Depositional Trends in Siliciclastic Deposits of the Stone City Transgressive Systems Tract, Middle Eocene, Texas

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Abstract

Strata exposed at Stone City Bluff, Texas, contain shelf sediments deposited during progressive marine deepening (from shallow water depths) and then capped by a maximum flooding horizon. They are part of the early Bartonian (NP16) "Cook Mountain" transgressive systems tract, exposed in the type section of the Stone City Member of the Crockett Formation. This locality lies on the inner portion of a shelf transect about 175 km (110 mi) shoreward of the Late Eocene shelf-slope margin and probably never farther than 80 km (50 mi) from the shoreline.

Sedimentary structures in the sediments change upward, reflecting a shift from tidal current-dominated to storm-dominated deposition. In lower intervals, tidal control is dominant. The transition interval contains isolated storm sands, as sheets with lenses 40 cm (15 in) thick, in mudstones with tidal bedding. These storm beds contain teeth/bone concentrates and some gravel-size clasts at the bases of larger lenses. In higher intervals, storm deposition is dominant in all units, mostly as thin, distal layers of very fine, sand or silt. Amalgamated storm deposits form larger units (e.g., the Moseley bed). Local hardground surfaces are developed where storm washing exposed concretionary layers or on condensed, winnowed zones. Glauconite occurrence and siderite concretion formation are most common in the upper intervals.

Storm deposits have dual sediment sources and contain 1) skeletal remains (shells/fish bone) and glauconite pellets concentrated by in-place winnowing, or 2) fine quartzose sand washed in from shallower water settings. Alternation of amalgamated storm deposits and mudstone units with thin storm deposits indicate a cyclic record of storm activity.

Introduction

Marine strata exposed at Stone City Bluff, on the banks of the Brazos River near Bryan, Texas (Figure 1), contain sediments deposited during an interval of rising sea level. These are part of a transgressive systems tract (in sequence numbered TA3.5 by Haq et al., 1988) which includes strata of the upper part of the Sparta Formation and the lower part (Stone City Member) of the Crockett Formation (Davidoff & Yancey, 1993; Yancey & Davidoff, 1991, 1994) in the Brazos River Valley outcrop belt. The Crockett Formation is a thick unit of marine sediments deposited on an open shelf setting during the early Bartonian regional marine transgression and highstand. The Stone City Bluff section contains the upper part of this transgressive systems tract. Ocean water depths increased during deposition of these sediments, producing changes in grain size, depositional structures, and bed morphology expected during deepening water conditions and increasing distances from a shoreline. Water depth changed from shallow to mid shelf settings. Stone City Bluff is a place where depositional trends of a transgressive systems tract can be examined in detail, in siliciclastic sediments that retain depositional fabric rather than biogenic or diagenetic disturbance fabric.

The transgressive interval exposed at Stone City Bluff contains a minimum of 20 m of strata deposited during the late stages of sea level rise (Figure 2). This site (and other parts of the outcrop belt) lay updip and shoreward of areas with a thin condensed section, present in many parts of the northern Gulf Coast (Baum et al., 1994; Loutit et al., 1988; Ewing, 1994a). The expanded Stone City Bluff section results from deposition in an area of high rate of sedimentation (Figure 3), not a relatively slow rate of rise in water depth. This conclusion is based on observations that thickening occurs in the highstand systems tract of the sequence as well as the transgressive systems tract (see Yancey & Davidoff, 1991, 1994, for data). In the central Texas segment of the Gulf Coast, areas of change from high to low sedimentation rate generally correspond with the position of the boundary between inner and outer shelf settings.

Transgressive intervals in the outcrop belt are identified primarily on basis of indications of increasing water depth, a set of criteria different from those used to identify transgressive interval deposits in subsurface studies. Well log responses used to identify subsurface portions of the Stone City transgressive systems tract (Ewing, 1994b) are generated, in large part, by the presence of siderite concretions and glauconite in the sediment. In the outcrop belt, these lithologies are more characteristic of a thick interval of early high-stand deposits (Wheelock Member of the Crockett Formation) than the transgressive interval. Only the upper part of the Stone City Member contains considerable glauconite and siderite. The maximum flooding surface occurs low in the stratigraphic interval containing much glauconite and siderite, not at the top.

