Cyclic sedimentation in the Fort Hays Limestone Member, Niobrara Formation (Upper Cretaceous) in northeastern New Mexico and southeastern Colorado

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CYCLIC SEDIMENTATION IN THE FORT HAYS LIMESTONE MEMBER, NIOBRARA FORMATION (UPPER CRETACEOUS) IN NORTHEASTERN NEW MEXICO AND SOUTHEASTERN COLORADO

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Abstract—Rhythmically interbedded isochronous limestones and shales of the Fort Hays Limestone Member were deposited during the transgressive phase of the Niobrara marine cycle in Late Cretaceous time. Limestone beds were formed from coccolith-rich pelagic ooze that was deposited during periods of minimal clastic-detrital influx. Dilution of carbonates during periods of increased runoff from siliciclastic source areas resulted in deposition of shaly beds. Non-carbonate material has been further concentrated in shaly horizons by pressure solution during burial diagenesis. Recent investigations of the Fort Hays suggest that shale-limestone interbedding was generated by orbitally-forced climatic variations. This hypothesis is supported by the occurrence of these cyclic deposits over much of Colorado, New Mexico and Kansas. Detailed regional correlation of individual cycles, however, indicates that climatically-induced bedding patterns were overprinted by effects of Upper Cretaceous tectonic activity along the Sevier orogenic belt and by erosional events associated with tectono-eustatic sea level oscillations. Correlation of the Fort Hays from Pueblo, Colorado into northeastern New Mexico documents progressive disappearance of climatically-induced depositional cyclicity with increasing proximity to terrigenous detrital source areas.

INTRODUCTION

The Fort Hays Limestone Member (Upper Turonian-Coniacian) is an excellent example of epicontinental pelagic carbonate deposition that occurred during one of North America's most extensive Cretaceous marine transgressions. The Fort Hays consists of an alternating sequence of relatively resistant limestone and shaly beds that make up the lowest part of the Niobrara Formation across a wide area of the central Great Plains and southern Rocky Mountains. Relevant measured sections (Fig. 1) occur in roadcuts, streams and hogbacks along the structurally disturbed western flank and gently dipping eastern edge of the Denver-Julesburg and Raton basins. Within the Fort Hays, individual beds are time-parallel and extend far from the northeastern New Mexico-southeastern Colorado conference area through much of Colorado, Kansas, Nebraska and South Dakota (Fig. 2). Rhythmic interbeds within the member yield valuable information regarding Cretaceous climate, tectonics and sea-level changes in the U.S. Western Interior region. This study furnishes an overview of the stratigraphy, sedimentology and depositional environments of the Fort Hays and interprets changes in patterns of cyclic deposition that occur in southeastern Colorado and northeastern New Mexico sections. It represents an extension of work conducted on the Fort Hays in Kansas and Colorado by Laferriere et al. (1987).

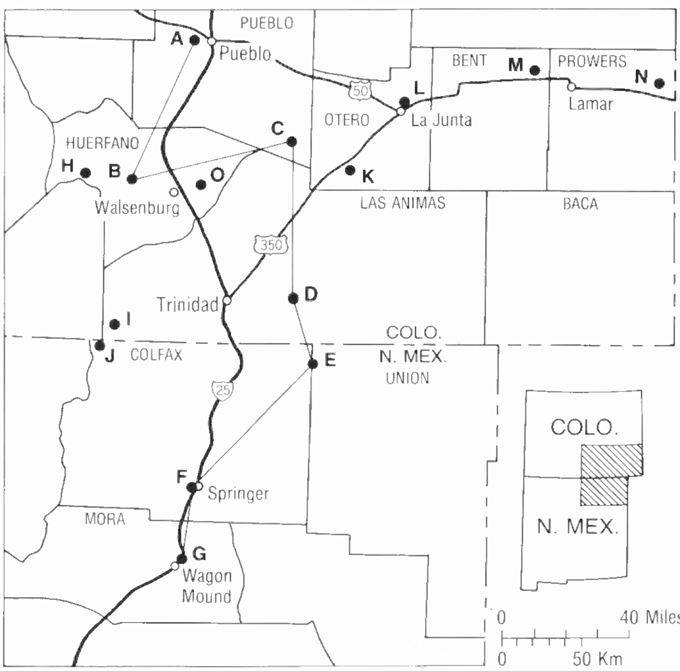

FIGURE 1. Map of southeastern Colorado and northeastern New Mexico showing location of measured sections. Township-range coordinates are included in appendix. Localities connected by solid line correspond to those shown in correlation diagram (Fig. 4).

