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A CONTRIBUTION TO THE EVOLVING STRATIGRAPHIC FRAMEWORK OF MIDDLE PERMIAN STRATA OF THE DELAWARE BASIN, TEXAS AND NEW MEXICO

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Abstract—We propose a new scheme for correlation of upper Leonardian through Guadalupian units of the Permian Basin and focus on two key correlations within the older, San Andres equivalent, portion of this succession. The lower San Andres Formation of the Algerita Escarpment is here considered equivalent to the uppermost Victorio Peak Formation of the western Escarpment and not the Cutoff Formation as proposed by earlier workers. This revised correlation is derived from extensive measured section data from the Algerita Escarpment, Brokeoff Mountains, Cutoff Mountain and the Western Escarpment, and conodont biostratigraphic data from Lawyer Canyon on the Algerita Escarpment. Conodont data, when reconciled with existing fusulinid biostratigraphic data from Lawyer Canyon, establish the position of the Leonardian-Guadalupian boundary well within the San Andres and support the lower San Andres to upper Victorio Peak correlation that was originally derived from lithostratigraphic correlation. A second key correlation involves the position within the San Andres Formation platform carbonates of bypass surfaces coeval with basinal Brushy Canyon and Cherry Canyon siliciclastics. We assert that the shelf equivalent of the voluminous Brushy Canyon sandstone succession is reflected by a single bypass surface recorded on the Algerita Escarpment as the first widespread karstic surface within the San Andres. A basinward shift in the ramp-crest facies tract of at least 5 mi also occurs across this karst-modified sequence boundary, emphasizing the significance of this surface in the platform stratigraphy. The Brushy Canyon bypass surface is 100 ft below the Lovington sandstones, which are in turn tied to the lower Cherry Canyon Formation or Cherry Canyon Tongue. Thus, two key bypass surfaces occur in the upper San Andres depositional sequence, one at the base, which is equivalent to the Brushy Canyon Formation and one in the middle, equivalent to the Cherry Canyon Tongue.

INTRODUCTION

In earlier papers (Kerans et al., 1992a, b), we presented a synopsis of a stratigraphic framework for Leonardian through Guadalupian strata that has been developed over the past several years by researchers at the Bureau of Economic Geology and affiliated institutions (Fitchen et al., 1992; Gardner, 1992). This contribution presents a new correlation scheme, but it also emphasizes an approach to shelf-to-basin correlation in which comparable levels of stratigraphic cyclicity are identified within both the shelf and basin and are used to guide correlation between the two depositional regimes. This approach, which is based upon fundamental sequence stratigraphic principles (Vail et al., 1977; Van Wagoner et al., 1990), defines time-significant units of strata bounded by unconformities and their correlative conformities. In contrast to other workers (Vail, 1987; Van Wagoner et al., 1990), we choose to emphasize the variability in the proportion of systems tracts within a sequence in response to changing conditions of accommodation and sediment supply.

This paper reviews briefly the foundation for the stratigraphic framework of Yeso—Victorio Peak through Tansill Formations on the platform and Bone Spring through Bell Canyon Formations in the basin and then discusses key problem areas in the San Andres Formation and equivalent units. These correlations are particularly important because they form the foundation for much of the stratigraphic model.

DATA

Extensive new outcrop and subsurface stratigraphic data and refined biostratigraphy from both basin and platform settings are integrated with existing studies in this paper (Figs. 1, 2) to construct a detailed sequence framework. The classic work of King (1948), numerous student theses, most notably from the University of Wisconsin and synthesis studies by Sarg and Lehmann (1986) and Sarg et al. (1988) provided a starting point for this research. Major sources of data for two uppermost Leonardian sequences (L4, L5) and Guadalupian sequences G1—G12, including parts of the San Andres, upper Victorio Peak, Cutoff, Brushy Canyon and lower Cherry Canyon formations, are King (1948), McDaniel and Pray (1967), Harris (1982), Kirkby

