Distinguishing the roles of autogenic versus allogenic processes in cyclic sedimentation, Cisco Group (Virgilian and Wolfcampian), north-central Texas

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ABSTRACT

Meter-scale transgressive-regressive cycles of the subsurface Cisco Group are composed of marine and nonmarine carbonate and siliciclastic rocks deposited on the Eastern shelf of the Midland basin during Late Pennsylvanian and Early Permian time. Five cycle types are characterized by thickness, magnitude, order, and principal lithofacies. Cycle magnitude is defined as the maximum facies shift in a cycle, indicating extent of shoreline migration. Cisco cycles belong to three orders—minor, intermediate, and major—and they are superimposed and form a stratigraphic hierarchy. Each order of cycles has a distinct range of thickness and possibly duration. A cycle is also divided into a lower sand-poor interval, during which coarse siliciclastic supply at the depositional site was diminishing, and an upper sand-rich interval, during which coarse siliciclastic supply was high. Regional thickness and lithofacies variations of sand-rich intervals indicate that progradational infilling at a depositional site lagged marine regression, suggesting a delay in sediment supply from the upland source relative to the time of base-level fall.

Regional systematic variations in cycle abundance, continuity, and characteristics along depositional dip and strike record the interplay among regional topography, pattern of siliciclastic supply, and shelf subsidence, which controlled distribution of depocenters and bypass zones and, thus, stratigraphic completeness and resolution. Regional persistence of cycles suggests a eustatic control on regional, ordered transgressive-regressive events. In contrast, local variations of cycle characters suggest controls by local topography and depositional dynamics, which determined depositional loci, differential compaction, and erosion. A predominantly autocyclic Cisco record in the upper platform does not imply the absence of allogenic processes. An allocyclic Cisco record in the lower platform contains abundant autocyclic imprints, because allogenic controls on cyclic sedimentation were accomplished through local autogenic processes. Distinguishing the roles of autogenic versus allogenic processes in cyclic sedimentation is an important step in establishing a high-resolution (meter-scale) chronostratigraphy of any sedimentary record[1].

INTRODUCTION

Meter-scale depositional cycles are fundamental stratigraphic entities. Cyclicity at this scale is commonly defined by stratal repetition of physical and chemical characters of sedimentary rocks, such as lithofacies, biofacies, and stable isotopic composition. Temporal regularity of depositional cyclicity, which may be derived from stratigraphic regularity, is the basis for establishing a high-resolution cyclostratigraphy (e.g., Herbert, 1992; Hinnov and Goldhammer, 1991; House and Gale, 1995; Yang et al., 1995). Stratigraphic regularity, however, is commonly altered or destroyed by the complex dynamics of processes controlling deposition and erosion, as demonstrated in this study.

Stratigraphic regularity is controlled by the interplay of many autogenic and allogenic processes in cyclic sedimentation (e.g., Wanless and Shepard, 1936; Galloway, 1971). The two types of processes are separable by their physical scales. Allogenic processes operate at a basin-wide or global scale, such as sea-level change, basin-wide tectonics, and regional climatic change, whereas autogenic processes operate locally, such as those intrinsic to specific depositional or geomorphic environments. Autogenic and allogenic processes interact and produce cycles of variable characteristics. Thus, differentiation of local vs. regional and short-term vs. long-term variations of cycle characteristics is critical to establishing a reliable high-resolution cyclostratigraphy (Schwarzacher, 1993).

In this study we analyzed the formation, destruction, and preservation of meter-scale cyclicity of the Cisco Group by examining three-dimensional variation of cycle characteristics, including cycle abundance, continuity, type, magnitude, thickness, and variation in siliciclastic supply. The mechanisms of allogenic and autogenic processes in cyclic sedimentation are demonstrated through cycle correlation. This study also displays the stratigraphic variability of late Paleozoic cyclothems that could be missed in a one- or two-dimensional analysis.

GEOLOGIC SETTING AND PREVIOUS WORK

The Cisco Group is composed of nonmarine and marine, mixed carbonate and siliciclastic rocks deposited on the shallow and stable Eastern shelf of the Midland basin, north-central Texas, during Late Pennsylvanian and Early Permian time (Figs. 1, 2, and 3; Lee, 1938; Wermund and Jenkins, 1969; Brown et al., 1990). Deposition of the Cisco Group was influenced by a variety of local and regional processes, such as carbonate and siliciclastic depositional dynamics, climate,

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[1]Please contact the senior author to obtain six complete stratigraphic and structural cross sections of this study.

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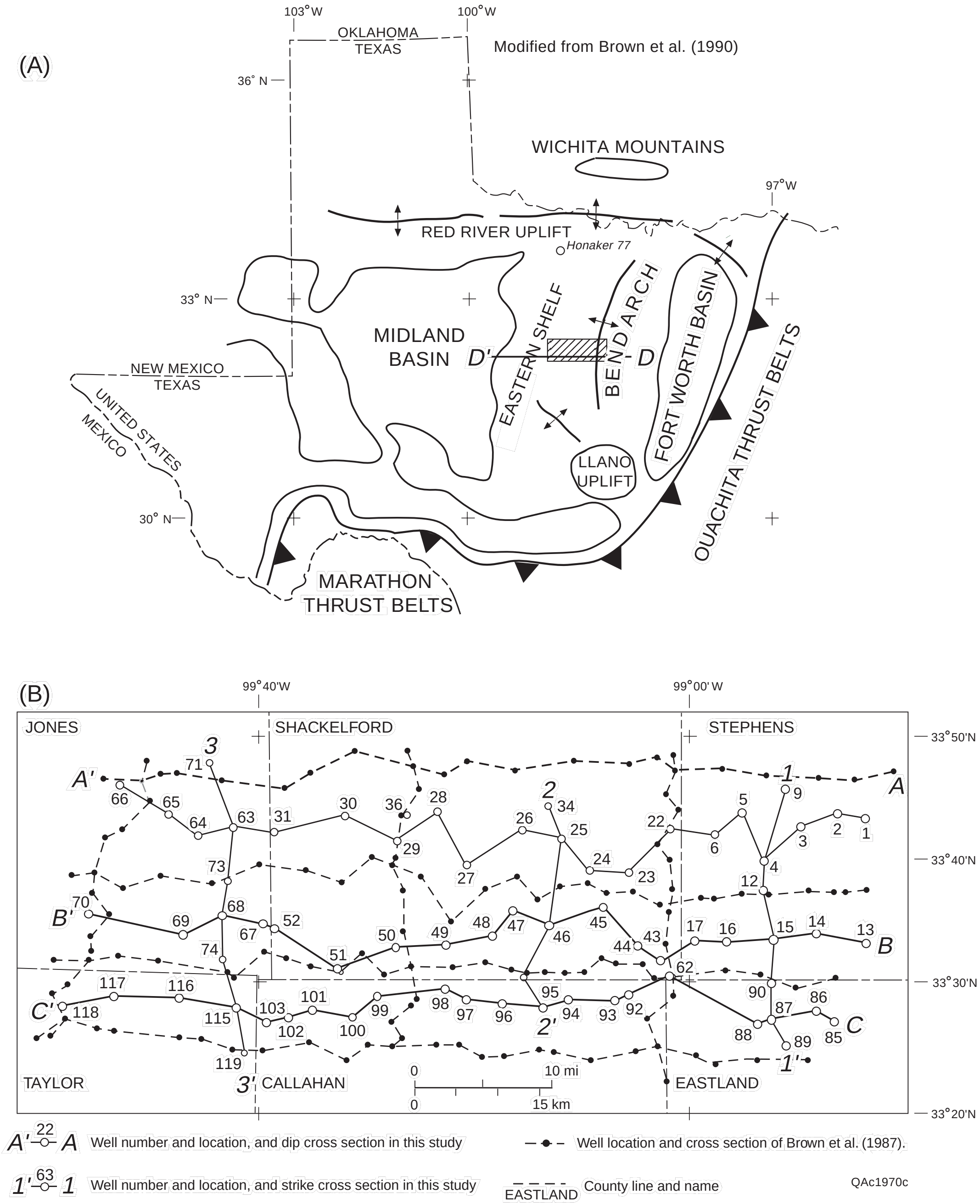


Figure 1. (A) Tectonic elements of north-central Texas and location of study area (hachured). (B) Location of wells and cross sections in this study, including those of Brown et al. (1987).

and sea-level change, which controlled sediment supply and accommodation space with an evolving depositional topography (e.g., Lee, 1938; Brown, 1969; Galloway, 1971; Harrison, 1973; Brown et al., 1987, 1990; Boardman and Heckel, 1989; Yang, 1995, 1996).

Previous cyclostratigraphic studies of the Cisco Group have concentrated on cycle delineation and regional correlation of fragmentary outcrop sections, resulting in limited understanding of the interplay among autogenic and allogenic processes (e.g., Lee, 1938; Boardman and Malinky, 1985; Boardman and Heckel, 1989; Yancey, 1991). This study uses subsurface data to provide a more complete three-dimensional description of Cisco cyclostratigraphy and a more thorough assessment of autogenic and allogenic controls on cyclic sedimentation of the Cisco Group.

DATA AND METHODOLOGY

Three dip and three strike cross sections of the Cisco Group covering ~35 × 100 km^2 (Fig. 1) were constructed, using 71 wells. Average well spacing is 5 km. Dip cross sections begin at the outcrop belt in the updip part of the shelf and extend basinward to the west. The study area is also covered by cross sections of Brown et al. (1987; Fig. 1B). They correlated 23 regional limestones in ~5000 wells on the Eastern shelf with those in the outcrop to establish a stratigraphic framework composed of 16 depositional sequences (Figs. 2 and 3). In our study we identified and correlated these limestones in 71 wells with the ~270 wells of Brown et al. (1987) and with outcrop counter-

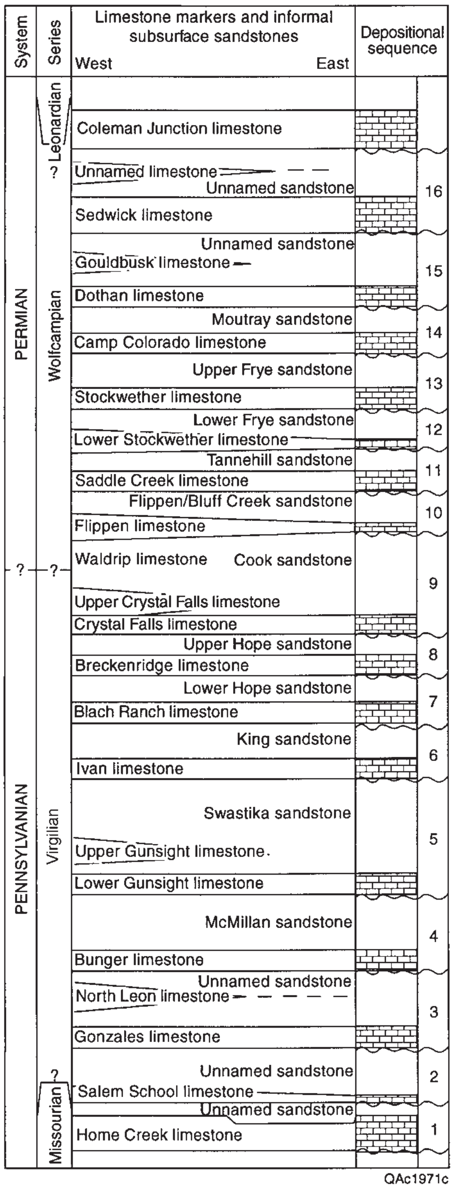


Figure 2. Operational nomenclature, Virgilian and Wolfcampian Series in the subsurface Eastern shelf. No vertical scale is intended. Depositional sequences bounded by unconformities (wavy lines) of Brown et al. (1990) are shown. Modified from Brown et al. (1990).

parts to identify major stratigraphic intervals. Subsequent cycle delineation and correlation were conducted within this framework.

Lithofacies were interpreted mainly on gamma-ray and resistivity logs. Typical signatures of various lithofacies and inferred depositional environments were established by log calibration of ~1500 m of Cisco Group core (Fig. 4). Lithofacies include nonmarine paleosol, fluvial, delta-plain, and marginal marine siliciclastic rocks, shallow-marine siliciclastic and carbonate rocks, and basin-slope shales. Log patterns established by Brown et al. (1987) and other workers (e.g., Dresser Atlas, 1974; Schlumberger, 1987; Serra, 1985, 1986) and characteristics of 188 Cisco cycles in outcrop (Yang, 1995) also serve as important guidelines for log interpretations.

CYCLE CHARACTERISTICS

Observed and interpreted characteristics of more than 1000 cycles include component lithofacies, type, magnitude, thickness, order, and intracycle sediment-supply variations. Correlation of these characteristics along depositional dip and strike establishes the three-dimensional cycle architecture and trends of cyclic sedimentation to be used to analyze the roles of autogenic and allogenic processes in cyclic sedimentation.

Component Lithofacies

A composite Cisco cycle has a sharp base. Early-transgressive, thin carbonaceous shales and lignites are overlain by sandstones and shales that become increasingly calcareous. Some clean and porous sandstones coarsen upward, suggesting that they were well washed and reworked in transgressive, upper shoreface to barrier bar environments (Fig. 5, A and C). Limestones overlie these siliciclastic rocks, many of which consist of a lower transgressive limestone and an upper regressive limestone separated by a thin shale or shaly carbonate (Fig. 5, B and D). The shale is equivalent to the maximum-transgressive core shale of midcontinent “Kansas-type” cyclothems and separates the transgressive interval from the regressive interval of a cycle (Heckel, 1977).

Regressive calcareous shales overlie limestones and commonly contain thin to moderately thick, upward-fining sandstones. The sandstones are probably lower shoreface or shelf sand ridge deposits. They are overlain by thin to thick, shoreface and prodeltaic shales (Fig. 5, B and D). They become increasingly sandy, grade into upward-coarsening and upward-thickening, delta-front sandstones and shales, and finally, massive channel-mouth-bar sandstones.

Some channel-mouth-bar sandstones are multistoried. They are overlain by delta-plain shales intercalated with sandstones and, in some cases, by thick distributary channel sandstones (Fig. 5A). Fluvial sandstones and shales of levee, crevasse-splay, and flood-plain environments occupy the upper regressive interval. Thick, upward-fining and upward-thinning, or massive, fluvial channel sandstones are common; some are multistoried, and some are in sharp contact with underlying limestones (Fig. 5C). Calcareous and sandy shales, which have irregular log patterns and may contain thin, very calcareous layers in the uppermost regressive interval, are calcareous paleosols formed on fluvial and delta-plain sediments (Fig. 5D). It should be emphasized that many cycles consist of only a subset of the lithofacies in a composite cycle.

Cycle Type, Magnitude, Thickness, Duration, and Order

A couplet of upward-deepening and upward-shallowing trends of depositional environments defines a transgressive-regressive cycle (Figs. 4 and 5). Principal component lithofacies, i.e., transgressive and regressive limestones, and maximum-transgressive core shale, define five cycle types, as defined from outcrops (Yang, 1996) (Fig. 6A). Type I cycles consist of all three principal lithofacies, type II cycles do not contain core shale, type III cycles do not contain transgressive limestone, type IV cycles do not contain regressive limestone, and type V cycles do not contain any limestones (Figs. 5 and 6A). Types III, IV, and V may or may not contain core shale; they are not as common in the subsurface as in outcrop, partly owing to uncertain log interpretation of core shales (Fig. 5). Cycle type signifies lithofacies variations among cycles (Yancey, 1991; Yang, 1996).