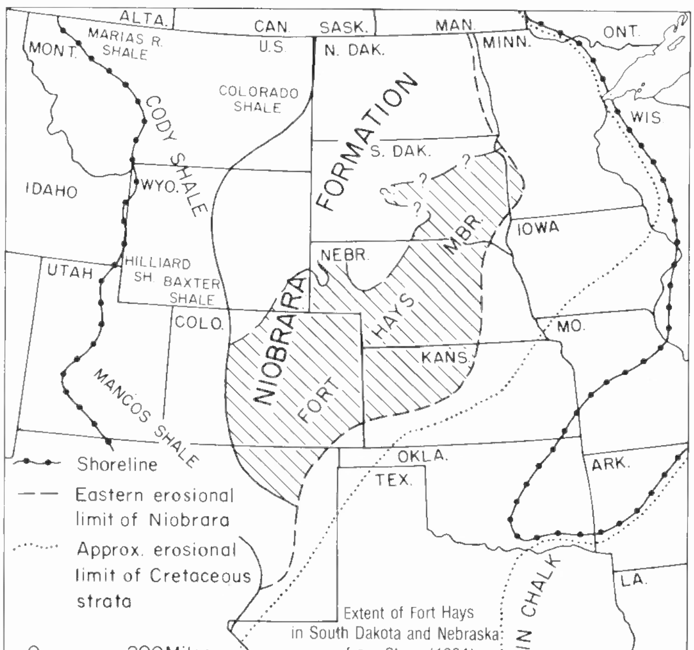

FIGURE 2. Distribution of Niobrara Formation and Fort Hays Member. Extent of Fort Hays in South Dakota and Nebraska is based on Shurr (1984).

STRATIGRAPHY

Within the conference area, the Fort Hays comprises interbedded dark-olive gray, calcareous, pelagic/hemipelagic shale and light olive-gray, pelagic limestone. Shale intervals form pronounced recesses between resistant yellowish-gray-weathering limestone ledges (Fig. 3). Limestone beds are biomicrosparites consisting of about 5% inoceramid bivalve remains and 10% pelagic foraminiferal test fragments in a largely recrystallized coccolith-rich matrix. Inoceramid bivalves are the most common macrofossils. These bivalves provided one of the few available hard substrates during Fort Hays deposition (Hattin, 1986) and were commonly bored by cirripeds and encrusted by small oysters. Trace fossils are abundant in limestone beds, and include *Planolites, Chondrites, Teichichnus, Thalassinoides, Trichichnus, Tigillites* and *Zoophycus* (Frey, 1970; Archer, 1983). During limestone deposition, progressive early lithification of relatively pure carbonate mud resulted in increased substrate firmness and induced a succession of burrow structures, culminating in open dwelling-structures (Hattin, 1986). These dwelling structures are now preserved as calcite spar-, limonite- or pyrite-filled burrows. In shale beds, trace fossils are less abundant and diverse than in limestone beds and consist mainly of *Planolites* that are filled with chalk piped down from overlying carbonate muds. A thorough description of trace and body fossils of the Fort Hays in Kansas is provided by Frey (1970, 1972). Archer (1983) documented Fort Hays trace fossil assemblages in southeastern Colorado.