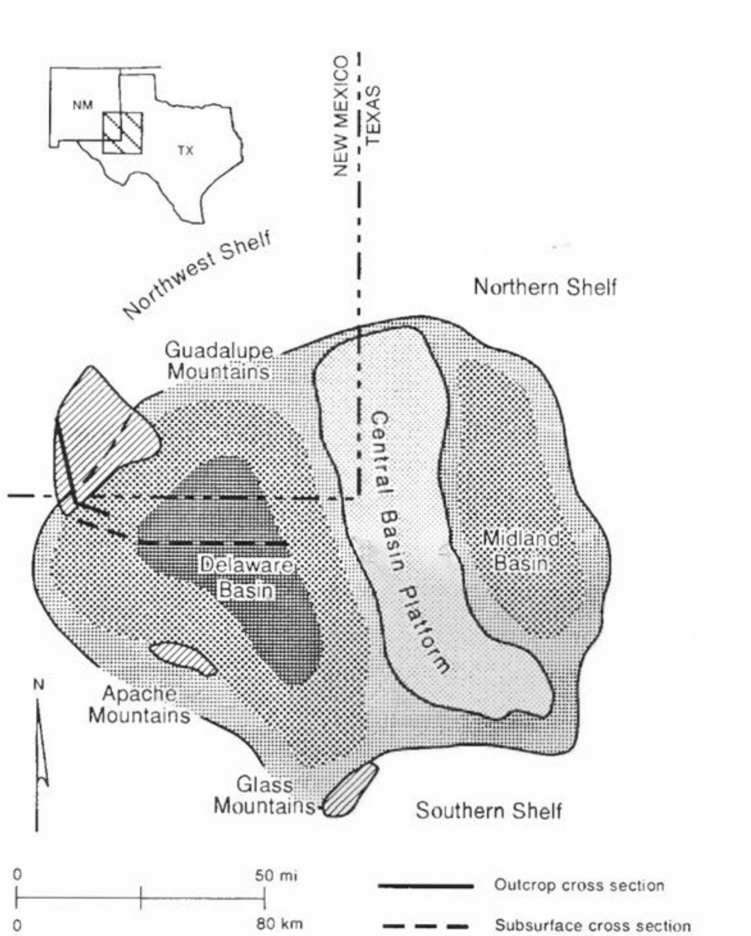

FIGURE 1. Location map showing general paleogeography of Permian Basin during the Guadalupian and position of the cross section lines shown in Fig. 3.

