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FUSULINID SEQUENCE EVOLUTION AND SEQUENCE EXTINCTION IN WOLFCAMPIAN AND LEONARDIAN SERIES (LOWER PERMIAN), GLASS MOUNTAINS, WEST TEXAS

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Key words: Permian, Wolfcampian, Leonardian, fusulinids, depositional sequences, sequence evolution, sequence extinction.

Abstract. In the Permian Wolfcampian and Leonardian Series of West Texas, sequence evolution and sequence extinction record the appearance and disappearance of morphological species in stratigraphic successions that show repeated sea level fluctuations and associated depositional hiatuses. The lower Wolfcampian Nealian Stage includes 16 relatively short term sea-level fluctuations (fourth-order depositional sequences) and contains a diverse fusulinid fauna of more than 39 species and eight genera. Most Nealian species range through three or four fourth-order cycles before becoming extinct and none extends into the overlying upper Wolfcampian Lenoxian Stage. The succeeding Lenox Hills Formation overlies a tectonic unconformity (and hiatus) and includes three third-order depositional sequences. Four Lenoxian species are restricted to the lower sequence, 16 to the middle sequence, and six to the upper sequence.

In the Leonardian Series, at the base, the Hessian Stage includes seven third-order depositional sequences and numerous minor fourth-order and smaller parasequences. Hessian carbonate platform facies have low fusulinid species diversity and high abundances. The lower four Hessian lowstand clastic wedges of the shelf margin and basin include at least six species of schwagerinids. The three upper wedges include only three species of *Parafusulina.* The Cathedralian (upper) Stage has one main third-order depositional sequence, and perhaps a second, which is mostly missing on the platform below the Mid-Permian unconformity below the Middle Permian Guadalupian Series.

Suggested correlations of the Wolfcampian and Leonardian with the Tethyan succession in Darvas and the Pamirs of Middle Asia place the Nealian as equivalent to the Asselian and Sakmarian. The Lenoxian is probably equivalent to the lower and middle parts of the Yakhtashian. The Hessian is equivalent to the upper part of the Yakhtashian and the Bolorian. The Cathedralian seems to be equivalent to the Kubergandian. There is little evidence that the upper part of the Kubergandian extends higher into the Middle Permian Roadian Stage.

Riassunto. Nelle Serie permiane del Wolfcampiano e Leonardiano del Texas occidentale, sono documentate comparsa e scomparsa di specie morfologiche in sequenze stratigrafiche, controllate da ripetute oscillazioni eustatiche e connessi hiatus deposizionali. Il piano Nealiano del Wolfcampiano inferiore comprende 16 oscillazioni del livello del mare relativamente brevi (sequenze deposizionali di quarto ordine) e contengono una fauna a fusuline diversificata con più di 39 specie e 8 generi. Molte specie del Nealiano si estendono per 3 o 4 cicli di quarto ordine prima di divenire estinte. Nessuna di queste giunge sino al soprastante piano Lenoxiano del Wolfcampiano superiore. La successiva Lenox Hills Formation poggia su una discontinuità tettonica (e relativo hiatus) e include 3 sequenze deposizionali di terzo ordine. Quattro specie del Lenoxiano sono esclusive della sequenza inferiore, 16 della sequenza intermedia e 6 di quella superiore.

Nella Serie del Leonardiano, nella parte inferiore il piano Hessiano include 7 sequenze di terzo ordine, numerose sequenze minori di quarto ordine e ancor più brevi parasequenze. Le facies Hessiane di piattaforma carbonatica hanno una bassa diversità specifica nelle fusuline ed alta densità. I quattro prismi clastici di stazionamento basso dell'Hessiano presenti sul margine della piattaforma e del bacino includono almeno 6 specie di schwagerinidi. I tre prismi superiori includono solo tre specie di *Parafusulina.* Il piano Cathedraliano (Leonardiano superiore) contiene principalmente una sola sequenza deposizionale di terzo ordine e forse una seconda, che solitamente manca sulla piattaforma sotto la discontinuità del Permiano medio, sotto la Serie Guadalupiana.

Le correlazioni del Wolfcampiano e Leonardiano con le successioni Tetidiane del Darvas dei Pamirs in Asia centrale indicano che il Nealiano è equivalente dell'Asseliano e del Sakmariano. Il Lenoxiano è probabilmente equivalente delle parti inferiore e media dello Yakhtashiano. L'Hessiano è equivalente della parte superiore dello Yakhtashiano e del Boloriano. Il Cathedraliano sembra equivalente del Kubergandiano. Vi sono scarse evidenze che la parte superiore del Kubergandiano si estenda verso l'alto nel piano Roadiano del Permiano medio.

Introduction

Lower Permian fusulinid genera and species appear and disappear in a succession of 28 or more depositional sequences in the Wolfcampian and Leonardian Series in the Glass Mountains of West Texas. The stratigraphic ranges of these genera and species, their biostratigraphy, sedimentary relations, sea level fluctuations, and paleoecology, and the tectonic activity of the area emphasize

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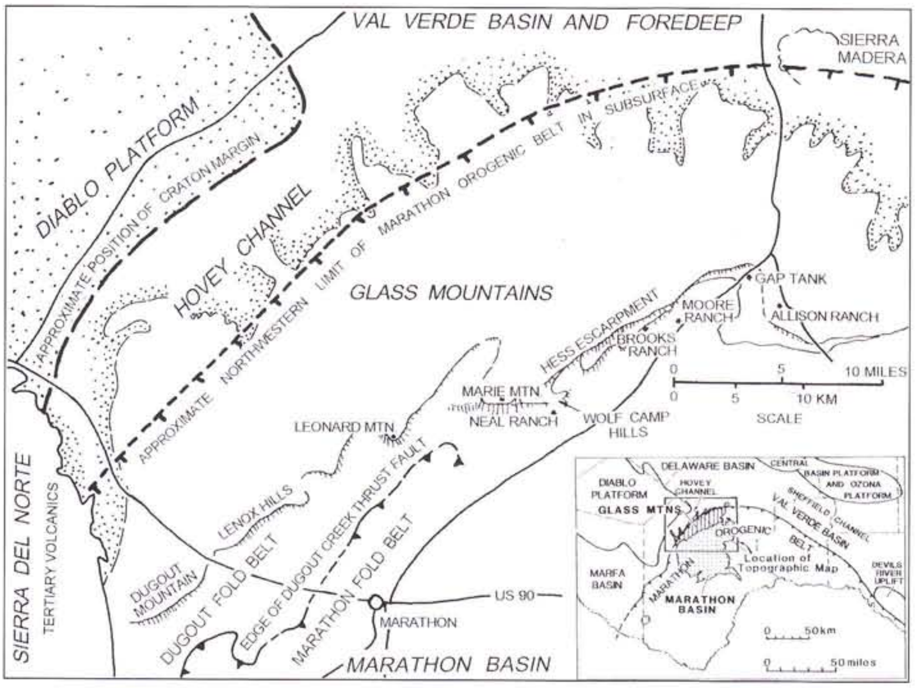


Fig. 1 - Index map to major geographic names, geological structures, and localities in the Glass Mountains and northern part of the Marathon Basin, West Texas.

the interaction of sedimentary history and fossil preservation and the recognition of species evolution and species extinction.

The Glass Mountains (Fig. 1) are the type areas for both the Wolfcampian and Leonardian Series (Fig. 2), which are widely used in North America as standard reference sections for the Lower Permian (King 1934; Adams et al. 1939; Hill 1996). The Glass Mountains also contain the standard reference sections for the Roadian and Wordian stages that form the lower part of the Middle Permian Guadalupian Series which recently has been adopted as the Global Middle Permian Series. Although these strata are well exposed in the semiarid Glass Mountains, they have complex lateral sedimentary facies and contemporaneous structural complexities so that their relationships in outcrop have been the subject of numerous studies and interpretations over the last 80 years.

These well-exposed and well-defined Lower Permian stratigraphic units are of global importance and correspond to and are largely equivalent to the international Lower Permian Cisuralian Series. The placement of the Cisuralian stage boundaries remains uncertain between the southern Urals and North America, particularly for the upper part of the Artinskian, Kungurian and Ufimian stages. The North American Lower Permian sections display more adequately and faunally than those from the higher parts of the Cisuralian interval, particularly for the upper part of the Artinskian, the Kungurian, and the Ufimian in the Cisuralian type sections. For that reason, the North American Leonardian Series was proposed as a replacement for the Kungurian and Ufimian stages. Although this arrangement was initially agreed to by the Permian Subcommission members in discussion, it was later rejected by vote on the grounds that the Russians did not know enough about the North American standard reference sections. This paper, thus, also serves to summarize the stratigraphy on the North American Lower Permian standard sections in the Glass Mountains.

The underlying, complexly folded and faulted thrust sheets of the Marathon orogenic belt are mainly composed of clastic and cherty, slope and basinal sediments that have been incorporated into a number of thrust belts that became well-cemented, semistable structural belts. As the Carboniferous and Early Permian Marathon orogeny progressed, additional thrust sheets continually deformed the thick, frontal Val Verde foredeep sediments and incorporated them into a series of progressively younger structural belts which formed northwestward. Thus, in the eastern part of the Glass Mountains, the Gaptank Formation (Upper Pennsylvanian) lies on a folded belt of clastic and cherty, slope and basinal sediments that contain faunas as young as middle Desmoinesian (middle Strawn) age. In the western part of the Glass Mountains, the Lenox Hills Formation (Lenoxian, late Wolfcampian) lies on a younger structural fold belt, the Dugout fold belt, which includes clastic and cherty, slope and basinal sediments, and some upper slope-margin limestones, as young as Nealian age (early Early Permian).

In this paper, we review the physical stratigraphy of the Lower and part of the Middle Permian succession in the Glass Mountains, the distribution of fusulinid faunas and assemblages, and the current understanding of the 28 or more depositional sequences as interpreted from eustatic sea level changes and by occasional disruption by tectonic activity (Ross and Ross, in press).

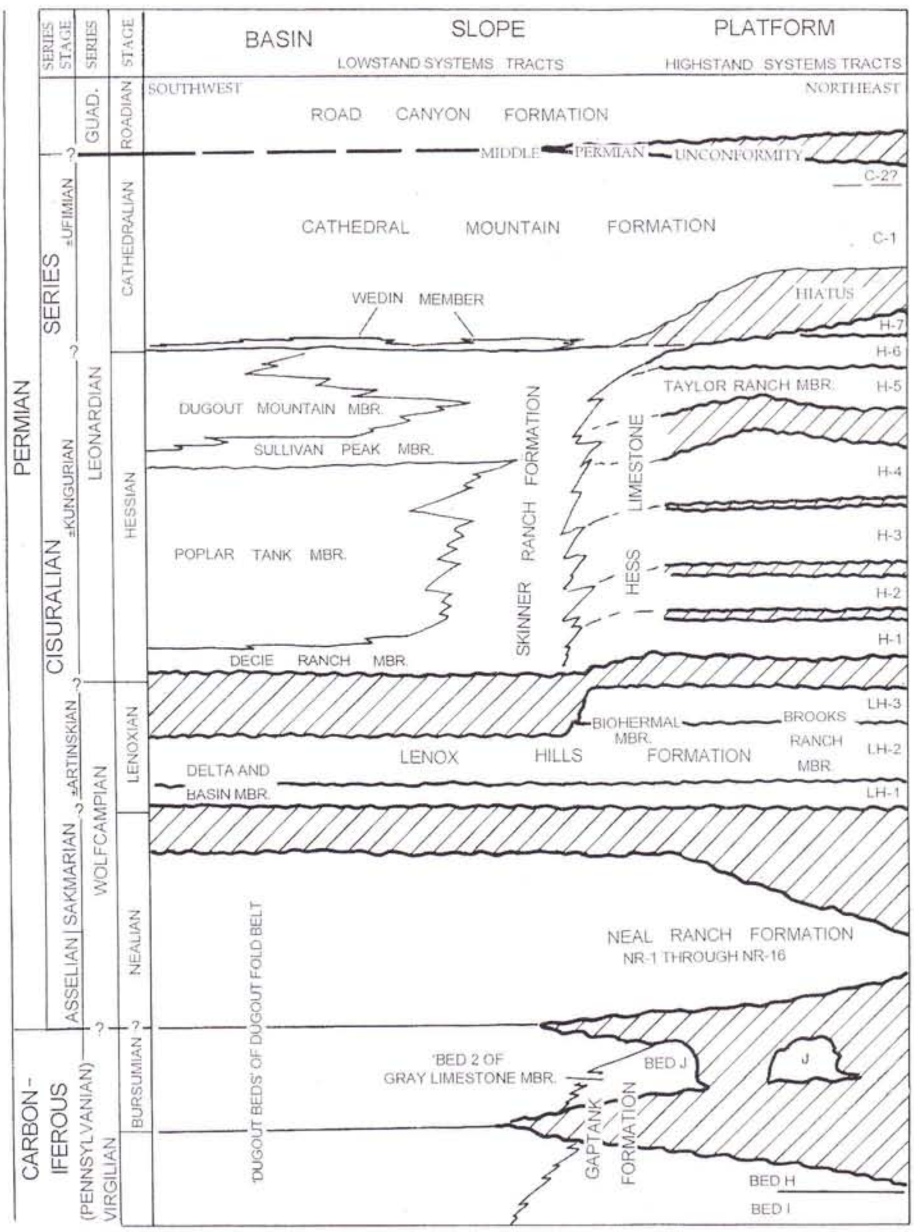


Fig. 2 - Stratigraphic nomenclature and time relations of formations, stages and series of the Upper Carboniferous and Lower Permian succession in the Glass Mountains with probable correlations to the stages of the Cisuralian Series. (Modified from Ross & Ross, in press).