Strata of the Crockett Formation interval are referred to the "Cook Mountain Formation" in the subsurface, where the unit expands upward to include fine grained strata equivalent to the lower part of the Yegua Formation (Ewing, 1994a).

Stenzel (1936) designated the exposures at Stone City Bluff as the type section of the Stone City "Formation," which he separated from the overlying Crockett Formation on the basis of a supposed erosional surface overlain by "conglomerate." He interpreted this as an unconformity of regional extent associated with the erosion of large amounts of sediment in shoreward locations. However, the Stone City interval contains sediments lithologically similar to those of the overlying Wheelock Member of the Crockett Formation. Furthermore, subsequent work (Thornton & Stanton, 1994) has shown that the supposed erosional surface designated as the upper formation boundary is a submarine hardground in an interval deposited in deep marine environments. The objects Stenzel (1936, p.275) identified as conglomerate clasts are locally formed concretions, reworked and winnowed in place from underlying sediments. The original basis for establishing the Stone City unit as a formation is not valid and the unit should be treated as a member of the Crockett Formation.

Location and Age of Selection

The Stone City Bluff section is located on the southwest bank of the Brazos River at the Rt. 21 highway crossing over the river, about 18 km (12 miles) west of Bryan, Texas, in the east-central part of the state (Figure 1). This location corresponds with the site of the Old San Antonio Road crossing of the Brazos River, a place that has been named both Stone City Bluff and Moseley Ferry in various reports. A discussion of the history of this site and the place names is given in Stenzel et al. (1957). This is a well known fossil locality, a place examined by many people and the source of fossils reported in many publications appearing during the past 150 years. Calcareous nannoplankton indicate, the sediments were deposited during biochronozone NP16 (age determination by M. M. Jiang, reported in Yancey & Davidoff, 1991) and planktic foraminifers indicate an age of P12 or P13 (Gaskell, 1988).

The Stone City Bluff locality lies on the inner portion of a shelf transect about 175 km (110 mi) shoreward of the Late Eocene shelf-slope margin. The depositional site probably was never farther than 80 km (50 mi) from the shoreline. This estimate is based on reconstruction of a 50 km (30 mi) sand-dominated nearshore zone and the observation that small amounts of storm-deposited quartzose sand are present in the deeper water deposits of the section.

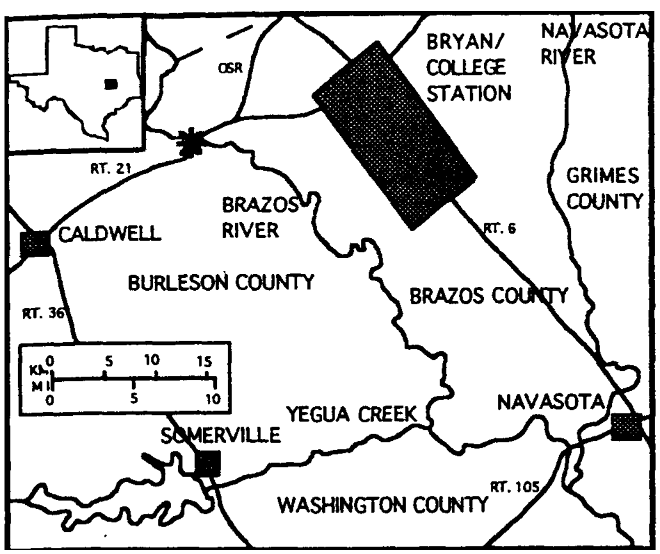

Figure 1. Location of the Stone City Bluff section.

