Recognition of maximum flooding events in mixed siliciclastic-carbonate systems: Key to global chronostratigraphic correlation

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ABSTRACT

The maximum flooding event within a depositional sequence is an important datum for correlation because it represents a virtually synchronous horizon. This event is typically recognized by a distinctive physical surface and/or a significant change in microfossil assemblages (relative fossil abundance peaks) in siliciclastic deposits from shoreline to continental slope environments in a passive margin setting. Recognition of maximum flooding events in mixed siliciclastic-carbonate sediments is more complicated because the entire section usually represents deposition in continental shelf environments with varying rates of biologic and carbonate productivity versus siliciclastic influx. Hence, this event cannot be consistently identified simply by relative fossil abundance peaks. Factors such as siliciclastic input, carbonate productivity, sediment accumulation rates, and paleoenvironmental conditions dramatically affect the relative abundances of microfossils. Failure to recognize these complications can lead to a sequence stratigraphic interpretation that substantially overestimates the number of depositional sequences of 1 to 10 m.y. duration.

INTRODUCTION

The surface of maximum flooding of Van Wagoner et al. (1988) and Posamentier et al. (1988) within a depositional sequence is an important datum for correlation because this surface represents a virtually synchronous horizon. The utility of the point of maximum transgression in a cycle of sea-level fluctuation was first used as a means of correlation by Israelsky (1949), who expressed it as the maximum depth in a bathymetric cycle as determined by analysis of foraminifera. This practice continues to be employed by geologists mapping subsurface strata; however, these scientists refer to Israelsky's (1949) point of maximum depth as the maximum flooding surface within a depositional sequence (Vail and Wornhardt, 1990).

The surface of maximum flooding is also recognized as the downlap surface on seismic sections which defines the top of the transgressive systems tract and marks the change from retrogradation (transgression) to progradation and aggradation (regression) (Van Wagoner et al., 1988; Posamentier et al., 1988). This turnaround point from transgression to regression is useful for correlation within a bathymetric cycle and is regionally correlative. Xue and Galloway (1995) advocated using regional marine flooding surfaces, rather than depositional sequence boundaries, for definition and correlation of stratigraphic sequences in siliciclastic deposition systems.

The downlap surface may be associated with a surface of maximum sediment starvation, which along with its condensed section, indicates low sediment accumulation rates that may even produce a marine hiatus (Loutit et al., 1988). Condensed sections represent maximum water depths of a depositional cycle and are deposited during a period of maximum relative sea-level rise and maximum transgression of the shoreline (Posamentier et al., 1988). In the absence of sediment accumulation, maximum water depths occur at the time of maximum accommodation (Loutit et al., 1988).

The recognition of maximum flooding events in mixed siliciclastic-carbonate systems is more complicated in that the entire section represents deposition in marine environments characterized by varying rates of biologic and carbonate productivity versus siliciclastic influx.

MAXIMUM FLOODING SURFACE

The synchronous nature of maximum flooding surfaces and their associated condensed sections can be illustrated by studying depositional sequences in the Gulf and Atlantic coastal plains. For each of the recognized sequences, beds immediately above maximum flooding events rest within the same biozone. This is not the case for first transgressive surfaces or sequence boundaries associated with these depositional sequences. These diachronous physical surfaces are time transgressive, the strata above each disconformity becom-