Cycle magnitude is defined as the maximum facies shift over the transgressive or regressive interval of a cycle (Fig. 6B; Yang, 1996). It indicates the maximum extent of shoreline movement over a cycle. Type I cycles generally have high magnitude, whereas type V cycles have low magnitude.

Cycle thickness ranges from less than 3 to 90 m. It approximates, to the first order, cycle duration. Assuming steady rates of shoreline transgression and regression and a constant sedimentation rate for all lithofacies, cycles of high magnitude and large thickness should have long duration. Cycle thickness is also a first-order approximation of accommodation space.

Three orders of cyclicity—major, intermediate, and minor—are observed. Cycle magnitude, thickness, and stacking pattern determine the order of a cycle. Cycle duration is not used explicitly to define cycle orders because it is a function of cycle magnitude and thickness. Within a major cycle, however, minor cycles have smaller duration than intermediate cycles, which have smaller duration than the major cycle. Orders of cyclicity probably represent the degree of perturbation of processes driving transgression and regression.

The relationship among minor, intermediate, and major cycles is one of superimposition in terms of thickness and magnitude (Fig. 6B). This relationship, however, is commonly complicated

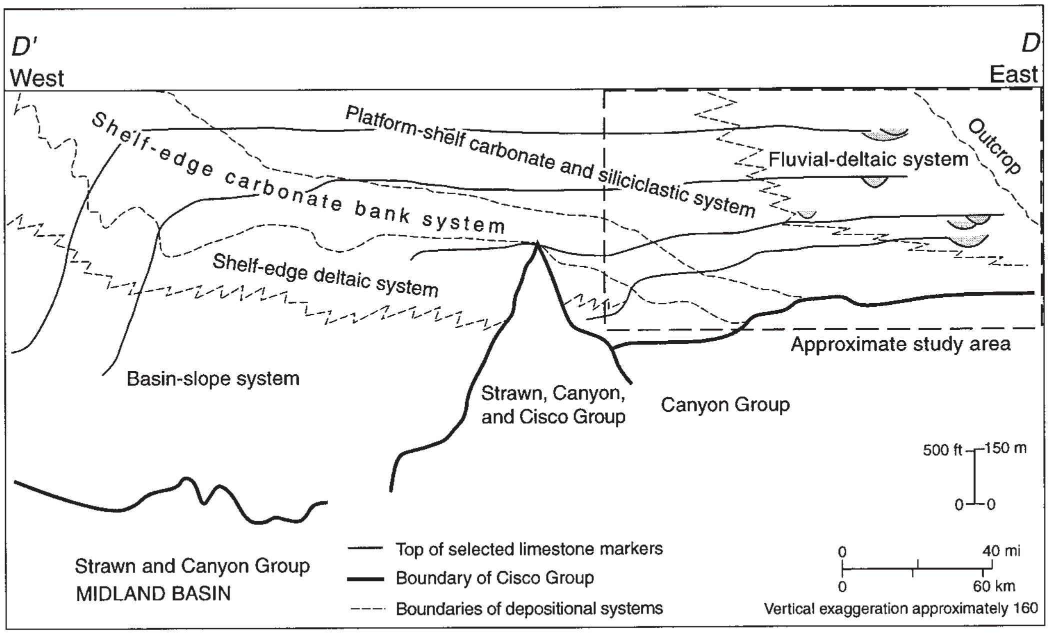


Figure 3. Dip stratigraphic cross section of the Cisco Group showing the progradational and aggradational configurations of the Eastern shelf and depositional systems of the Cisco Group. Location is shown in Figure 1A. Horizontal scale is approximate. Highly simplified from section D–D′ of Brown et al. (1990).

by lateral variations in cycle magnitude, thickness, and cycle absence. Minor cycles are thin, only several meters thick. Their facies shifts occur mainly in marine environments and are generally small (Figs. 6B and 7). Intermediate cycles are several to tens of meters thick, with large facies shifts from marginal marine or nonmarine to marine (Figs. 6B and 7).

An intermediate cycle commonly contains two to three minor cycles. For example, the Ivan no. 1 and no. 2 minor cycles and the Breckenridge no. 1 and no. 2 minor cycles in well 27 constitute two intermediate cycles, respectively (Fig. 7). The minor cycle located in the regressive interval of an intermediate cycle, such as the Gunsight no. 2 cycle in well 30, has a large regressive facies shift or magnitude, which is equal to that of the intermediate cycle itself (Figs. 6B and 7). The minor cycles in an intermediate cycle may be absent in the adjacent well, where only one minor cycle remains to define the intermediate cycle (Fig. 7). This intermediate cycle can be regarded as consisting of no minor cycles or only one minor cycle. Here the latter view is taken. For example, the intermediate cycle containing Bunger no. 1 and no. 2 minor cycles in well 27 contains only the Bunger no. 1 cycle in well 24 (Fig. 7).

Major cycles are tens to hundreds of meters thick with large facies shifts. They contain one or more intermediate cycles. Some contain only one intermediate cycle that itself contains only one minor cycle, such as the Ivan and Blach Ranch major cycles (Fig. 7). On the platform, major cycles usually conform with the third-order depositional sequences of Brown et al. (1990).

In summary, minor cycles are the building blocks of intermediate and major cycles. The three orders of cycles form a stratigraphic hierarchy. Complication of cycle ordering by variations in type, magnitude, thickness, and cycle absence can be resolved through cycle correlation (Fig. 7).

Trend of Siliciclastic Sediment-Supply Variations

Many Cisco cycles can be divided into two intervals, sand rich and sand poor, as an alternative subdivision to the more interpretive transgressive and regressive intervals of a cycle. Commonly, but not always, a significant increase of coarse siliciclastic supply at a depositional site indicates the approach of a clastic sediment source to that site, whereas a decrease indicates retreat of the source. This subdivision scheme uses depositional site as the reference point, emphasizing processes operating at the site. It facilitates discussion of the timing, type, and amount of siliciclastic supply in cyclic sedimentation in mixed carbonate and siliciclastic environments.

The sand-poor interval occupies the lower part of a cycle (Figs. 4, 5, and 6). It consists of transgressive siliciclastic and carbonate rocks, as well as regressive carbonate rocks and marine to marginal marine siliciclastic rocks. The siliciclastics are mostly shale and siltstone; sandstones are thin and shaly. An overall upward-fining log pattern is typical of this interval. The presence of carbonate rocks and a small amount of sandstone indicates minimal siliciclastic supply at the site, and the upward-fining pattern indicates a diminishing supply of coarse sand over this interval, especially after the deposition of regressive limestones (Figs. 4, 5, and 6B). Sandstones of marine and marginal marine origin are probably derived mainly from coarse-grained sediments of the underlying cycle and were transported by longshore currents to the depositional site.

The sand-rich interval occupies the upper part of a cycle. It consists of late and maximum regressive siliciclastics of deltaic and fluvial origin. An overall upward-coarsening and upward-thickening log pattern is typical. Sands were mainly land derived and transported to the depositional site by rivers. The boundaries between sand-poor and sand-rich intervals are commonly gradational and generally placed at the base of delta-front sandstones. Gradational boundaries suggest a gradual approach of a clastic sediment source toward the site.

The sand-rich interval is thinner than the regressive interval (Figs. 4, 5, and 6B). Transgression is defined as landward shoreline movement, and regression is defined as seaward shoreline movement. This relationship suggests that significant siliciclastic supply to a depositional site occurred sometime after shoreline regression. This agrees with the outcrop observation that sediment supply at a site lags sediment yield in the source area (Yang, 1996). Moreover, the sand-rich interval is absent in some cycles, especially minor cycles, indicating that landward sediment supply is insignificant and/or that the site is distant from major depositional loci during late and maximum regression.

Most intermediate and major cycles contain a sand-rich interval because they have a relatively long period of regression for significant progradation of coarse sediments to the depositional

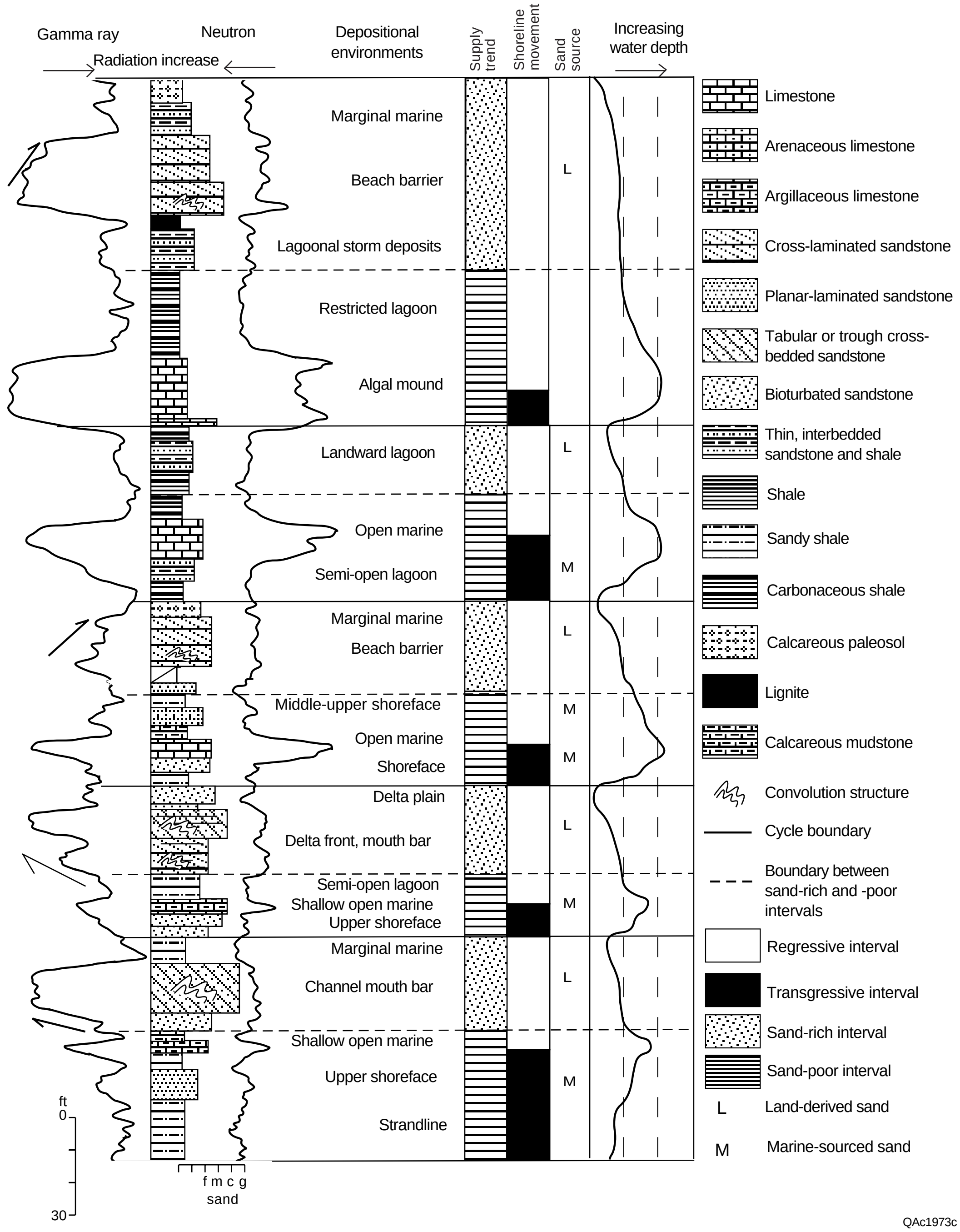


Figure 4. Lithology, depositional environments, and wireline logs of Honaker 77 core in Wichita County (Fig. 1A) as an example of log calibration. Cycles and their subdivisions are delineated from lithofacies and trends of environment and water-depth changes. All cycles are type II according to the classification scheme in Figure 6A.

site. Regional correlation of the lithofacies and thickness of sand-rich intervals displays the changing pattern of sediment supply on the Eastern shelf in cycle development.

CYCLE CORRELATION

Cycle Correlation on Stratigraphic Dip Cross Sections (Figs. 8, 9, and 10)

Topography. The top of the Home Creek interval outlines the pre-Cisco depositional topography (Fig. 11). The shelf consists of platform, shelf edge, and basin slope. The platform dips gently to the west and has broad highs and lows. A prominent high at well 29 on A–A′ is caused by a shelf-edge carbonate buildup underneath the Home Creek interval; the high at the east end of B–B′ corresponds to an underlying carbonate bank (Brown et al., 1987; Figs. 3 and 11). The shelf edge dips abruptly basinward, and two shelf breaks are present. The area between the breaks is monoclinal in B–B′ and C–C′, and is a deep trough in A–A′ (Fig. 11). The steep basin slope shallows to the west. A complete basin-to-slope topography is seen in the lower Cisco Group (Fig. 11).

The shelf edge migrated westward in steps (Fig. 11). It aggraded during carbonate-rich deposition, generating a large basin-slope accommodation space. Shelf-edge progradation followed as deltaic and fluvial sediments progressively filled the space. Apart from the overall shelf edge migration, some major pre-Cisco topographic features, such as the two shelf breaks on A–A′, persisted during most of the Cisco Group time (Fig. 8).