Limestones are thoroughly homogenized by bioturbation and display few physical sedimentary structures. Conversely, laminations and thin bentonite seams are common in many shale beds where bioturbation was less pervasive. Limestones consist of relatively pure low-magnesium calcite, and have insoluble residue contents (obtained by leaching whole-rock samples with hydrochloric acid) generally less than 10%. Insoluble residue content of shaly interbeds ranges from about 20% to 80% and increases to the west and southwest, closer to inferred source areas of terrigenous detritus. In Kansas, shaly interbeds are thin, and often occur only as marly partings between massive limestone beds. Shaly interbeds thicken westward and southwestward toward the Front Range and southward into New Mexico (Fig. 4). At the southernmost occurrence of the Fort Hays (near Wagon Mound, New Mexico), shale beds are the predominant lithofacies in the section (Fig. 3d). Characteristic Fort Hays deposition occurred over an extensive geographic area (Fig. 2), and individual shale-limestone couplets can be correlated over 800 km, throughout much of Kansas, Colorado and northeastern New Mexico (Laferriere et al., 1987). Consistent position of distinctive bentonite seams relative to Fort Hays marker beds demonstrates that Fort Hays depositional cycles were regionally synchronous events, and individual beds are time-parallel.

Regional continuity of limestone and shale beds, presence of limestone-filled burrows extending downward into shale units, common occurrence of carbonate fossils in both shale and limestone beds and thickening of shale beds toward Cordilleran source areas indicate that Fort Hays cycles are largely depositional in origin, and not the result of diagenetic segregation of calcium carbonate. Nodular limestones and complimentary limestone pairs (one bed thickening at the expense of an adjacent bed), which Hallam (1986) has shown to be characteristic of diagenetically induced shale-limestone couplets, are absent in the Fort Hays. Shale beds in the Fort Hays, however, have been modified by compaction, and pressure solution has occurred along abundant microstylolites as evidenced by dissolution truncation of foraminiferal and inoceramid bivalve grains in microstylolitic zones (Fig. 5). In