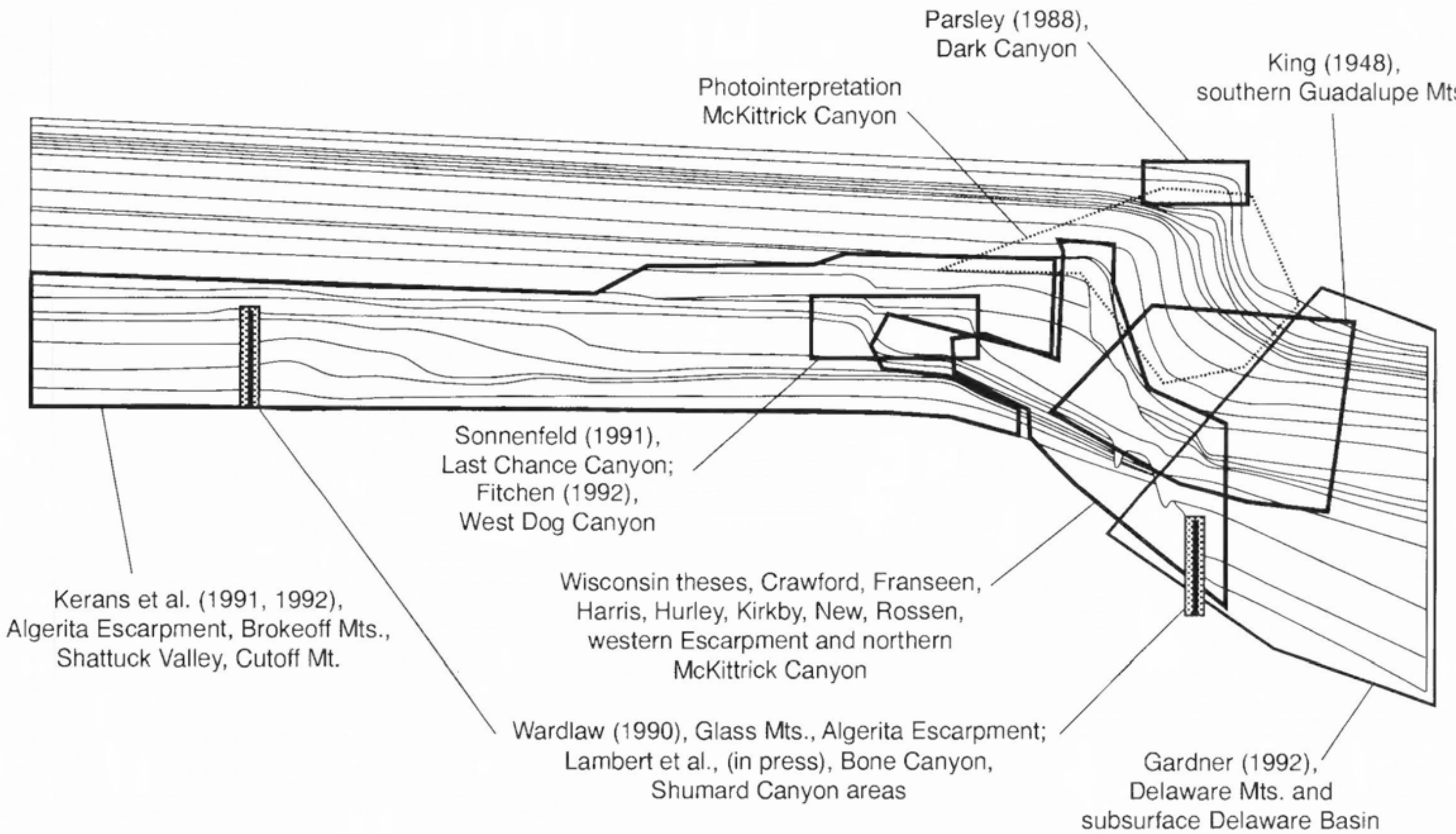

FIGURE 2. Sources of data used for this synthesis and their areas of coverage. Full references are given in reference list. Location of measured sections used to construct the San Andres portion of this illustration are given in Fig. 9. Modified from Kerans et al. (1992b).

(1982), Rossen (1985), New (1988), Kerans et al. (1991 and unpublished), Sonnenfeld (1991a, b), Fitchen (1992) and Gardner (1992). For Grayburg and related Cherry Canyon units (G13, G14), Kerans and Nance (1991) and Franseen et al. (1989) are the major sources. Sequences that include Queen, Goat Seep and Cherry Canyon units (G15—G18) are covered by King (1948), Crawford (1981), Wheeler (1985, 1989), Franseen et al. (1989) and additional data collected for this study. Uppermost Cherry Canyon, Manzanita and youngest Goat Seep units are covered in part by Sarg (1980), Crawford (1981), Hampton (1983) and Gardner (1992). For Seven Rivers/Bell Canyon sequences (G19—G21), King (1948), Hayes (1964) and Hurley (1978, 1989) provide partial coverage, supplemented here by photomosaic interpretation. Data for sequences that include Yates and Bell Canyon Formations (G22—G26) come from King (1948), Candelaria (1989), Borer and Harris (1991) and data collected for this study. Tansill/Bell Canyon sequences (G27, G28) have been constrained in part by data from King (1948), Tyrrell (1969) and Parsley (1988).

Ongoing biostratigraphic studies in the Guadalupe Mountains, in particular those focusing on recently developed conodont zonation (Wardlaw and Grant, 1991; Lambert et al., in press), have refined critical time-lines across shelf and basin. Major advances are focused in the San Andres, Cutoff and Bone Spring intervals.

The synthesis cross section (Fig. 3) and related results derived from this study are concerned with the linked evolution of platform and basin settings. The high-resolution sequence framework on which the cross section is based illustrates the genetic relationships between shelf and basin, which in turn provide a greater understanding of temporal relations that impact the styles and facies architecture that are critical to hydrocarbon accumulations.

STRATIGRAPHIC NOMENCLATURE

A stratigraphic classification based on multiple scales of cyclicity, designated as low-, intermediate- and high-order, is used to emphasize comparable scales of cyclicity rather than fixed cycle periods and the implicit forcing mechanisms (i.e., second-order = tectonic, third-order = eustatic, etc.) (Figs. 4-7). Five low-order cycles, each containing 4 to 8 intermediate-order cycles (= high frequency sequences or HFS), can be recognized in the uppermost Leonardian through Guadalupian succession. These intermediate-order cycles, in turn, consist of 10 to 15 high-order cycles. Some intermediate-order cycles are entirely basin restricted, whereas others have very thin, starved basinal records and thick platform successions (Fig. 3).

In more commonly applied sequence stratigraphic terminology (used in Figs. 7, 8) the low-order cycles can be approximately equated to 3rd-order depositional sequences, whereas intermediate-order cycles equate to 4th-order or high-frequency sequences (HFS) and high-order cycles are most comparable to 5th-order cycles or parasequences (compare with Mitchum and Van Wagoner, 1991). The low-order cycles or depositional sequences described here are composite in nature with multiple internal unconformity surfaces. These are referred to as composite sequences by Mitchum and Van Wagoner (1991), but we have chosen to retain the term depositional sequence as we feel that with additional detailed work, most, if not all Vail-type depositional sequences will be shown to be of composite nature.