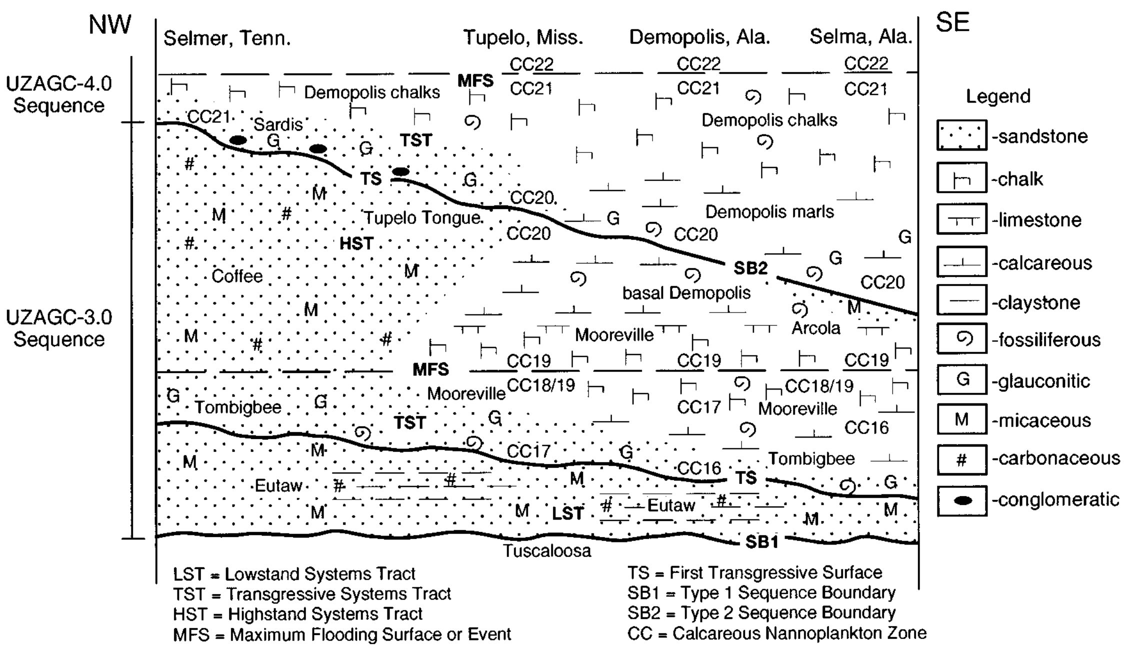


Figure 1. Schematic cross section illustrating synchroneity of maximum flooding surfaces and diachroneity of sequence boundaries and initial transgressive surfaces in Upper Cretaceous strata of the Gulf Coastal Plain (modified from Mancini et al., 1996).

ing progressively younger from the shelf to the shoreline (Fig. 1).

The maximum flooding event may be marked by a distinctive physical surface but often is recognized by a change in microfossil assemblages (Mancini et al., 1987, 1996). Associated condensed sections consist of characteristic limestone or chalk beds. The dominance in carbonate probably reflects maximum accommodation and highest relative sea level with minimum siliciclastic sediment influx.

Because of the synchronous nature of the maximum flooding event and associated condensed section deposits, this event and these beds have chronostratigraphic significance and potentially can be used for global correlation. The difficulty arises in the identification of a maximum flooding surface, particularly in mixed siliciclastic-carbonate systems.

RECOGNITION OF MAXIMUM FLOODING EVENTS

Maximum flooding events are most frequently recognized by relative abundance peaks of microfossils (Vail and Wornhardt, 1990). Other means of recognition may include gamma-ray signature, physical surfaces, petrologic characteristics, type of organic matter, and stable isotope signatures (Baum and Vail, 1988; Loutit et al., 1988; Pasley and Hazel, 1990). For Paleogene strata of the Gulf and Atlantic coastal plains, the identification of relative abundance peaks of microfossils is a reasonable means to recognize maximum flooding events.

For example, the contact of the upper Eocene (Priabonian) Yazoo Clay with the lower Oligocene (Rupelian) Red Bluff Clay has been described as a maximum flooding surface and surface of maximum sediment starvation (Mancini et al., 1987; Loutit et al., 1988; Baum and Vail, 1988; Pasley and Hazel, 1990; Tew and Mancini, 1995). The upper Yazoo Clay beds represent part of a stratigraphically condensed section and record sediment starvation on the outer shelf at maximum transgression of the shoreline (Loutit et al., 1988; Tew and Mancini, 1995). The lowest amounts of terrestrial organic matter exhibiting the highest degree of degradation (Pasley and Hazel, 1990) and the highest percentage of planktonic foraminifera and outer neritic benthic foraminifera (Mancini et al., 1987) occur in the upper Yazoo beds (Fig. 2). The Red Bluff Clay beds contain higher amounts of structured terrestrial organic matter (Pasley and Hazel, 1990) and a lower percentage of planktonic foraminifera (Mancini et al., 1987). The maximum flooding event signals the change from overall transgression to overall regression within this depositional sequence. In this section, this event is characterized by a burrowed surface representing a marine hiatus of 288 000 yr, based on graphic correlation methods (Pasley and Hazel, 1990). This example is typical of Paleogene depositional sequences in siliciclastic-dominated systems in the Gulf and Atlantic coastal plains.