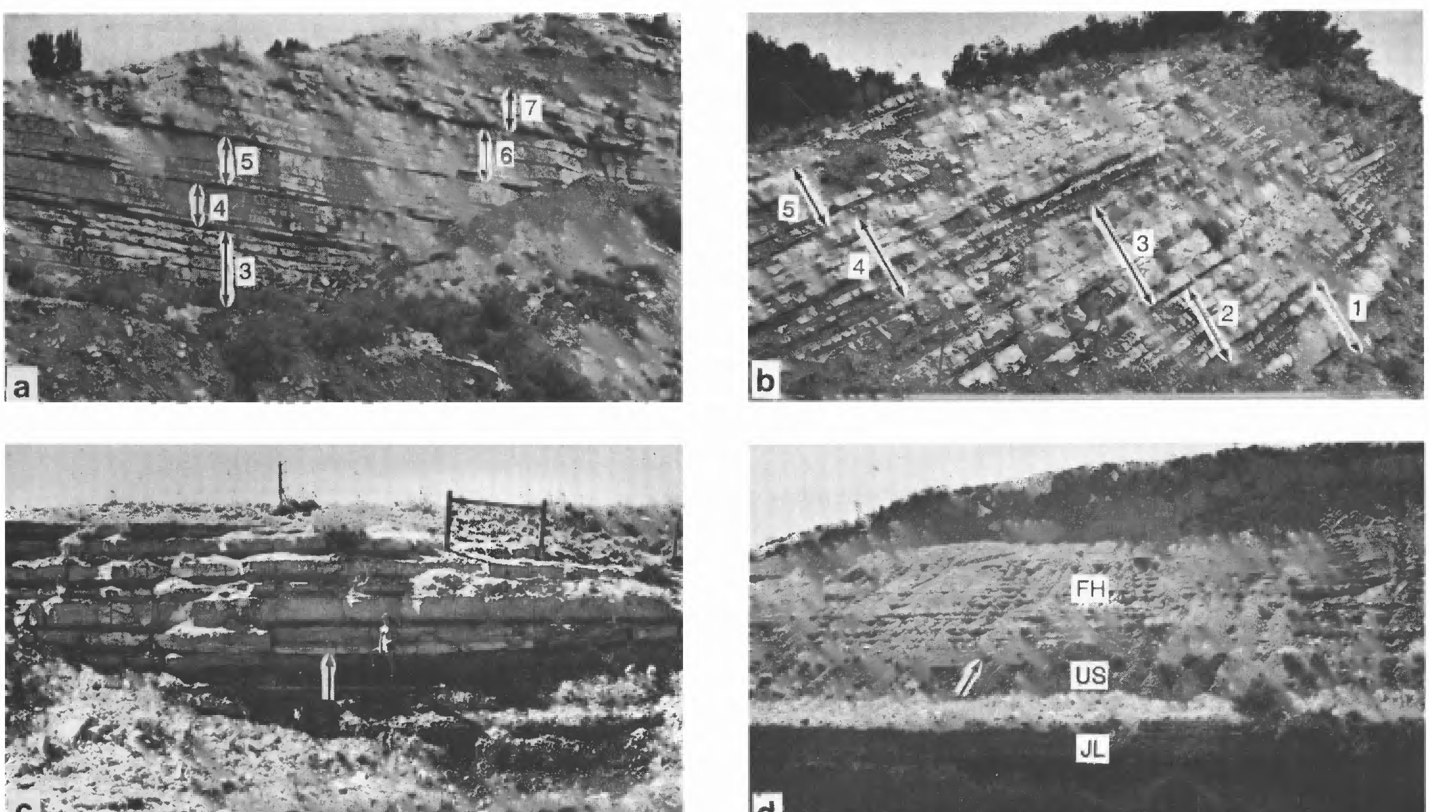

FIGURE 3. a, Field photograph of Fort Hays exposure near Pueblo, Colorado (locality A of Fig. 1). Numbers correspond to bundles of shale-limestone couplets labeled in Figure 4. b, Fort Hays exposed in roadcut situated northwest of Walsenburg, Colorado (locality B of Fig. 1). Numbers correspond to bundles of shale-limestone couplets labeled in Figure 4. c, Exposure of Fort Hays in stream bank in Springer, New Mexico (locality F of Fig. 1). Development of channel-like scour structure resulted in thickening of limestone bed at base of Fort Hays (arrow indicates basal contact). This limestone bed is underlain by unnamed shale member of Carlile Shale. d, Fort Hays exposure in roadcut and hillside along Interstate 25 near Wagon Mound, New Mexico (locality G of Fig. 1). Arrow marks base of Fort Hays (FH), which is underlain by unnamed shale member of Carlile Shale (us). Dark ledge in foreground is Juana Lopez Calcarenite Member of Carlile (JL). Outcrop is capped by Upper Cenozoic volcanics.

