shaly interbeds, an increase in grain size from very fine to fine sand, and by the upward change from HCS to swaley cross-stratification (SCS) and, ultimately, subparallel undulatory lamination. Trough crossbeds are atypical of the Point Lookout shoreface. This vertical sequence of sedimentary structures supports the interpretation

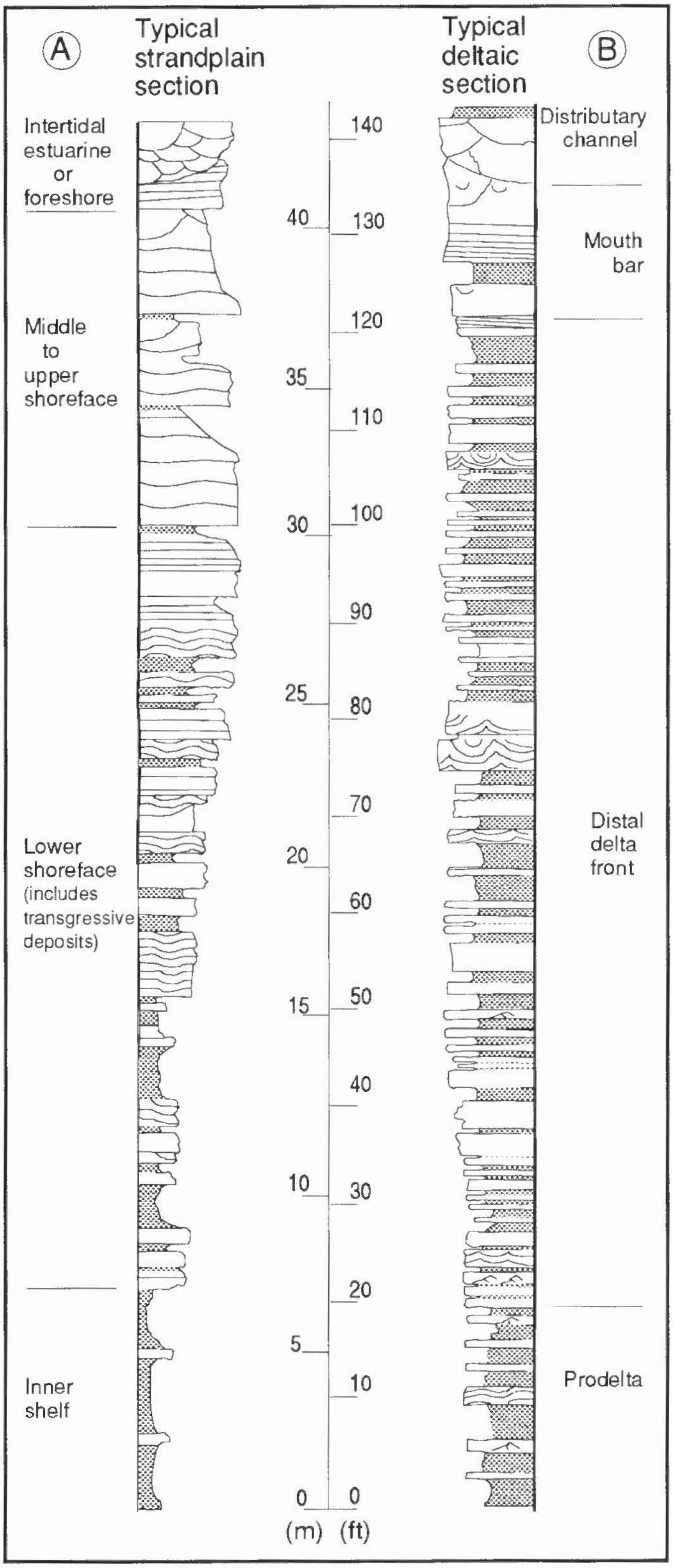

FIGURE 4. Typical strandplain (A) and deltaic (B) vertical sections. Note greater abundance of shale (shaded) and sandstone:shale interbedding in the deltaic section.