The upper Cisco Group topography could be related to the precedent topography or could have been caused by regional structural upwarping or

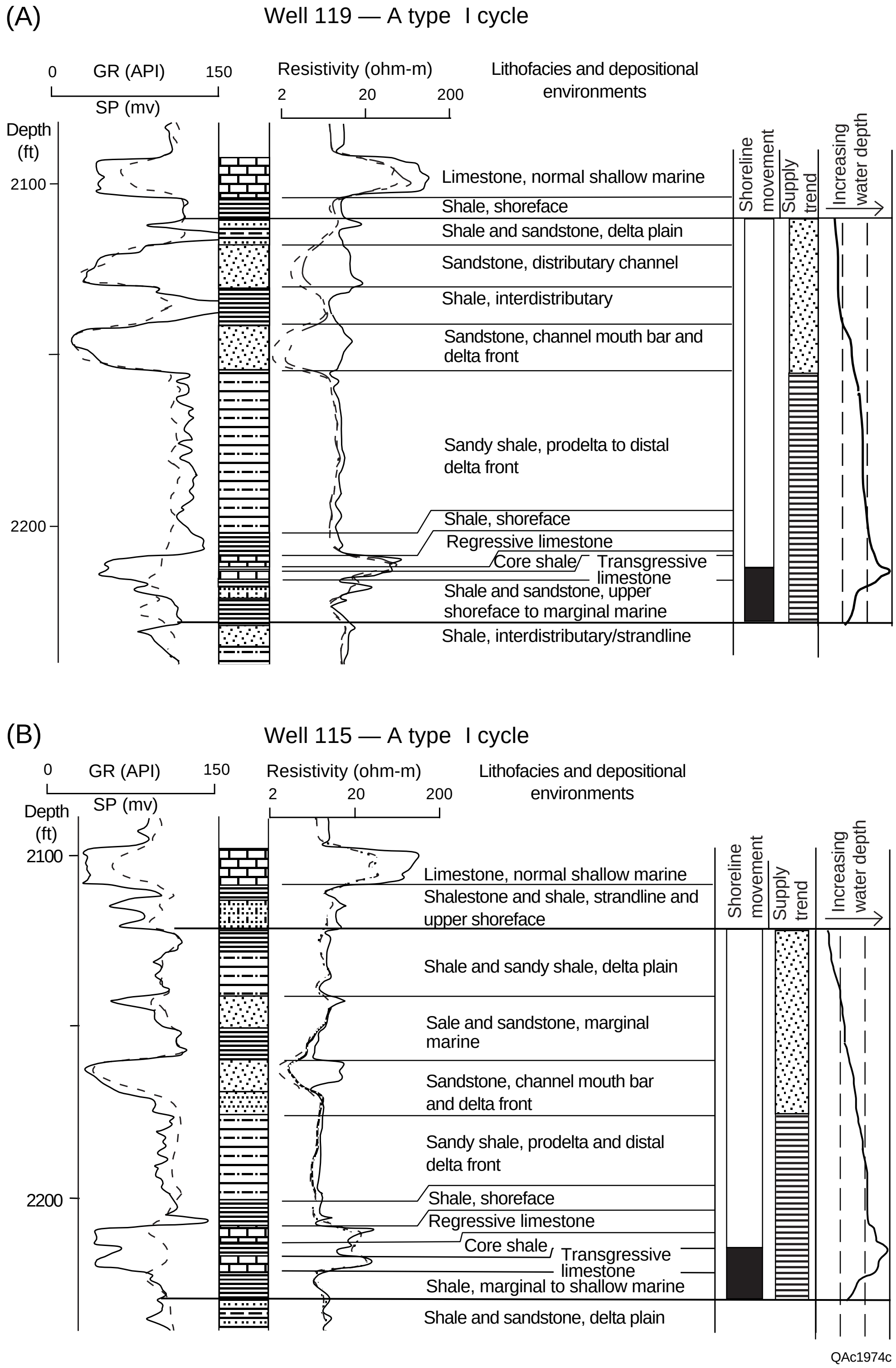


Figure 5. Typical well-log signatures of various lithofacies. Cycles and their subdivisions are delineated from trends of environment and water-depth changes. See text and Figure 6A for cycle type classification. See Figure 4 for more lithologic keys.

differential compaction. Two broad highs in the middle parts of B–B′ and C–C′ are ~16 to 19 km wide and 90 to 120 m thick (Figs. 9 and 10). The high in B–B′ is located at or near a major depositional locus with abundant coarse siliciclastic deposits. Differential compaction between sandstones in the high and the finer grained rocks in adjacent lows created the relief. It was accentuated by continuous deposition of coarse siliciclastics over the high until a later time. A high similar to those in B–B′ and C–C′ is not present in A–A′, because coarse siliciclastics were filling the deep pre-Cisco trough (Fig. 8).

Preexisting and evolving topography defines the general framework of cycle architecture,

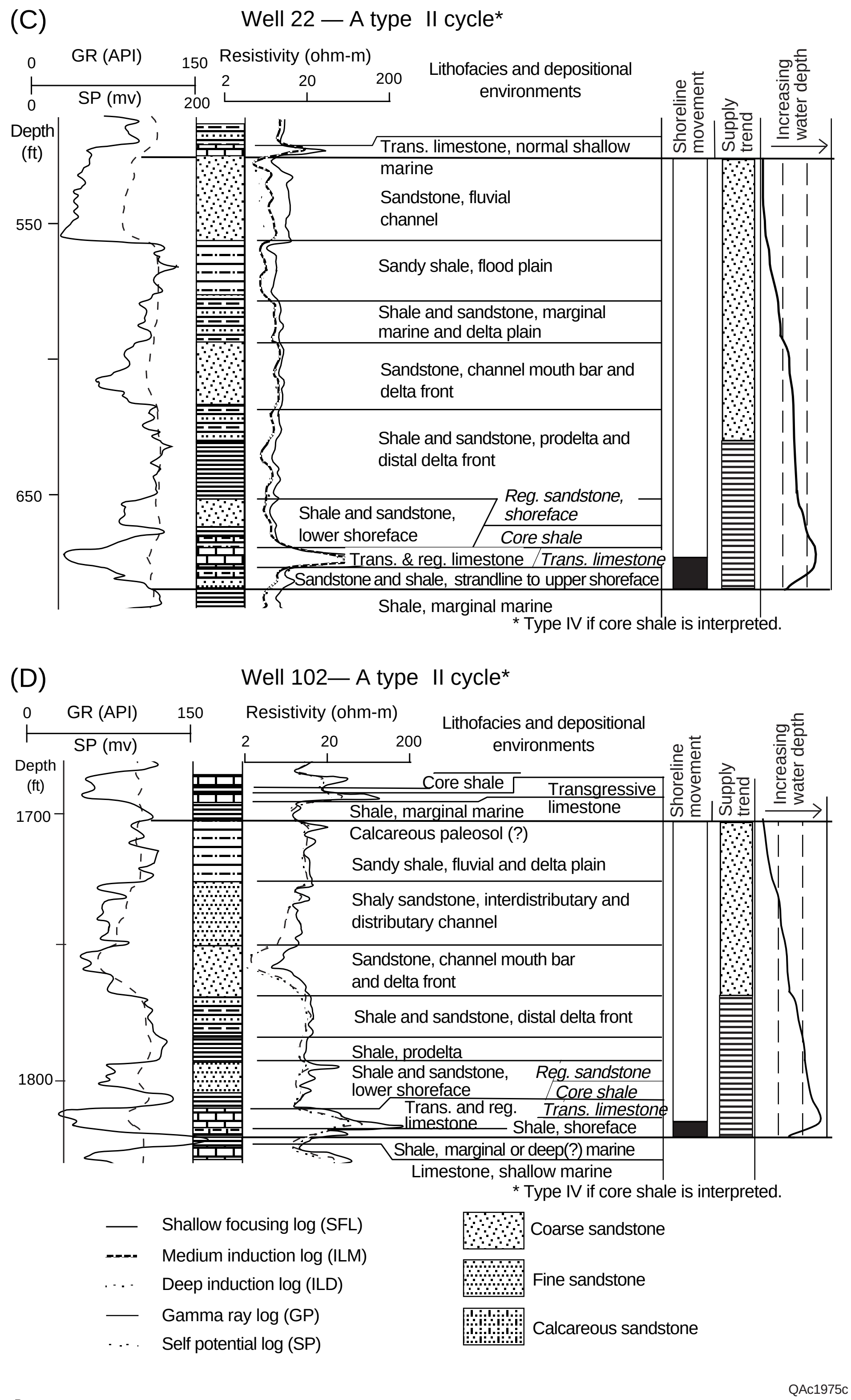


Figure 5. (*Continued*).

within which basin-wide tectonics and sedimentation interact with local topography and depositional dynamics. This will be demonstrated in the following sections.

Cycle Abundance and Continuity. Cycle abundance and continuity vary systematically on dip sections. The number of minor cycles increases in the downdip direction except in the basin slope. For example, 32 to 36 minor cycles are found in updip wells, but 44 to 46 cycles are found in downdip wells in A–A′ (Fig. 8). There are a total of 68 minor cycles in the Cisco Group, whereas the maximum number of minor cycles in a single well is 46. These discrepancies are caused by common cycle absence on the Eastern shelf.

Three processes, amalgamation, siliciclastic sediment suppression, and erosion, caused cycle absence. Amalgamation occurs where two, rarely three, minor cycles merge into one in an adjacent well, where regressive siliciclastics of the subjacent cycle and transgressive siliciclastics of the superjacent cycle are absent (Fig. 12A). It occurs commonly in the lower platform, where cycles merge mostly in the updip direction. Amalgamation of intermediate cycles is not observed. In some cases, the resolution of wireline logs prohibits pinpointing the exact location of amalgamation.

Cycles amalgamate toward either topographic highs or lows. In the case of amalgamation toward topographic highs, the absence of regressive siliciclastics of the lower cycle and transgressive siliciclastics of the upper cycle was caused by sediment bypassing, erosion, and/or nondeposition in the updip location. These strata are represented by a surface separating the amalgamated limestones of the lower and upper cycles (Fig. 12A). In most cases, the upper cycle has a smaller magnitude than the lower one and thus represents a transgressive-regressive event of smaller extent. In the case of amalgamation toward topographic lows, the absence of regressive and transgressive siliciclastics in the downdip location was most likely caused by sediment starvation or bypassing.

Many minor and intermediate cycles pinch out into siliciclastics in the updip direction or toward topographic lows on the platform (Fig. 12B). Pinch-outs are gradational or abrupt. Gradational cycle absence was caused by suppression of carbonate deposition in nearshore siliciclastics-rich environments due to siliciclastic contamination in the form of reduced light penetration, nutritional poisoning of calcite-secreting organisms, unsuitable substrate, or carbonate dilution (Mount, 1984). As a result, limestones in a cycle, the principal lithofacies in cycle delineation, were not deposited and the cycle could not be defined. The gradual change from marine carbonate environments to marine and nonmarine siliciclastic environments in the updip direction suggests that gradational cycle absence is controlled by the extent of shoreline transgression.

Abrupt cycle absence was caused by fluvial channel cutting into underlying limestones for tens of meters, as is commonly observed in outcrops (Fig. 12B; Yang, 1995). It is not an indication of the extent of marine transgression. Many minor cycles are absent before reaching the upper platform. As a result, the absence of intermediate cycles composed of one minor cycle predominates in the middle and upper platform.

Cycle absence results in cycle discontinuity. Most minor cycles persist more than 16 km. Many intermediate cycles persist more than 48 km and extend farther landward than minor cy-

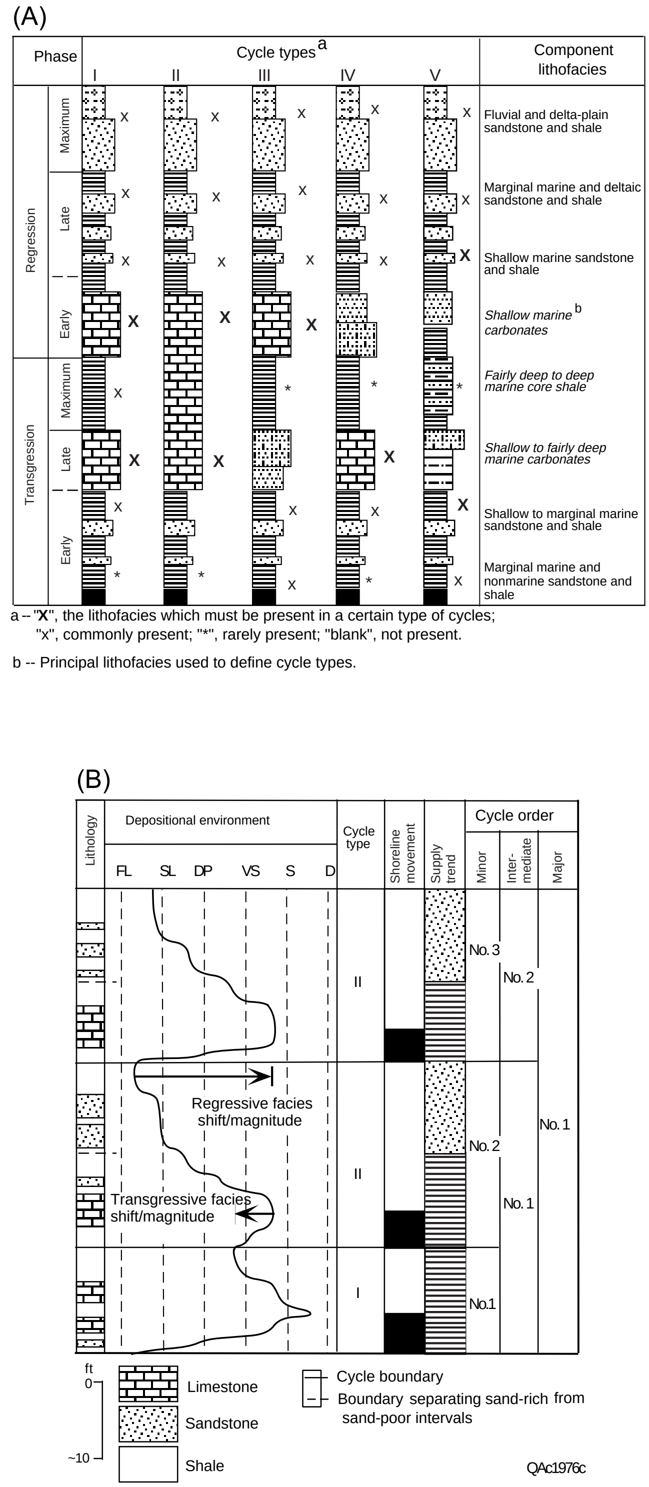


Figure 6. (A) Cycle type classification by principal component lithofacies. (B) Illustration of cycle characteristics including component lithofacies, magnitude, type, transgressive and regressive intervals, sand-rich and sand-poor intervals, and order. Cycles are delineated from trends of depositional environment and/or water-depth changes, which are displayed as a facies curve on a grid with the horizontal axis as environments and vertical axis as thickness. Environmental keys: FL—fluvial; DP—delta plain; SL—strandline marginal marine; VS—very shallow marine; S—shallow marine; FD—fairly deep marine around normal wave base; D—deep marine about storm wave base. See Figures 4 and 5 for lithologic patterns and Figure 4 for patterns of supply trend and shoreline movement.