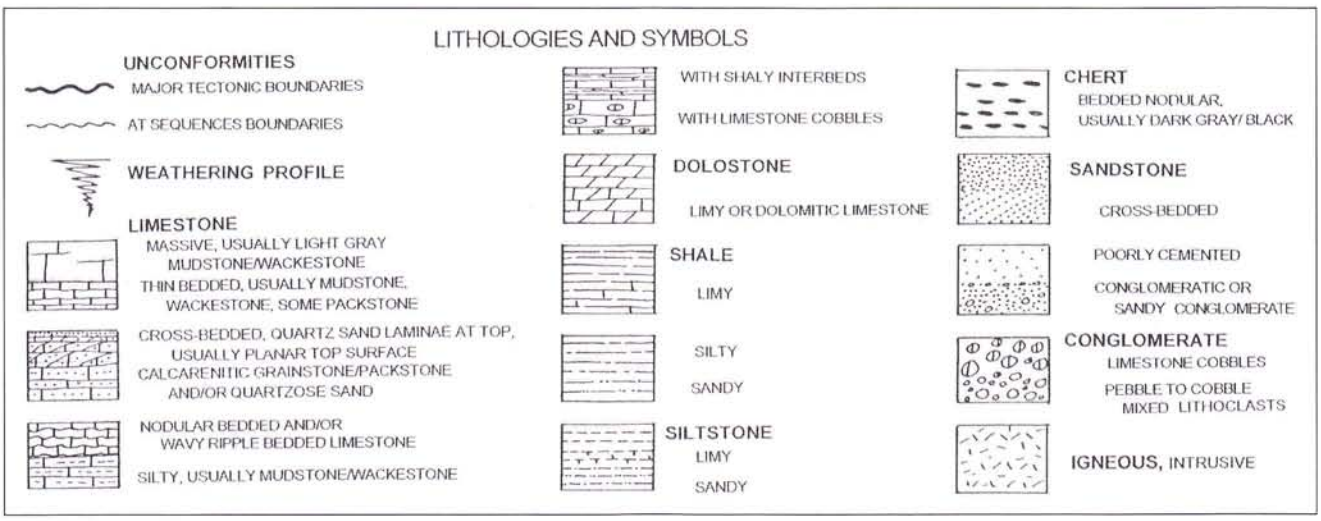
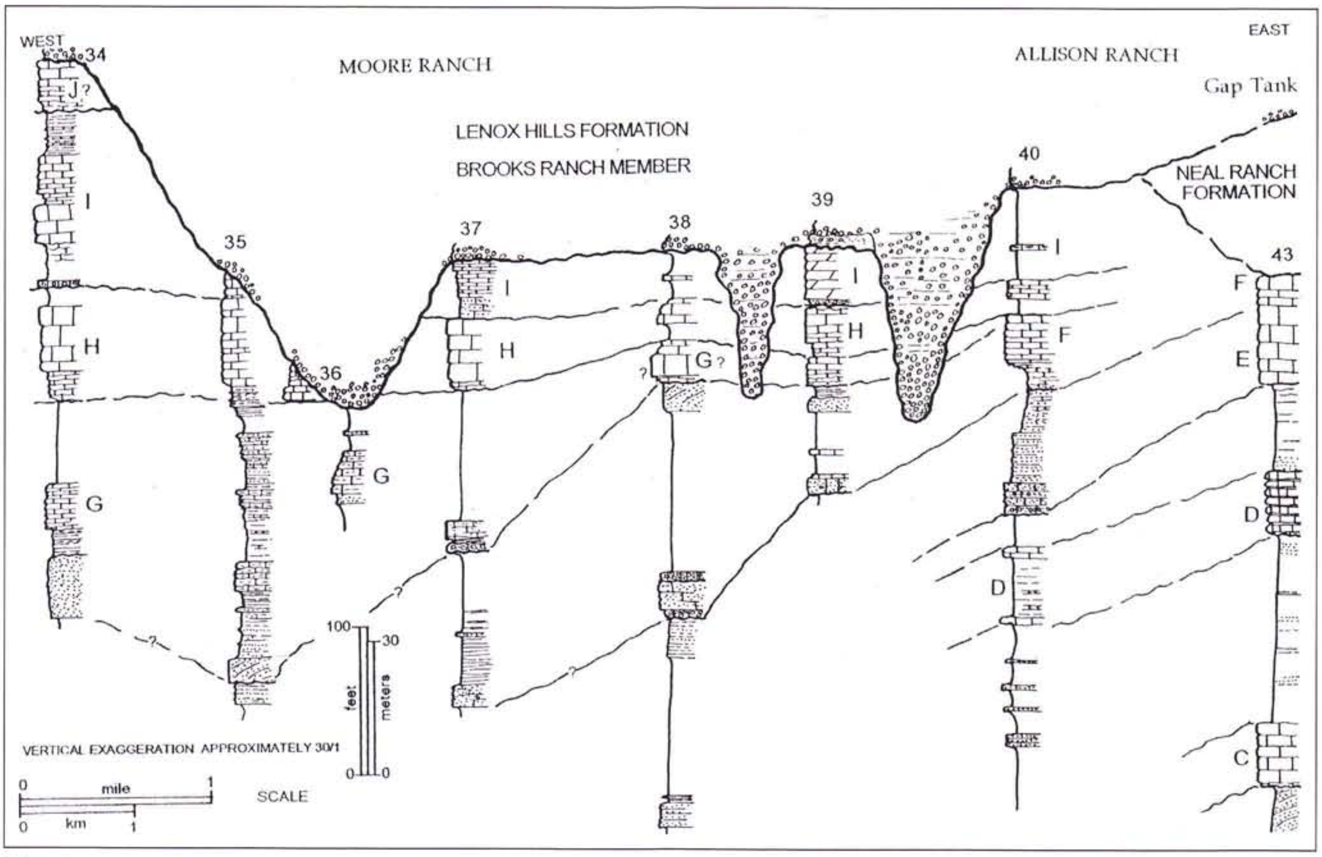
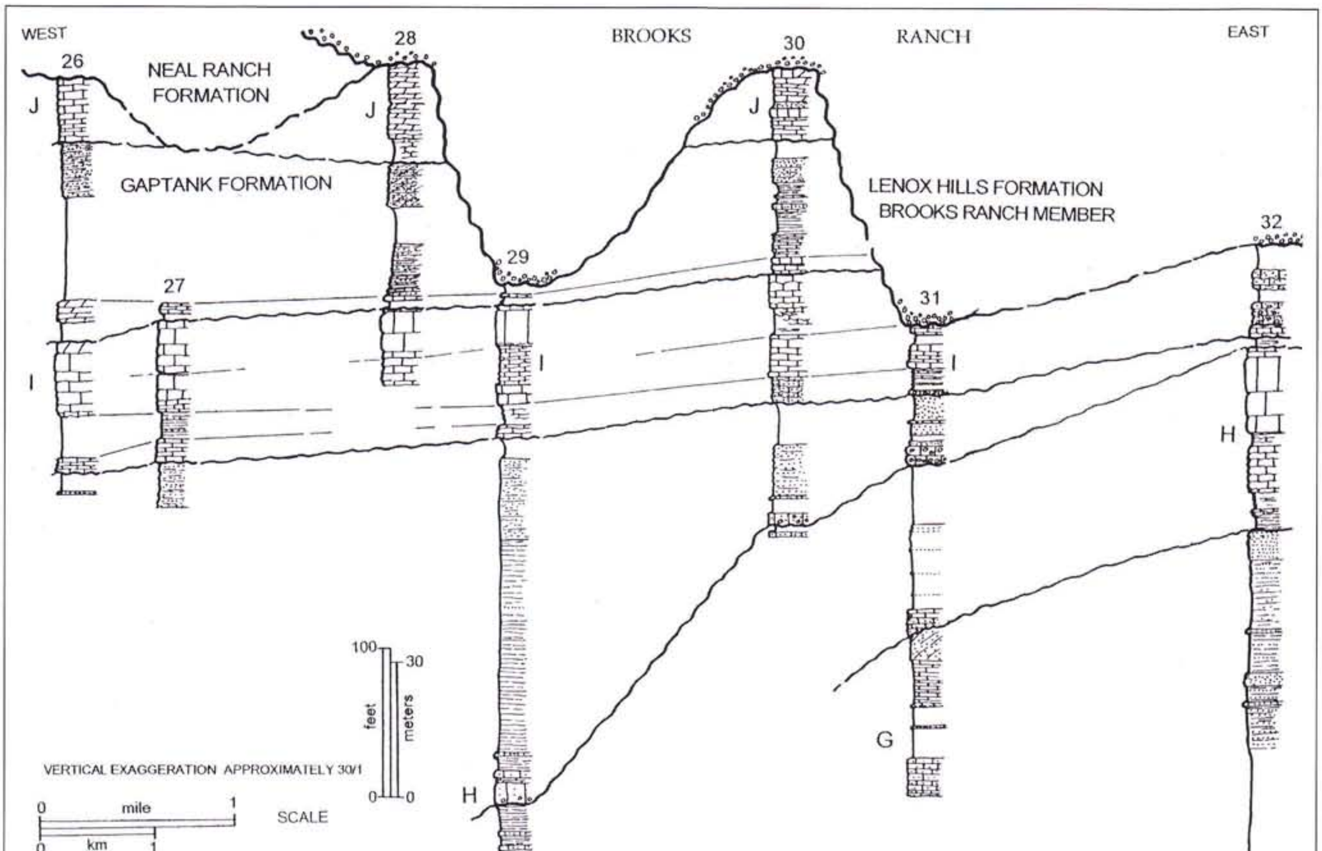


Fig. 3 - Lithologic and other symbols used on stratigraphic sections.



WEST
EAST
34
MOORE RANCH
ALLISON RANCH
Gap Tank
LENOX HILLS FORMATION
BROOKS RANCH MEMBER
NEAL RANCH FORMATION
35
36
37
38
39
40
43
J?
I
H
G
G?
F
E
D
C
VERTICAL EXAGGERATION APPROXIMATELY 30/1
100 feet 30 meters 0 0
0 mile 1
0 km 1
SCALE

Fig. 4A



WEST
EAST
26
28
BROOKS
30
RANCH
NEAL RANCH FORMATION
GAPTANK FORMATION
LENOX HILLS FORMATION
BROOKS RANCH MEMBER
27
29
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VERTICAL EXAGGERATION APPROXIMATELY 30/1
100 feet 30 meters 0 0
0 mile 1
0 km 1
SCALE

Fig. 4B

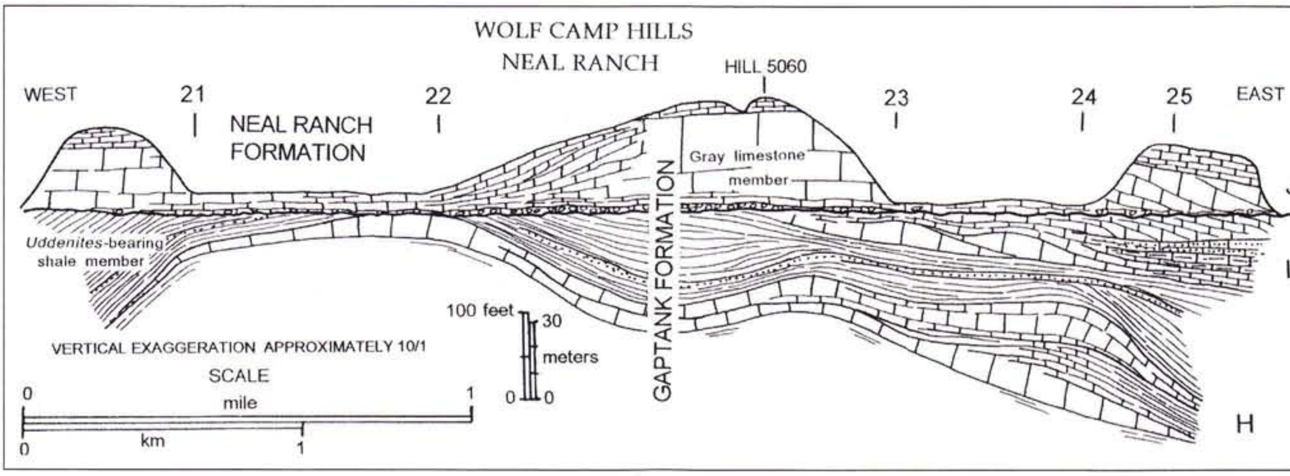

Fig. 4C

Fig. 4 - Upper Pennsylvanian Gaptank Formation, eastern part of the Glass Mountains, from its type section at Gap Tank westward to the Wolf Camp Hills; A, from Gaptank on the Allison Ranch to the Moore Ranch; B, Brooks Ranch; C, Wolf Camp Hills on the Neal Ranch. See figure 3 for explanation of lithologic and other symbols. (Data are from Ross 1963, 1965, 1967a; lettered beds are from Ross 1965, 1967a).

Depositional sequences and fusulind sequence evolution and extinction

Identifying depositional sequences is based on interpreting the depositional and paleoecologic record of sediments and the exposure surfaces and weathering features associated with the unconformities at sequence boundaries (SB) (Ross & Ross 1987a, 1987b). From these interpretations, it is possible to infer in rock successions the depth of sedimentation and changes in those sedimentary depths (Kendall & Schlager 1982) through the successions. It also is feasible to make estimates of the amount of weathering, recrystallization, cementation, soil development, and erosion at unconformities and, hopefully, to estimate the duration of some of the hiatuses.

Many of these events and changes may be explained readily as being the result of fluctuations of eustatic sea-levels. However, because the Marathon orogenic belt was active through the Carboniferous and well into the Early Permian, several major depositional sequence breaks and hiatuses are clearly related to folding, faulting, and thrusting activities of the fold belt and are considered tectonic sequence boundaries (TSB). It also is likely that minor folding and other movements locally affected relative local sea level in different parts of the outcrop belt.

Evolution of species within a phylogenetic lineage is gradual with small changes occurring between successive generations. Within depositional parasequences and between small parasequences sets, we observe that species vary morphologically, often in a systematic manner. For example, in the well-exposed and well-studied middle part of the Lenox Hills Formation (depositional sequence LH-2), specimens of *Chalaroschwagerina nelsoni* (Dunbar & Skinner) (Ross 1963) from successive parasequence cycles become slightly more inflated and septal folding in inflated chambers becomes more irregular upwards in higher parasequences. The same type of systematic changes occurs in *Schwagerina dispansa* Ross in the upper part of the Lenox Hills Formations in which axial secondary deposits decreased in successive higher samples. Specimens of *Schwagerina bellula* (Dunbar & Skinner)(Ross 1963) from the middle part of the Lenox Hills Formation show slight changes in inflation of the chambers and the geometry of the septal folds. In the lower sequence of the Hess Limestone (H-1, which is subdivided into sequence sets H-1a, H-1b, H-1c and H-1d), *Schwagerina crassitectoria* Dunbar & Skinner shows changes in axial deposits becoming more concentrated along the axis of coiling in higher samples, and *S. guembeli* Dunbar & Skinner shows progressive differentiation of axial deposits as a fan shape pattern adjacent to the tunnel in higher samples, and, the highest occurrence, a more fusiform shape (Ross 1960, 1963). Even in apparently morphologically very stable species, it is possible to recognize small, minor changes. Such an example is *Eoparafuslina linearis* (Dunbar & Skinner), which adapted to cross-bedded sandy facies in beaches and shallow subtidal conditions, and shows a gradual increase in the diameter of proloculi and in overall size from the base of its range in the lower part of the Lenox Hills (sequence LH-1) to the top of its range in the upper of part of the Lenox Hills (LH-3). It is possible to recognize the three depositional sequences (LH-1, LH-2, and LH-3) based on these features. Thus these fusulind species do not display morphological "stasis" within or even between parasequences or between closely related parasequence sets.

Ideally, with a complete fossil record, it would be difficult to pick a level in such a continuously gradually changing species lineage to divide the lineage into separate species. In shallow water, carbonate marine faunas, the hiatuses between depositional sequences (and occasionally the deep-water condensed black shale intervals) separate the successive shallow-water carbonate faunal facies by considerable time (Ross & Ross 1995). In these situations, the fossil record may be incomplete for a sufficient length of time for the paleontologist to separate these segments of fossil lineages into what are considered different species. Thus, the discontinuous fossil record inherent in the deposition/nondeposition cyclicity of depositional sequence sediments in many stratigraphic successions breaks the fossil record into discrete segments that are perceived as different species (Ross & Ross 1995, 2001).

Pre-Wolfcampian

The Gaptank Formation was described by King (1930) for late Middle (Desmoinesian) to Late Pennsylvanian rocks in the Glass Mountains-Marathon Basin with its type area in the Gap Tank area (Figs. 3, 4). The Gaptank was revised by Ross (1963, 1965, 1967a) to exclude the Desmoinesian part which was found to be part of the strongly folded underlying stratigraphic succession (Haymond Formation) and to lie within the thrust sheet below a major late Desmoinesian to early Missourian tectonic unconformity. In the eastern Glass Mountains, the Gaptank Formation is about 600 m thick, and the upper parts are a series of lenticular, shelf margin carbonate banks of Late Pennsylvanian age that prograde westward over a shallow clastic basin. The depositional strike of these banks is generally northeast and cuts obliquely across the outcrop belt at a low angle. At the type locality near the eastern end of the outcrop belt (Fig. 4A), the highest carbonate banks below the sub-Permian unconformity are latest Missourian and early Virgilian in age. Westward across the Allison, Moore, and Brooks Ranches, the marginal carbonate banks prograde in a series of depositional sequences during the Virgilian (beds F to I, Fig.4B). At the Wolf Camp Hills (Neal Ranch), the carbonate bank facies reverses east and then west again around a former topographic high (peninsula or island) (Fig.4C).

This complex of shelf marginal carbonates was gently folded after Gaptank depositional sequence I, and was locally eroded. In several places, these folds were eroded to positions below the carbonate bank facies, such as on the Moore Ranch. Deposited on this middle to late Virgilian unconformity was a carbonate bank (or possibly several closely spaced banks) that is characterized by mainly sublithographic limestones with a few, and generally unusual for this area, fossils, mostly near the upper or lower boundaries of the bank. This depositional sequence is labelled bed J on Fig. 4. In the Wolf Camp Hills, King (1930, section 24), called this 'bed 2' of his Gray Limestone Member and included it, the underlying *Uddenites* shale member, and the overlying shale, 'bed 3', and conglomerate, 'bed 4', in his Gray Limestone Member. King (1930) also included the prograding Virgilian carbonate banks eastward as far as Gap Tank in the lower part of his Permian Wolfcampian Formation.

Lithologically, bed 2 of King's Gray Limestone Member is a shelf margin carbonate bank and a continuation of the depositional pattern of the Gaptank Formation. In the Wolf Camp Hills, it crops out as a thick, 30 to 40 m, massive lens in Hill 5060 and also in an outlier just to the west (Fig. 4C). These lenses thin abruptly northwestward and pass into stacked, well-bedded wedge-shaped beds that, in turn, pass into thin calcarenitic sandstone and siltstones and shales of an upper slope facies. The northern dip slope of the massive facies is overlain by thinner bedded, micritic limestones with some laminated beds of algal mats (Fig. 5).