CORRELATION OF UPPERMOST LEONARDIAN AND LOWERMOST GUADALUPIAN STRATA

Outcrops of Leonardian through Guadalupian strata in the Guadalupe Mountains can be divided into an earlier bank/ramp phase of development and a later reef complex phase characterized by precipitous slopes into a starved basin (Pray and Esteban, 1977). The vertically extensive and laterally compressed outcrops of mixed siliciclastic-carbonate platforms of the upper Guadalupian reef rocks, which include the Capitan Formation and its shelf and basin equivalents (Figs. 3 and 6), allowed King (1948) to construct a robust correlation framework for these units. Subsequent biostratigraphic studies (Tyrrell, 1969; Wilde,

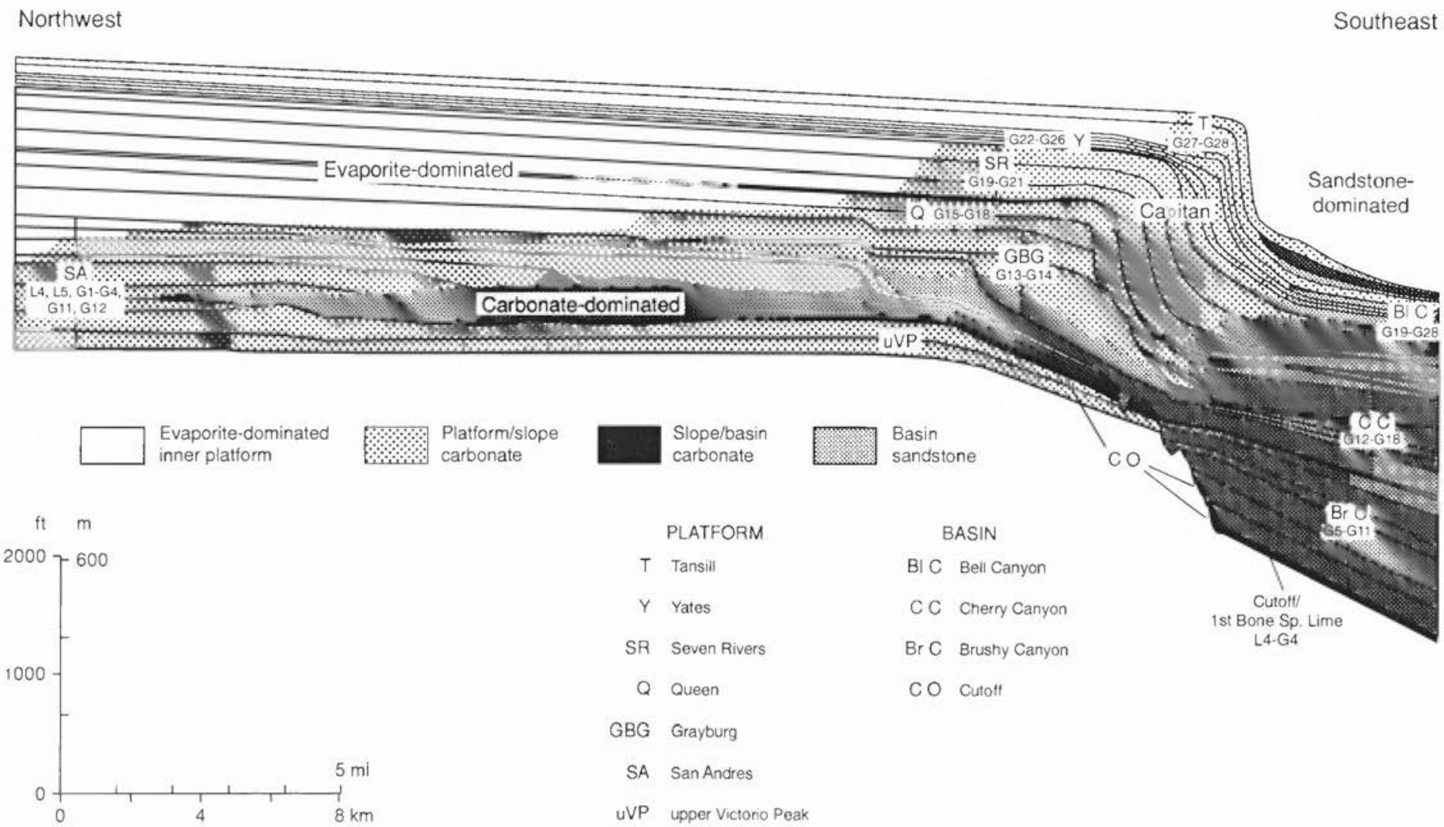

FIGURE 3. Generalized stratigraphic model of upper Leonardian through upper Guadalupian high-frequency sequences in the Guadalupe Mountains and Delaware Basin, Texas and New Mexico. Gross relationships among evaporite, shoal-water carbonate, deep-water carbonate and basinal sandstone are illustrated. Sequence abbreviations include a letter for age (L = Leonardian, G = Guadalupian) and a number for relative position within a series. Broad carbonate ramps with decoupled basinal siliciclastics typify uppermost Leonardian–lower Guadalupian sequences (L4–G13). Significant contraction of carbonate facies tracts, increased preservation of siliciclastics on the platform and coupled siliciclastic-carbonate facies tracts at intermediate- and high-order cycle scales characterize middle-upper Guadalupian sequences (G14–G28). Modified from Kerans et al. (1992b).

1975, 1990; Wilde and Todd, 1968) and general stratigraphic studies (Newell et al., 1953; Silver and Todd, 1969; Meissner, 1972) have upheld most aspects of King's (1948) correlations between Seven Rivers, Yates and Tansill shelfal strata through the Capitan Formation and into their equivalents in the Bell Canyon Formation of the Delaware Mountain Group (Fig. 6).

In contrast, the more geographically widespread outcrops of the geomorphically ramp-like carbonate and mixed siliciclastic-carbonate strata of latest Leonardian through earliest Guadalupian age in the Guadalupe and Delaware Mountains (compare area of platform/slope carbonate of G I—G4 and G11—G12 with that covered by G19-29) have proven more difficult to correlate on the shelf and between shelf and basin. Several significantly different temporal and physical correlations have been proposed for the uppermost Yeso, Victorio Peak, Bone Spring, San Andres, Brushy Canyon and Cherry Canyon Formations (Silver and Todd, 1969; Meissner, 1972; Sarg and Lehmann, 1986; Kerans et al., 1992) (Fig. 7). We will focus here on two outstanding problem areas. First, we will address age relationships and correlation of lower San Andres strata to the Yeso and Victorio Peak Formations. Second, we will examine the correlation of the Brushy Canyon Formation basinal sandstones and siltstones with the San Andres Formation (see also Fitchen, this volume).