Depositional Framework

Sediments exposed at Stone City Bluff were deposited during progressive marine deepening from shallow to deeper water depths accompanied by changes in depositional processes from primary control by tidal currents to domination by storm events. Within the storm-dominated interval, evidence suggest there was a progressive decline in strength of storm waves and storm generated currents affecting sediments, reflected in a change in storm deposits from proximal deposits with basal lag components to very thin distal deposits. This site never lay beyond the reach of storm disturbance, because even the deepest water deposits in the section contain thin layers (or laminae) of coarse silt that were probably deposited from distal storm plumes. Overall, rates of sediment deposition were high enough to limit bioturbation, thus preserving primary sedimentary structures throughout the section.

Deepening also corresponds with an upward decline in quartzose sand content and an increase in content of glauconite pellets and siderite concretions. The lower interval of the Stone City Member is composed of quartzose sand and mudstones with quartzose sand. The upper one-third of the transgressive section described here (the uppermost part of the transgressive systems tract) contains the most glauconite and siderite, which is common within the Main Glauconite bed, the Inter Glauconite bed, and the Moseley bed (partly glauconite-rich). Glauconite also occurs commonly as dispersed pellets in mudstone layers between storm sands in the upper interval of the section. The glauconite consists of small pellets, presumably of fecal origin, with relatively few glauconite grains originating as fillings in foram tests or snail shells. The uppermost part of the Stone City Member also contains abundant planktic pteropods; planktic foraminifers, and calcareous nannoplankton.

Deposition by Tidal Currents

The lower parts of the Stone City Member are characterized by mudstones and sands with tidalite depositional structures (Figure 2). Tidalite structures are pervasive in the Main Sand bed and the underlying Cannonball bed unit and are common at higher levels in the interval between the Main Sand bed and Main Glauconite bed. Tidal current influence at higher levels in the section was not strong enough to produce recognizable structures.

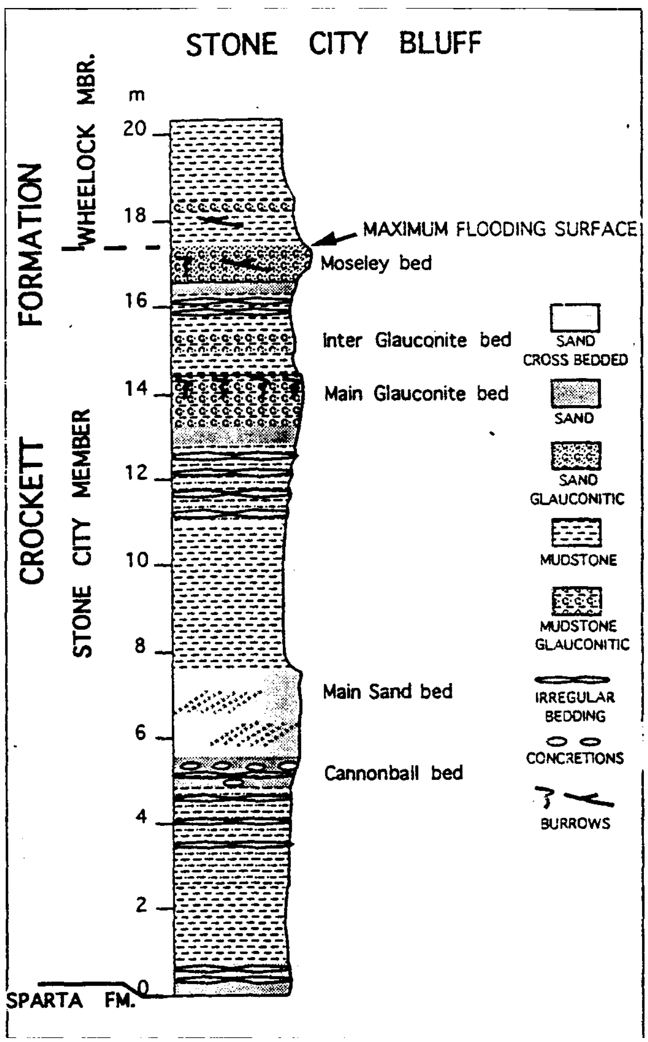

Figure 2. Stratigraphic section exposed at Stone City Bluff. Placement of the Crockett-Sparta formation contact follows Stenzel (1936), but the boundary is hidden in modern river flow conditions. The section shown here is based on descriptions

made over the past few years and contains modifications of the section description presented in Stenzel et al. (1957). A more detailed section description is available in Yancey & Davidoff (1994).