that much of the Point Lookout coastline was dominated by storm events (Montz et al., 1985) that periodically introduced sands to the offshore environment via combined flow transport (Harms, 1975; Dott and Bourgeois, 1982) along the seafloor. During fair-weather conditions, little or no sand was transported across the lower shoreface or onto the inner

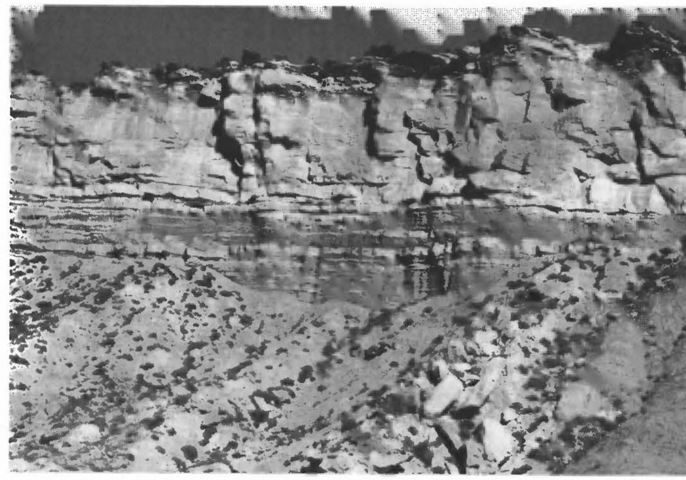

FIGURE 5. Coarsening-upward transition from Mancos Shale to Point Lookout shoreface sandstones in the Cuba, New Mexico, study area. Thinly interbedded sandstone units at the top of the section are amalgamated small tidal channels cut into the upper shoreface. Amalgamated sandstone cliff is approximately 25 m high.

continental shelf, and, thus, relatively sand-free mudrocks separate individual HCS subunits.

Trough crossbedded upper shoreface sandstones, although uncommon in the Point Lookout basinwide, are well represented in shoreface deposits in the Gallup, New Mexico, study area (Zech, 1982). These crossbeds preserve southeast-migrating dune bedforms driven by wave-generated longshore currents and document local dominance by shoaling-wave processes (Elliott, 1989). At these outcrops evidence for discrete, storm-generated depositional events is restricted to the lower shoreface and inner shelf.

Foreshore deposits are planar laminated and seaward dipping and are generally thin and poorly preserved across the basin. Lack of preservation resulted from fluvial and distributary channel scour and, on a local basis, replacement by tidal-inlet and tidal-channel deposits. Unusual and excellent preservation of foreshore sandstones in the Gallup study area resulted from parasequence aggradation near the landward limit of Point Lookout deposition. Vertical accommodation of these sandstones was sufficiently complete such that beach-ridge and inter-ridge swale paleorelief was preserved (Zech, 1982). Now exhumed, these paleorelief elements produce linear trends and subtle trellis drainage patterns that are visible in aerial photographs (Fig. 6) and on Landsat images of the Gallup area (Zech and Knepper, 1989). These photos provide visible evidence of the shoreline orientation, straightness and and continuity. Foreshore deposits in the Four Corners area, mapped by correlating heavy mineral placer deposits (Zech and Brownfield, 1990), have similar length, orientation and continuity as those near Gallup.

Although preserved in the rock record, tidal creeks and distributaries removed very little of the subaerial beach deposits near Gallup. Wright and Zech (1986) contrasted this depositional pattern with that of Point Lookout outcrops south of Cuba, which indicate that much of the subaerial beach record was removed and replaced by an amalgamated tidal-channel facies (see Day 1 Road Log, Stop 2, this volume). Two factors best explain this difference. First, strongly progradational parasequences near Cuba produced a thin (<30 m thick) coastal sandbody that reflects less accommodation space than deposits near Gallup. Second, the shoreline near Cuba was embayed (Wright, 1986), rather than straight, and thus may have locally enhanced tidal range and the influence of the tidal channel network. Observations from all three Point Lookout study areas confirm that tidal creeks and (or) distributaries were a common coastal plain feature. These channels contain sand grains that are much coarser than those in equivalent shoreface deposits (and could not have been derived via tidal or storm processes from the shoreface), and a fluvial connection for many of these tidal creeks and