However, in Upper Cretaceous carbonate-siliciclastic strata along these same passive margins, the maximum flooding event cannot be recognized simply by relative fossil abundance peaks. Factors such as siliciclastic sediment influx, carbonate productivity, sediment accumulation rates, and paleoenvironmental conditions (bathymetry, distance from shoreline, etc.) dramatically affect the relative abundances of microfossils. Sediment accumulation rates may have a major impact on the timing of changes in water depths; minor siliciclastic input into a basin delays the effects of a maximum rate of eustatic rise (Loutit et al., 1988).

For example, in the Santonian-Campanian Eutaw Formation–Mooreville Chalk–Demopolis Chalk depositional sequence, there are three distinct relative fossil abundance peaks (Fig. 3). These peaks are interpreted to reflect the first significant marine flooding event, the change from siliciclastic-dominated sedimentation to carbonate-rich deposition, or the maximum flooding event in the depositional sequence. The key to identifying the maximum flooding event is in recognizing the trend shift from high counts of planktonic foraminifera to lower counts. In addition, the benthic foraminiferal assemblages for each systems tract are distinct. If one utilizes only the relative fossil abundance peaks and ignores the lithologic, sequence stratigraphic, and paleoecologic changes recorded in this depositional sequence of 9 m.y. duration, three sequences could be inferred for these Santonian-Campanian strata. However, these sequences would lack the characteristic systems tracts and associated physical surfaces of the third-order depositional sequences described by Haq et al. (1988). Globally, Haq et al. (1988) recognized five sequences for this late Santonian–early Campanian time interval, whereas Hancock (1993) reported two trans-