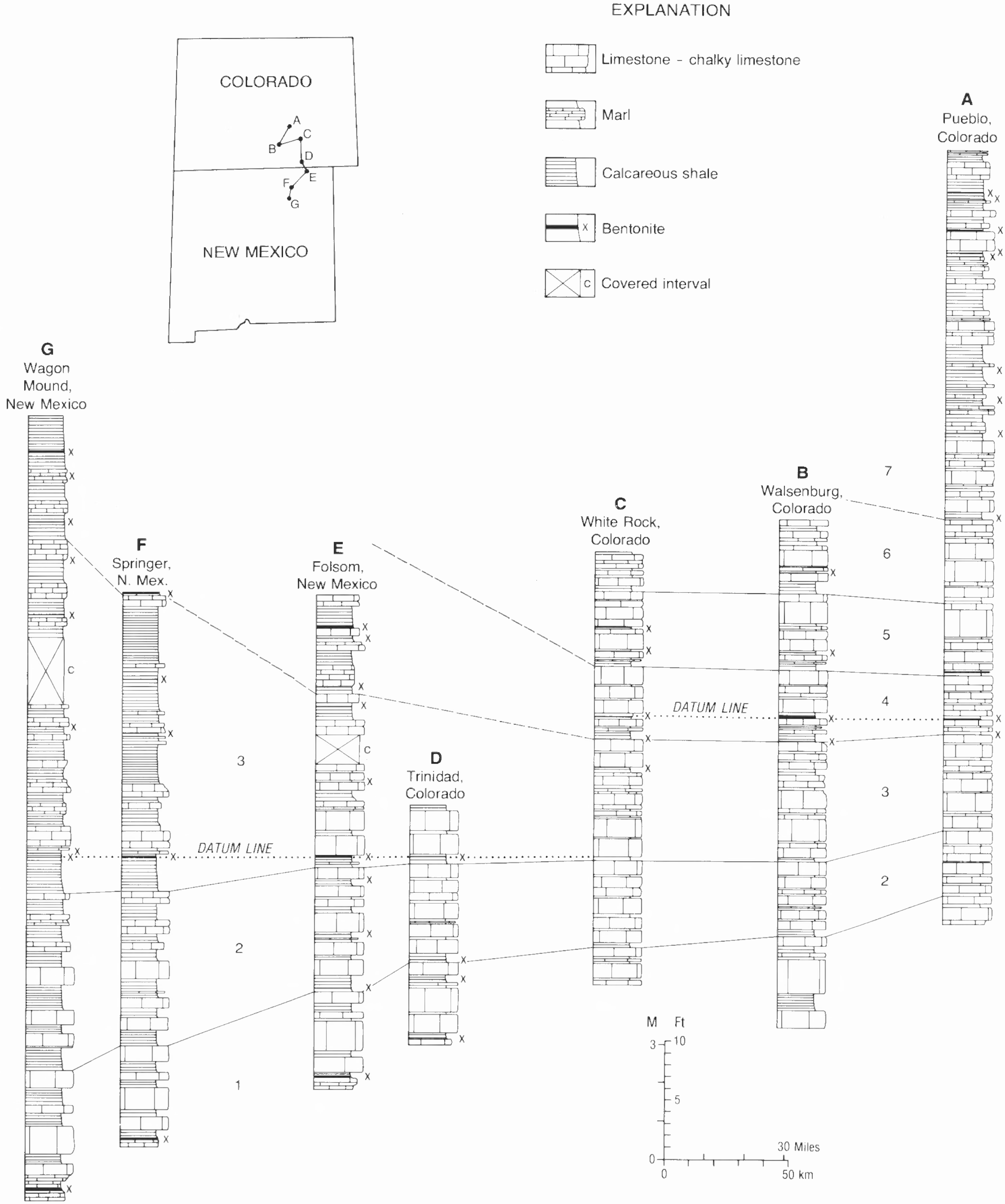

FIGURE 4. Graphic sections of Fort Hays Member along transect from Pueblo, Colorado to Wagon Mound, New Mexico. Lettered localities correspond to those in Figure 1. Solid correlation lines denote boundaries between bundles of shale-limestone couplets. Dashed lines indicate less certain correlations. Bundles of shale-limestone couplets are labeled 1 (lowest) through 7 (uppermost). Sections A, F and G show upward transition from limestone-dominated Fort Hays Member to shale-dominated Smoky Hill Member of Niobrara Formation.