Bed 2 of the Gray Limestone Member and lateral equivalents have long been associated with the Pennsylvanian-Permian boundary question. Böse (1917) considered the ammonite *Uddenites* to be Permian, as initially did P. B. King (1930) and R. E. King (1931). Dunbar & Skinner (1936, 1937), who used the first appearence of the inflated schwagerinids *Paraschwagerina* or *Pseudoschwagerina* to indicate the Permian boundary, raised questions as to where that schwagerinid boundary was in King's (1930, section 24) type section of the Wolfcamp Formation. The first *Paraschwagerina* and *Pseudoschwagerina* were reported from above King's limestone bed 2. *Paraschwagerina* was reported at the top of King's bed 4 conglomerate and *Pseudoschwagerina* in King's bed 12 by Beede & Kniker (1924) and Dunbar & Skinner (1937)(Fig. 5). R. E. King (1931) and Cooper & Grant (1973) found early representatives of the brachiopod genus *Scacchinella* in the *Uddenites*-bearing shale and, because *Scacchinella* is typical and widespread in the Permian, they considered that the Permian boundary should be placed at the base of the *Uddenites*-bearing shale. Thompson (1954) and Bostwick (1962) described and illustrated a few fusulinid specimens from this general stratigraphic interval (and from the lower part of the overlying clastic calcarenites and calcirudites of the Neal Ranch Formation). Bostwick (1962) also included specimens from depositional sequences I and J to the east on the Brooks Ranch and from upper slope debris beds of similar age in the Dugout Fold belt 6.5 km west of the town of Marathon.

Recent definition of the Carboniferous-Permian boundary (Davydov et al. 1995; Chernykh & Ritter 1997) is based on the first appearance of the conodont *Streptognathodus isolatus* in successions in southern Urals. Wardlaw & Davydov (2000) believe this conodont boundary should lie somewhere within bed J (= bed 2 of Gray Limestone Member), but did not find the actual critical conodont change in their samples, so this conodont defined boundary remains poorly known in the Glass Mountains succession.

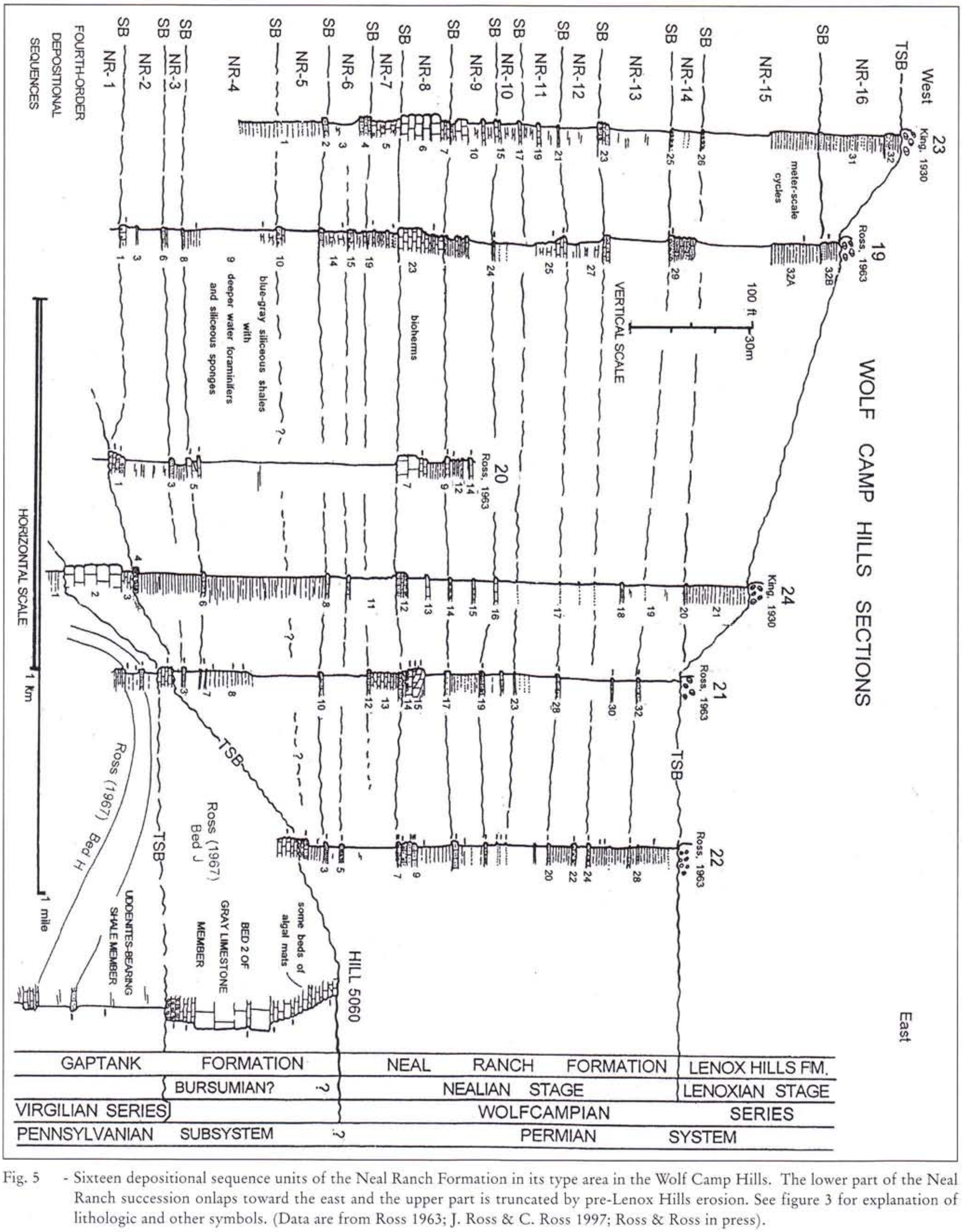

Fig. 5 - Sixteen depositional sequence units of the Neal Ranch Formation in its type area in the Wolf Camp Hills. The lower part of the Neal Ranch succession onlaps toward the east and the upper part is truncated by pre-Lenox Hills erosion. See figure 3 for explanation of lithologic and other symbols. (Data are from Ross 1963; J. Ross & C. Ross 1997; Ross & Ross in press).

Fusulinids recorded from the upper part of the Gaptank Formation are listed in Tab. 1.

These include identifications by Dunbar & Skinner (1937), Ross (1959, 1963, 1967a,b) and Bostwick (1962).

Triticites comptus Ross is the only common species in interval J (= Bed 2 of the Gray Limestone Member) and it is restricted to beds near the base and those near the top of the bed. This species is closely related to *T. cuchilloen-*

Upper part of Gaptank Formation	Eastern shelf				Slope & Basin
	bed G	bed H	bed I	bed J	West of Marathon
Species					
Schwagerina cf. S. longissimoidea					X
T. aff.T. subventricosus					X
Schwagerina? sp.					X
Triticites confertus					X
S. turki					X
T. cf. T. directus					X
Triticites pointensis				X	
T. cf. T. creekensis				X	
T. aff. T. creekensis				X	
T. rockensis				X	
Schwagerina aff. S. pinosensis				X	
T. nealensis				X	
T. cameratoides			X		
T. capaxoides			X	X	
T. cf. T. oryziformis			X		
Dunbarinella? sp.			X		
T. pinguis			X	X	
T.? comptus		X	X	X	
T. turgidus		X			
T. beedei		X	X	?	
T. elegantoides		X	X	X	
T. cullomensis		X	X	?	
T. gallowayi	X	X	X	X	
T. confertoides	X	X			
T. asperoides	X	X	?		
T. moorensis	X				
T. marathonensis	X				
T. pygmaeous	X?				
T. aff. directus	X				

Table 1 - Fusulinacean distribution in the upper part of the Gaptank Formation in eastern part of the Glass Mountains. (Data are from Dunbar & Skinner 1937; Bostwick 1962; Ross 1963, 1965).

sis Needham which is known from the uppermost Virgilian of New Mexico and southeastern Arizona (Ross & Sabins 1963). Conglomerates lying on Bed 2 and as thin lenses in the immediately overlying Neal Ranch Formation, and the rock matrix between the conglomerate cobbles, contain more robust species of *Triticites,* including *T. pinguis* Dunbar & Skinner, *T. subventricosus* Dunbar & Skinner, and *T. ventricosus* (Meek & Hayden). Based on the occurrence of these robust species of *Triticites,* Ross (1963, 1965, 1967a) considered Gaptank bed J (= bed 2 of King's Gray Limestone Member), and its lateral equivalent beds, to most likely be equivalent to the Bursum interval as used by Thompson (1954) in New Mexico and westernmost Texas. Thompson (1954) included the Bursum Formation (and lateral equivalent beds) in the Permian, because it had been the custom in the West Texas-southeastern New Mexico petroleum province (Hollingsworth, privately published 1955) to include beds above the top of the Kansas Pennsylvanian Virgilian Series, that is above the Brownville Limestone (Moore 1936; Moore et al. 1951), in the Permian.

The Bursum interval is easily recognized because it is characterized by a number of species of *Pseudofusulina,* primitive *Schwagerina, Leptotriticites,* and robustly-shelled species of *Triticites,* such as *T. meeki, T. ventricosus, T. creekensis,* and *T. pinguis,* but lacks the inflated genera *Paraschwagerina* and *Pseudoschwagerina.* These Bursum fusulinids appeared to Ross (1963) to be not as advanced as fusulinids in the Russian Asselian Stage which, at that time, were considered to mark the base of the Permian in the southern Pre-Urals. To accommodate this interval between the top of the Virgilian Series and the base of the Permian in the North American stratigraphic nomenclature, Ross & Ross (1987a, 1987b) introduced the name Bursumian Stage. As presently defined, the Bursumian Stage is equivalent to beds of the Admire Group (about 40 m) and the lower part (about 15 m) of the Council Grove Group (Foraker Limestone, Johnson Shale, and the Glenrock limestone bed at the base of the Red Eagle Limestone) in Kansas, based on conodont studies by Boardman & Mazzullo (1998).

Lucas & Wilde (2000) redescribed a section of the Bursum Formation in its type area in central New Mexico as about 50 m of mostly shale and siltstone with about 20 generally thin limestone interbeds. This section of Bursum is mainly non-marine or marginally marine with about 20 brief marine carbonate incursions, some of which appear to be parasequences and may include several depositional sequences. At its base, nodular limestones have robust species of *Triticites* and thicker limestones near its middle contain *Leptotriticites,* robust species of *Triticites,* and early *Schwagerina* (or *Pseudofusulina*). Farther to the south, in the Sacramento Mountains of New Mexico, (Lloyd 1949; Pray 1959) applied the name Bursum Formation to this same interval where it becomes more marine, and the marine cycles become more prominent with a considerable increase in the number of fusulinids. For the Bursum interval and an overlying 50 to 60 m of additional beds, but still below the Hueco Limestone, in the northern Sacramento Mountains, Otte (1959) introduced the name Laborcita Formation for exposures in Laborcita Canyon where the formation reaches a thickness of about 200 m. Steiner & Williams (1968) reported principally *Leptotriticites, Schwagerina,* and robust *Triticites* from Otte's Bursum equivalent (lower part of the Laborcita Formation) and correlated these faunas with those in the Admire Group and lower part of the Council Grove Group of Kansas.

Wolfcampian Series (Lower Permian)

The Wofcampian Series, as represented by the Wolfcamp Formation and described by King (1930, 1937) from the Glass Mountains, was selected by Adams et al. (1939) as the North American standard reference section for the lower part of the Lower Permian. At that time, and up to the recent selection of a conodont-defined Carboniferous–Permian boundary in the southern Pre-Urals, placement of the basal Permian boundary was uncertain. Murchison (Murchison et al. 1845) originally used the base of the Kungurian evaporites but that placement proved difficult to correlate because of a scarcity of adequate faunas. The boundary was successively lowered to include the Artinskian ammonoid beds (Artinskian Stage), then lowered farther to include the Sakmarian Stage and, finally, lowered further to include the Asselian beds (Asselian Stage) (Nalivkin 1973). Subsequently, various lower parts of the Asselian were either included in the Permian, or not, depending on individual author's preferences. Adams et al.'s (1939) use of standard reference sections for the North America Permian provided a valuable and workable nomenclature for stratigraphic research and for an active petroleum industry in western North America.

In the middle 1950s, it became apparent that there was an eastern facies and a western facies of the Wolfcamp Formation in the Glass Mountains. Ross (1963) demonstrated that these units were not lateral facies, but were two separate units of different age. The western Wolfcamp facies was younger and was deposited on an eroded surface that cut across faulted and folded beds of the Dugout Fold belt. This fold belt included folded and faulted beds that were the same age as the eastern Wolfcamp facies and illustrated that the two Wolfcamp units were separated by an episode of thrusting. For the older Wolfcampian beds, Ross (1963) assigned the name Neal Ranch Formation based on the long and excellent exposures in the Wolf Camp Hills on the Neal Ranch. These beds form the basis for the Nealian Stage for the lower part of the Wolfcampian Series. For the younger Wolfcampian beds, Ross (1963) assigned the name Lenox Hills Formation based on exposures in the Lenox Hills and also to the southwest and northeast along the base of the Glass Mountains. These beds form the basis for the Lenoxian Stage of the upper part of the Wolfcampian Series.

Nealian Stage. The Neal Ranch Formation in the Wolf Camp Hills forms the basis for the Nealian Stage. There, the formation is about 100 m thick in its eastern outcrops and thickens westward to about 200 m thick in its western outcrops, a distance of 2 km (Fig. 5). The Neal Ranch type section is P. B. King's (1930) Section 24, beds 4 to 21. Sixteen fourth-order depositional sequences (NR-1 through NR-16) are recognized (Ross 1963). In the lower part of the Formation, the lower 5 or 6 depositional sequences progressively lap higher and higher on to an eroded surface on Gaptank bed J (bed 2 of King's Gray Limestone Member). At the top, post-Neal Ranch erosion has removed the upper two depositional sequences near the eastern end of the Wolf Camp Hills outcrops. The lower 5 depositional sequences show evidence of deep to shoaling upwards sea level cycles, ranging from deep-water black shales dominated by siliceous sponges, through progressively shallower-water dark gray shales with solitary corals and fenestrate bryozoans, followed upwards by lighter gray shales and siltstones with abundant crinoids, then calcarenitic beds with abundant fusulinids, and finally by laminated cross-bedded sandstone commonly having siliceous cements. We estimate the sea level ranges in these depositional sequences at more than 10 m, perhaps as much as 30 to 40 m.

Depositional sequences NR-6 to NR-8 are shallower-water intervals with well-developed, offlapping biohermal mounds a few meters thick in NR-8. These show little evidence for the large magnitude in sea level fluctuations estimated for the lower depositional sequences. Depostional sequences NR-9 through NR-16 are mostly shallow-water cycles. In the exposure surfaces, thin sheets of transgressive sandstones and pebble conglomerates are common at sequence boundaries, and yellowish to light green and reddish silty shales, siltstones and sandy siltstones comprise most of the units. Fusulinids are concentrated in the thin transgressive clastic beds.

East of the Wolf Camp Hills, about 1 km, the basal conglomerates of the overlying Lenox Hills Formation rest on an eroded topography of limestone beds I and J in the upper part of the Gaptank Formation (Fig. 4B). At Gap Tank on the Allison Ranch, near the eastern end of the Glass Mountains, a 35 m thick section of the Neal Ranch Formation reappears at the top of Section 43 with its characteristic fauna (Fig. 4A) (Tab. 2). Neal Ranch age strata containing *Pseudoschwagerina* also appear within folded and faulted beds of the Dugout Fold Belt just east of the central part of the Lenox Hills (Ross 1963). These beds are considered Nealian in age and may represent beds as young as depositional sequences NR-14 or higher in the Wolf Camp Hills succession.

The ranges of fusulinid species recorded in the Neal Ranch Formation show a great diversity of early species of triticitids, leptotriticitids, schwagerines (and pseudofusulines), paraschwagerines, and pseudoschwagerines (Tab. 2). A taxonomic shift in common genera occurs between the lower six or seven Nealian depositional sequences and the upper sequences. The lower Nealian cycles (NR-1 to NR-6) are dominated by various species of large, stoutly constructed *Triticites*, early species of *Leptotriticites*, and transitional to early species of *Schwagerina*. The species of *Triticites* include *T. ventricosus* (Meek & Hayden), *T. subventricosus* Dunbar & Skinner, *T. pinguis* Dunbar & Skinner, *T. meeki* (Möller), *T.* cf. *T. creekensis* Thompson, *T. uddeni* Dunbar & Skinner, and several other related species. As an assemblage they are typical of *Triticites* species from the Foraker Limestone of Kansas, however, many of them are both in the matrix and limestone cobbles in conglomerates that lie on bed J (= bed 2 of Gray Limestones Member) or are tongues of conglomerates that lap on to that bed and are suspected of being redeposited. Some specimens, principally from the matrix, of *T. uddeni*, *T. subventricosus*, and *T. pinguis*, are partially silicified, but those in cobbles are not silicified. However, specimens from the matrix of *T. ventricosus*, *T. meeki*, and *T.* cf. *T. creekensis* are not partially silicified. *Tritictes pinguis* ranges higher and *T.* cf. *T. creekensis* ranges into the highest Nealian sequence in the Wolf Camp Hills.