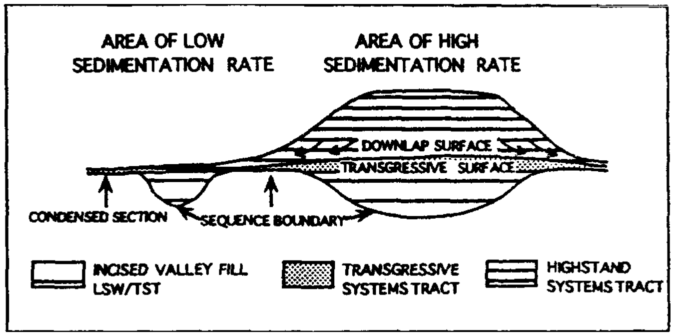

Figure 3. Schematic diagram showing development of transgressive systems tract and equivalent condensed section in areas of high and low rates of sediment accumulation on shelf surfaces. The Stone City Member at Stone City Bluff is an example of deposition in area of high sedimentation rate. Modified from Loutit et al. (1988).

Figure 4. Cross-bedded sands with clay drapes on sand laminae, an example of tidal structures in sands. Gash in sand face marks site of small pyrite concretion extracted from the bed. Main Sand bed of Stone City Member, Crockett Formation. Scale in cm.

Tidalite structure in mudstones ranges from occurrences of distinctive lenticular bedding (as defined by Reineck & Singh, 1980) to irregular alternations of thin layers of sand and mud. There are some occurrences of flaser bedding, but cross-bedding is weakly developed in most small sand lenses. Scour surfaces and thin layers of shell concentrates are scattered throughout the tidal units. These are indicators of frequent moderate energy disturbance of the seafloor, involving removal of mud and sand and concentration of coarse materials compatible with shifting tidal currents or small storm activity. The repeated change from sand to mud deposition, small size of structures, and irregularity of layers indicates these sediments were deposited by tidal currents. Repeated thin alternations between sand and mud deposition is common on tidal flats, shallow subtidal environments, and delta-front settings (Boggs, 1987).

Tidalite structures in sandstones, like those of the Main Sand bed, consist of clay draping on crossbed surfaces in dune deposits and in thicker mud layers interspersed within the sand deposits. Most sands in the Main Sand bed have laminae with clay draping (Figure 4). Clay draping over sand laminae in crossbed sets is clear evidence of alternating current conditions involving higher energy conditions (sand transport) and slack water conditions (mud deposition). Intercalation of irregular mud layers between crossbed sets in the Main Sand bed is another indicator of tidal deposition. This type of deposit is common on tidal flats (and subtidal sand sheets) where dunes are periodically active. After initial sand deposition, mud accumulates on the sand dune surface or between dune tops during monthly lows in tides and tidal currents. These muds become cohesive and are then covered with sands during episodes of renewed sand migration.

Mudstone units with lenticular tidalite bedding also have bedding in which thin, irregular sand layers are laterally persistent over long distances in outcrop. Both thin layers and thicker units of these layers can be traced laterally. These are produced in areas of high sediment input with frequent variation in sediment supply and current velocity: Such settings are often identified as delta front (Boggs, 1987), but the conditions are more general and indicate strong tidal control on sediment deposition. This type of bedding is common in Paleogene strata in east-central Texas.

Storm Deposits

Storm deposits occur throughout the Stone City Member, but are most common and distinctive in the upper part of the section. In the lower portion of the section, storm deposits consist of thin irregular layers with scattered shells, lacking the regular lamination of tidal deposits. There are many erosion surfaces in the shallow water, tidal-dominated deposits, especially the reactivation surfaces in the Main Sand bed, that may represent erosion by storm events. In shallow water settings, even small storms can mobilize sediment and move it away, so the record of storm activity is more varied and less distinctive than storm deposits present in deep water settings.