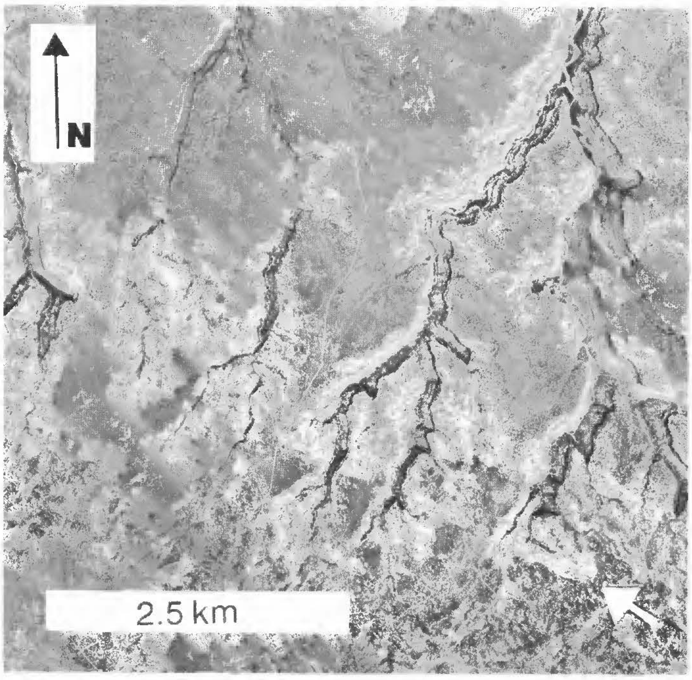

FIGURE 6. Aerial photograph of exhumed paleoshorelines in the Gallup, New Mexico, area. Linear trends oriented northwest-southeast (arrow) represent foreshore sandstones separated from one another by interridge swales. Note that trellis drainage developed parallel with beach ridges in the modern topographic lows that correspond to the Cretaceous interridge swales.

distributaries is thus required. Restriction of coarse sand to channel deposits further suggests that fluvial input along strandplain coastlines was mostly trapped within the estuarine environment and had limited impact on the character of the adjacent shoreface.

Stratigraphic position within the parasequence hierarchy also exerts a major control on the character and distribution of estuarine and marine strandplain sandstones. Recent workers (Wright, 1988; Wright et al., 1989; Katzman, 1991; Devine, 1991) have interpreted a major component of estuarine and inner-shelf Point Lookout sandstone deposits as having accumulated during the transgressive, rather than regressive, depositional phase. Wright Dunbar et al. (1992) included various scales of transgressive phase deposits within parasequences and parasequence sets, requiring modification of the parasequence model of van Wagoner (1985) and van Wagoner et al. (1988). Lithologic characteristics of these deposits in the northwestern San Juan Basin are discussed in detail by Devine (1991), Katzman (1991) and Katzman and Wright Dunbar (this volume).

DELTAIC SHORELINES

The regressive strandplain model has been widely applied to explain the Point Lookout Sandstone, whereas deltaic deposits (Fig. 3B) have been considered to be rather local, and perhaps, anomalous features (Wright, 1986). Ongoing fieldwork suggests, however, that delta deposits are a significant part of the depositional record and, in fact, dominate strata in the vicinity of Durango, Colorado (Newman, 1982; Zech and Wright, 1989). The change from strandplain to deltaic deposition is characterized by significant differences in sandbody geometry and thickness, sedimentary structures, sorting and organic content.