Table 2 - Fusulinacean distribution in Neal Ranch (Nealian) depositional sequences. (Data are from Beede & Kniker 1924; White 1932; Dunbar & Skinner 1937; Thompson 1954; Bostwick 1962; Ross 1963; Ross & Ross in press).

	Wolf Camp Hills area																Gap Tank area					Fold belt	
Nealian depositional sequence (NR-)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	7	8	9?	10	11?	7	8
Species																							
Pseudoschwagerina beedei														X		X							
Schwagerina sp. 3													X										
Leptotriticites sp.												X		X									
Pseudoschwagerina aff. P. uddeni																							X
Paraschwagerina sp.												X											X
Schwagerina sp. 2											X												
Triticites spp.											X												
Eoparafusulina allisonensis																					X		
Eoparafusulina aff. E. allisonensis											X									X			
Paraschwagerina gigantea									X	X	X												X
Eoparafusulina cf. E. allisonensis										X	X												
Pseudoschwagerina texana									X	X				X									
Paraschwagerina aff. P. gigantea									X														
Schwagerina cf. S. longissimoidea									X		X							X					
Schwagerina spp.								X		X	X		X	X		X		X					
Pseudoschwagerina spp.								X		X	X	X							X	X			
Schwagerina sp. 1								X		X													
Schwagerina emaciata								X		cf.	X	X	X	X				X					X
Schwagerina pugunculus								X		X	X	?		X						X		X	X
Leptotriticites sp.								X		X													
Leptotriticites koschmanni								X			X						X						
Leptotricities tumida																	X						
Paraschwagerina acuminata							X	X				X						X					
Leptotriticites cf. L. wetherensis																	X						
Rugosofusulina spp.							X		X														
Pseudoschwagerina uddeni						X		X	X	X	X		X					X		X			
Schwagerina cf. S. campa					X			X														?	
*Triticites cf. T. creekensis**					X			X		X	X	X	?	X		X							
*Triticites meeki**					X																		
*Triticites spp.**					X																		
Schwagerina gracilitatis				X			X	X					cf.	cf.			X	X	X	X			
Schwagerina compacta	cf.				X						X							X	cf.				
Paraschwagerina kansasensis	X?					X												X					
*Triticites pinguis**	X	X		X	X		X	X		X		?											
*Schwagerina aff. grandensis**	X									?	X												
*Leptotriticites cf. L. eoextenta**	X			X																			
*Triticites ventricosus**	X	X																					
*Triticites subventricosus**	X	X																					
*Triticites uddeni**	X																						

* species that are possibly redeposited from older strata

Leptotriticites species may be grouped into two evolutionary stages, early forms with small size, relatively low chambers and later forms with large size, more open chambers, and prominent chomata. A number of specimens of *Leptotriticites* occur in the Nealian NR-1 and NR-4 and belong to the early group of species. They are placed in *L.* cf. *L. eoextenta* (Thompson). *Leptotriticites eoextenta* is also distinctive of the base of the Foraker Limestone of Kansas. Higher *Leptotriticites* species in Nealian NR-7 to NR-11 are *L. timida* (Skinner), *L. koschmanni* (Skinner), *L.* cf. *L. wetherensis* Thompson, and *Leptotriticites* sp. and are similar to forms of *Leptotricites* from the Neva Limestone Member of the Grenola Limestone of Kansas and the Stockwether Limestone of Texas. Higher, in NR-12 and NR-14, other undescribed species of advanced *Leptotriticites* occur late in the Nealian.

The earliest specimens of *Schwagerina* start in the Nealian with *S.* aff. *S. grandensis* Thompson in NR-1 through NR-11. Other early species, such as *S. compacta* (White), *S.* cf. *S. campa* Thompson, *S. gracilitatis* Dunbar & Skinner occur as a consistent part of the fauna in NR-4 and NR-5 and range through most the Nealian.

Initially the occurrences of specimens of Foraker age in the lower Nealian were considered to be reworked specimens from the eroded strata above Gaptank bed J (bed 2 of Gray Limestone Member) which are either no longer exposed or were removed by pre-Nealian erosion and no long preserved. At about the level of the bioherm development (NR-8 and higher), the source of the reworked specimens was presumed to have been covered so that the number of reworked specimens was greatly reduced. While this may be the correct explanation, the succession of these species of *Leptotritictes* and *Triticites* through NR-1 to NR-6 or NR-7 follows closely their vertical succession in the Foraker Limestone in Kansas. In the Neal Ranch Formation, these lower beds have common black shales with abundant opaline siliceous sponges and silicification was common during diagenesis. This suggests that the fusulinid fauna could be in place, and not reworked. Another alternative is that the interval from NR-1 through NR-7 is actually a lateral facies of the thin-bedded upper portion of Gaptank bed J with the limestone facies separated by limestone-pebble conglomerate beds from Neal Ranch lithologies but we consider this alternative less likely. In the Wolf Camp Hills, Wardlaw & Davydov (2000) reported the first appearance of *Streptognathodus barskovi* at 52 m above the base of the Neal Ranch Formation, which they identify as the base of the Sakamarian Stage.

In NR-8 and higher, *Schwagerina* cf. *S. longissimoidea* (Beede) and *S. pugunculus* Ross show more developed features for the genus and are comparable to species from the Neva Limestone in Kansas. Other, large, elongate specimens of *Schwagerina* also mark this and higher levels in the Nealian and are here listed as *Schwagerina* sp. 1, 2, and 3.

Species of *Paraschwagerina* appear successively through nearly the entire formation and are characteristic of the Nealian interval. *Paraschwagerina kansasensis* (Beede & Kniker) is characteristic of NR-1 and NR-6, *P. acuminata* Dunbar & Skinner of NR-7 through NR-12, and *P. gigantea* (White) of NR-8 through NR-11. *Paraschwagerina kansasensis* and *P. acuminata* occur also in the Neva Limestone of Kansas and Oklahoma. Species of *Pseudoschwagerina* are not as common as species of *Paraschwagerina*. *Pseudoschwagerina* first appears in NR-7, extends to the top of the formation, and in some beds is common. *Pseudoschwagerina uddeni* ranges from NR-6 to NR-13; *P. texana* Dunbar & Skinner from NR-9 to NR-14, and *P. beedei* Dunbar & Skinner first appears in NR-14 and extends to the top of the formation.

Rare forms include specimens of *Rugosofusulina* sp. in NR-7 and NR-9. In southeast Arizona a similar rare occurrence of a *Rugosofusulina* sp. occurs with *Schwagerina dunnensis* (Sabins & Ross) and *Triticites pinguis* at approximately the same stratigraphic position. Another rare form is a early species of *Eoparafusulina, E.* aff. *E. allisonensis* Ross, from NR-10 and NR-11 and, at Gap Tank, *E. allisonensis* from NR-11.

Lenoxian Stage. The upper part of the Wolfcampian Series is represented by the Lenox Hills Formation (Figs. 6A-D), named for outcrops in the western Glass Mountains that King (1930) had originally mapped as a western facies of the Wolfcamp Formation. Ross's (1963) section 8 in the Lenox Hills is nominally the type section, however, only 60 m of the lower two Lenoxian depositional sequences are preserved in the Lenox Hills, Dugout Mountain, and low hills just west of Iron Mountain (a Tertiary basic intrusive). The upper Lexonian depositional sequence (LH-3), about 60 m thick, forms the southeastern face of the highest part of Leonard Mountain and is widely distributed eastward along the base of the eastern Glass Mountains escarpment. The most complete Lenox Hills succession at Marie Mountain has well-developed shallow marine facies. In the western Glass Mountains, Lenoxian depositional sequence LH-3 was eroded and redeposited as huge blocks, up to 5 m high and 10 m long, and boulders in the overlying basal Leonardian transgressive systems tract.

The lowest Lenox Hills depositional sequence (LH-1) filled topographic relief on the eroded surfaces of the Dugout fold belt in the western Glass Mountains and the eroded tops of the Neal Ranch and Gaptank Formations in the eastern Glass Mountains (Fig. 6C, 6D). East of the Wolf Camp Hills, Late Wolfcampian valleys cut into this eroded surface and are filled with lower Lenox Hills conglomerates which pass upward into marginal marine siltstone, shales, sandstones (some variously cross-bedded), and fluvial beds. West of the Wolf Camp Hills, the lower conglomerates gradually pass into a fan-delta complex dominatedly by coarse pebble and small boulder (5 to 10 cm) clastics with some fossiliferous, limestone-cemented conglomerates. These pass upwards into marine siltstones, shales, and fossiliferous calcarenites. Near Marie Mountain (King's 1930, section 22, Fig. 6C), the upper few meters of LH-1 are dolostone and dolomitic limestones that have poorly preserved fossils beneath a subareal exposure surface and unconformity. Although well developed along the southeastern face of Leonard Mountain (Fig. 6B, Ross 1963, section 12), the fan-delta complex pinches out within a short distance to the west along the southwestern face of Leonard Mountain. One to 2 km to the northwest along the southwest flank of Leonard Mountain, LH-1 passes abruptly into deeper slope deposits of black shales having tongues of coarse clastics. In the western Glass Mountains (Fig. 6A), the fan-delta conglomerates of LH-1 are relatively thin and locally pass upward into thin marine shale and siltstone. Between Lenox Hills and Dugout Mountain, the fan-delta conglomerate complex of LH-1 and the one in the overlying LH-2 appear to coalesce and become stacked to reach more than 40 m thickness.

The middle Lenox Hills depositional sequence (LH-2) can be traced from fluvial, beach, and eolian facies in the eastern part of the Glass Mountains platform facies (Fig. 6 C, 6D) through marginal marine, and dolomitic facies in the western part of the Brooks Ranch, to dolomitic limestones at Marie Mountain, and shallow carbonate facies, and then into a series of offlapping bioherms that form a ramp facies on the southeastern side of Leonard Mountain (Fig. 6B). Farther west, these facies pass within a short distance into interdistributary fan, upper slope, and basinal facies that form distinctive sets of shale, siltstone, and calcarenite cycles in the outcrops in the Lenox Hills and Dugout Mountain (Fig. 6A). Locally, as between the Lenox Hills and Dugout Mountain, submarine fan-delta conglomerates intertongue with these basinal sediments.

In the past, the highest Lenox Hills depositional sequence, LH-3, has been the most difficult part of the Lenox Hills Formation to map and interpret. From Leonard Mountain to Marie Mountain, and eastward to the Wolf Camp Hills, King (1930) placed most of this interval in the lower part of the Leonardian Series, as an 'eastern facies and western facies' in the lower part of the Hess Limestone. Ross (1963), in following King's measured sections, also had trouble separating LH-3 from lower Hess Limestone beds, particularly in the area of Marie Mountain. Finally, we realized that we had missed a very important sea-level event. The platform margin carbonate bank which forms the southeastern face of Leonard Mountain was actually the remnant of a 50 to 60 m west facing topographic cliff, not unlike the chalk cliffs of Dover, which marked the remains of an eastern upper

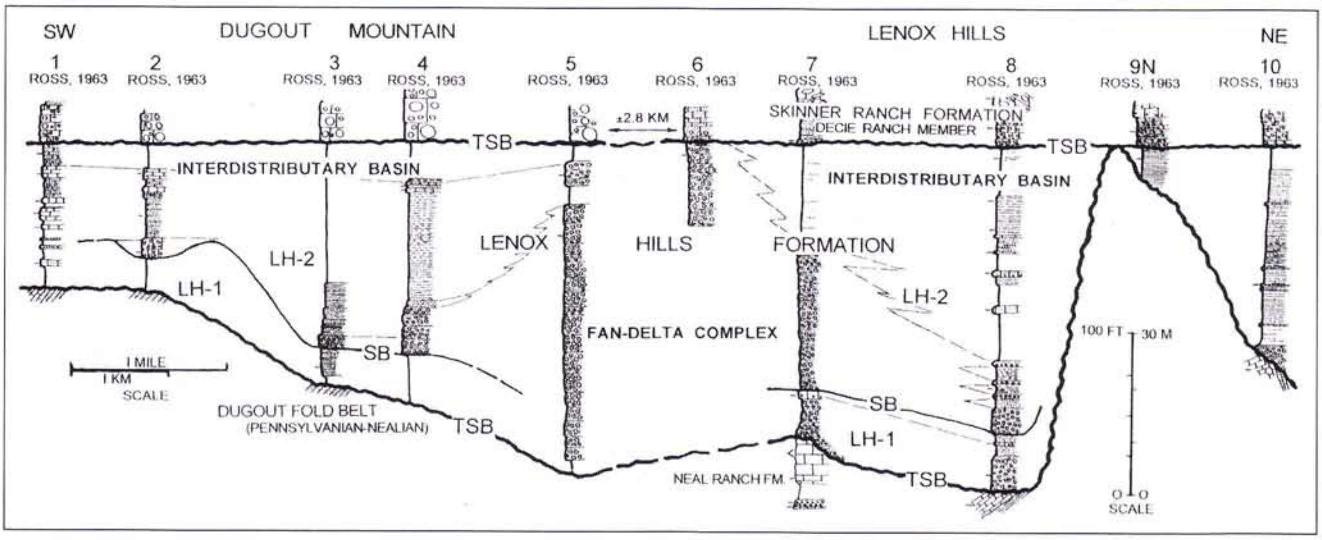

Fig. 6A

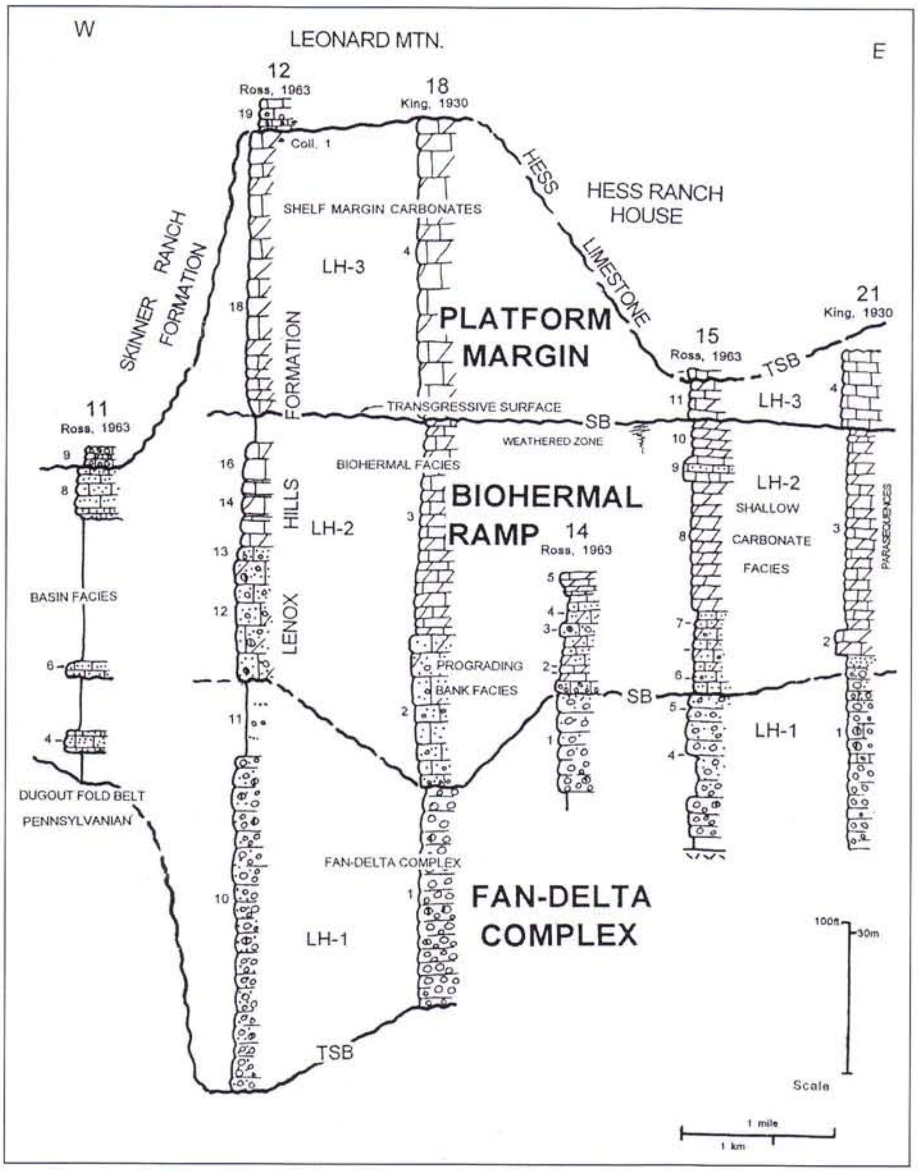

Fig. 6B

Fig. 6 - Lenox Hills Formation; 6A, western facies from Dugout Mountain to the Lenox Hills; 6B, central facies from southern and eastern slopes of Leonard Mountain eastward to Marie Mountain from the basinal clastics and carbonate turbidites into conglomeratic limestone and biohermal shelf-margin facies; 6C, eastward from Marie Mountain along the base of the Hess escarpment, Wolf Camp Hills, to western part of Brooks Ranch; and 6D, eastern part of Brooks Ranch, Moore Ranch and Allison Ranch. See figure 3 for explanation of lithologic and other symbols. (Data are from P. B. King 1930; Ross 1963; Ross & Ross in press).