The middle portion of the Stone City Member contains common and distinctive storm deposits which occur encased in mudstone having lenticular and wavy tidalite bedding. These storm deposits are quartzose sand sheets with a lensing bed morphology, in which adjacent lenses are linked by a thin layer of sand. In thicker storm layers, single lenses occur with thickness up to 40 cm (15 in) and attain widths a few metres across (Figure 5). Lamination in the sand parallels the margins of the lens and there is no indication of internal hummocky cross-bedding within larger lenses. Smaller lenses have dimensions similar to individual hummocks seen in beds with we'll developed hummocky cross-bedding.

The larger lenses have a distinct basal lag layer, composed of coarse materials winnowed from underlying sediments (Figure 6). These large clasts are mostly shells and shell fragments, but may also include locally derived concretions and some gravel clasts carried in from more distant sources. Most of the reworked concretions have a platy form, with the largest ones having maximum dimensions of 5-10 cm (2-4 in). These basal lag layers often contain accumulations of high density teeth and bones from sharks and fish, concentrated from the underlying sediments. The basal lag has a sharp contact with the overlying laminated sands (Figure 7), indicating it was formed during winnowing and sediment mobilization. In contrast, the overlying laminated sand was deposited from suspended bedload.

The quartzose sand in storm lenses comes from a distant source. Sands of well developed storm lenses tend to contain little glauconite and few shells, unlike the basal lag layers derived from local muds. The sand is probably derived from shallow, nearshore environments, where it was suspended by high energy wave action and carried offshore by storm-generated bottom currents and deposited during the waning episode of a storm (Duke et al., 1991). The grain size of sands in the storm layers (fine sand size) and their depositional geometry corresponds with sand that would be moved by this mechanism.

Figure 5 (below). Laminated sand in thick lens of proximal storm deposit. This lens has little basal lag concentrate, although laterally adjacent lenses contain a thick lag layer. Sediments below basal contact are fine grained mudstones. Storm deposit 2 m below base of Main Glauconite bed, Crockett Formation. Scale in cm and inches.

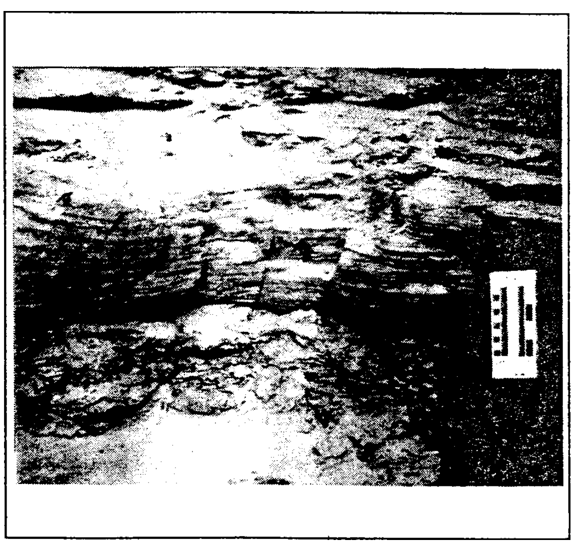

Figure 6. Bedding plane view of lag concentrate at base of proximal storm deposit. Note the presence of large unbroken shells and broken shell and large concretions (dark objects). Smaller black objects are fish bone and teeth. Storm deposit 2 m below base of Main Glauconite bed, Crockett Formation. Scale in cm.