Deposits interpreted as deltaic coarsen upward in vertical section (Fig. 4B), but sandstone distribution is very different from the coars-

FIGURE 7. Prodelta and distal delta-front deposits of the Mancos Shale to Point Lookout Sandstone transition west of Durango, Colorado (lower 50 meters of measured section 5, Fig. 11). This interval is characterized by abundant, thin, rippled sandstone interbedded with thin, organic-rich shale. Broad, lenticular channel forms (near person in lower left) are common in distal delta-front deposits, as are convoluted beds.

ening-upward strandplain succession. Compared to strandplain offshore transition facies, distal deltaic deposits contain much more evenly distributed, interbedded sandstone. Prodelta and distal delta-front deposits are characterized by repeated thin (1–50 cm), very fine-grained, rippled and climbing-rippled sandstone beds that are thinly interbedded with organic marine shale and minor HCS sandstone (Fig. 7). Soft-sediment deformation is abundant in distal delta-front deposits and ranges from thin contorted beds to large, meter-scale ball and pillow structures (Fig. 8)

Sediment delivery mechanisms therefore probably were quite different for the strandplain and deltaic shorelines. Hummocky cross-stratified distal strandplain deposits (introduced to a mostly mud-dominated inner shelf during storm events), contrast with rippled distal delta sandstone units that suggest reasonably uniform sand accumulation during fair weather as well as storm conditions. Rapid sediment accumulation on the delta is indicated by high organic content, climbing ripples, and abundant soft-sediment deformation features. Localized HCS within distal delta-front sandstone units implies that storms occasionally reworked some of the distal delta-front sandstones. The fact that abundant sand-sized material and terrigenous organic matter accumulated in between storm events suggests proximity to a fluvial system (Durango delta) capable of discharging sediment to the inner shelf on a regular basis.

Shallow-marine mouthbar sandstone bodies (Fig. 9), in contrast to well-sorted, fine-grained, massive shoreface deposits, are fine to coarse grained and consist of stacked, broadly lenticular beds that fine upward on a scale of a few meters (Fig. 4B). Beds are sharp based and many are capped by thin (<30 cm) organic-rich mudrock. Individual mouthbar sandstone beds are parallel laminated with parting lineation and traction current indicators. Trough and planar-tabular cross-stratification is interbedded with parallel-laminated sandstone in beds of the uppermost mouthbar. Delta sandstone bodies contain more feldspar, lithic components, and mica than shoreface sandstone bodies (Crandall, 1992a; I. Espejo, Rice University, written comm. 1992). Although a few delta sandstone beds are completely churned, burrowing is most common on bed tops and decreases downward within the upper 20–30 cm of the bed from approximately 50 to 0 percent. Nowhere within mouthbar sandstone deposits has burrowing destroyed the sharpness of individual bed contacts. This distinct burrowing pattern, not observed in the shoreface sandstones, indicates colonization of the sediment surface during hiatal periods between depositional events; only rarely did burrowing keep pace with sediment accumulation and result in a chumed bed. Taken together, these physical characteristics suggest that distinct, waning-energy traction currents transported relatively less mature fluvial sediment into a shallow-marine, friction-dominated mouthbar and delta front (Elliott, 1989). Mouthbar deposits are overlain either by fluvial channel-fill deposits or organic-rich, delta-plain mudrock and coal.

Reconnaissance work in the Durango area reveals much local variability within the main cliff-forming sandstones of the Point Lookout. Well-developed, bedded mouthbar deposits are limited to exposures less than 1–2 km in extent and are laterally transitional to poorly sorted, mineralogically immature (Hicks, 1991), delta-front or delta-transitional upper shoreface sandstone deposits. Detailed paleoshoreline maps have not yet been constructed for this area; however, deltaic sandstones that appear to pinch out downdip just east of Durango probably represent discrete mouthbar bodies.