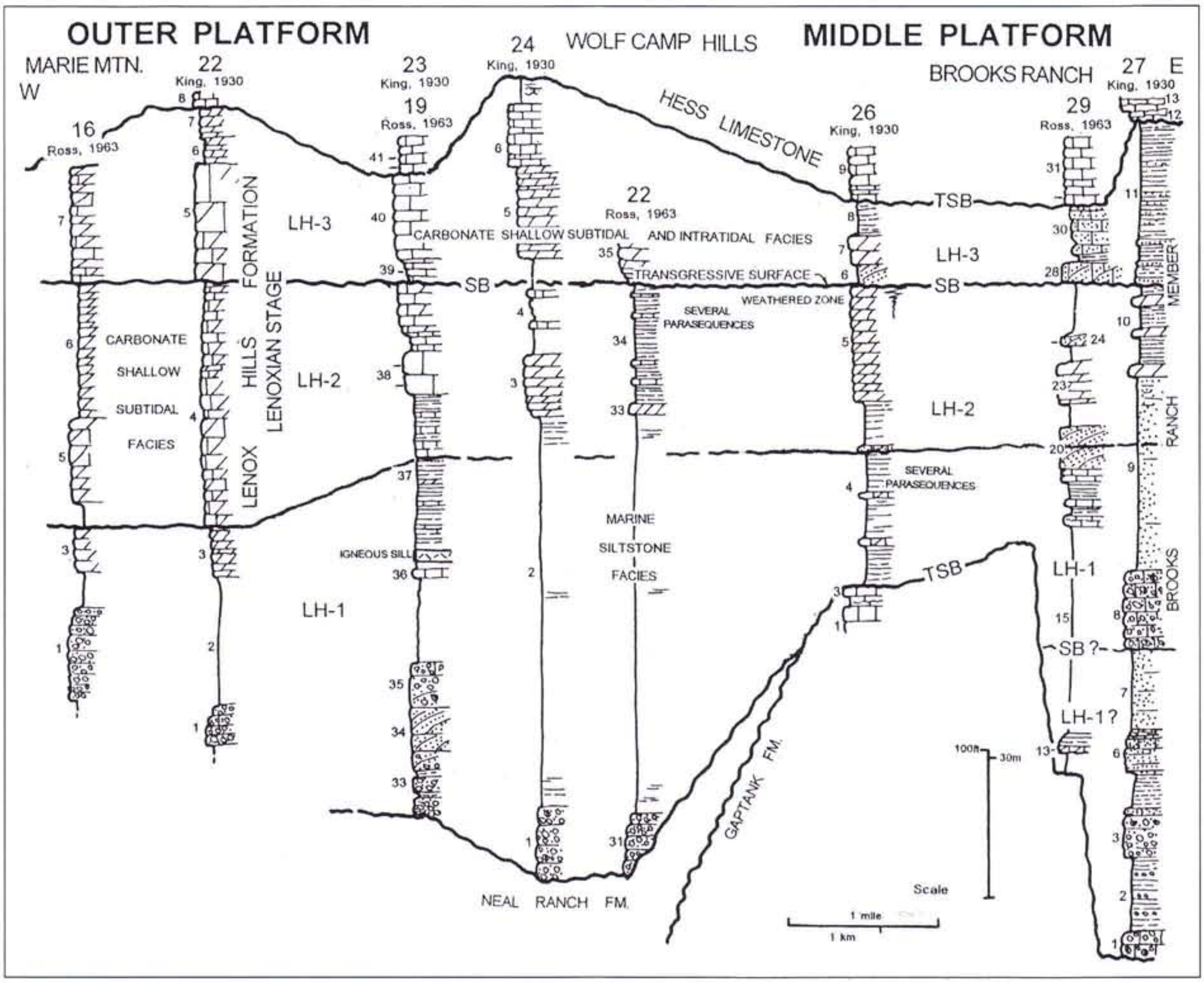
OUTER PLATFORM
MIDDLE PLATFORM
WOLF CAMP HILLS
MARIE MTN.
BROOKS RANCH
W
E
HESS LIMESTONE
LENOX HILLS FORMATION
LENOXIAN STAGE
LH-3
LH-2
LH-1
LH-1?
SB
SB ?
TSB
CARBONATE SHALLOW SUBTIDAL AND INTRATIDAL FACIES
TRANSGRESSIVE SURFACE
WEATHERED ZONE
SEVERAL PARASEQUENCES
CARBONATE SHALLOW SUBTIDAL FACIES
MARINE SILTSTONE FACIES
IGNEOUS SILL
GAPTANK FM.
NEAL RANCH FM.
BROOKS RANCH MEMBER
Scale
1 mile
1 km
100ft
30m

Fig. 6C

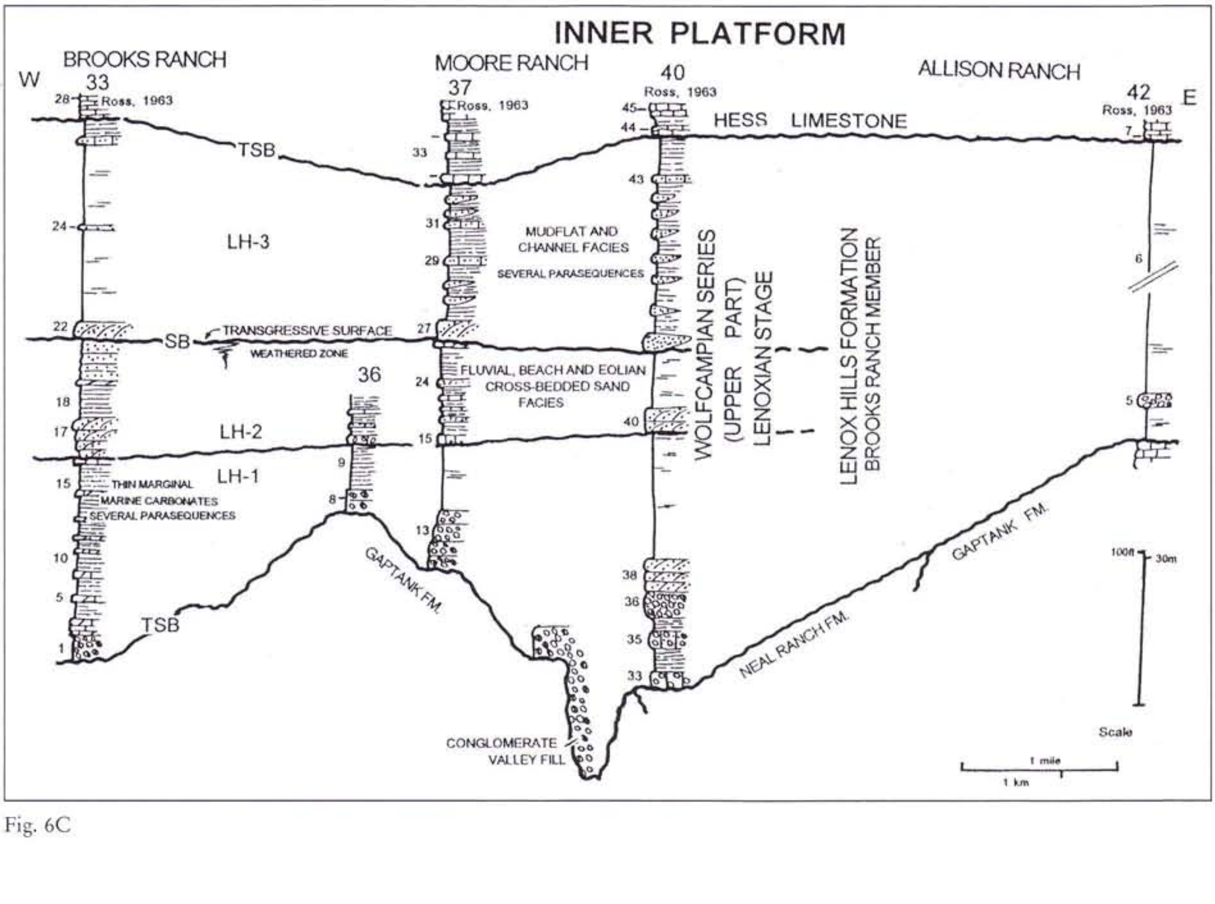
INNER PLATFORM
BROOKS RANCH
MOORE RANCH
ALLISON RANCH
W
E
HESS LIMESTONE
TSB
SB
LH-3
LH-2
LH-1
MUDFLAT AND CHANNEL FACIES
SEVERAL PARASEQUENCES
TRANSGRESSIVE SURFACE
WEATHERED ZONE
FLUVIAL, BEACH AND EOLIAN CROSS-BEDDED SAND FACIES
THIN MARGINAL MARINE CARBONATES SEVERAL PARASEQUENCES
WOLFCAMPIAN SERIES (UPPER PART)
LENOXIAN STAGE
LENOX HILLS FORMATION
BROOKS RANCH MEMBER
GAPTANK FM.
NEAL RANCH FM.
CONGLOMERATE VALLEY FILL
Scale
1 mile
1 km
100ft
30m

Fig. 6C

Lenoxian carbonate shelf platform. The top of this upper Lenoxian platform in the area of Leonard Mountain and the Hess Ranch House has been differentially eroded. The outer platform sections at Marie Mountain (Fig. 6B) were far enough back (east) from the erosion escarpment that it represents a fairly complete section even if truncated at its top by pre-Hessian (i.e., pre-Leonardian) erosion. In the central part of the Glass Mountains, the post-Lenoxian erosion surface was irregular and from there eastward it was fairly deeply weathered. This weathering partially dolomitized most of the upper limestones of LH-3, including most of the fusulinid fossils, and the first appearance of a limestone with well-preserved and abundant fusulinid fossils (usually *Schwagerina crassitectoria)* marked the transgression of the initial Leonardian sea-level rise. LH-3 is traceable eastward through a succession of lithologic facies and faunal changes from shallow water marine carbonates into marine siltstones and shales, subtidal, intratidal, mudflat, and channel facies, as well as the lithologic break and erosional and weathered unconformity at its top.

The distribution of Lenoxian fusulinid faunas is shown in Tab. 3. The distinctive *Eoparafusulina linearis* (Dunbar & Skinner) is present in all three depositional sequences in laminated, cross-bedded, shore and near shore sandstones and its three morphological forms (mentioned earlier) identify each sequence. LH-1 has a meager fusulinid fauna, probably because of the predominance of the channel conglomerates and fan-delta clastic facies. The middle Lenoxian fusulinid faunas that characterize depositional sequence LH-2 include *Chalaroschwagerina nelsoni* (Dunbar & Skinner), *Schwagerina tersa* Ross, several other species of larger *Schwagerina* with prominent axial deposits, *Pseudoschwagerina robusta*, and *Staffella ? lacunosa* and form a distinctive fauna. The facies changes in LH-2 from an outer platform facies into a middle platform, to inner platform, and finally to a eastern marginal marine facies are accompanied by an decrease in both the number of fusulinid-bearing beds and the diversity of those fusulinid faunas, although, where found, the number of specimens may be high. Faunas from LH-3 are not complete because of limited access to LH-3 exposures and dolomitization of many fossiliferous beds. *Pseudoschwagerina convexa* Thompson, *Schwagerina dispansa* Ross and *S. lineanoda* Ross characterize this interval.

The unconformity at the top of the Lenox Hills Formation, we believe, is the result of a major fall in sea level between the end of late Wolfcampian Lenoxian and the beginning of Leonardian Hessian deposition. At least a 60 to 70 m fall, perhaps more, in sea level is required (Fig. 6B). Based on similar suggestions for a major sea-level fall after Hueco Limestone deposition in the Sierra Diablo range (Corboy & Kerans 2000), we infer this drop in sea level was a global eustatic sea level event, although a West Texas regional tectonic event could produce a similar result.

Lenoxian depositional sequences	LH-1	LH-2	LH-3
Species			
Pseudoschwagerina convexa			X
Schwagerina dispansa			X
Schwagerina lineanoda			X
Paraschwagerina sp. A			X
Schwagerina sp. A			X
Pseudoschwagerina elongata		X	
Pseudoschwagerina robusta		X	
Pseudoschwagerina tumidosa		X	
Pseudoschwagerina cf. P. texana		X	
Schwagerina tersa		X	
Schwagerina ironmountainensis		X	
Schwagerina laxissima		X	
Schwagerina crebrisepta		X	
Paraschwagerina plena		X	
Schwagerina extumida		X	
Schwagerina lineanoda?		X	
Chalaroschwagerina nelsoni		X	
Chalaroschwagerina sp. A		X	
Schwagerina sp. B		X	
Pseudoschwagerina parabeedei?		X	
Staffella sp.		X	
Staffella? lacunosa		X	
Eoparafusulina linearis	X	X	X
Pseudoschwagerina aff. tumidosa	X		
Pseudoschwagerina parabeedei	X		
Schwagerina bellula	X		

Table 3 - Fusulinacean distribution in Lenox Hills (Lenoxian) depositional sequences. (Data are from Ross 1963; Ross & Ross in press).

Leonardian Series (Lower Permian)

The Leonardian Series is the upper part of the Lower Permian North American standard section as proposed by Adams et al. (1939) who used the concept of the Leonardian as King (1937) had proposed. King (1930) originally placed the Hess Limestone beneath, and hence, older than the Leonard Formation. By 1937, King had established that the thicknesses of the two formations were nearly the same and rather than being of different ages, the eastern Hess Limestone was a carbonate platform facies of the western Leonard Formation basinal clastic facies and that the two were complementary in both thicknesses and ages. In a series of papers, Cooper & Grant (1964, 1966, 1972-1977, 1973) introduced a number of new stratigraphic names (Fig. 2) for various numbered beds and informally named beds in King's (1930) Leonard and Hess Formations. In the eastern carbonate Hess Limestone facies, they introduced the name Taylor Ranch Member for beds previously called the 'Hess fossil bed', a bed with remarkably diverse, and locally well-silicified, faunas including the ammonoid *Perrinites*. In the western Glass Mountains, Cooper & Grant (1964) introduced the name Skinner Ranch Formation for the limestone-pebble and -boulder conglomerates of the slope facies on the southwestern face of Leonard Mountain and the name Cathedral Mountain Formation for the shales, siltstones, siliceous siltstones/arenites and turbiditic calcarenites of the basin facies. In the Lenox Hills and Dugout Mountain exposures of the Skinner Ranch Formation, they further subdivided the Skinner Ranch Formation into four members. At the base, for King's (1930) limestone conglomerate bed of his western Hess Formation, they recognized the Decie Ranch Member, overlain by a shaly, silty, siliceous turbidite succession, the Poplar Tank Member. For King's (1930) numbered Leonard 'limestone' beds (mainly limestone-pebble and -cobble conglomerates), Cooper & Grant introduced the name Sullivan Peak Member. They named the overlying, predominately siltstone and conglomeratic turbidite beds the Dugout Mountain Member.

At the base of the Cathedral Mountain Formation, Cooper & Grant (1966) named the conglomeratic Wedin Member. This conglomerate contains within its cobbles a younger brachiopod fauna which they recognized as the same fauna as occurring in the relatively thin facies of their Cathedral Mountain Formation (formerly the eastern facies of King's, 1930, Leonard Formation) in the eastern Glass Mountains above the Hess Limestone. At the top of the Leonardian succession, Cooper & Grant (1964, 1966) inserted an additional formation, the Road Canyon Formation, as a name for King's (1930) first limestone member of the Word Formation. They initially used these strata as the basis for a new stage at the top of the Leonardian because they found both *Perrinites*, the ammonoid guide to the Leonardian and *Waagenoceras*, the ammonoid guide to the Guadalupian in that member. Later, it was recognized that only the lowest ledges of the Road Canyon limestone has *Perrinites*. These lowest beds are discontinous along outcrop and are separated from the upper three or four limestone beds of the Road Canyon Formation by a major unconformity, the mid-Permian unconformity.