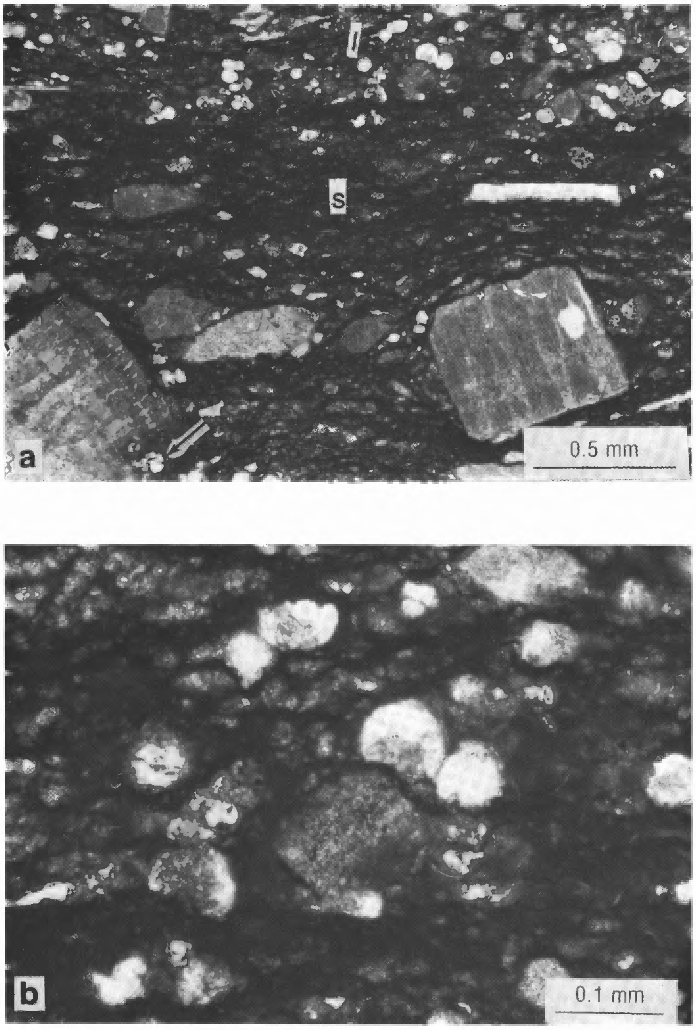

FIGURE 5. a, Photomicrograph of Fort Hays shaly interval showing development of microstylolites. Note highly reduced number of Foraminifera in shaly interval (s) as compared with overlying limestone (l). Some Foraminifera in shaly bed are preserved in shelter created by inoceramid fragment (arrow). b, Photomicrograph showing partially dissolved Foraminifera along microstylolites in Fort Hays shaly interval. Photos from Fort Hays core sample: Forest Oil 1-4 Continental, sec. 4, T19S, R69W, Fremont County, Colorado.

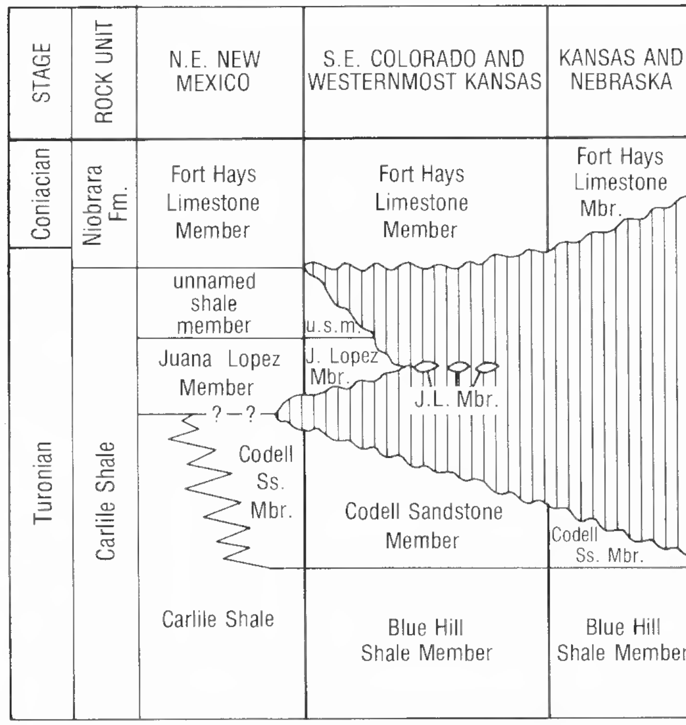

FIGURE 6. Relationship of Fort Hays Member to underlying members of Carlile Shale in New Mexico, southeastern Colorado and Kansas. Isolated bodies labeled JL denote clasts of Juana Lopez calcarenite that have been incorporated within the basal Fort Hays Member.

contrast, the well-cemented limestone beds show little evidence of compaction or pressure solution. Dissolution along microstylolites that selectively formed within shale beds may have provided a large part of the calcium carbonate required for cementation within adjacent limestones (Garrison and Kennedy, 1977; Scholle, 1977; Arthur et al., 1984). Initially, clay-rich intervals are vulnerable to pressure solution owing to greater rates of diffusion of pressure-dissolved solutes along clay films than along simple solution films between mineral grains (Weyl, 1959). Concentration of insoluble material along shaly horizons by pressure-solution may have enhanced cyclic patterns (Arthur et al., 1984).