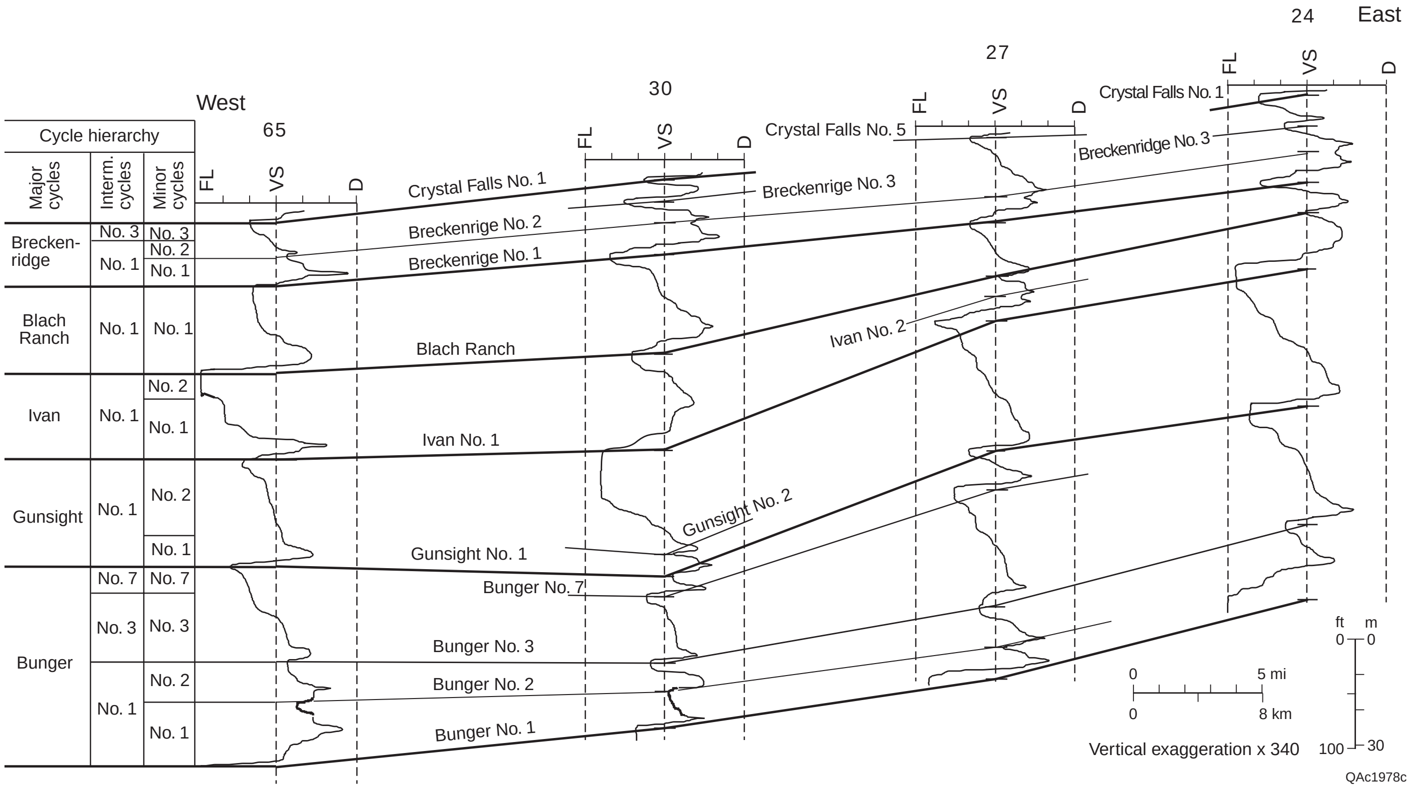


Figure 7. Part of cross section A–A′ illustrating cycle ordering and continuity. Minor, intermediate, and major cycles are indicated by thin, medium, and thick correlation lines. The left panel illustrates the hierarchical relation among the three orders of cycles. Continuity of minor and intermediate cycles varies. Some cycles identified in other sections, such as Bunger numbers 4, 5, and 6 cycles, are not present in this part of A–A′, indicating common cycle absence. See Figure 6 for environmental keys.

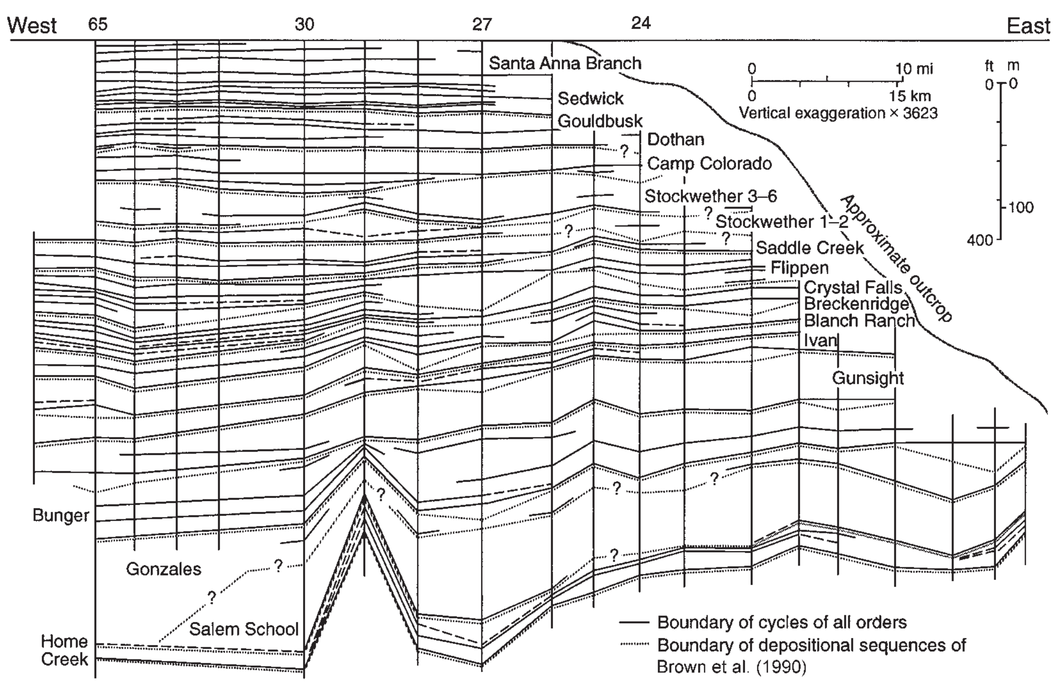


Figure 8. Highly simplified dip stratigraphic cross section A–A′ of Cisco Group, Eastern shelf, north-central Texas.

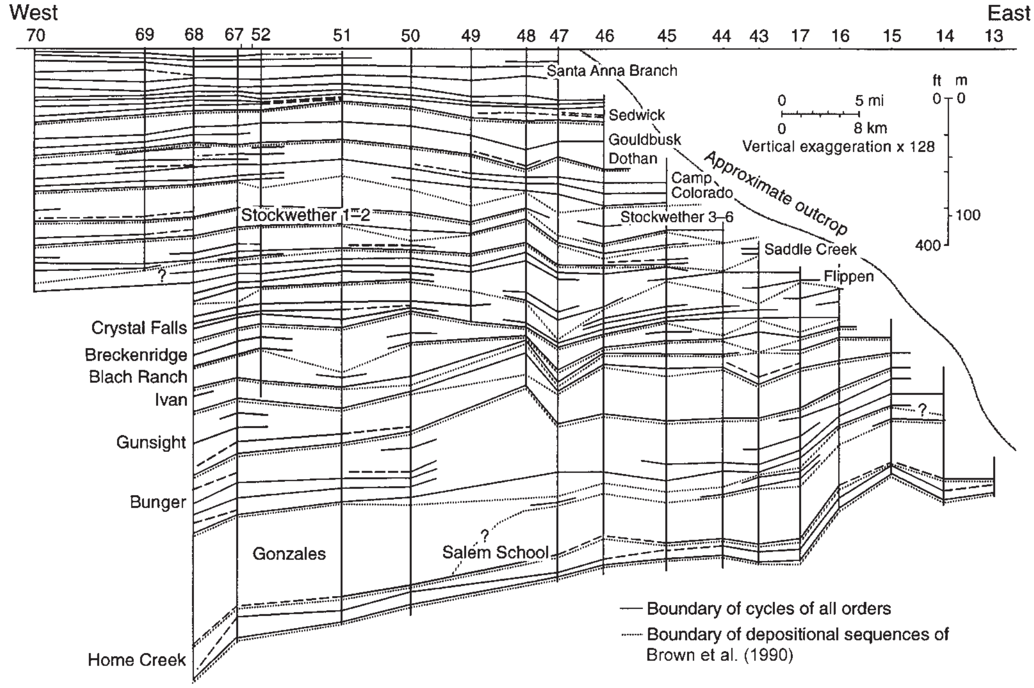


Figure 9. Highly simplified dip stratigraphic cross section B–B′ of Cisco Group, Eastern shelf, north-central Texas.

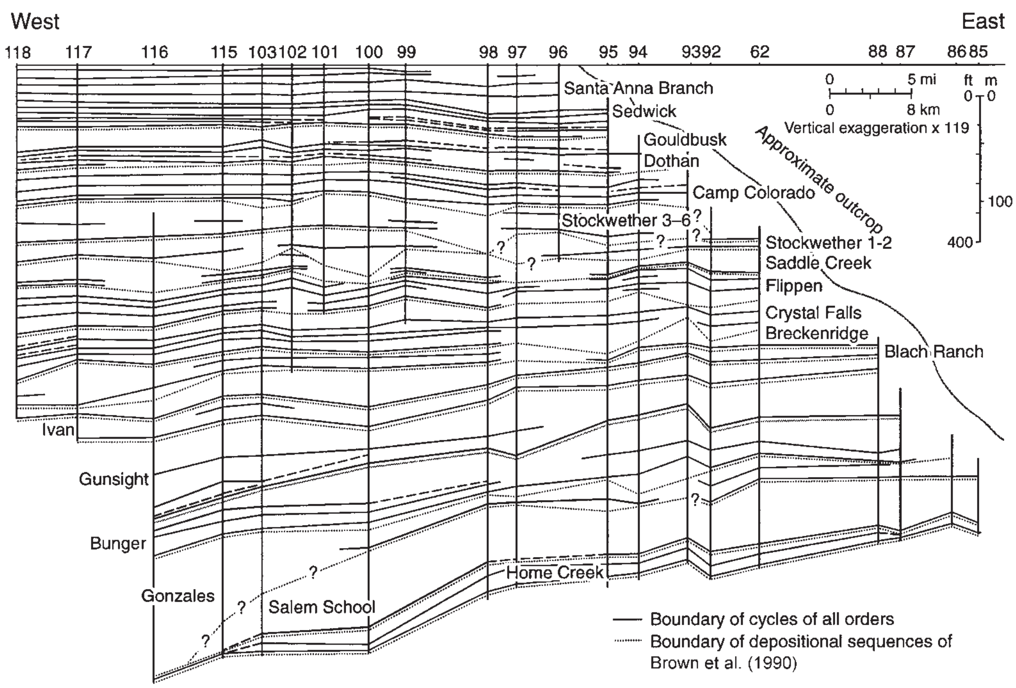


Figure 10. Highly simplified dip stratigraphic cross section C–C′ of Cisco Group, Eastern shelf, north-central Texas.

cles, suggesting small extent and magnitude of minor transgressive-regressive events (Figs. 7 and 11). However, where the platform is flat, as in the upper Cisco Group, minor cycles persist over a long distance (Figs. 8, 9, and 10). Laterally persistent cycles represent regional transgressive-regressive events controlled by regional processes.

Nonpersistent minor and intermediate cycles occur in three modes. First, some cycles occur fragmentarily from place to place, such as many Flippen cycles (Figs. 7 and 11). They are regional but nonpersistent. Second, some cycles are only present in the lower platform (Fig. 11). They may extend farther downdip out of the study area and thus could represent regional transgressive-regressive events that did not reach the upper platform. Lastly, very few cycles are of only local extent.

Cycle Type and Magnitude. Cycle type is determined by water depth, lithofacies, and depositional dynamics, and cycle magnitude is determined by the change of water depth over a cycle interval. Thus, regional trends of cycle type and magnitude indicate changes of water depth and lithofacies, modified by depositional dynamics.

Minor cycles exhibit two regional trends. First, ~20 regional cycles change from type II to type I and increase in magnitude in the downdip direc-

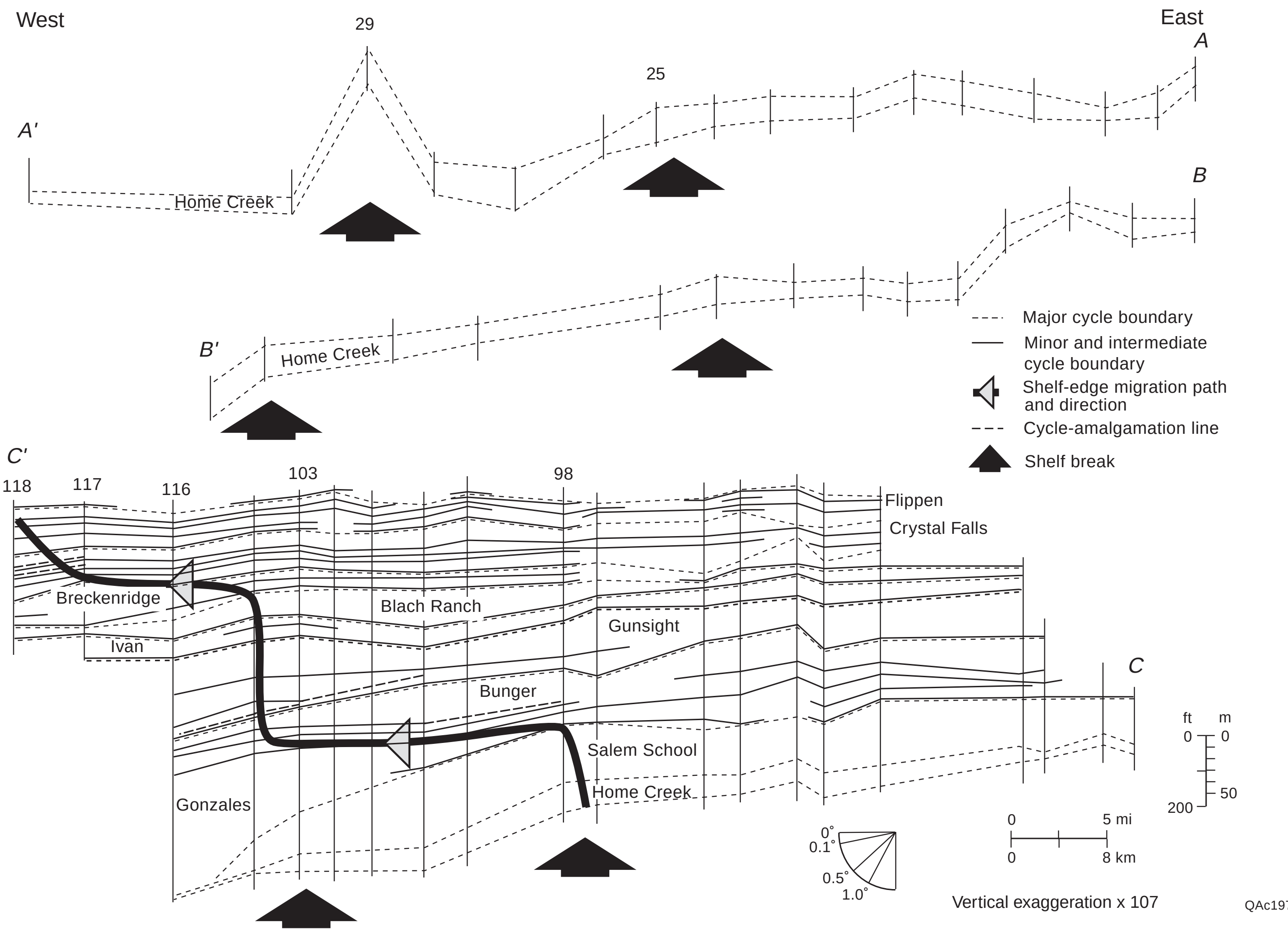


Figure 11. Pre–Cisco Group depositional topography outlined by the top of Home Creek interval in dip cross sections. Stepwise progradation and aggradation of shelf edge are shown in C–C′. Stratigraphic datum is the top of Cisco Group. A datum in the lower Cisco Group only slightly changes the pre-Cisco topography.

tion. Many minor cycles in the lower platform also show this trend.