Hessian Stage. The Hess Limestone is a shallow water, platform carbonate that formed on the eroded surface of the upper Lenox Hills Formation in the eastern Glass Mountains. This carbonate topographic plateau was inundated, possibly rapidly, by the rise in sea level that marked the basal Leonardian transgression and the erosion of Lenox Hills sequence LH-3 in the western part of the Glass Mountains.

The Hess Limestone is subdivided into a lower and upper part at the sequence boundary at the base of the Taylor Ranch Member (Fig. 7 and 8). This subdivision separates well-developed, shallow-platform, meter-scale depositional cyclicity in the lower part of the Hess Limestone from deeper, more open shelf cyclicity in the upper part of the Hess Limestone. It also marks a distinct unconformity and a major erosional truncational surface which have regional significances.

The lower part of the Hess Limestone reaches more than 360 m in thickness and comprises four well-defined depositional sequences. These sequences are separated from one another by clearly defined erosional and weathered surfaces and discontinuous, thin, irregular sheet sandstones. Below each unconformity (and sequence boundary) at the base of these four depositional sequences, beds have altered cementation and fossil preservation.

The lowest Hess sequence, H-1, has four well-developed sequence sets, 20 to 30 m thick. The lowest set, H-1A, rests on the deeply eroded and weathered post-Lenox Hills unconformity. This is a major sequence boundary, certainly a major sea level event and perhaps a significant tectonic sequence boundary with regional significance. The transgressive carbonates of H-1A deepen to a well-defined maximum flooding surface about 15 to 20 m above its base. Parasequence sets H-1B, H-1C, and H-1D are succeeding shallowing-upwards cycles within H-1. They are separated by exposure surfaces that lack much alteration of cements or recyrstallized fossil shells in the strata immediately beneath them. Depositional sequence H-1 appears to be be truncated near the platform margin and rim and this suggests some tectonic warping along the platform edge. H-1 fusulinids are characterized by the first appearance of *Schwagerina crassitectoria* Dunbar & Skinner and *S. guembeli* Dunbar & Skinner and form the carbonate platform fusulinid assemblage. The type specimens for these species are in H-1A and they have derived morphological forms in H-1B and H-1C.

Hess sequence 2, H-2, is separated by King's (1930) 'double limestone ledge' into three parts. The double ledge is dominately a calcareous sponge facies with a deeper water, more silty tongue near its middle and contains abundant *Eoverbeekina*? aff. *E. americana* Thompson. The lower part of this sequence, parasequence set H-2A, is mainly well developed massive carbonate beds in a platform margin and middle platform facies and becomes more silty and shaly in the inner platform and more shoreward facies. The calcareous sponge-rich 'double-ledge' (H-2B) is likely the deeper water part of this marine transgression with the middle, more shaly beds being the maximum flooding surface. The upper parasequence set, H-2C, became increasingly silty and shaly and, in the eastern shoreward facies it is sandy, suggesting an increased input of clastics from the Marathon orogenic belt. This increase in fine clastics is present in the sediments into the middle platform facies. In addition to *E.?* aff. *E. americana*, *Parafusulina allisonensis* Ross is common, however, few other species are present. These are very primitive parafusulines with consistent, low cunniculi in their outer volutions.

Hess sequence 3, H-3, 50 to 60 m thick, has well-developed parasequence sets in the inner platform that pass across the platform into silty and dolomitic, thin-bedded carbonates in the platform margin and rim facies.

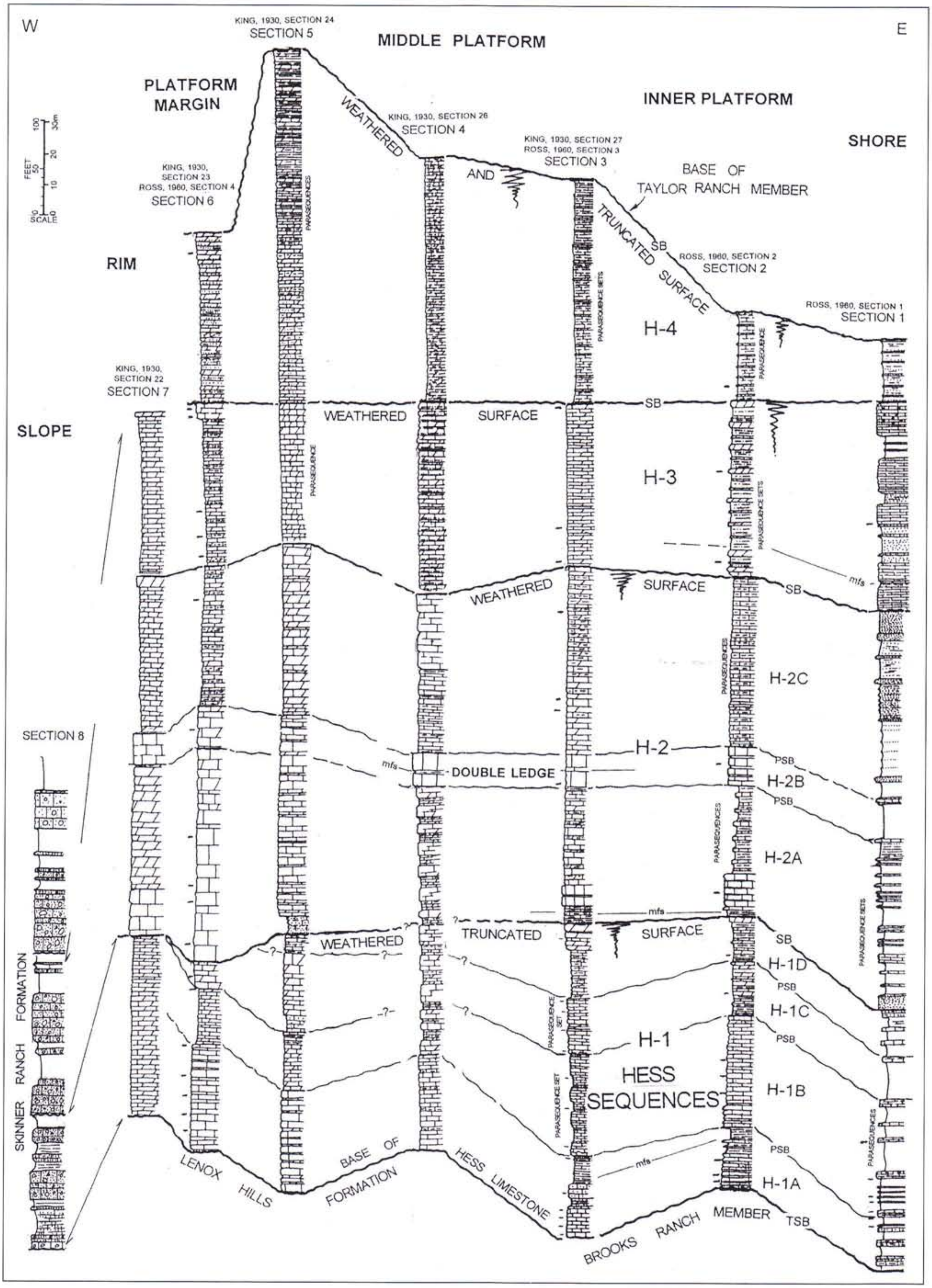

Fig. 7 - Hess Limestone depositional sequences H-1through H-4 on eastern carbonate platform. H-1 has four parasequence sets (H-1A through D) and H-2 has three parasequence sets (H-2A through H-2C) in platform margin, platform, and shore facies. See figure 3 for explanation of lithologic and other symbols. (Data are from King 1930; Ross 1987; Ross & Ross in press).

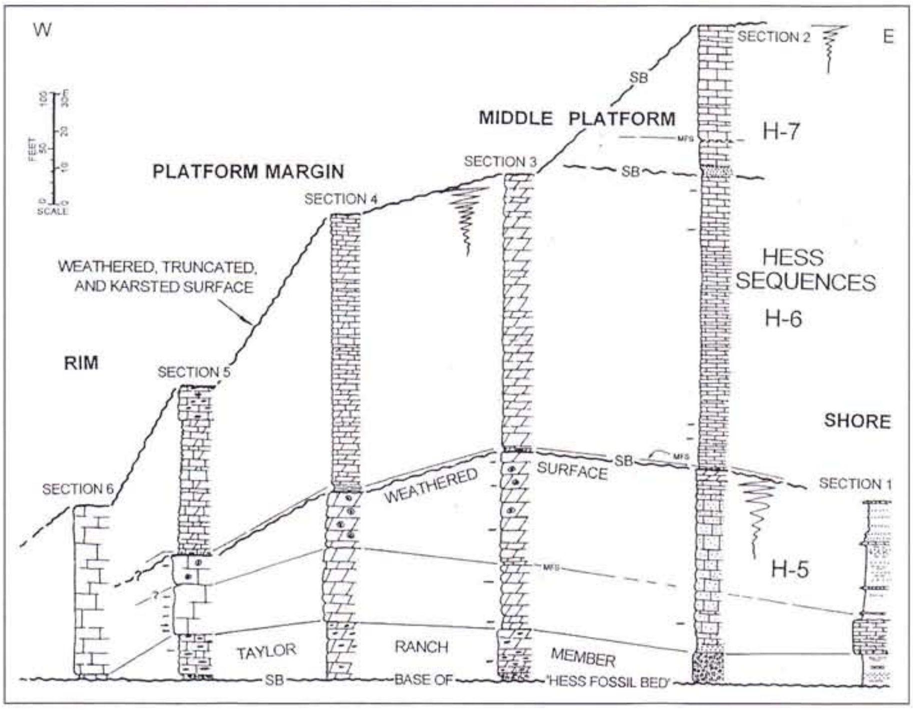

Fig. 8 - Hess depositional sequences H-5, H-6, and H-7 on eastern carbonate platform. See figure 3 for explanation of lithologic and other symbols. (Data are from King 1930; Ross 1987; Ross C. & Ross J. 1997; Ross & Ross in press).

Again, the fusulinid fauna is dominated by a single, but abundant, species, *Parafusulina deltoides* Ross.

Hess sequence 4, H-4, 30 to 110 m thick, shows considerable increase in clays, shales, and siltstones, and parasequence sets are particularly well displayed. Most of the carbonates are dolomitic, silty, and even sandy and the calcareous fossils in this sequence are poorly preserved either because of recrystallization or dolomitization. Locally, sequence H-4 reaches 110 m in thickness in the middle part of the platform, as in section 5, however, it is deeply eroded and truncated across most of the platform so that it thins markedly both to the east toward the shore and west toward the platform margin. Among the weathered surfaces in the lower part of the Hess Limestone, the surface at the top of H-4 is the most extensively developed. Fusulinids in these sequences show poor preservation because of this weathering, cementation, and diagensis. *Parafusulina* sp. *A* (Ross, 1960) and comparable forms of parafusulines, and *Pseudoreichelina?* sp. are present in H-4.

The upper part of the Hess Limestone has three well-defined depositional sequences, H-5 through H-7. Sequence H-5 is conglomeratic at its base and includes the Taylor Ranch Member (Hess fossil bed of King 1930) and about 45 m of sandy, dolomitic, fusulinid-rich, calcarenitic banks. The lower part of H-5 contains abundant ammonids including *Perrinites.* The higher parts are shallow-water banks which are mainly dolomitized and, in places, the intergranular porosity and the replaced fusulinids are filled with anhydrite. They are reminiscent of many of the subsurface Leonardian and Guadalupian age petroleum reservoirs in the adjacent Permian Basin which developed in this depositional position. *Parafusulina spissisepta* Ross is the abundant and distinctive species for H-5. It appears to belong to a lineage derived from earlier *P. allisonensis, P. deltoides,* and *P.*? sp. lineage in the beds below.

Sequence H-6 is comprised of 110 m of well-bedded limestones in 1 to 1.5 m beds. In section 3, this interval is largely replaced by dolostones. Fusulinids and other fossils, except calcareous sponges, are relatively rare in H-6 beds suggesting that, in general, these beds were deposited in a slightly deeper marine shelf or platform environment than H-5. Two species, *Parafusulina rookensis* Ross and *P. vidriensis* Ross dominate the fauna in H-6.

The sequence boundary between H-6 and H-7 is marked by an unconformity and a thin, transgressive sheet sandstone which is recorded only from section 2. H-7 is 40 m thick and has a maximum flooding event at about 8 to 10 m above its base. This sequence gradually shoals upward through a number of parasequences to the unconformity at its top. Fusulinids are rare and not reported, in part because the carbonate facies are in a slightly deeper platform environment than H-5 and, also, because of poor preservation that resulted from weathering and diagenesis that worked down from the eroded upper sequence boundary of H-7. Toward the platform margin and rim, the sequence boundary and unconformity at the top of H-7 cuts down, about 120 m, through sequence H-7 and nearly through H-6. This suggests that much of the coarse clastic material in the upper part of the Skinner Ranch Formation and the overlying Wedin Member of the Cathedral Mountain Formation in the western Glass Mountains was derived from the erosion of this upper Hess platform margin and rim. The upper surface of the Hess Limestone locally has karst features and caves, some of which may date to the exposure of this platform at the end of Hess deposition.

Some fusulinids reported from the different sequences of the platform facies of the Hess Limestone and Cathedral Mountain Formation are compared to species reported from different members of the low-stand systems tracts of the Skinner Ranch Formation and basinal facies of the Cathedral Mountain Formation (Tab. 4). Fusulinids listed from the Skinner Ranch Formation include those from the shaly turbidite intervals as well as some from the matrix between cobbles and boulders. However, the Decie Ranch Member of the Skinner Ranch Formation may contain both penecontemporaneous and reworked faunas from erosion and resedimentation of LH-3 debris. Elsewhere in West Texas, the Bone Springs Limestone is the equivalent lower Hessian beds and contains the main zone of abundant *Skinnerella* (Wilde 1990) and also *Robustoschwagerina stanislavi* Dunbar, so that the lower part of the Hessian had a diverse fauna with strong carbonate facies preferences.

Skinner Ranch Formation. The Skinner Ranch Formation type section is well exposed on the southwestern side of Leonard Mountain (Fig.1, 9) (Cys 1981) where it comprises 210 m of limestone pebble, cobble, and boulder conglomerates with abundant chert pebbles, some interbedded siliceous siltstones, and a number of displaced biohermal blocks. These conglomerates are a series of low-stand, clastic wedges or systems tracts that formed along the western margin of the Hess carbonate platform during Hessian deposition. At Leonard Mountain, Wardlaw & Davydov (2000) report *Neostreptognathodus "exsculptus"*, which they identify as the base of the Kungurian Stage, 17 m above the base of the Skinner Ranch Formation.

In the Lenox Hills and Dugout Mountain, the Skinner Ranch is divisible into a basal member, Decie Ranch Member (western facies of the Hess Limestone bed of King 1930), up to 30 to 35 m thick, which contains large, commonly overturned, boulders 10 m or more in length and 5 m high (Rogers 1978). These blocks are part of a transgressive sea level rise and were eroded from a nearby limestone sea cliff. Fusulinids listed within the Decie Ranch Member include specimens in the matrix between clasts (Tab. 4). These fusulinids generally have large, thickly fusiform, strongly constructed tests, such as *Chalaroschwagerina hawkinsi* Dunbar & Skinner, *C. hessensis* Dunbar & Skinner, and *C. dugoutensis* Ross, which suggest they were capable of living in strongly agitated water conditions. These robust species are not reported from the lower part of the Hess Limestone on the carbonate platform. In addition to being from a strongly contrasting depositional facies, this low-stand fauna is likely slightly earlier than the faunas in the lowest Hessian carbonate transgression H-1.

The overlying Poplar Tank Member, 60 to 75 m thick, is mainly siliceous shales and siltstones and fine sandy and thin, lenticular bedded, pebble-bearing turbidites typical of a slope and basin setting. Fusulinds are present in some beds. *Schwagerina crassitectoria* and *S. guembeli* are rare in the lower 10 m and their presence suggests these basinal clastics are equivalent in age to Hess H-1.