STRANDPLAIN TO DELTA TRANSITION

Recognition of fluvial-deltaic elements within the Point Lookout Sandstone raises questions as to their magnitude and extent, and how

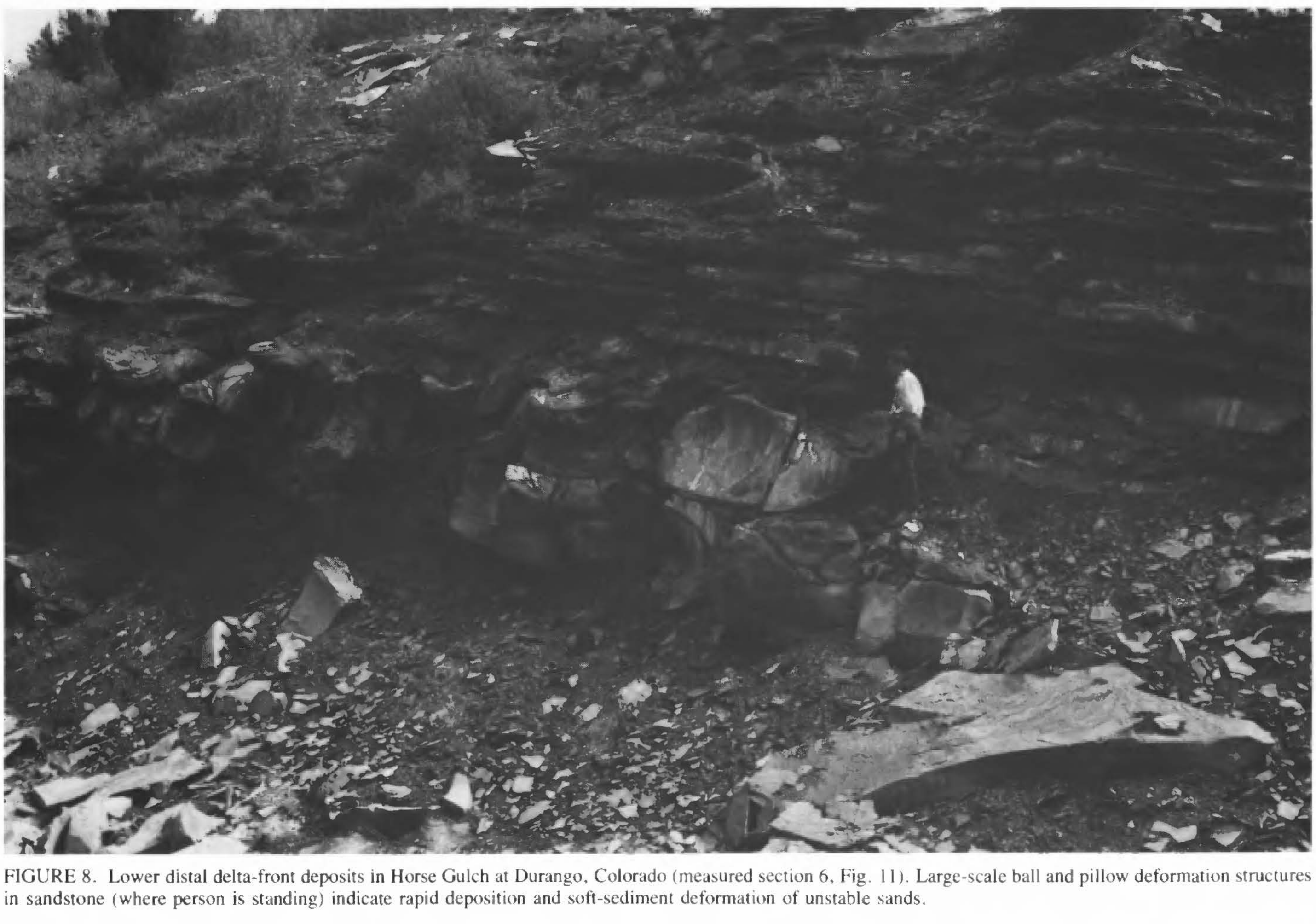

FIGURE 8. Lower distal delta-front deposits in Horse Gulch at Durango, Colorado (measured section 6, Fig. 11). Large-scale ball and pillow deformation structures in sandstone (where person is standing) indicate rapid deposition and soft-sediment deformation of unstable sands.