The Fort Hays unconformably overlies the Carlile Shale. This unconformity, which involves a northeastwardly widening lacuna (Hattin, 1975), was generated during a period of eustatic fall in sea level between the Greenhorn and Niobrara transgressive-regressive cycles which affected wide expanses of the U.S. Western Interior during Cretaceous time (Weimer, 1960; Kauffman, 1977). Progressively older members of the Carlile Shale are truncated, and successively younger beds of the Fort Hays wedge out along this unconformity in a northeastwardly direction (Fig. 6). In southeastern Colorado, the Fort Hays overlies the Codell Sandstone and Juana Lopez Calcarenite members of the Carlile, and the unconformity is marked by reworked Codell quartz sand, bivalve- and foraminifer-encrusted phosphorite nodules, extensively bored and partially phosphatized Juana Lopez clasts and fish teeth in the basal Fort Hays (Laferriere, 1981). In south-central Colorado, an unnamed shale member of the Carlile lies between the Juana Lopez and Fort Hays and thickens southward into New Mexico. Near Springer and Wagon Mound, New Mexico this unnamed shale member is well developed, and the Carlile-Niobrara contact appears to be gradational, except in areas of localized scour at the base of the Fort Hays (Fig. 3c–d). The Carlile-Niobrara contact likewise appears to be gradational along the western edge of the Raton Basin at Vermejo Park, New Mexico (Pillmore and Eicher, 1976). In Kansas, the Fort Hays is overlain conformably by the Smoky Hill Member of the Niobrara Formation (Hattin, 1982), and the upper part of the Fort Hays grades laterally into the Smoky Hill or its equivalents in a westwardly and southwestwardly direction, including the field conference area. Thickness of the Fort Hays ranges from 18.3 m near Pueblo and 15.3 m at La Junta, where the unit is well developed, to only 6.1 m near Wagon Mound, New Mexico. The total number of Fort Hays limestone beds ranges from 42 beds near Pueblo to only eight beds at Wagon Mound, where lateral lithofacies change to shale has replaced all but the lowermost limestones in the member (Fig. 4).

REGIONAL SETTING: DISCUSSION

Sediments of the Fort Hays Limestone Member were deposited in the Western Interior Sea during the transgressive phase of the Niobrara marine cycle (Weimer, 1960; McGookey et al., 1972; Kauffman, 1977). Deposition of the Fort Hays was preceded by that of the Juana Lopez Calcarenite and unnamed shale members of the Carlile. The Juana Lopez was deposited on an eroded Codell sandstone surface as a winnowed inoceramite in a high energy, nearshore environment (Kauffman et al., 1969). As water depth increased and effects of wave and current action diminished, sediments of the unnamed shale member were deposited in an inner and midshelf environment (Kauffman et al., 1969). Extensive removal of the Juana Lopez in southeastern Colorado and western

Kansas and inclusion of bored and phosphatized Juana Lopez clasts in the basal Fort Hays indicate that the early transgressional phase of the Niobrara cyclothem involved multiple erosional events (Laferriere, 1981; Fisher et al., 1985). As transgression continued, rising sea-level widened the seaway, influx of siliciclastic sediments to the central and eastern parts of the basin was greatly reduced, and large nannoplankton populations were established, resulting in widespread deposition of coccolith-rich pelagic ooze. The laterally persistent nature of individual Fort Hays bedding couplets throughout much of northeastern New Mexico and southern Colorado (Fig. 4), and the lack of significant evidence of current reworking, suggest that following initial Fort Hays deposition, the seafloor lay below effective wave base. Winnowed zones or calcarenites are rare and occur only near the base of the Fort Hays or within widely scattered channel-like structures associated with local thickening of limestone beds. Farther to the northeast in central Kansas, however, beds equivalent to the lower part of the Colorado Fort Hays are absent (Hattin, 1975; Laferriere et al., 1987). In this area, limestone beds near the base of the formation contain large amounts of reworked Codell sandstone, and shaly interbeds are thin or absent.