The Sullivan Peak Member of the Skinner Ranch Formation (Fig. 9) is dominated by seven or more coarser, lenticular clastic beds of limestone and cherty pebble, cobble, and boulder conglomerates which form the crest of the Lenox Hills and most of the crest of Dugout Mountain. Individual conglomerate beds thicken and thin and pinch out along strike throughout the outcrop of the Sullivan Peak Member. This member reaches a thickness of more than 60 m in some measured sections. From sections at Dugout Mountain, Cooper & Grant (1966) introduced the name Dugout Mountain Member for siltstone and other clastic beds lying above the Sullivan Peak Member, i.e., above King's (1930) Leonard bed 1 and below King's Leonard bed 5. They (Cooper

Leonardian depositional sequences	Platform										Slope & Basin		
	H-1A	H-1B	H-1C	H-2	H-3	H-4	H-5	H-6	H-7	C-1	H-1—H-4	H-5—H-7	C-1
Species													
Parafusulina leonardensis												X	X
Parafusulina durhami										X			
Parafusulina vidriensis								X					
Parafusulina brooksensis								X					
Parafusulina spissisepta							X					X	
Schubertella muellerriedi												X	
Pseudoreichelina? sp.						X							
Parafusulina sp. A						X							
Parafusulina cf. P. sp. A						X							
Parafusulina deltoides					X								
Eoverbeekina? aff. E. americana				X									
Parafusulina allisonensis				X									
Parafusulina leonardensis?											X		
Schwagerina hessensis											X		
Schwagerina dugoutensis											X		
Schwagerina hawkinsi											X		
Schwagerina cf. S. guembeli			X										
Schwagerina guembeli	X	X									X		
Schwagerina crassitectoria	X	X									X		

Table 4 - Fusulinacean distribution in Hess Limestone (Hessian) and Cathedral Mountain Formation (Cathedralian) depositional sequences. (Data are from Ross 1960, 1962; Ross & Ross in press).

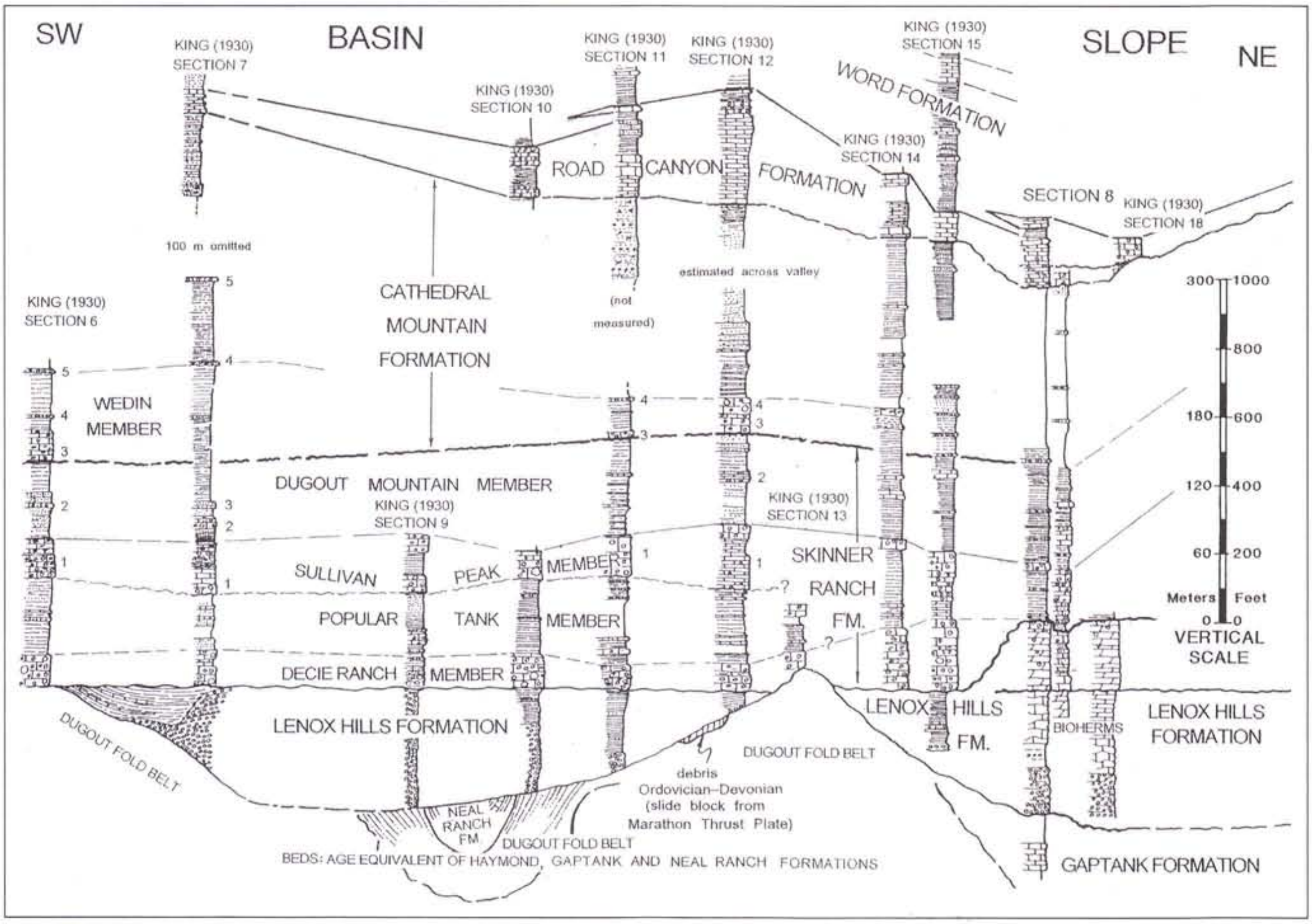

Figure 9 - Basinal stratigraphic sections of the Leonardian Series, Glass Mountains, West Texas. The right half side of section 8 at Leonard Mountain is section 8a, Cys' (1981) lectostratotype. See figure 3 for explanation of lithologic and other symbols. (Data are from King 1930; Ross 1960, 1962, 1987; Ross C. & Ross J. 1997; Ross & Ross, in press).

& Grant 1973) later extended the Sullivan Peak Member higher to include the Dugout Mountain Member as a lateral facies equivalent to the Taylor Ranch Member of the Hess Limestone. The Sullivan Peak beds are low-stand systems-tracts of coarse limestone clastics derived from the erosion of parts of the Hess H-1 through H-4 depositional sequences and older strata from the carbonate platform margin. *Schubertella muellerriedi* Thompson & Miller and *Parafusulina spissisepta* are reported from the slope and basin facies interval H-5 to H-7.

Cathedralian Stage. Cooper & Grant (1964, 1966) used the occurrence of the brachiopod genus *Institella* as a guide to the Wedin Conglomerate Member in order to define the base of the Cathedral Mountain Formation in the western Glass Mountains (Fig. 9). Cys (1981) selected a 'lectostratotype' section for Cooper & Grant's (1964) Cathedral Mountain Formation along the ridge that makes the northwestern part of Leonard Mountain and extends northwestward across a valley and up an escarpment to the base of the Road Canyon Formation (Fig. 9, section 8a). Here, a lithologic contact with the underlying Skinner Ranch Formation, the lower 130 m of the Cathedral Mountain Formation, and the overlying Road Canyon Formation are well defined; however, the brachiopod *Institella* has not been reported. In Cys' stratigraphic section, the middle and upper parts of the Cathedral Mountain Formation are poorly exposed, slope and basinal siltstones, shales, fine sands and thin pebbly turbidites. It is a section typical of the Cathedral Mountain lithologies to the southwest along strike but contrasts strongly with the eastern carbonate platform succession which is a much thinner, shelfal or platform facies that lies on deeply eroded Hess H-6 and H-7 beds.

The eastern exposures of the Cathedral Mountain Formation (Fig. 10) are the eastern facies of King's (1930, 1937) Leonard Formation. At the base, a distinctive 10 to 25 m unit of coarsely recrystallized clastic limestones has 'floating' chert pebbles and large scale cross-beds and are likely beach or shoreline deposits (Measures 1987). This is overlain by up to 75 m of dark brown to black bituminous shales and siltstones with two or more levels of isolated mounds of 'deeper' water bioherms which are well-known for their silicified fossils. The highest part just beneath the mid-Permian unconformity comprises 15 to 20 m of laminated, platy-weathering, bituminous limestones (mostly calcisiltites) suggesting two depositional sequences are present. These laminated beds are similar to the 'Cutoff beds' which occur at a similar stratigraphic position at the top of the Leonardian Bone Springs Limestone on the northwest side of the Delaware Basin in the southern Guadalupe Mountains. Eastward across the top of the Hess Platform, the Cathedral Mountain succession gradually passes into shallow-water dolomitic limestones and dolostones in the inner platform section (Section 2, 2A, Fig. 10).

Along the platform rim and upper part of the slope, erosion at the mid-Permian unconformity has removed most of the bituminous platy limestone. In Cys' (1981) 'lectostratotype' section of the Cathedral Mountain Formation and the Road Canyon Formation (Fig.10, Section 8), the youngest Cathedralian is an eroded and truncated remnant of a calcarenitic and pebbly limestone beneath the mid-Permian unconformity. These clastics are probably a regressive, or low-stand systems tract and upper slope clastic limestone conglomerate facies. Cooper & Grant (1964, 1966, 1973) originally placed these beds in the basal part of the Road Canyon Formation and traced them in discontinous exposures eastward for a few kilometers where they found the typical Leonardian ammonoid *Perrinites*. Later, these beds were placed beneath the mid-Permian unconformity (Wardlaw & Grant 1987).

In the western Glass Mountains (Fig. 9), the Cathedral Mountain Formation thickens to as much as 350 m or more and is mainly composed of siliceous siltstones, shales, thin pebbly turbidites, a few massive lenticular, pebble and cobble conglomerates. Chert cements are present but are not as pervasive as in the underlying Skinner Ranch Formation. The siltstones and shales of the western exposures of the Cathedral Mountain Formation generally form a broad topographic depression immediately west of the Lenox Hills and Dugout Mountain. The lenticular conglomeratic beds of the Wedin Member crop out locally and probably at stratigraphically different positions (from 70 to 150 m above its base) and contain redeposited fossils displaced from both the higher parts of the Hess and Cathedral Mountain platform facies. The upper part the Formation has several thick, well-sorted, fine sandstones and some pebbly sandstones.

Parafusulina durham Thompson & Miller is typical of the Cathedralian C-1 in the Glass Mountains. Elsewhere in West Texas, Dunbar and Skinner (1937) and Wilde (1990) report from Cathedralian equivalents *P. fountaini* Dunbar & Skinner, *P. setum* Dunbar & Skinner, *P.*

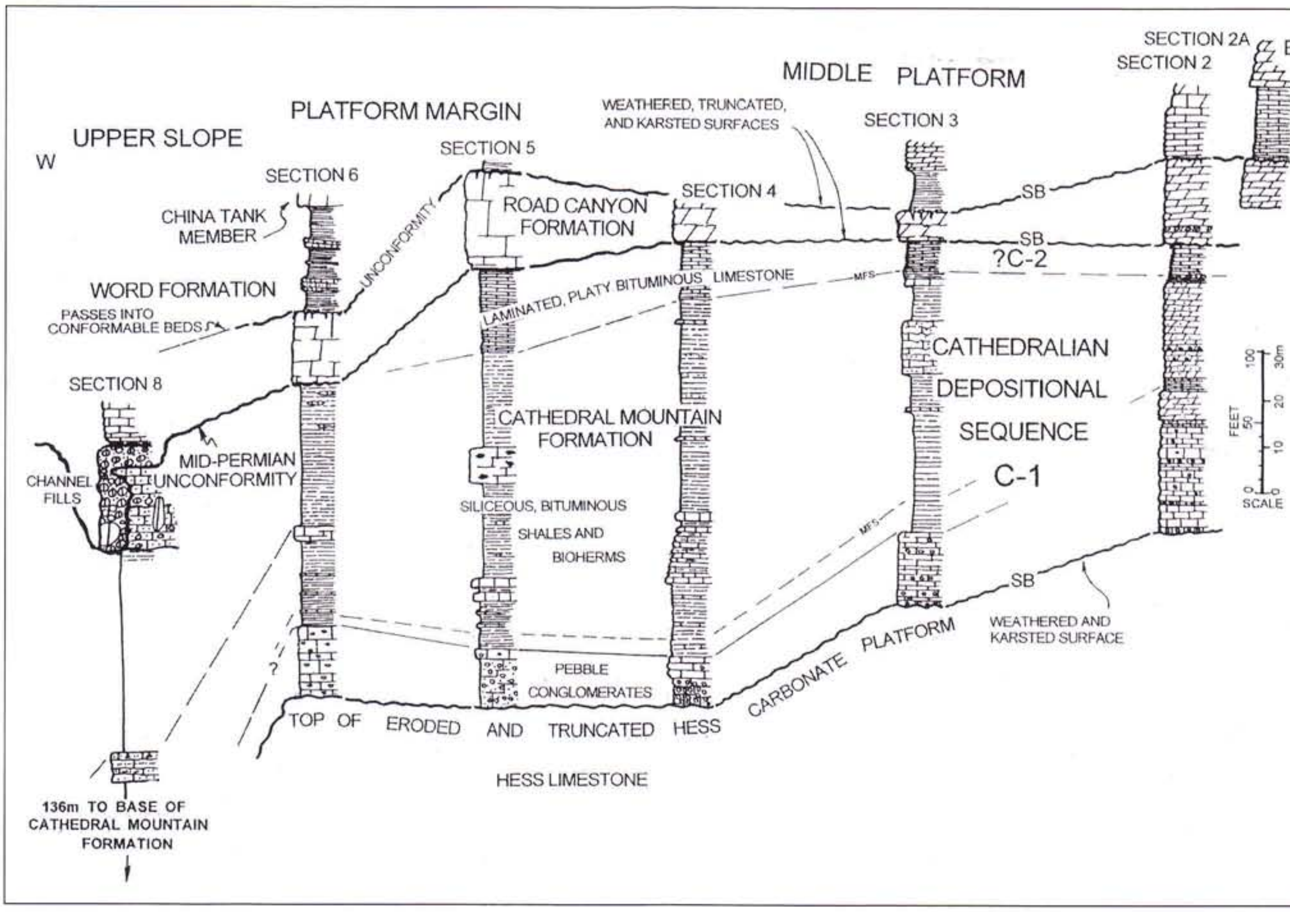

Fig. 10 - Shelf to upper slope facies of depositional sequences in the Cathedral Mountain Formation in eastern and central part of Glass Mountains; the upper part (?C-2) is a distinctive dark brown to black, silty, thinly laminated, weathered, dolomitic limestone which P. B. King (1930) originally included as the lower bed of his Word number 1 limestone member. See figure 3 for explanation of lithologic and other symbols. (Data are from King 1930; Ross & Ross in press).

bakeri? Dunbar & Skinner, *Boultonia guadalupensis* Skinner & Wilde, rare *Rauserella* spp. and rare *Schubertella melonica* Dunbar & Skinner. The Cathedralian includes the upper part of the *Neostreptognathodus prayi* conodont zone and the overlying *Neostreptognathodus sulcoplicatus* conodont zone and is considered by Wardlaw & Grant (1987) to be equivalent to parts of the Kungurian Stage.

Guadalupian Series (Middle Permian)

Roadian Stage. Above the mid-Permian unconformity, the Road Canyon limestone lenses have typical Middle Permian *Waagenoceras* and the fusulinids *Parafusulina wordensis* Dunbar & Skinner, *P. boesei* Dunbar & Skinner, and *Skinnerina rotundata* (Dunbar & Skinner, 1937) (Ross 1964). Elsewhere in West Texas, Dunbar & Skinner (1937) and Wilde (1990) reported *Parafusulina splendens* Dunbar & Skinner and *P. rothi* Dunbar & Skinner from this interval. Conodonts of the *Neogondolella serrata* zone (Wardlaw & Grant 1987) occur above the mid-Permian unconformity and identify the base of the Roadian Stage of the Guadalupian Series.

The Road Canyon Member of Cooper & Grant (1964) has had a tortuous history. It was first named by Cooper & Grant (1964) as a replacement name for King's (1930) 'First limestone member' of the Word Formation and they retained it as the basal unit of the Guadalupian Series, but noted it contained both the ammonoids *Perrinites* and *Waagenoceras.* In 1966, Cooper & Grant raised the unit to a formation, the Road Canyon Formation, and placed it in the top of the Leonardian Series because, to them, the brachiopods 'clearly are more closely related to those of the Leonardian Series...'. Subsequent field studies by Wardlaw & Grant (1987) showed that the formation has a number of limestone ledges and that *Perrinites* occurs in the discontinuous lowest bed which has an unconformity at its top, is locally removed by erosion, and the middle Permian conodont boundary lies in the ledges a few meters above the unconformity. *Waagenoceras* is in the higher three or four ledges.