The type of intermediate cycles is not defined because they are composed of several minor cycles. A minor cycle in the lower platform becomes the sole minor cycle in an intermediate cycle in the upper platform, where other minor cycles in the same intermediate cycle are absent. Therefore, in the upper platform, the magnitude of this minor cycle is that of the intermediate cycle. The magnitude of the intermediate cycle in the lower platform should be higher than that of the minor cycle, or be equal to that of the minor cycle if this minor cycle has the highest magnitude among all the minor cycles in the intermediate cycle. Thus, the magnitude of the intermediate cycles containing the 20 regional minor cycles also increases in the downdip direction. The downdip change from type II to type I of minor cycles and increase in magnitude of minor and intermediate cycles indicate a larger change of water depth over a cycle interval, and more core shale deposition in the lower platform than in the upper platform. They were probably caused by the downdip increase in accommodation space and decrease in land-derived siliciclastic sediment supply.

The second trend is that ~10 regional minor cycles have consistent type and magnitude across the shelf. This trend, as reasoned above, suggests that the magnitude of intermediate cycles containing these minor cycles increases in the downdip direction. The 10 cycles are either type I or type II. Type I cycles indicate that shelf deepening was large and fast enough to prohibit large landward siliciclastic influx and core shales were deposited on the upper platform. Type II cycles represent fast, low-magnitude shelf deepening, during which a large amount of siliciclastic material was yet to be delivered to the depositional site to suppress carbonate production.

About 10 regional minor cycles, however, do not show any systematic variation. They represent low-magnitude minor transgressive events, during which local topography and depositional dynamics largely controlled water depth and distribution of carbonate-suppressing, land-derived siliciclastics. The other possible scenario is that a large and irregular distribution of siliciclastic supply, combined with irregular local topography, could have caused these variations regardless of the magnitude of marine transgressions. The magnitude of intermediate cycles containing these minor cycles still increases in the downdip direction.

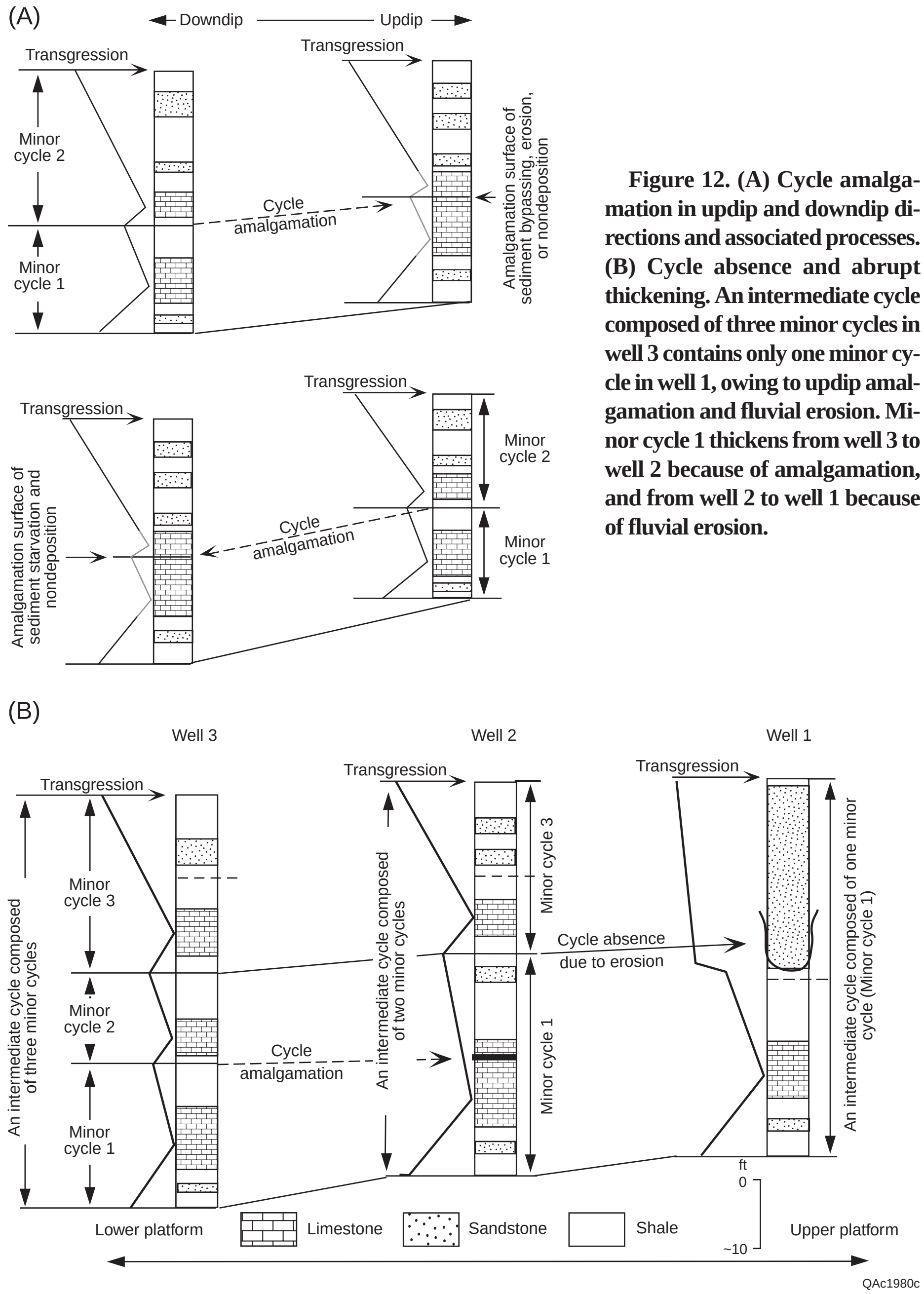


Figure 12. (A) Cycle amalgamation in updip and downdip directions and associated processes. (B) Cycle absence and abrupt thickening. An intermediate cycle composed of three minor cycles in well 3 contains only one minor cycle in well 1, owing to updip amalgamation and fluvial erosion. Minor cycle 1 thickens from well 3 to well 2 because of amalgamation, and from well 2 to well 1 because of fluvial erosion.

In a few cases, a cycle on the platform is of type I in local lows and type II on highs, or vice versa. Any subtle imbalance in the interplay among accommodation space, siliciclastic supply, local topography, and depositional dynamics could have caused these contrasting cases.

Cycle Thickness. Thickness is the most variable attribute of Cisco cycles. It is related to shelf position, local topography, component lithofacies and their compactability, and cycle order; these in turn are controlled by pre-Cisco topography, shelf subsidence, depositional dynamics, sediment supply, sea-level changes, and regional climate. To differentiate these controls from thickness trends is difficult (Yang, 1996). Here we speculate on the implications of generalized thickness trends on these controls.

Major and intermediate cycles contain one or more minor cycles and thus are thicker. Minor cycles are less than 3 m to more than 15 m thick, commonly 6 to 9 m. The minor cycle in the regressive interval of an intermediate cycle usually has thick regressive siliciclastic deposits and is therefore thicker than those in the transgressive interval of the intermediate cycle (Figs. 7 and 12B). Many minor cycles have fairly consistent thickness for more than 16 km. The less-consistent cycles commonly thicken toward topographic lows or in the downdip direction (Figs. 8, 9, and 10). Cycle thickness approximates the accommodation space if it is filled by sediments (Yang, 1996). Consistent thickness therefore implies that accommodation space is fairly uniform on a low-relief platform and space variations are controlled by local topography. A minor cycle thickens abruptly when the overlying cycles are absent (Figs. 7 and 12B). The abrupt thickening does not provide any information on variation of accommodation space.

Intermediate cycles are ~3 m to less than 60 m thick, commonly 15 to 30 m. They generally thicken in the downdip direction and toward local lows on the platform (Figs. 8, 9, and 10). This is because accommodation space was large in the lower platform and lows, and depositional loci were directed downslope by gravity, depositing thick regressive siliciclastic sediments. Intermediate cycles thin or thicken from shelf edge to basin slope. The thickness change is largely determined by the availability of regressive siliciclastic sediment supply because accommodation space is ample in the basin slope region.

Rarely, intermediate cycles thicken toward highs. The thickening is controlled by depositional dynamics and has to be explained on a case-by-case basis. For example, the thickening of Blach Ranch no. 1 cycle in A–A′ is caused by a thick, maximum-regressive sandstone filling a fluvial channel that developed on the underlying high (Fig. 13A). A fluvial channel situated on a topographic high is geomorphologically puzzling. A possible scenario is that the topography at the time of channel initiation may have been fairly flat. Once the initial small channel occupied or migrated into the location, it could deepen and stabilize during subsequent relative sea-level fall. In addition, this thickening was accentuated by later differential compaction between the sandstone and adjacent interfluve shale. The thickening of Gouldbusk no. 1 cycle in B–B′ is caused by a thick carbonate buildup on the underlying high during a maximum transgression (Fig. 13B). The submerged high was devoid of siliciclastic contamination, well lit, and well oxygenated, and had a suitable substrate for organisms to colonize.

The thickness of major cycles ranges widely from less than 15 to 60 m, increasing in the downdip direction on the platform and decreasing on the shelf edge and basin slope. It is controlled by sea-level changes, sediment supply, and local and regional topography (Brown et al., 1987, 1990; Galloway, 1971).

Sand-rich Intervals. Sand-rich intervals vary greatly in thickness and lithofacies at a local scale, although systematic variations exist. Five intermediate cycles in the Gunsight to Breckenridge interval in A–A′ are used to demonstrate these variations (Fig. 14).

Sand-rich intervals are 0 to ~30 m thick. They thicken in the upper and lower platform and are

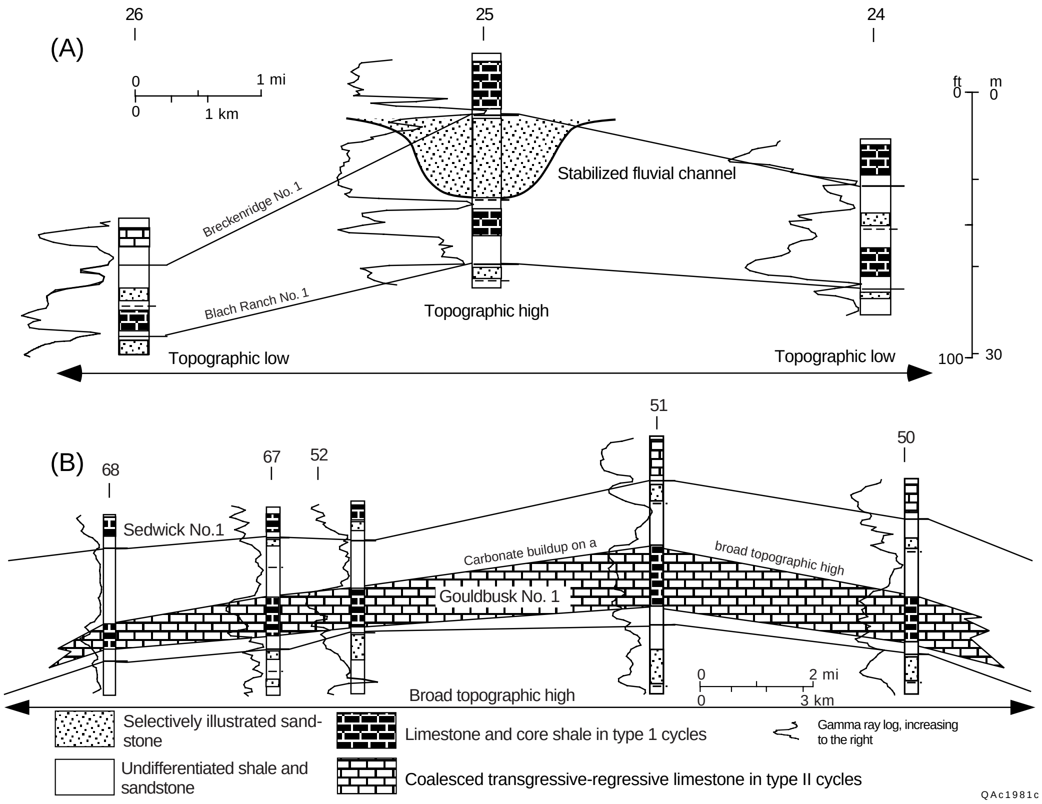


Figure 13. Examples of cycle thickening on highs: (A) thickening due to fluvial channel filling and stabilization; (B) thickening due to a carbonate buildup on the underlying high.

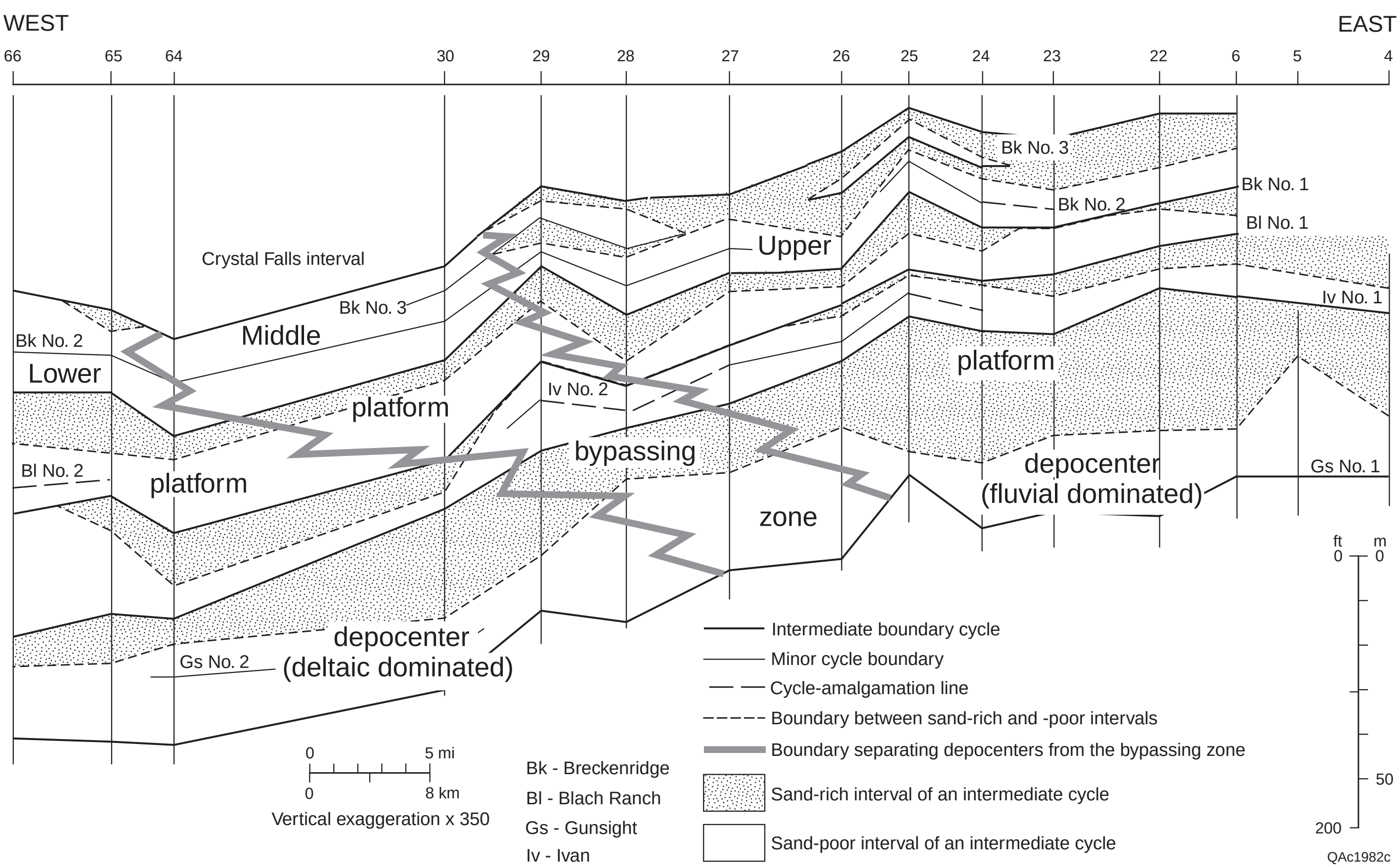


Figure 14. Part of simplified cross section A–A′ illustrating thickness and lithofacies variations of sand-rich intervals of intermediate cycles. See text for discussion.