On the basis of geochemical and paleontological evidence, cyclical alternations of shale and marlstone beds with pelagic limestone beds, such as those in the Fort Hays, have been attributed to alternating wet and dry climatic periods (Fischer, 1980; Pratt, 1984). During wet periods, increased influx of siliciclastics from the Sevier orogenic belt west of the seaway (Armstrong, 1968) diluted background deposition of pelagic carbonate material, resulting in accumulation of shale-forming muds. During dry periods, coccolith-rich pelagic mud settled from a well-circulated water column and incorporated little detritus from terrigenous source areas. Investigations of rhythmic bedding patterns within the Fort Hays suggest that these climatic oscillations were controlled by Milankovitch-type orbital variations (Gilbert, 1895; Fischer, 1980; Fischer et al., 1985). According to this hypothesis, shale-limestone couplets resulted from cyclical variations in climate that were forced by Earth's axial precession, with a period of approximately 20,000 years. Shale-limestone couplets are grouped into bundles that are separated by atypically-thick shale intervals (Figs. 3a–b and 4). In the vicinity of Pueblo, Colorado, each bundle contains approximately five shale-limestone couplets, leading to speculation that the bundles resulted from climatic variations linked to Earth's orbital eccentricity cycle, with a period of approximately 100,000 yrs (Schwarzacher, 1975; Fischer, 1980; Fischer et al., 1985). Regional analysis of bedding cycles in the Fort Hays over much of Kansas and Colorado shows that these apparently climate-induced bedding patterns were complicated by tectonic effects of the Sevier orogeny as well as by erosional events associated with sea-level changes, and consequently the number of shale-limestone couplets per bundle actually ranges from one to twelve (Laferriere et al., 1987). In central Kansas, progressive northeastward disappearance of couplets within the lower part of the Fort Hays Member resulted largely from erosional events associated with the Carlile-Niobrara unconformity. Farther westward, in southeastern Colorado, closer to the axis of the Late Cretaceous basin and to the major Cretaceous source areas of terrigenous detritus, the effects of erosional events are much less, and the number of shale interbeds increases. In northeastern New Mexico, still greater influx of terrigenous material almost completely conceals bundling of Fort Hays bedding sequences, and too few limestone beds remain to allow detection of bedding patterns. Correlation of individual shale-limestone couplets from Pueblo and Walsenburg, Colorado, to Wagon Mound, New Mexico, indicates disappearance of four of the six bedding bundles that are discernible near Pueblo (Fig. 4).

Synthetic stratigraphic columns generated by Fischer et al. (1985) by modeling the effects of orbital variations on shale and limestone deposition suggest that detailed records of climatic variations are generated only in depositionally sensitive settings, such as deeper water basin-centers. In these areas, even low-amplitude climatic fluctuations will produce sedimentary sequences that are characterized by rhythmic alternation of shale and limestone. Sections at Pueblo and Walsenburg, Colorado, furnish an example of such a depositionally sensitive setting; one that possessed the delicate balance between pelagic carbonate deposition and terrigenous detrital input required to preserve the orbitally-induced climatic signals in the sedimentary record. Outside of this region, however, cycles are partially masked by erosion or excessive terrigenous detrital input, and Fort Hays depositional patterns should be interpreted with caution.

ACKNOWLEDGMENTS

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APPENDIX: LOCALITIES

A. E½ sec. 32, T20S, R65W, Pueblo County, CO.
B. secs. 4 and 5, T27S, R68W, Huerfano County, CO.
C. SE¼ sec. 23 and N½ sec. 26, T25S, R61W, Pueblo County, CO.
D. NW¼ sec. 8, T33S, R60W, Las Animas County, CO (lower and middle parts of Fort Hays).
E. N½ sec. 6, T30N, R28E and S½ sec. 31, T31N, R28E, Union County, NM.
F. sec. 33, T25N, R22E, Colfax County, NM.
G. NW¼ sec. 27, T21N, R21E, Mora County, NM.
H. SW¼ sec. 26, T26S, R71W, Huerfano County, CO.
I. Cut on north side of Consolidated Irrigation Ditch, just north of ranch road, approximately 5.5 mi northwest of Tercio and 2.25 mi west of benchmark 8,125 ft on unsurveyed land in Maxwell Grant, Torres Quadrangle, Las Animas County, CO.
J. sec. 8, T31N, R17E, Colfax County, NM.
K. NW¼ sec. 2, T27S, R58W and W½ sec. 34, T26S, R57W, Otero County, CO.
L. NE¼ sec. 35, T23S, R55W, Otero County, CO.
M. SW¼ sec. 30, T21S, R48W, Bent County, CO (lower part of Fort Hays).
N. SE¼ sec. 21, T22S, R42W, Prowers County, CO (lower and middle parts of Fort Hays).
O. SE¼ sec. 14, T27S, R65W, Huerfano County, CO (lower part of Fort Hays).