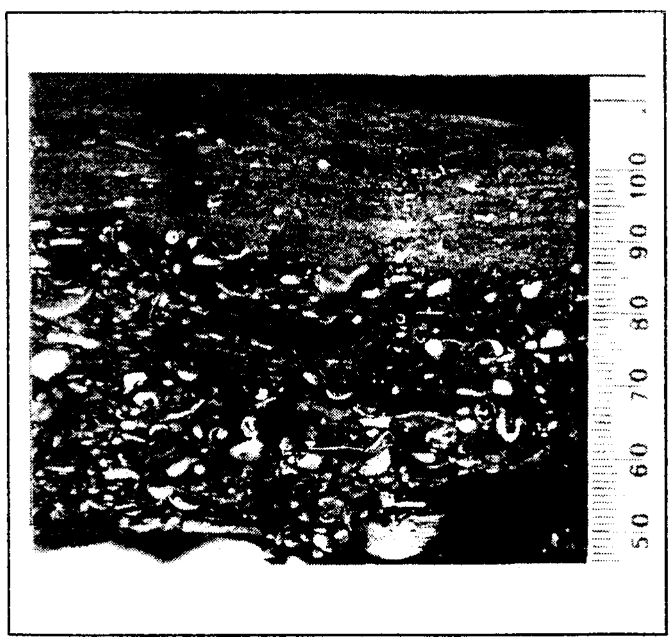

Figure 7. Section through lower part of a proximal storm deposit, with basal lag concentrate containing shells and concretions and an upper part (above 85 level on scale) of laminated sands. Note sharp contact between lag component and the upper suspension deposit component. Storm deposit 2 m below base of Main Glauconite bed, Crockett Formation. Scale in cm.

The upper portion of the Stone City Member contains numerous distal storm deposits of very fine sand or silt materials, deposited in thin layers, visible in the dark clayey matrix because of their lighter coloration. When fine grained intervals of the upper 10 m (33 ft) of the section are compared (disregarding the beds formed of amalgamated storm deposits), there is an average upward decrease in bed thickness and grain size of the contained storm deposits. This trend from proximal to distal storm deposition is interpreted to be the result of increase in water depths and distance from shoreline. Mudstones at the top of the section (basal Wheelock Member) contain laterally persistent laminae of silt that are probably of storm origin. Very thin layers are sometimes smeared out and obscured by bioturbation.

Amalgamated Storm Layers

Resistant beds (Main Glauconite bed; Inter Glauconite bed; Moseley bed) in the upper transgressive interval are formed of amalgamated storm layers, deposited under lower rates of sediment accumulation and/or intensified storm activity. These beds differ in their dominant lithology, but contain a similar depositional history, progressing from irregular storm layers containing small pods of shell concentrates, to a central body with less distinct or indistinct structures, to a thick, well developed, laterally extensive capping storm layer. Amalgamated beds are separated by intervals of mudstone with thin storm deposits, produced by less intense storm activity, indicating there is a cyclic record of storm activity in the section.

The Main Glauconite bed and Moseley bed have a basal zone containing several distinct storm layers separated by erosional surfaces. Individual storm layers are irregular in thickness and extent, being cut out by later erosional events, and have irregular scour surfaces. The lowest storm layers in this zone have small basal shell masses in pods up to 30 cm (1 ft) across, winnowed from underlying sediments and filling local irregularities or small channels (Figure 8). The basal zone of the Main Glauconite bed is also distinguished by variable sediment composition, with layers varying from quartzose sand to glauconite sand with shells.

The main body of amalgamated beds tends to have obscure bedding, especially in the glauconite-rich beds. In these, burrowing activity by organisms mixed mud with sand and shell and obliterated the bedding, apart from a few layers of larger shell material. Glauconite-rich beds have a high clay content, a material suitable for the formation of pelletal glauconite.

Amalgamated storm units have a capping zone composed of the deposits of a major storm event that eroded and reworked sediment. The capping storm layer on the Main Glauconite bed averages 25 cm (10 in) thick - about 25% of the thickness of the bed; for the inter Glauconite bed it is also about 10 cm (4 in) thick - about 20% of the thickness of the bed; and for the Moseley bed it is about 25 cm (10 in) thick - about 25 % of the thickness of the bed. The capping zone is measured from the scour horizon to the top of the tine grained portion of the storm layer. The scour horizon beneath the capping storm layer of the Main Glauconite bed (in all exposures of the bed) occurs at the top of a prominent zone of large burrows replaced by siderite concretions, about 20 cm (8 in) below the top of the bed. The placement of this scour horizon, localized on the tops of concretions, is strong evidence the burrows had been replaced and lithified *before* the storm event producing the capping layer. The closely spaced lithified burrows probably formed a barrier to deeper erosion by storm action.