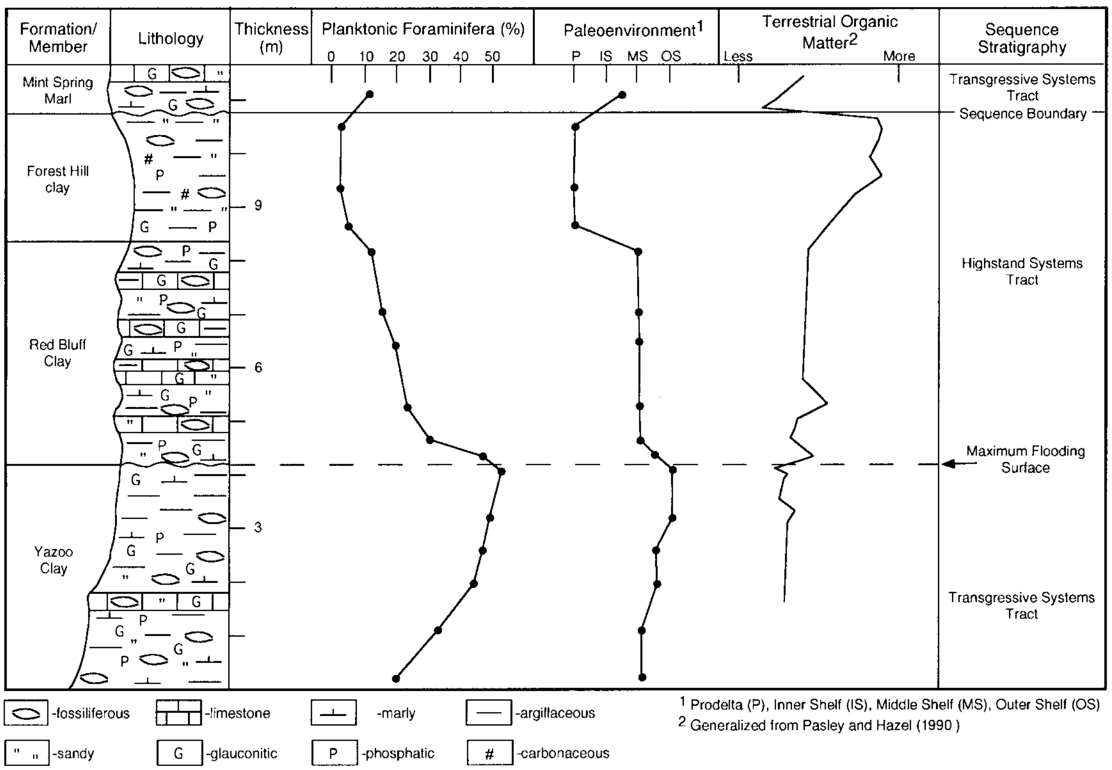


Figure 2. Vertical changes in relative abundance of planktonic foraminifera, in paleoenvironments as recognized by benthic foraminiferal assemblages, and in amounts of terrestrial organic matter across maximum flooding surface in upper Eocene and lower Oligocene siliciclastics of Gulf Coastal Plain (modified and compiled from Mancini et al., 1987; Pasley and Hazel, 1990; Tew and Mancini, 1995).

gressive peaks for this time period in strata from Europe and North America. Furthermore, because only the maximum flooding event represents an essentially synchronous horizon, use of the relative fossil abundance peaks, resulting from the first significant marine flooding event or siliciclastic-carbonate sediment transition, for stratigraphic correlation will produce conflicting results.

Maximum flooding surfaces can be difficult to discern in pure carbonate sequences. In carbonate systems, the maximum flooding event may be associated with a catch-up system, which is characterized by a low rate of carbonate accumulation (Sarg, 1988). This is the case with the Upper Jurassic carbonates of the Gulf Coastal Plain (Mancini et al., 1993).

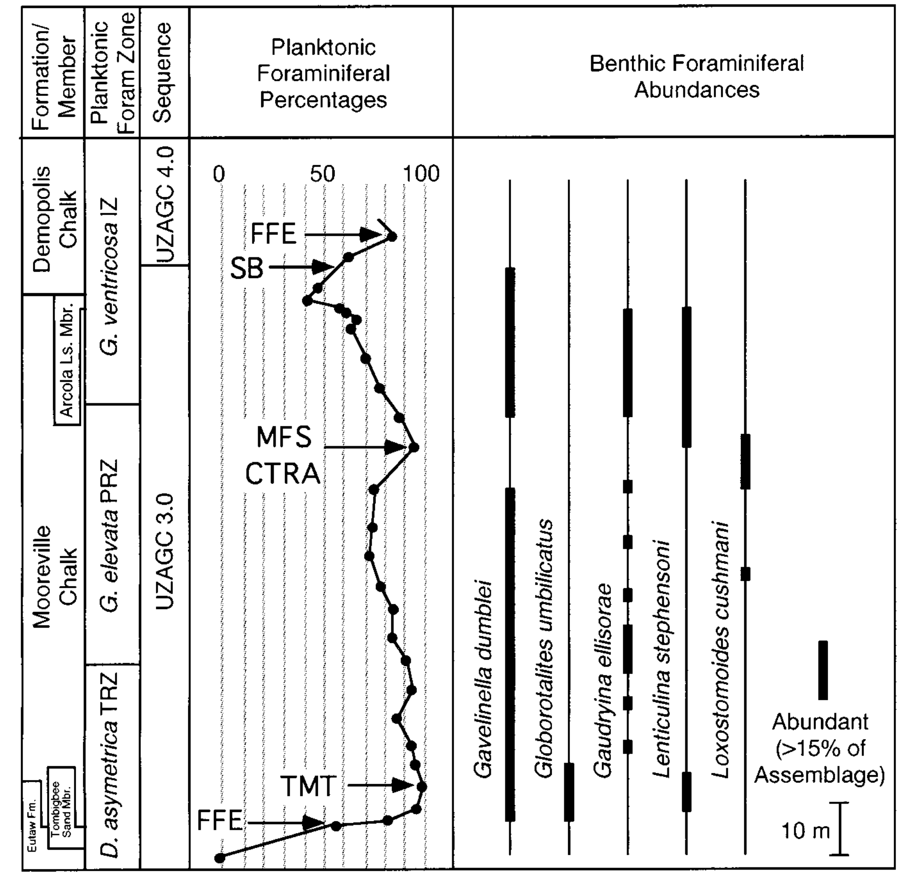
For example, the Upper Jurassic (Oxfordian) Smackover Formation consists of 140 m of limestones and dolostones in the Gulf Coastal Plain. The lower and middle carbonate mudstones of this formation are part of a catch-up system. These rocks accumulated in intertidal to subtidal environments characterized by high biologic productivity (Mancini et al., 1993). The marine organic matter is concentrated in the condensed section deposits associated with the maximum flooding event (Fig. 4). Although no physical surface is observed in cores from the Smackover Formation, the maximum flooding event is recognized by a relative abundance of organic carbon.