Stratigraphic Correlations

The correlations of the Glass Mountains Lower Permian beds with those of the Hueco and Franklin Mountains near El Paso, westernmost Texas (Williams 1964, 1966), are discussed by Ross & Ross (in press). Bed 2 of the Gray Limestone (Bed J) is considered of Bursumian age and an equivalent of the Bursum Formation of New Mexico and the Foraker Limestone of Kansas (Ross & Ross 1987a, 1987b, 1994, 1998). In the Hueco Mountains, the probable equivalent to the Neal Ranch Formation is in the '*Pseudoschwagerina*-bearing beds' mapped by King et al. (1945) and Williams (1963) that dip northwestward into the adjoining sedimentary basin. These beds are truncated beneath the angular unconformity at the base of the Powwow Conglomerate at the base of the Hueco Limestone Group. Fusulinds from these '*Pseudoschwagerina*-bearing beds' have not been described, so this correlation is based on stratigraphic position. The Hueco Limestone Group is mostly equivalent to the three depositional sequences of the Lenox Hills Formation, however, the lowest 100 m may be somewhat older than Lenoxian LH-1 and, at the top, the highest 5 to 6 m are early Hessian (H-1) in age (Williams 1963).

Comparisons with the late Paleozoic successions in the Darvas-Zaalay (Transalay) terranes in the Pamir region of the central Tethys region, studied by Leven (1967), Leven & Shcherbovich (1978), Leven et al. (1992), and Leven (1997), show some fusulinid and stratigraphic similarities with the Lower Permian successions in the Glass Mountains (Fig. 11). Based on their descriptions of fusulinid faunas and stratigraphy, it is possible to propose correlations with at least some of the Upper Carboniferous and Lower Permian succession in the Glass Mountains.

Leven et al. (1992) report the Upper Carboniferous carbonate succession, the Kalaikukhnin Formation, about 200 m thick. The formation has thin, multiple, carbonate depositional sequences and contains nine fusulinid zones starting with the zone of *Triticites quasiarcticus–T. acutus* through the zone of *Daixina bosbytauensis.* Correlations with the uppermost Missourian and lowermost Virgilian series, including portions of the Gaptank Formation, are possible though the zone of *T. rossicus* and perhaps the zone of *Jigulites altus*. The succeeding upper Carboniferous zones have increasingly endemic faunas and have little in common with middle and late Virgilian fusulinid faunas in southwestern North America. The Kalaikukhnin Formation was uplifted in its northern exposures where it was partially eroded before deposition of the Lower Permian (Asselian) Sebisurkh Formation.

The Lower Permian Asselian Sebisurkh Limestone, about 450 m thick, formed in a shallow basinal setting to the south on a relatively complete section of Upper Carboniferous limestones (Leven et al. 1992). In the northern exposures, only a discontinous, thin limestone of middle Asselian age was deposited on the eroded margin of the Carboniferous carbonate platform. The Sebisurkh has, in its lower part, a *Sphaeroschwagerina vulgaris–S. fusiformis* fauna, in the middle part, *Paraschwagerina ischimbajica* and *Pseudoschwagerina robusta* (as replacement for the *Sphaeroschwagerina moellei* zone). The upper part has the *Sphaeroschwagerina sphaerica–Pseudofusulina firma* zone that forms the top of Asselian Stage. Specimens identified by Leven et al. (1992) as *Pseudoschwagerina robusta* would suggest a correlation with Lenox Hills LH-2; however, that unit is considered Sakmarian or post-Sakmarian based on conodont studies in the Glass Mountains (Wardlaw & Davydov 2000).

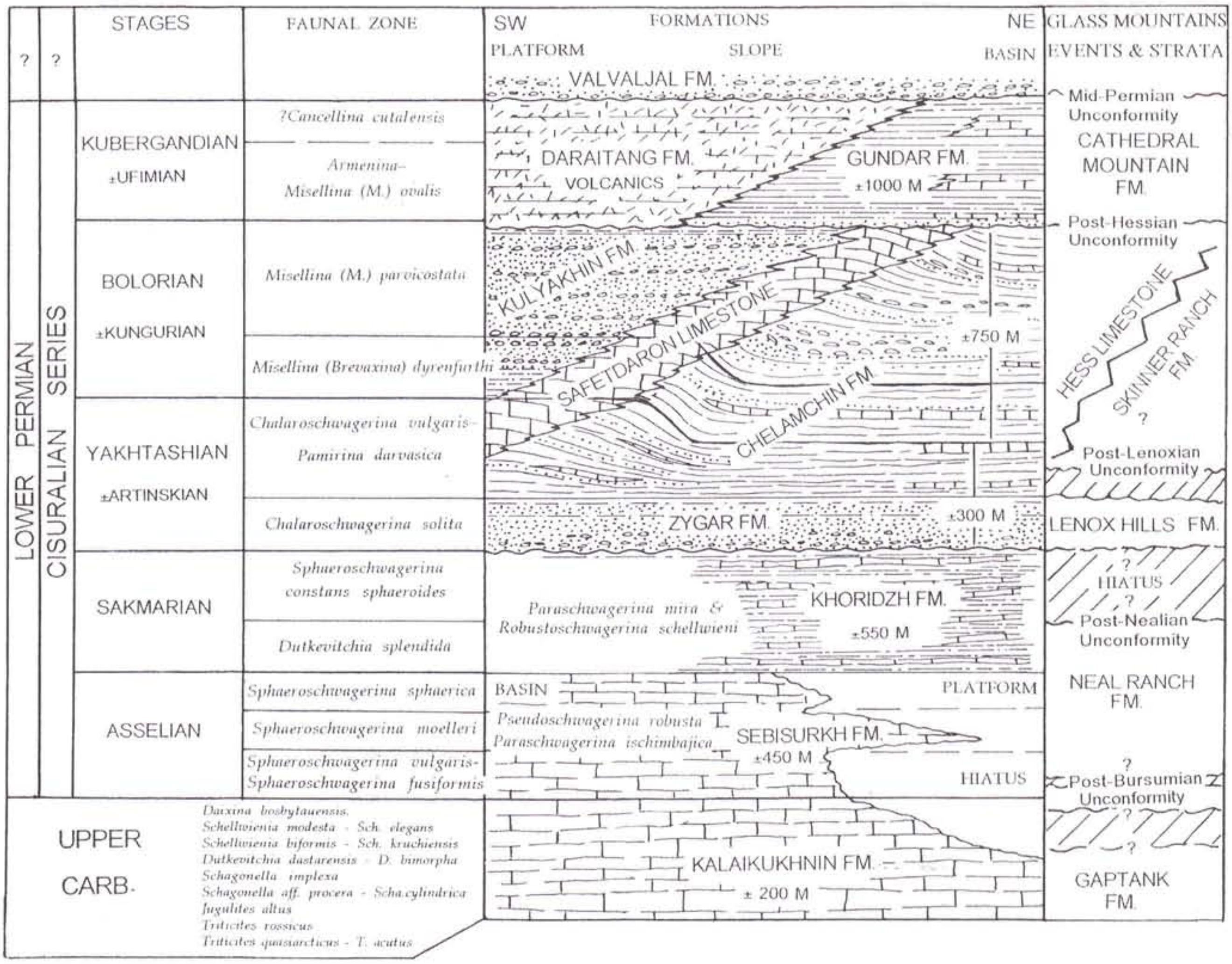

Fig. 11 - Tethyan succession of Upper Carboniferous and Lower Permian in Darvaz area in the Pamir region of southern Asia with comparison to North American strata and events. See figure 3 for explanation of lithologic and other symbols. (Data are from Leven & Shcherbovich 1978; Leven et al. 1992).

Above, the Sakmarian Khoridzh Formation, 400 m or more thick, is predominately clastic sandstones and siltstones with approximately 11, relatively evenly spaced, thin limestone beds (possibly depositional cycles) (Leven et al. 1992). Near the middle of the formation, thin conglomerates appear here and there. The Khoridzh Formation contains the zones of *Paraschwagerina mira* and *Robustoschwagerina schellwieni* which suggest a correlation with Ural zones of *Dutkevitchia splendida* and *Sphaeroschwagerina constans sphaeroides* and this suggests a correlation with the Sakmarian of the southern Pre-Ural region. Based on the common occurrence of *Paraschwagerina*, and other general fusulinid evolutionary features of the faunas, the fauna is probably Nealian.

The Yakhtashian Stage is a Tethyan provincial stage that approximates to the Artinskian Stage in the southern Pre-Ural region, but has a significantly different fusulind fauna (Leven et al. 1992). *Chalaroschwagerina* is common in both the Yakhashian Stage and the Lenoxian Stage which are probably largely stratigraphic equivalents. The Zygar Formation, about 300 m thick, lies at the base. Conglomeratic beds locally mark its base but it is mainly sandstones, sandy siltstones and siltstones (Fig. 11). Leven et al. (1992) place this unit in the zone of *Chalaroschwagerina solita* in the lower part of the Yakhtashian Stage. The Zygar lies on a major unconformity which we correlate with the post-Nealian unconformity with some help from the fusulinid faunas.

In the Darvas region, the upper part of the zone of *Charaloschwagerina vulgaris* and *Pamirina darvasica,* and the overlying Bolorian Stage, become three contrasting depositional facies of a platform, a shelf margin, and a slope. The shelf margin limestone facies, Safetdaron Limestone, includes 600 m of reefs, bioherms, and associated carbonate beds. It separates a platform facies of mainly nonmarine clastics, the Kulyakhin Formation, about 1200 m thick, from a basinal facies, the Chelamchin Formation, more than 750 m, of siltstones, shales and sandstones (turbidites?). The Safetdaron carbonates prograde over much of the basin facies. The lower part of the Safetdaron Limetone lies within the upper part of the zone of *Charaloschwagerina vulgaris* and *Pamirina darvasica* from which Leven et al. (1992) identified *C. vulgarisisformis* (Morikawa) and *C. inflata* Skinner & Wilde which are generally similar to *Schwagerina dugoutensis* Ross and *S. hawkinsi* Dunbar & Skinner from the Decie Ranch Member. The upper zone of the Yakhtashian, the zone of *Charaloschwagerina vulgaris* and *Pamirina darvasica,* has fusulinid faunas generally similiar to those found in Lenox Hills LH-2 and LH-3. Species assigned by Leven et al. (1992) to *Chalaroschwagerina* in the lower part of this zone are similar to *Charaloschwagerina nelsoni, Praeskinnerella zygarica* Leven to *Schwagerina dispansa* Ross and *P. jucunda* Leven to *S. diversiformis* Dunbar & Skinner. They indicate similar faunas with the middle and upper parts of the Lenox Hills Formation. *Robustoschwagerina tumida* (Licharev), also from this zone, is closely comparable to *Robustoschwagerina stanislavi* (Dunbar) from the lower beds of the Leonardian Bone Springs Limestone in the Apache Mountains, West Texas. This suggests the zone of *Charaloschwagerina vulgaris* and *Pamirina darvasica* includes the Lenoxian–Hessian boundary. In the overlying Bolorian zone of *Misellina (Brevaxina) dyrenfurthi* (part of the Safetdaron Formation), species appear that are morphologically similar to lower Hess (H-1) *Schwagerina crassitectoria* and *S. guembeli* and these also suggest the boundary between the Lenoxian and Hessian is lower than the base of the zone of *Misellina (Brevaxina) dyhrenfurthi.* A specimen of *Pseudoreichelina?* sp. occurs in Hess H-4, which lends further support that H-4 is Bolorian.

The upper part of the Bolorian is characterized by the zone of *Misellina (M.) parvicostata.* Specimens illustrated as *Praeskinnerella parviflucta* (Zhou) and *P. pavlovi* Leven by Leven et al. (1992, pl. 25, figs. 3, 4; pl. 26, fig. 1) are closely similar to *Parafusulina brooksensensis* Ross from Hess sequence H-6. This suggests that Hess sequences H-5, H-6, and probably H-7 are middle to late Bolorian. The top of the upper Bolorian *Misellina (M.) parvicosta* zone is eroded and truncated at an unconformity which we correlate with the post-Hessian unconformity.

Above this unconformity, the Gundar Formation, up to 150 m thick, is placed in the Kubergandian Stage by Leven et al. (1992). The formation is mostly an argillite and siltstone succession with rare sandstones having a few algal-fusulinid carbonates. Near the middle, massive carbonates, some of them reefs, have faunas of the *Armenina–Misellina (M.) ovalis* zone. Specimens illustrated from the Gundar Formation by Leven et al. (1992, pl. 26, figs 6, 7) as *Skinnerella loeyensis* (Pitakpaivan) are similar to specimens illustrated as *Parafusulina durhami* Thompson and Miller by Ross (1962, pl. 6, figs. 1-7) from the Cathedral Mountain Formation. Specimens illustrated as *Skinnerella quasigruperaensis* (Sheng) and *Parafusulina fusoidea* Leven by Leven at al. (1992, pl 26, figs. 3, 4; pl. 28, figs. 7, 8)) from the zone of *Armenina–Misellina (M.) ovalis* are not quite as advanced as, and therefore slight older than, parafusuline faunas than those from the Road Canyon Formation at the base of the Guadalupian Series. The Gundar Formation and the volcanic tuffs that make up the Daraitang Formation are both truncated by erosion at the mid-Permian unconformity and are overlain by the terrigenous Valvalyak Formation.

Conclusions

The North American Lower Permian standard sections in the Glass Mountains and adjacent parts of West Texas are a well known and valuable guide to the stratigraphy of North America. The lower Wolfcampian Neal Ranch Formation (Nealian Stage) is composed of 16 fourth-order depositional sequences and contains a diverse fusulinid fauna of about 40 species. Some of these species appear, extend through a few of these fourth-order depositional sequences and then disappear. Early species of *Pseudoschwagerina* and *Paraschwagerina* characterize this fauna. The upper Wolfcampian Lenox Hills Formation (Lenoxian) comprises three third-order depositional sequences and contains an abundant fusulinid fauna of about 25 species. This fauna is characterized by *Chalaroschwagerina nelsoni,* advanced species of *Pseudoschwagerina* and *Paraschwagerina,* and a number of advanced species of *Schwagerina.* Most species are recorded from the middle depositional sequence and both faunal diversity and abundance varies markedly across the platform, platform margin, and into the basinal facies from one depositional facies to the next.

Leonardian successions comprise nine third-order depositional sequences which are well exposed in platform, slope, and basinal facies. In the Hess limestone platform facies in the eastern Glass Mountains, fusulinid faunas in each depositional sequence have low diversity of one, or a few, generally abundant species. The lowest Hess platform sequence, H-1, has several parasequence sets characterized by *Schwagerina crassitectoria* and *S. guembeli.* The overlying Hess sequence H-2 contains a primitive species of *Parafusulina* which forms the beginning of a long parafusuline lineage extending into higher depositional sequences as a succession of more advanced species. In the clastics of the Skinner Ranch Formation in the slope and basinal facies in the western Glass Mountains, the lowest unit, the Decie Ranch Member, contains in the carbonate matrix between large blocks and boulders of eroded older beds, a fusulinid fauna of 5 or 6 advanced *Schwagerina* species having large, thickly constructed tests that appear to characterize this higher energy clastic slope facies. Higher, the clastic-bearing Sullivan Ranch Member contains a few species of *Parafusulina.*

The thin, eastern platform facies of the Cathedral Mountain Formation (Cathedralian Stage) contains a few discontinuous bioherms containing an advanced species of *Parafusulina.* The basinal western facies of mainly siltstones, shales, and thin pebbly turbidites has a few beds with a similar, advanced species of *Parafusulina.*

Several tectonic unconformities are important. In the eastern Glass Mountains, the first lies at the base and another at the top of the highest limestone bed (bed J) of the Gaptank Formation, and a third at the top of the type section of the Neal Ranch Formation. Higher in the exposures, major unconformities are present at the top of the Lenox Hills Formation, at the base of the Taylor Ranch Formation (base of H-5), at the top of the Hess Limestone (top of H-7) and a complex major, mid-Permian unconformity (perhaps two closely spaced unconformities) at the top of the Cathedralian. These unconformities probably are the result of eustatic events because hiatuses at these levels are well known within the West Texas regional stratigraphic framework.

Although many fusulinid provincial faunal differences exist between the late Paleozoic Tethyan belts of Asia and the Glass Mountains and Permian Basin in the southwest United States, a few distinctive genera and similar species seem to be common to both and suggest that correlation with the Tethys Lower Permian stages is possible. Such a correlation is more likely to result in a usable stratigraphic nomenclature than attempts to correlate the West Texas Lower Permian faunas directly with the Kungurian and Ufimian Stages of the Russian Platform and southern Pre-Ural region.

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