FIGURE 9. Delta mouthbar sandstone beds (upper 20 m of Horse Gulch measured section 6, Fig. 11). Arrows point to erosional bedding contacts between broad, lenticular channel forms. Here the Point Lookout main body is composed of stacked, fining-upward, lenticular and tabular sandstone bodies that are separated from one another by organic-rich mudrock.

the transition from strandplain deposition occurred. Wright (1986) documented the gradual southward shift of a small delta along the Point Lookout shoreline at San Luis (south of Cuba, New Mexico); it is not currently known how (or whether) this phase of deltaic deposition correlates with the Durango delta system. Zech and Wright (1989) correlated Cortez area strandplain sandstones with Durango delta deposits (Fig. 10) and noted a basinward thinning of the Point Lookout and an apparent decrease in stratigraphic rise that coincided with the onset of deltaic deposition. Crandall (1992a, b) tested their hypothesis that a baselevel fall accompanied these changes in formation architecture and concluded that an unconformity of probable regional significance is present within the upper Point Lookout between Cortez and Durango, Colorado. This unconformity has not yet been traced basinward in either outcrop or subsurface to confirm whether it drops stratigraphically beneath Durango delta deposits or remains above them. If the unconformity can be traced below deltaic deposits, the delta postdated the baselevel fall and the sequence stratigraphic position of the Durango delta is within the shelf-margin systems tract (van Wagoner et al., 1988). If