Moseley Bed and Maximum Flooding Horizon

The transgressive interval at Stone City Bluff is capped by a maximum flooding horizon, located at the top of the Moseley bed. This resistant, relatively well cemented layer contains a submarine hardground surface (Thornton & Stanton, 1994) which was colonized by encrusting marine organisms requiring a hard substrate for settlement and growth. These organisms encrusted concretions that were winnowed from underlying sediments to form a gravel pavement on the seafloor, subsequently cemented into a hardground layer. Identification of the maximum flooding surface at this level is based on the occurrence of this hardground at the top of an interval deposited under deepening conditions (evidence presented above) and at the base of an interval (Wheelock Member) with coarsening-upward cycles of deposition.

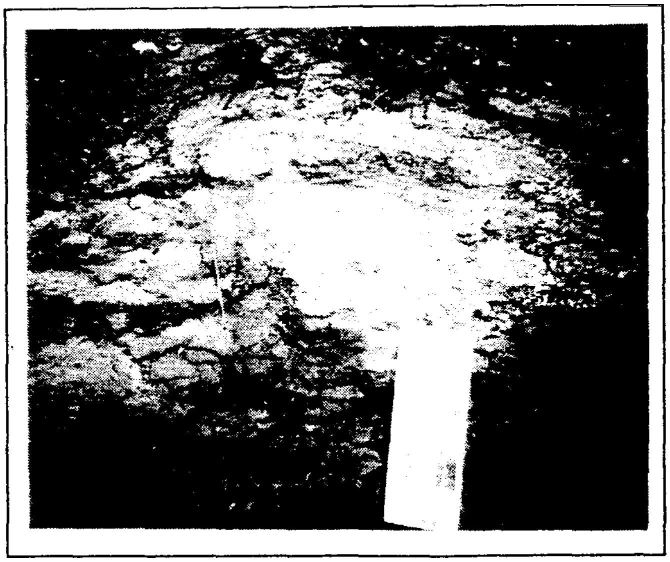

Figure 8. Shells concentrated in local mass at base of storm deposit overlying an irregular scour surface. Base of Moseley bed, top of Stone City Member, Crockett Formation. Scale in cm and inches.

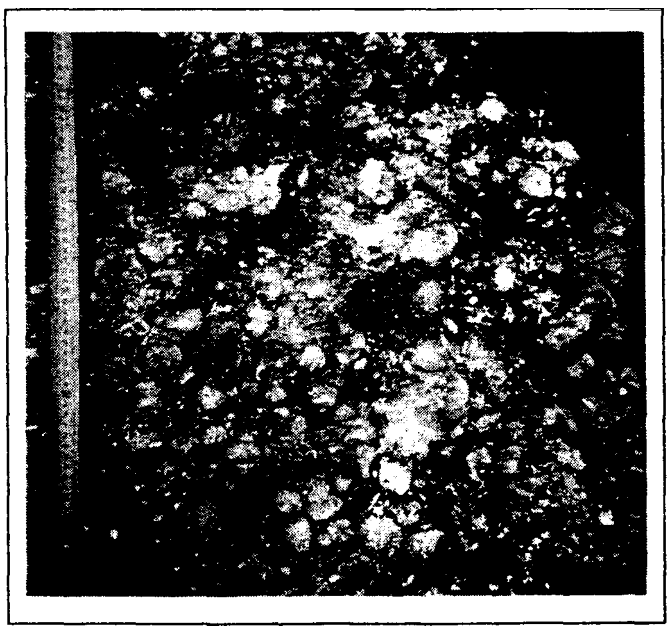

Figure 9. Top surface of Moseley bed, showing concentration of clasts of round concretions winnowed from lower parts of Moseley bed. The bed has been cemented by siderite. This forms the hardground surface at top of the Stone City Member, Crockett Formation. Scale in cm.

Figure 10. Cut section of a clast (reworked concretion) in hardground layer. Note the layers of shell within clast and similarity of clast lithology with surrounding matrix of shelly quartzose sand. Top of Moseley bed, Crockett Formation. Scale in cm.