Figure 15. Model explaining formation of depocenters and bypassing zones on the Eastern shelf, due to changing river gradient and subaerial accommodation space capped by the graded river profile. When shoreline regresses from the maximum-transgressive position to position (1) in the upper platform, the subaerial accommodation space increases to form a dominantly fluvial depocenter. From (1) to (2) in the middle platform, the river profile is below the shelf surface, creating negative accommodation space (hachured area) prone to erosion and sediment bypass. From (2) to (3) in the lower platform, the subaerial accommodation space increases to form a dominantly deltaic depocenter. When shoreline descends on the slope, the subaerial accommodation space is negative over the entire shelf. No scale is intended. Modified from Yang (1996).

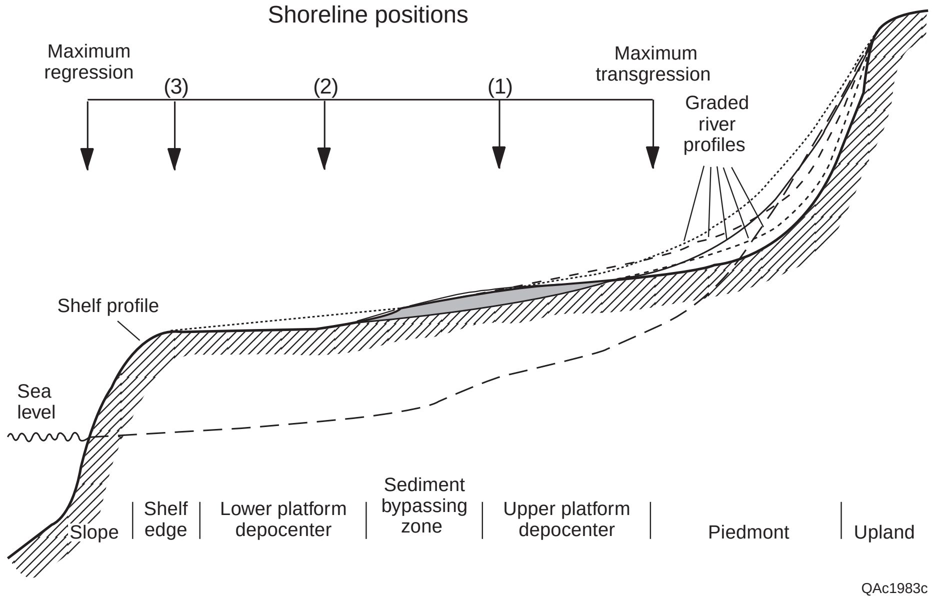
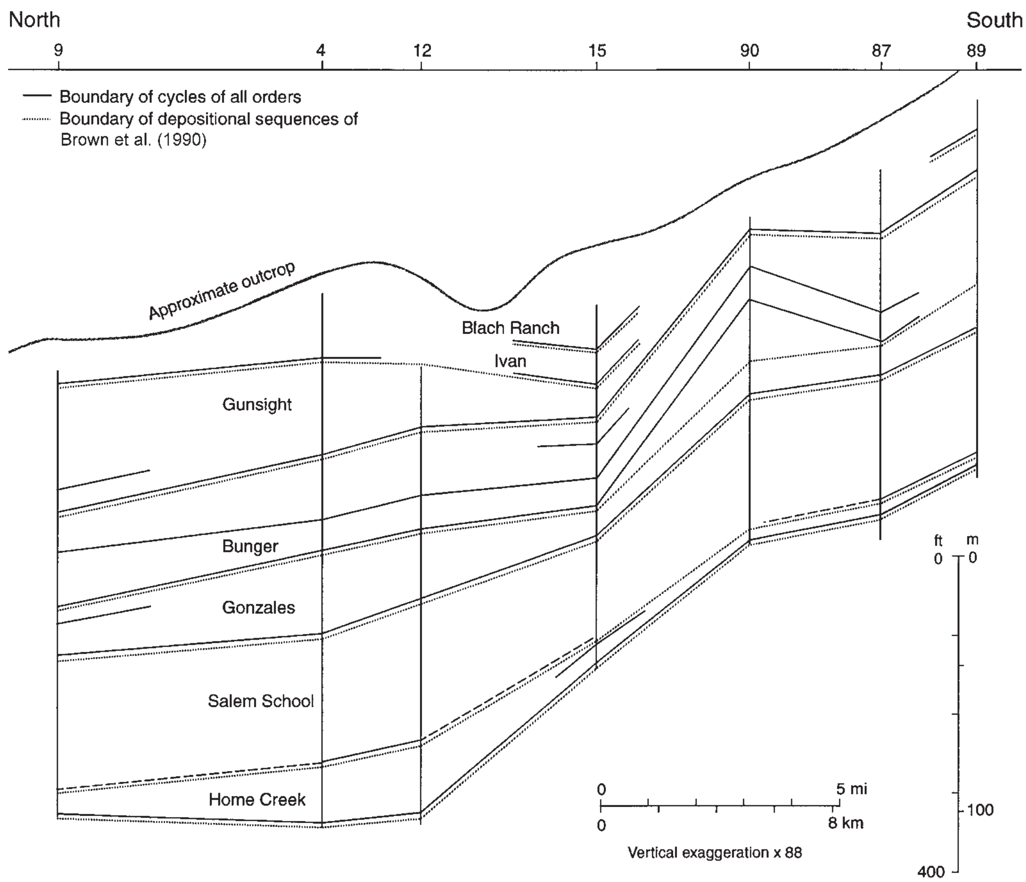


Figure 16. Highly simplified strike structural cross section 1–1′ of Cisco Group, Eastern shelf, north-central Texas.



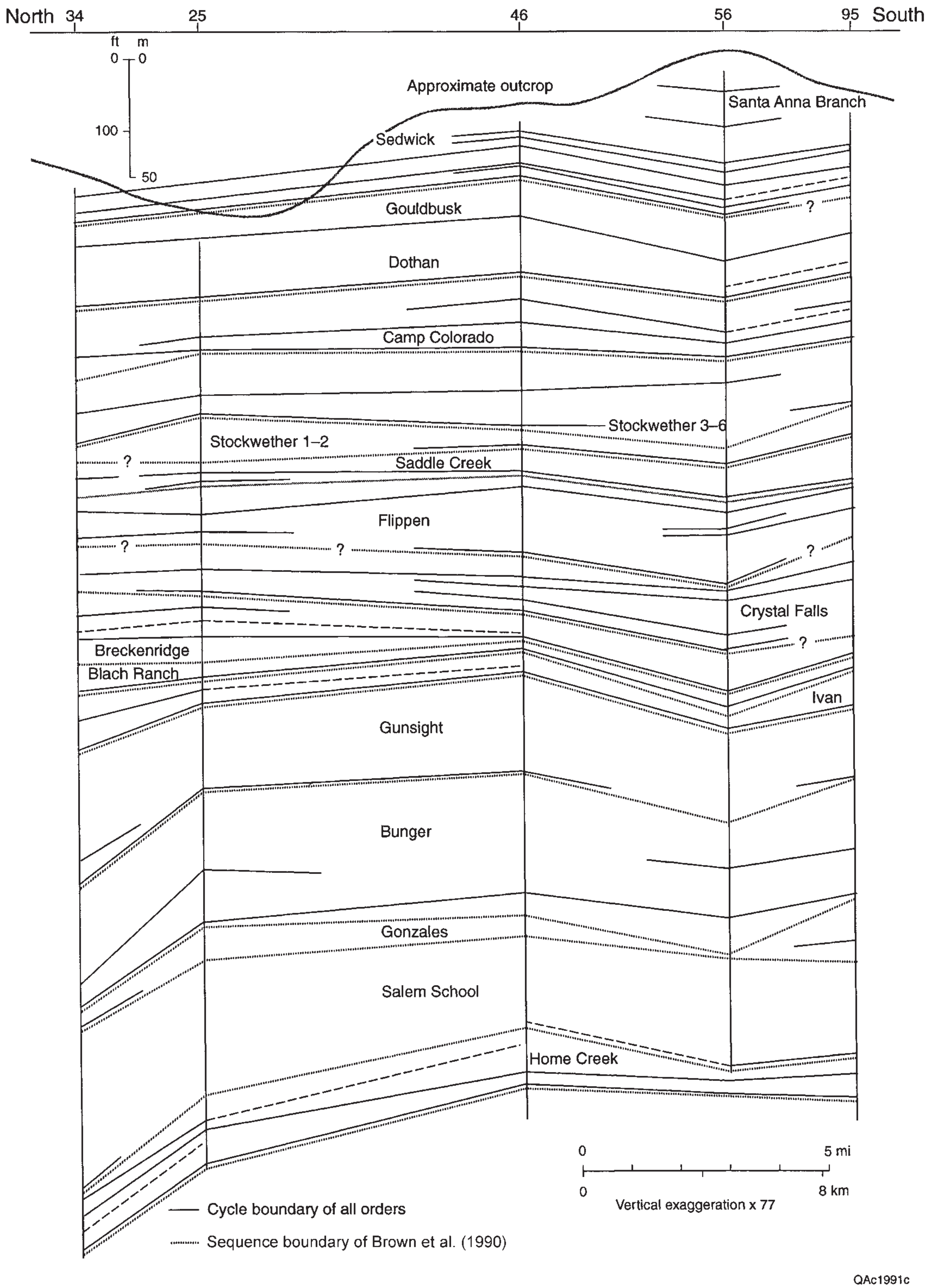


Figure 17. Highly simplified strike structural cross section 2–2′ of Cisco Group, Eastern shelf, north-central Texas.

thicker in the upper platform. They thin in the relatively steep middle platform and toward the shelf edge (Fig. 14). The thickness variations outline a fluvial and a deltaic depocenter in the upper and lower platform, respectively, and a zone dominated by coarse sediment bypass in the middle platform during marine regression (Fig. 14). The sand-rich intervals are upward-shallowing, marine deltaic to fluvial facies successions (Figs. 4 and 5). Fluvial deposits, especially channel sandstones, are more common in the upper platform than in the lower platform.

Regional thickness and lithofacies variations of these intervals suggest diminishing, but persistent, progradation of coarse siliciclastics in the downdip direction during late and maximum regression. Coarse sediments were first deposited in the upper platform; remaining sediments mostly bypassed the middle platform and were deposited in the lower platform.

As discussed previously, progradation of coarse sediments lags shoreline regression at a given location (Figs. 4 and 5). This lag increases in downdip wells, as indicated by the downdip decrease in thickness of these intervals (Fig. 14). The increased lag was caused by delayed progradational infilling of coarse sediments in downdip sites or by extensive shoaling due to aggradational infilling of fine sediments in downdip sites before the progradational front of coarse sediments arrived. The delay of coarse siliciclastic infilling at depositional sites after shoreline regression is consistent with the outcrop observation that maximum sediment supply at a depositional site occurred during late regression, whereas maximum sediment yield in the source area occurred during maximum transgression and early regression (Yang, 1996).

The pattern of shelfwide progradational infilling suggests regional controls on shoreline regression and sediment infill. Possible controls are (1) sea-level change, which mainly controlled shoreline movement and submarine accommodation space; (2) episodic platform subsidence, which controlled submarine and subaerial accommodation space as well as shoreline movement; and/or (3) episodic sediment influx into the platform due to tectonic and/or climatic changes in upland source areas. Regional sea-level changes are a likely cause of regional repetitive transgression and regression. There is no direct evidence of episodic subsidence in the study area. On the contrary, some studies have suggested tectonic stability of the Eastern shelf (e.g., Wermund and Jenkins, 1969; Brown et al., 1990). Episodic sediment influx caused by upland climatic changes is suggested in the outcrop study (Yang, 1996).

Preservation of thick nonmarine and marginal marine rocks and the distribution of depocenters and bypassing zones indicate large but unevenly distributed submarine and subaerial accommodation space on the platform during late and maximum regression. Shelf configuration and changes in base level, including absolute sea level and graded river profile, determine the spatial and temporal variations of subaerial and submarine accommodation space on the platform (Fig. 15; Yang, 1996). In addition, the thick sand-rich intervals suggest significant platform subsidence, which is the ultimate control on sediment preservation. In summary, the interplay among topography, siliciclastic supply, base-level change, subsidence, and depositional dynamics controlled the deposition and preservation of coarse siliciclastic rocks of sand-rich intervals.

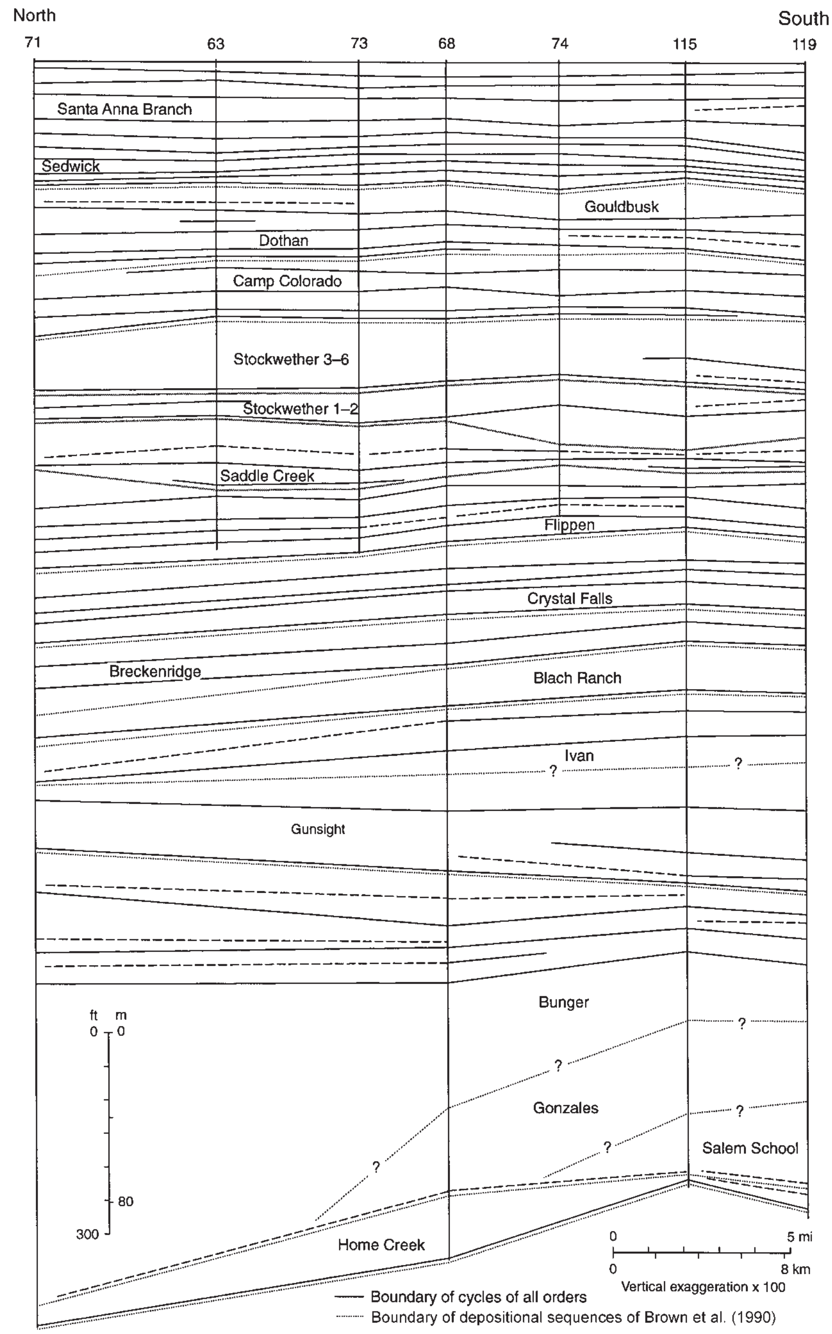


Figure 18. Highly simplified strike stratigraphic cross section 3–3′ of Cisco Group, Eastern shelf, north-central Texas.