DISCUSSION AND CONCLUSIONS

In the Gulf and Atlantic coastal plains, the Paleogene was typified by widely fluctuating climates and dynamic changes in depositional conditions. Depositional sequences represent relatively short durations of geologic time and were greatly affected by differential rates of siliciclastic sedimentation. In the eastern Gulf Coastal Plain, a Paleogene sediment-accumulation rate of 2.3 cm/ 1000 yr is common (Mancini and Tew, 1993). Usually, only the transgressive systems tracts and associated condensed sections were characterized by marine depositional conditions.

The Paleogene section in the Gulf Coastal Plain includes 762 m of principally siliciclastic sediments and is characterized by 21 genetic deposition sequences of 0.5 to 5 m.y. duration (Mancini and Tew, 1991). These deposits accumulated under rapidly fluctuating sea-level conditions. A Paleogene delta complex that periodically prograded onto a shallow continental shelf from west to east dominated deposition.

These climatic, sedimentologic, and paleoenvironmental conditions were conducive to producing short duration depositional sequences with maximum flooding events that are recognizable by the relative abundance peaks of microfossils (Fig. 2). The identification and use of relative fossil abundance peaks as signatures for the maximum flooding events in these shoreline to slope, siliciclastic-dominated deposits are reasonable. These relative abundance peaks are useful for re-



SB=Sequence Boundary MFS=Maximum Flooding Surface or Event FFE-First Significant Marine Flooding Event TMT=Tombigbee-Mooreville Transition CTRA=Change in Trend of Relative Abundance

Figure 3. Vertical changes in relative abundances of planktonic and benthic foraminifera in Upper Cretaceous mixed carbonate-siliciclastic depositional sequence of Gulf Coastal Plain (modified and compiled from Mancini and Soens, 1994; Gan, 1996; Mancini et al., 1996).