The Moseley bed is an amalgamated storm unit with a hardground horizon at the top of the main body portion. Other special features include more distinct bedding and a predominantly quartzose sand lithology. Bedding within the Moseley is irregular and not laterally persistent, formed of numerous irregular lenses. Cross-bedded quartzose sand lenses up to 30 cm thick are present, but most layers are much thinner and thin shell-rich layers are present throughout, commonly separated by thin shelly mudstone layers. Some burrowing is apparent, but much of the sand retains depositional lamination. Therefore, the lack of laterally traceable layers is a result of repeated disruption by later storms, not a result of bioturbation.

The hardground horizon is developed on a zone of clasts (Figure 9). Although this was originally identified as a conglomerate

(Stenzel; 1936; Stenzel et al., 1957) that supposedly indicated the presence of a regional erosional unconformity, it developed in a submarine environment. The clasts consist of spherical concretions, formed of cemented shelly sand of the same lithology as the underlying sediment in the main body of the Moseley bed (Figure 10). There are also a few dark, fine-grained concretions of cemented mudstone. The clasts occur in a lag deposit concentrated from underlying sediment, showing that the Moseley deposit was relatively unconsolidated at the time of concentration:

The clast gravel layer was subsequently cemented to produce a hardground surface before deposition of the capping layer. The presence of encrusting organisms on the tops of concretions in the clast zone indicates a period of submarine exposure before being covered. Basal portions of the capping layer contain few concretion clasts, although the deposit does contain some very thickened Cubitostrea shells of much larger size and hydraulic density than the reworked concretions. The clast zone is nearly entirely cemented, whereas the capping layer of glauconitic sand is uncemented.

Dual Sediment Sources

Storm deposits of this section have contrasting sediment sources for basal lags and overlying components. Lag deposits present at the base of many storm layers are derived from local sources and contain a wide variety of skeletal material, concretions, and clasts originally present within the sediments being winnowed. These lags may contain some quartzose sand added from moving bedload, but this does not form the bulk of the deposit. They may also contain a few clasts derived from distant sources (originally deposited as drop-stones from floating or swimming carriers) that were part of the underlying sediment, adding an element of complexity to the lag deposit.

Sands that form the main part of storm deposits, however, were derived from distant sources and moved into the area of deposition during a storm event. They are composed of well sorted quartzose sand that could not be easily produced by winnowing underlying sediment. The only major source of quartzose sand lies shoreward of the glauconite-bearing muds that surround the storm deposits. Fine grained sand is the right size to have been suspended by storm activity and carried offshore

(Duke et a1., 1991). The agreement between observed sediment character and control predicted by storm activity is convincing evidence of distant, shallow water source for the quartzose sands.

Conclusions

The Stone City Member contains the upper part of a transgressive systems tract, including three units of amalgamated storm deposits in the deepest water interval, and is capped by a submarine hardground surface. Sediments in the Stone City Bluff section were deposited in environments progressing from inner shelf settings just offshore of the wave-dominated shorezone to mid shelf settings receiving occasional distal storm deposits. Alternation of amalgamated storm deposit units with units of mudstones containing thin storm deposits indicates a cyclic record of storm activity, with regular variations in storm intensity. The succession of depositional structures indicating change from tidal current control to storm dominance on deposition can be plotted as a ratio of tidal currents to storm deposits, providing an index useful for determining relative water depths of shelfal sediments in areas of high sedimentation rate.

The depositional record of this section is interpreted in the context of open shelf deposition, although depositional units could be fit into a delta model. Assuming that this location was part of a delta is unnecessary, because sedimentary structures seen in the section occur commonly in Paleogene exposures i n the region and are expected on coastlines characterized by high rates of sedimentation. Designating units as delta components (delta-front, prodelta, etc.) is avoided, because no delta geometry could be identified in the outcrop belt and this approach is unnecessary for a good process-oriented determination of depositional conditions. Although determination of depositional environments is usually model-driven, the use of process-scale models rather than regional geometry or facies trend models is more useful in understanding specifics of depositional conditions.

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