Cycle Correlation on Stratigraphic and Structural Strike Cross Sections (Figs. 16, 17, and 18)

Topography. The pre-Cisco Group topography along strike is essentially a north-dipping monocline (Figs. 16, 17, and 18). Its relief decreases from ~150 m in the upper platform and ~60 m in the middle platform to ~45 m in the lower platform. Thus, the overall pre-Cisco Group topography of the study area dips to the northwest.

Pre-Cisco Group lows were largely filled during the beginning of deposition of the Cisco Group. Lower Cisco Group cycles thicken to the north owing to apparent northward regressive fluvial and deltaic progradation, suggesting a major sediment source to the south and southeast (Fig. 19). Some local features persisted or were enhanced during deposition of the Cisco Group. For example, the high at well 90 was accentuated by regressive fluvial channel sandstones (Fig. 19). The persistent low at well 56 of section 2–2′ shallowed where it was filled by less-compactable, thick sandstones and deepened where the sandstones are thin or carbonate buildups in adjacent highs are thick (Fig. 20). The type of lithofacies, depositional dynamics, and differential compaction had controlled the shallowing and deepening.

Shelf topography gradually flattened upward. The relief is much lower in the downdip section

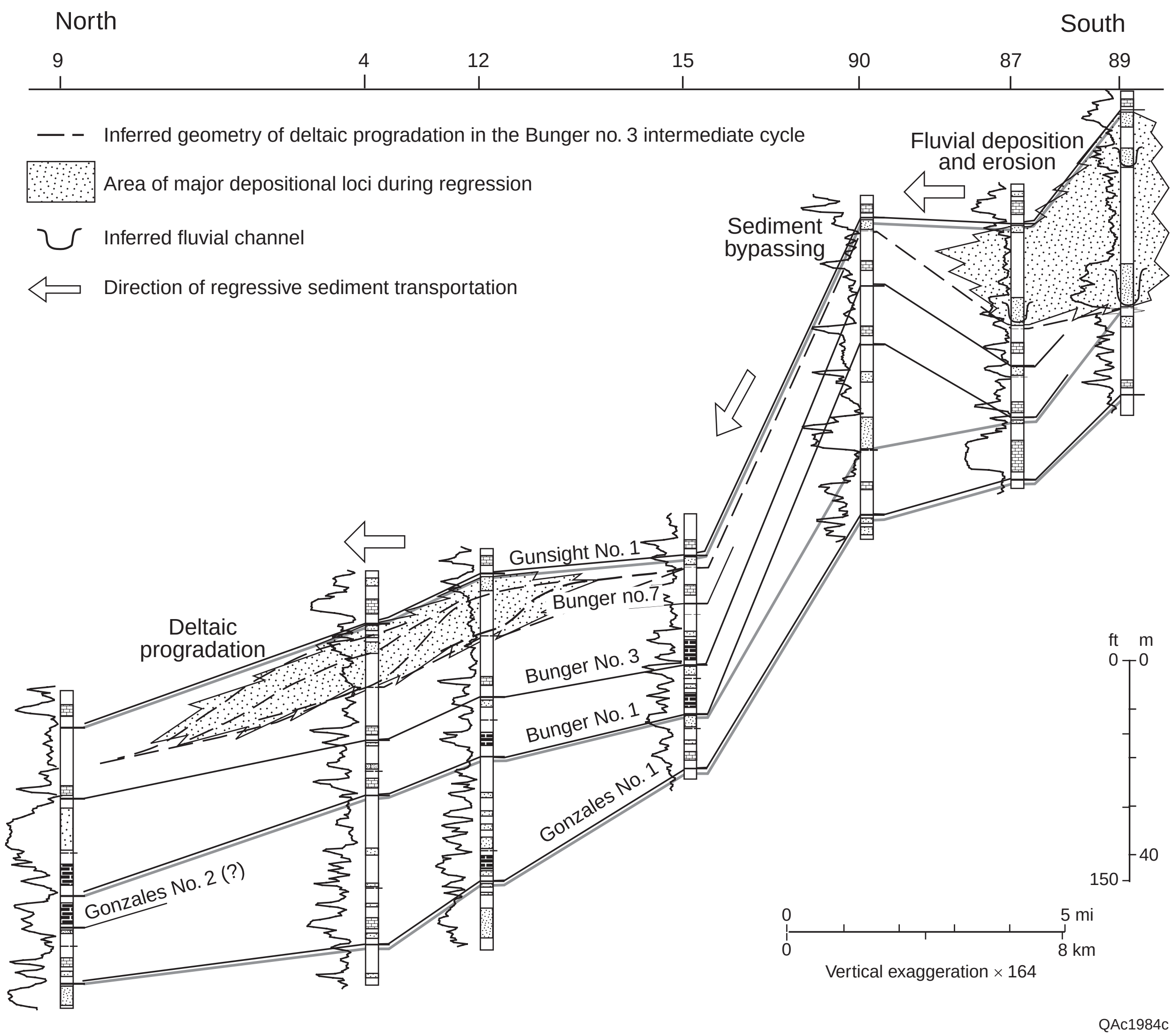


Figure 19. Part of cross section 1–1′ showing variations in cycle continuity and thickness, and in lithofacies and thickness of sand-rich intervals, as controlled by local and regional topography, timing, type, and amount of siliciclastic sediment supply, and depositional dynamics. A sea-level datum is used because of extreme topographic variations and small tectonic disturbance in the Eastern shelf since late Paleozoic time (Wermund and Jenkins, 1969; Brown et al., 1987). In the lower Cisco Group, this section is at a high angle to depositional strike, reflecting the nature of evolving topography and sediment supply pattern. See text for discussion. See Figures 11, 13, and 14 for more keys.

than in the updip sections (Figs. 16, 17, and 18). As a result, topographic control on cycle abundance, continuity, and thickness diminishes upward and basinward.

Cycle Abundance and Continuity. Many minor cycles are absent toward highs as a result of limited accommodation space, siliciclastic suppression of carbonate deposition, and fluvial erosion (Figs. 19, 20, and 21). Some cycles, however, are absent in lows where depositional loci of coarse sediments were directed (Fig. 21). These observations suggest a combined control of topography, accommodation space, and depositional dynamics on cycle abundance.

Gradational and abrupt cycle pinch-out caused by siliciclastic suppression and erosion is common in updip sections, whereas cycle amalgamation is common in downdip section 3–3′, as in the dip sections. Moreover, there are more minor cycles in section 3–3′. For example, the Bunger interval has three cycles in section 1–1′, but six in section 3–3′ (Figs. 16 and 18). The lack of fluvial erosion in section 3–3′ results in increased cycle continuity and abundance.

Most minor cycles are continuous throughout section 3–3′. More than half of the minor cycles are continuous for more than 8 km in sections 1–1′ and 2–2′. Intermediate cycles are more continuous than minor cycles. It is surprising that lower Cisco cycles, such as these in the Gonzales to Gunsight interval, are more persistent and abundant in section 1–1′ than in section 2–2′ (Figs. 16 and 17). This is because section 2–2′ is located in the upper sediment bypass zone, where regressive sediment bypassing and erosion were extensive (Figs. 14 and 21).

Cycle Type and Magnitude. Contrasting trends are present between the lower and upper Cisco Group and between updip and downdip sections. In the lower Cisco Group, low-magnitude, type II minor cycles are common on highs, whereas high-magnitude, type I cycles are common in lows, such as the minor cycles in section 1–1′ (Fig. 19). This trend suggests that the magnitude of high-order transgressive-regressive events decreases toward highs where accommodation space is small. Because many minor cycles in the lower Cisco Group are the only cycle in an intermediate cycle, this trend indicates that the magnitude of intermediate transgressive-regressive events also decreases toward highs.

Topographic control, however, weakens in the upper Cisco Group, where gentle topography resulted in many minor cycles of persistent or varying type and magnitude along strike (Figs. 17 and 18). Any subtle imbalances among local topography, siliciclastic influx, magnitude of transgression, and depositional dynamics could cause lateral variations of cycle type and magnitude. The persistent type and magnitude, however, could occur because (1) the topography was flat, such as in the Sedwick and Santa Anna Branch intervals, (2) the magnitude of transgression was large, or (3) the siliciclastic influx was minimal.

Cycle type and magnitude are much less persistent in 2–2′ than in 3–3′. This is because section 2–2′ is located in the sediment bypass zone where sedimentation was erratic. In fact, some cycles in section 2–2′ are type I on highs and type II in lows, such as the Saddle Creek no. 1 and Stockwether no. 1 cycles (Fig. 21). The highs were most likely devoid of major depositional loci, so that siliciclastic suppression and contamination of carbonate and core shale deposition were greatly reduced.

Cycle Thickness. The consistency of cycle thickness varies greatly between sections and between different orders of cycles. Minor cycles thicken toward lows or have constant thickness in section 2–2′, but they have constant thickness or thicken gently toward lows in section 3–3′.

Intermediate cycles thicken toward lows or highs or have constant thickness. Large thickness changes occur commonly in updip sections 1–1′ and 2–2′. For example, from south to north, the Bunger no. 3 cycle in section 1–1′ thickens where thick fluvial sediments were deposited, thins over a local high due to sediment bypassing, thickens again in a low due to deltaic progradation, and finally thins again where sediment supply from the south diminished (Fig. 19).

Topographic and depositional dynamics controls on thickness variations of intermediate cycles are also well demonstrated in section 2–2′ (Fig. 21). The depositional loci were located in preexisting lows, where thick sandstones were deposited. The sandstones formed highs owing to their large thickness and small compactability, toward which the overlying cycles thin. This great lateral and vertical thickness change is in accordance with the common cycle absence and poor cycle continuity. They were caused by extensive erosion, frequent switching of depositional loci, and the relatively steep topography in the sediment bypass zone on the middle platform.

In contrast, the consistent thickness of both minor and intermediate cycles in section 3–3′ indicates diminished influences of fluvial and deltaic sedimentation and topography on cycle thickness in the lower platform. As a result, regional high-frequency transgressive-regressive events were well recorded, strongly suggesting a eustatic origin for these events.

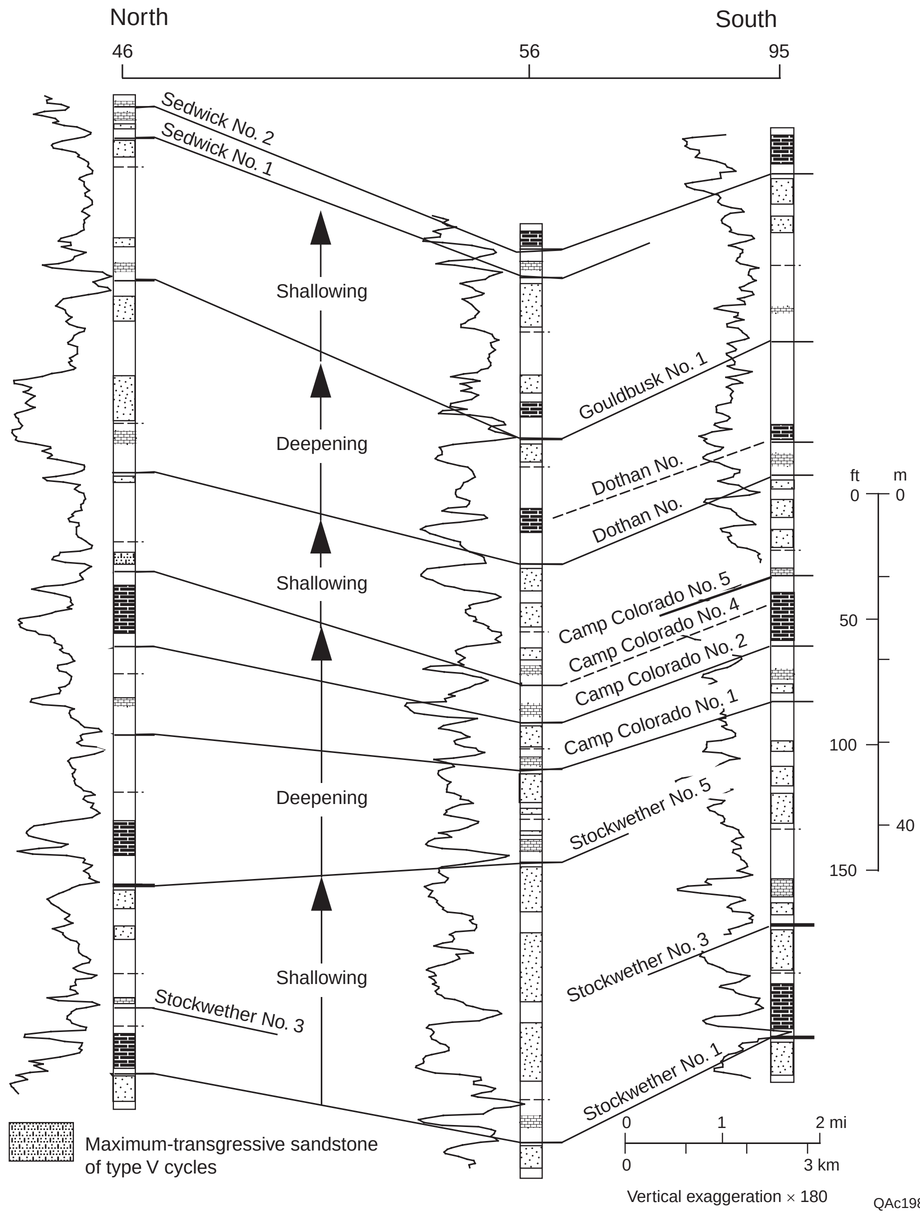


Figure 20. Part of cross section 2–2′ showing varying cycle continuity and repeated shallowing and deepening of a topographic low, as controlled by the dynamics of siliciclastic and carbonate deposition and differential compaction. See Figures 11, 13, and 14 for more keys.