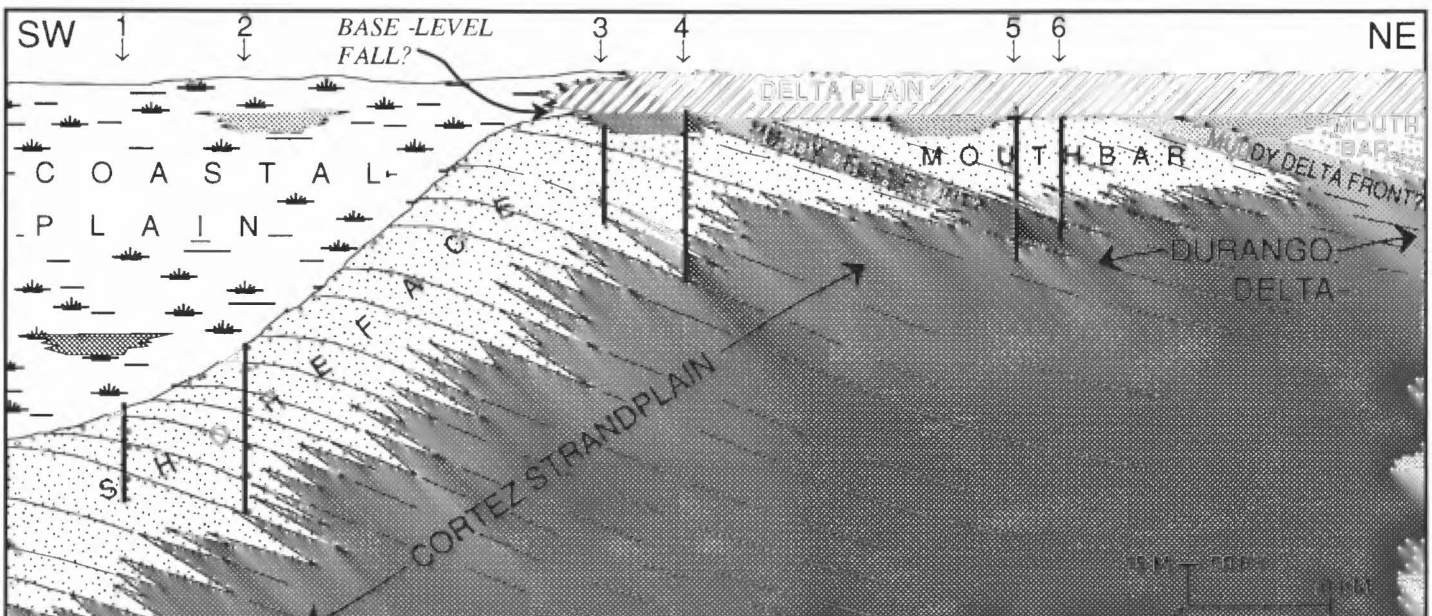

FIGURE 10. Schematic cross section from Mancos Canyon northeast to Durango, showing changes from shoreface to deltaic facies of the Point Lookout Sandstone. Details and locations of measured sections are in Fig. 11. The stratigraphic rise between sections 2 and 3 was estimated from field and subsurface data of Katzman (1991) and Devine (1991) and checked by comparison to nearby subsurface data (Molenaar and Baird, 1989). The inferred baselevel fall and unconformity begins near section 3. Position of this unconformity above or below Durango delta deposits (sections 5, 6) has not yet been confirmed. The decrease in stratigraphic rise between sections 3 and 6 is based on outcrop reconnaissance observations. Modified from Zech and Wright (1989).

the unconformity correlates above the deltaic deposits, the delta probably built seaward within the very latest highstand, or "falling sea level" systems tract of Nummedal (1992).

Although a strong deltaic influence is visible in the Durango area, evidence for active fluvial processes is present throughout sections in the Cortez strandplain as well. Sediment distributed by fluvial channels and fluvial-connected tidal channels in Mancos Canyon outcrops (sections 1 and 2, Fig. 11) was primarily restricted to estuarine and back-beach environments (Katzman, 1991). Geographically restricted heavy-mineral deposits in nearby foreshore sandstones (Zech and Brownfield, 1990) indicate, however, that fluvial sources locally contributed material to the swash-dominated beach. In Mancos Canyon, well-developed shoreface deposits show little, if any, influence of riverine processes. In contrast, Crandall (1992a, b) described development of small shelf-modified deltas (between sections 3 and 4, Fig. 11) throughout most of the progradational strandplain deposits at Cherry Creek. An increase in organic content and a decrease in mineralogic and textural maturity characterize these deposits, which locally perturbed the straight strandplain coastline (Crandall, 1992a). Thus, during late highstand prior to onset of widespread fluvial-deltaic deposition, rivers probably had an increasing impact on the Point Lookout shoreline.

CONCLUSIONS

The classic prograding strandplain depositional model fails to adequately account for widespread fluvial-deltaic deposits of the Point Lookout Sandstone. In a regional context (McGookey et al., 1972), the Point Lookout Sandstone can be thought of as having accumulated along a straight northwest-southeast-aligned strandplain system. This model is still widely applicable within the basin, but significant local perturbations in shoreline orientation and sandbody thickness may be resolved using parasequence-scale mapping and correlation techniques.

Such perturbations reflect locally strong fluvial influences that affected both formation continuity and lithologic maturity. Compared to shoreface sandstone beds, deltaic deposits are more poorly sorted, contain a higher percentage of lithic fragments, feldspar, and organic material, and display greater lateral variability. Although fluvial channels distributed sediment to the Point Lookout coastal zone throughout the formation's history, their impact on local shoreline orientation and shallow-marine lithofacies increases in deposits of the latest highstand. Baselevel fall, documented by a subtle regional unconformity within the upper Point Lookout Sandstone, coincided with maximum deltaic development. Further subsurface and outcrop work is required to conclusively trace this unconformity into Durango delta deposits.