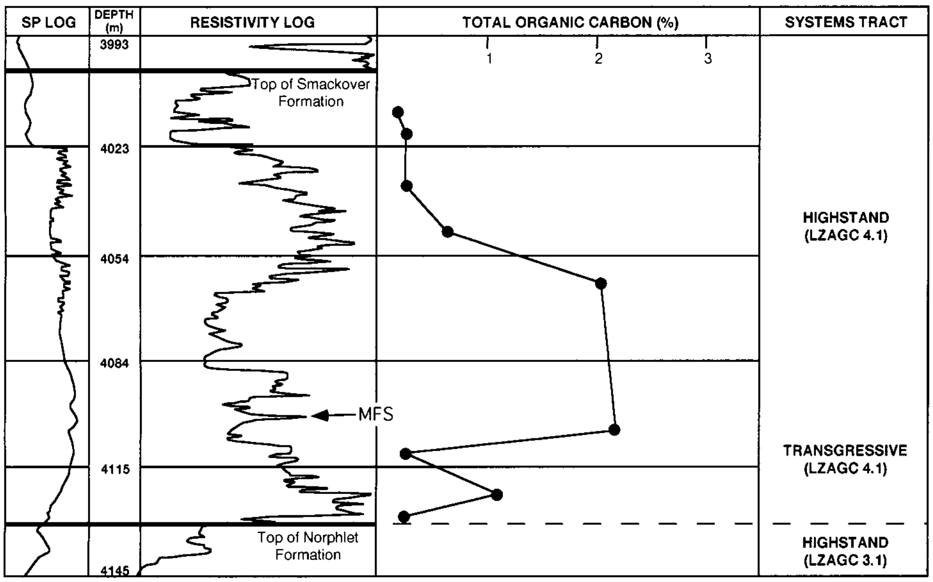


Figure 4. Vertical changes in spontaneous potential (SP) and resistivity log patterns and in total organic carbon content across maximum flooding surface in Upper Jurassic Smackover carbonates in subsurface of Gulf Coastal Plain (modified from Mancini et al., 1993).

gional correlation and have potential for global correlation. Starvation surfaces and condensed sections are rarely developed as a part of these sequences because these deposits generally accumulated under nearshore depositional conditions which included relatively high sediment accumulation rates. Under these conditions, the maximum flooding event closely approximates the point of maximum rate of eustatic rise (Loutit et al., 1988).

On the other hand, the Upper Cretaceous section includes 270 m of carbonates and siliciclastics and exhibits three cycles of 4 to 9 m.y. duration (Mancini et al., 1996). These sediments accumulated under universally warmer and more stable climatic conditions during an overall highstand in sea level characterized by relatively slow changes. Siliciclastic sediment influx into the area during this time was relatively minor. These sequences represent longer periods of geologic time, resulted from lower sediment accumulation rates, and, generally, reflect continental-shelf, normal-marine paleoenvironmental conditions. An Upper Cretaceous sediment-accumulation rate of 1.6 cm/1000 yr is common in the eastern Gulf Coastal Plain. Paleowater depths never exceeded 40 or 50 m in these shelf environments (Puckett, 1995). Because of the low siliciclastic influx, maximum water depths were sustained and are reflected in high counts of planktonic organisms into the highstand systems tract deposits.

Time duration, in combination with differential subsidence, climate, and sediment supply (carbonate productivity versus siliciclastic input), has a significant impact upon the degree of development of these systems tracts and associated events. The sediment accumulation rates and patterns, stable depositional conditions, and high biologic productivity during the Late Cretaceous result in a stratigraphic section that has potential as a standard for global correlation. These Upper Cretaceous mixed carbonate-siliciclastic sequences are assigned to more than one biozone (Figs. 1, 3), indicating accumulation over a relatively long period of geologic time with low siliciclastic sedimentation rates and stable paleoenvironmental conditions conducive to high carbonate productivity. Such conditions resulted in highly developed systems tracts, distinct physical surfaces and recognizable marine flooding events useful for high-resolution sequence analysis.

However, the presence of relative fossil abundance peaks in these depositional sequences can be attributed to factors other than the conditions associated with a maximum flooding event. Paleoecological conditions are favorable, during a first significant marine flooding event and at the change from siliciclastic-dominated sedimentation to carbonate-rich deposition, for high biologic productivity and carbonate accumulation in these Upper Cretaceous strata. Failure to recognize these other possibilities can lead to an interpretation that significantly overestimates the number of depositional sequences of 1 to 10 m.y. duration. For example, Haq et al. (1988) reported nine depositional sequences for the late Santonian-Maastrichtian time interval, whereas Mancini et al. (1996) have documented the occurrence of only three genetic depositional sequences of 4 to 9 m.y. duration in mixed siliciclastic-carbonate sediments of the eastern Gulf Coastal Plain. The key to identifying the maximum flooding event in a given genetic depositional sequence in a mixed siliciclastic-carbonate system is recognition of the overall trend shift from high counts of planktonic foraminifera to lower counts, accompanied by changes in the benthic foraminiferal assemblages, and the identification of the characteristic systems tracts and their associated bounding surfaces. With the delineation of the maximum flooding event, the stratigrapher has an essentially synchronous event for potential global interbasin correlation.

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