Sand-rich Intervals. Variations in lithofacies and thickness of sand-rich intervals in intermediate cycles along strike are closely related to the location of depositional loci and the pattern of siliciclastic supply. This relationship is evident in the progradational interval of Bunger no. 3 cycle in section 1–1′ (Fig. 19). This interval thickens in the updip part, where fluvial sandstones dominate, and in the downdip part, where deltaic sandstones dominate. It thins over a high separating the fluvial depocenter from the deltaic depocenter, and thins farther downdip, where deltaic progradation ceased. Thickening of sand-rich intervals toward fluvial and deltaic depocenters also occurs throughout section 2–2′ (Fig. 21).

Sand-rich intervals in section 3–3′ are thin and laterally consistent and, in some cases, thicken gently toward topographic lows. This is attributed to the diminished supply of coarse sediments, especially fluvial deposits, and the attenuated topography in the lower platform.

TABLE 1. VARIATIONS OF CYCLE CHARACTERS AND THEIR CONTROLS, SUBSURFACE CISCO GROUP, EASTERN SHELF

	Cycle characters	Variations of cycle characters in the study area	Controls
	Abundance	More minor and intermediate cycles in lower platform	
	Absence	Amalgamation of minor cycles in highs or lows, common in lower platform Siliciclastic sediment suppression of carbonate deposition common in upper platform	Allogenic
		Fluvial erosion common in middle and upper platform Common absent in highs or lows where depositional loci present	Eustatic sea-level changes of different orders
	Continuity	Persistent: most minor cycles continuous more than 16 km, many intermediate cycles more than 48 km Intermediate cycles extend farther landward than minor cycles Nonpersistent cycles: continuous but fragmentary; only in lower platform; only of local extent Most continuous on lower platform, least in bypass zone	Regional topography and/or shelf configuration Timing, type, and amount of regional siliciclastic sediment supply Shelf subsidence
	Type and magnitude	20 minor cycles: type II to type I, increased magnitude in downdip direction 10 minor cycles: consistent type and magnitude across the shelf Other minor cycles: No systematic changes	Possible climatic changes
		Intermediate cycles: increased magnitude in downdip direction High magnitude, type I in lows, low-magnitude, type II in highs in lower Cisco Group, more consistent in upper Cisco Group More consistent in lower platform than in middle and upper platform	Autogenic
	Thickness	In a major cycle, intermediate cycles are thicker than minor cycles Minor cycles: many have consistent thickness for more than 16 km; some thicken in downdip direction or lows; some thicken abruptly Intermediate cycles: thicken in downdip direction or lows; thin or thicken from shelf edge to basin slope; rare thickening in highs More consistent in lower platform than in middle and upper platform	Local depositional topography Local subsidence caused by differential compaction Carbonate and siliciclastic depositional dynamics
Sand-rich intervals	Thickness	Thickens toward upper- and lower-platform depocenters, thins in middle-platform bypass zone The lag between coarse siliciclastic progradation and regression increases in downdip direction	Local variations of depositional locus
Sand-rich intervals	Lithofacies	Upward-shallowing, dominantly deltaic in lower-platform depocenter, dominantly fluvial in upper platform depocenter	

DISCUSSION

Autogenic and Allogenic Processes

Allogenic processes operate at a basin or global scale and are external to the depositional site; autogenic processes operate within the depositional site at a local scale. These two types of processes are distinguished by their end products, i.e., regional systematic vs. local nonsystematic variations of cycle characters identified through cycle correlation and stratigraphic and sedimentologic analyses. Distinguishing these processes enables us to better understand the mechanisms of individual processes in cyclic sedimentation.

Regional systematic variations of Cisco cycle characters indicate allogenic controls (Table 1). They include high-frequency sea-level changes, shelfwide subsidence, regional pattern of siliciclastic supply, and regional topography. Regional topography determines the regional geometry of progradation and aggradation and location of depocenters and sediment bypass zones. Timing, type, and amount of siliciclastic sediment supply mainly determine lithofacies distribution and thickness, which change from dominantly fluvial and deltaic in the upper platform to dominantly shelf siliciclastic and carbonate in the lower platform because of diminishing coarse siliciclastic sediment supply. Shelf subsidence is the ultimate control on sediment preservation. Shelf configuration, supply pattern, and subsidence combine to determine stratigraphic completeness and resolution of the Cisco Group. Climatic controls on sediment yield in source areas may have controlled the timing of regressive progradation of intermediate cycles, as inferred from the outcrop study (Yang, 1996).

Local variations of cycle characters indicate autogenic controls (Table 1). They include local topography, differential compaction, and depositional dynamics, which control lateral facies changes, depositional locus switching, and carbonate and siliciclastic deposition and erosion. Local faulting and folding are not evident in the study area.

Autogenic processes operate within the framework and boundary conditions set up by allogenic processes. Autogenic processes locally modify or even destroy the framework through grain-by-grain sedimentation at a specific site and time, to record the ambient conditions of depositional environments at different scales. Therefore, autogenic processes modulate and modify the detailed character of allogenic products. For example, fluvial sediment influx and deltaic progradation could outpace sea-level rise, causing shoreline regression and cycle absence; fluvial channel erosion could excavate the underlying sediments, fragmenting cycles and destroying the previous record (Figs. 19 and 21). As a result, the Cisco record in the upper platform and sediment bypass zone displays poor cyclicity because of cycle absence and discontinuity and is essentially an autocyclic record, whereas the record in the lower platform is dominantly an allocyclic record, where signatures of allogenic processes were clearly preserved by relatively continuous and uniform shelf siliciclastic and carbonate sedimentation.

Allogenic and autogenic signatures, however, are highly mixed. This study demonstrates that a predominantly autocyclic record in the upper platform does not imply the absence of allogenic processes. Allogenic controls on sedimentation in the lower platform were accomplished via autogenic processes. Therefore, an allocyclic record may inherit many autogenic imprints.

High-Frequency Sea-Level Changes

Persistent and repetitive transgression-regression in the study area can easily be explained by high-frequency sea-level changes. This, however, can also be caused by cyclic shelf subsidence or variations in siliciclastic influx when accommodation space steadily increases (Yang, 1996).

There is no direct evidence in the Cisco Group suggesting episodic regional subsidence, in particular, different orders of subsidence. To the contrary, tectonic stability of the Eastern shelf during Cisco Group deposition has been suggested in this and previous studies (e.g., Brown et al., 1990; Elam, 1969; Wermund and Jenkins, 1969; Yang and Dorobek, 1992).

Cyclic siliciclastic influx onto the shelf could be caused by episodic tectonic uplift or cyclic climatic changes in source areas. There is no evidence from either the subsurface or the outcrop to suggest episodic uplift of the source areas (Yang, 1995). High-frequency, regional episodic uplift of different orders over a period of several million years is yet to be documented, and it is unlikely to have occurred in the study area.

Cyclic waxing and waning of sediment yield in the source areas caused by high-frequency climatic changes are suggested in the outcrop study of the Cisco Group (Yang, 1996). Assuming a sea-level stillstand and constant shelf subsidence, high siliciclastic sediment supply on the shelf would cause shoreline regression and low supply would cause shoreline transgression (Curray, 1964; Yang, 1996). The effect of varying siliciclastic supply on shoreline movement should be more prominent in the upper platform, close to the sediment source, than in the lower platform. However, all characteristics of Cisco cycles become much more persistent in the downdip direction, away from the influence of land-derived siliciclastics. Therefore, cyclic siliciclastic supply cannot adequately account for high-frequency, multiorder transgression-regression throughout the Cisco Group.

Exclusion of tectonic and sediment-supply causes for regional transgression and regression leaves high-frequency sea-level changes as the major cause of cyclicity. Continental glaciation similar to that of the Pliocene-Pleistocene has been documented for late Paleozoic time (Crowell, 1978; Veevers and Powell, 1987) and probably caused high-frequency, high-amplitude sea-level changes. They have been suggested as the cause for many Pennsylvanian and Permian cycles (Wanless and Shepard, 1936; Wilson, 1967; Heckel, 1977, 1986; Goldhammer et al., 1994), including transgressive-regressive cycles of the Cisco Group in outcrop (e.g., Lee, 1938; Harrison, 1973; Boardman and Malinky, 1985; Boardman and Heckel, 1989; Yancey, 1991; Yang, 1996).

In addition, cycle ordering indicates ordered high-frequency sea-level changes related to Milankovitch climatic cycles. A 2:1 or 3:1 ratio between minor and intermediate cycles is comparable to the ratio between Milankovitch short-eccentricity and obliquity cycles, as in the outcrop cycles (Yang, 1995, 1996). More significantly, spectra of 15 Cisco records display distinct Milankovitch eccentricity, obliquity, and precessional-index peaks (Yang and Kominz, 1996). In summary, geologic and quantitative evidence strongly suggests, but does not prove, a major high-frequency sea-level control on cyclic sedimentation of the Cisco Group.

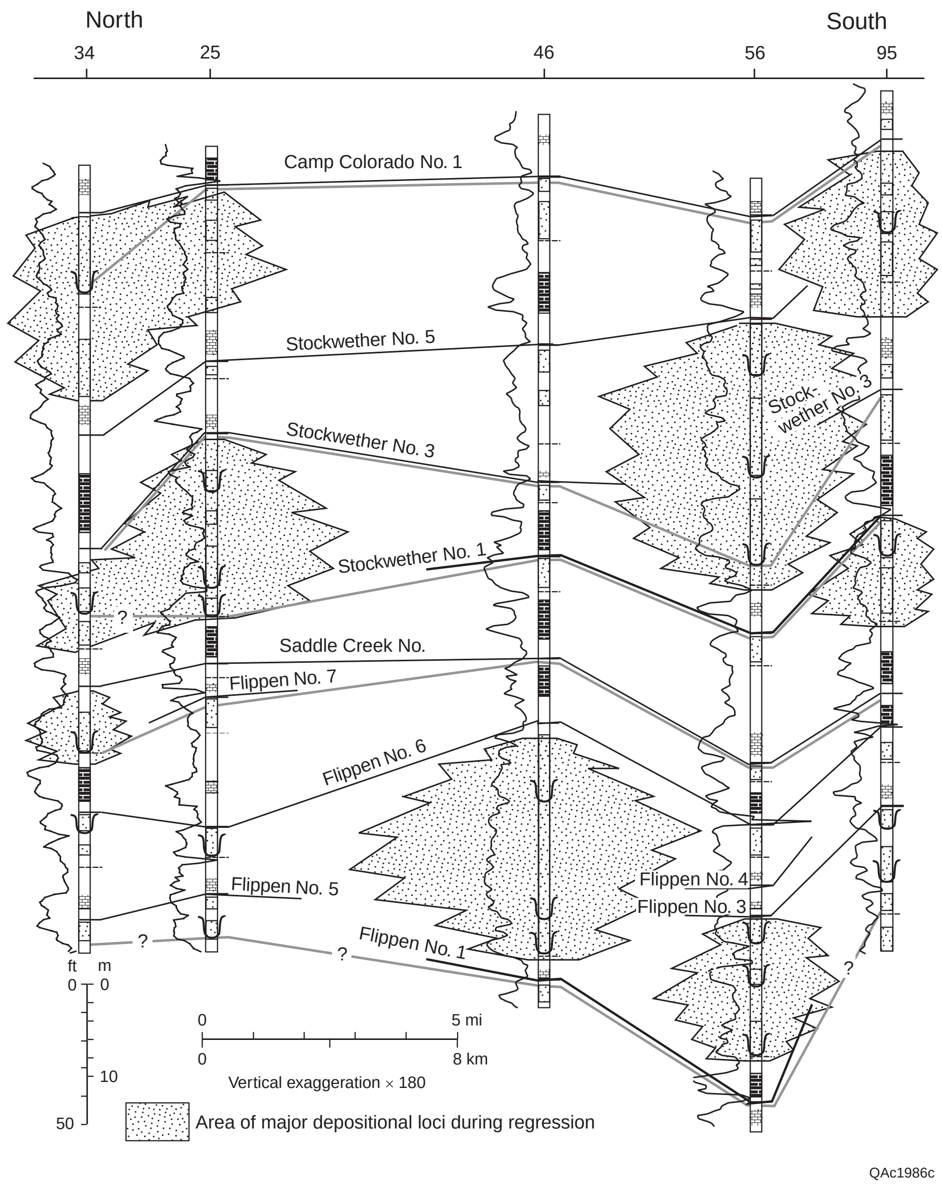


Figure 21. Part of section 2–2′ showing frequent depositional locus switching during regression to demonstrate the relation between local topography and depositional locus and their controls on cycle thickness, type, and continuity. See Figures 11, 13, 14, and 19 for more keys.

Cyclostratigraphy and Autogenic and Allogenic Processes

A major goal in meter-scale cycle studies is to establish a high-resolution cyclostratigraphy calibrated to the periods of Milankovitch climatic cycles (e.g., Herbert, 1992; Hinnov and Goldhammer, 1991; House and Gale, 1995; Schwarzacher, 1993; Yang et al., 1995). This is only possible if Milankovitch orbitally induced physical processes, such as climatic and sea-level changes, are indeed the major controls on the stratigraphic and temporal regularities of a cyclic record. Because non-Milankovitch processes could also produce meter-scale cycles, it is imperative to distinguish these processes by examining their stratigraphic signatures (Brown, 1969). In addition, understanding the mechanisms and interplay of these processes will undoubtedly increase the predictive power of cyclostratigraphy.

In some studies, average cycle periods are matched with the periods of Milankovitch climatic cycles, to suggest a Milankovitch origin for ancient cycles, and even to calibrate the chronostratigraphy. The results of this study suggest extreme caution in this practice because of the presence of different orders of cycles and local autogenic cycles, and the common cycle absence caused by amalgamation, siliciclastic sediment suppression, and erosion.

SUMMARY

1. Minor, intermediate, and major transgressive-regressive cycles of the Cisco Group vary in type, magnitude, thickness, and probably duration. They form a stratigraphic hierarchy.

2. Regional systematic variations in cycle abundance, continuity, type, magnitude, thickness, and the lithofacies and thickness of sand-rich intervals indicate allogenic controls on cyclic sedimentation of the Cisco Group. High-frequency sea-level changes controlled the extent and order of regional transgressive-regressive events. Regional topography controlled the distribution of depocenters and bypass zones. Regional siliciclastic supply patterns controlled component lithofacies and thickness of cycles. Shelf subsidence is the ultimate control on cycle preservation.

3. Autogenic processes caused local variations of cycle characters. Local topography, differential compaction, and depositional dynamics combined to control lateral facies changes, local depositional loci, and erosion. Regressive fluvial and deltaic sedimentation was extensive in the upper and middle platform, causing common cycle absence and obliterating the signatures of allogenic processes. In contrast, shelf carbonate and siliciclastic sedimentation in the lower platform have clearly recorded allogenic signatures.

4. Comparison of cycle characters across the shelf indicates that a predominantly autocyclic record does not imply the absence of allogenic processes, and a seemingly allocyclic record may contain many autocyclic imprints.

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