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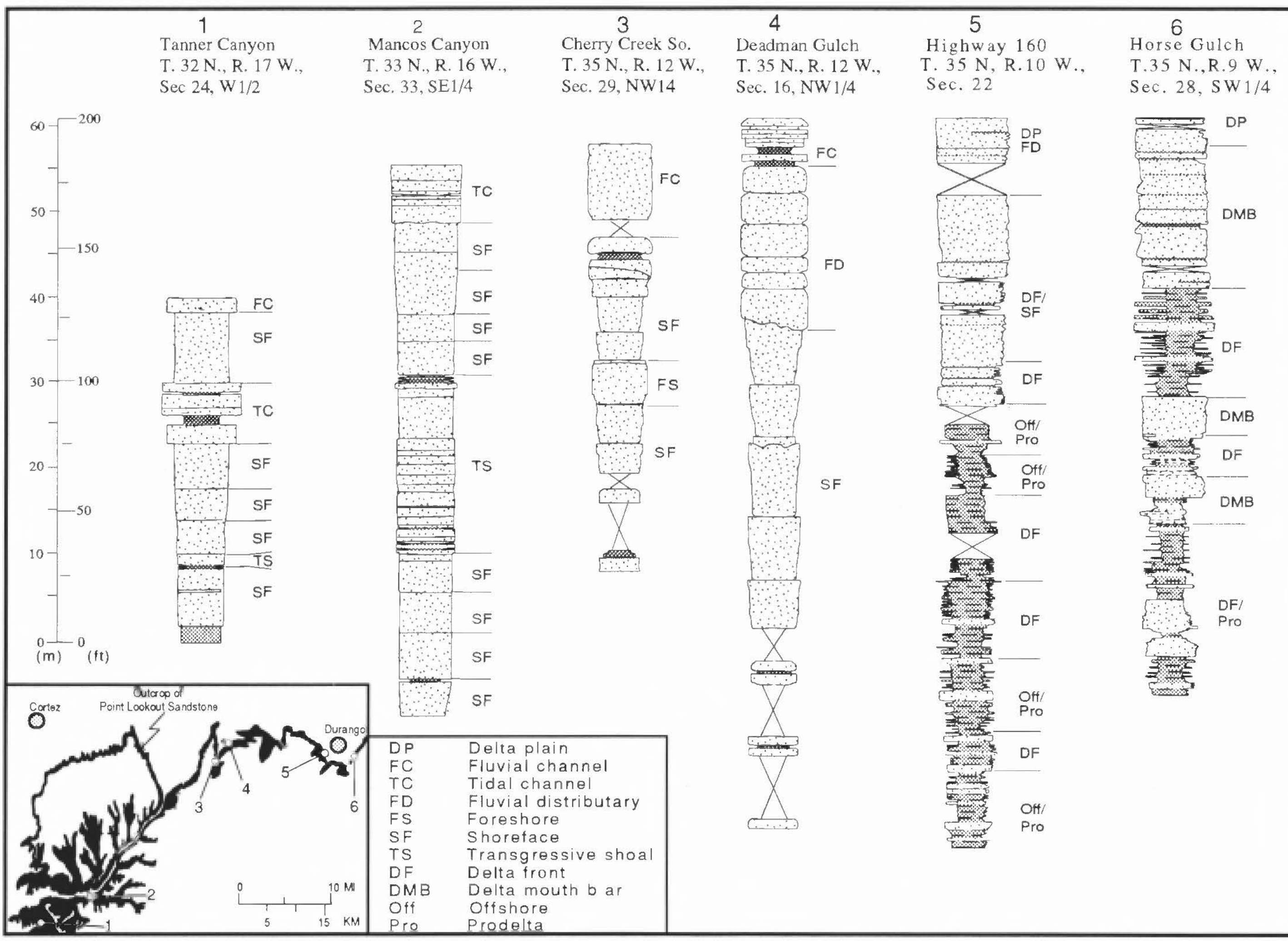

FIGURE 11. Selected measured sections along outcrops of Point Lookout Sandstone from Mancos Canyon to Durango showing characteristics of strandplain (secs. 1, 2), strandplain-delta transition (secs. 3, 4) and deltaic (secs. 5, 6) deposits. Relative stratigraphic relationship between sections is shown in Fig. 10.

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