YESO, VICTORIO PEAK AND LOWER SAN ANDRES CORRELATIONS

Uppermost Leonardian through lower Guadalupian strata in the Guadalupe Mountains include, on the platform, the Yeso, Victorio Peak and San Andres Formations, and, in the basin, the upper Bone Spring, Cutoff, Brushy Canyon and lower Cherry Canyon Formations (Fig. 6). King (1942, 1948), Newell et al. (1953), Boyd (1958), Hayes (1964), Wilde and Todd (1968), Silver and Todd (1969), Meissner (1972), Pray and Esteban (1977) and most recently Sarg and Lehmann (1986) and Wilde (1986) have proposed differing correlation schemes for uppermost Leonardian through lower Guadalupian strata. Beginning with early biostratigraphic work of Girty (1902, 1908), designation of the San Andres Formation type section in the San Andres Mountains (Lee and Girty, 1909) and the subsequent revision of this type section (Needham and Bates, 1943; Kottlowski et al., 1956; Kottlowski, 1969), the San Andres Formation has been considered to be largely Leonardian in age and equivalent to the Bone Spring Formation of the basin (Tyrrell, 1969; Meissner, 1972). The exclusively Leonardian age of the San Andres type section contrasted with the Leonardian-Guadalupian age determined for the San Andres in Guadalupe Mountains outcrops and in the subsurface (Adams et al., 1939; Wilde and Todd, 1968; Silver and Todd, 1969; Meissner, 1972). This discrepancy was attributed to erosion of younger San Andres strata at the type locality (Kottlowski, 1969). A similar situation occurs on the Eastern Shelf of the Permian Basin where outcropping San Andres strata are entirely Leonardian, whereas subsurface San Andres strata of the Eastern Shelf are predominately Guadalupian (Silver and Todd, 1969). The Leonardian-Guadalupian range of the San Andres Formation has only recently been challenged by Sarg and Lehmann (1986) and Wilde (1986), who have indicated an entirely Guadalupian age for the San Andres of the Algerita Escarpment.

Uncertainty concerning the Leonardian versus Guadalupian age of the San Andres Formation and its outcrop to subsurface correlation was compounded by confusion resulting from a state line geologic mismatch between the southern Guadalupe Mountains of Texas (King, 1942, 1948) and the central and northern Guadalupe Mountains studied by Lang (1937), Boyd (1958) and Hayes (1964). Lang (1937) mapped the

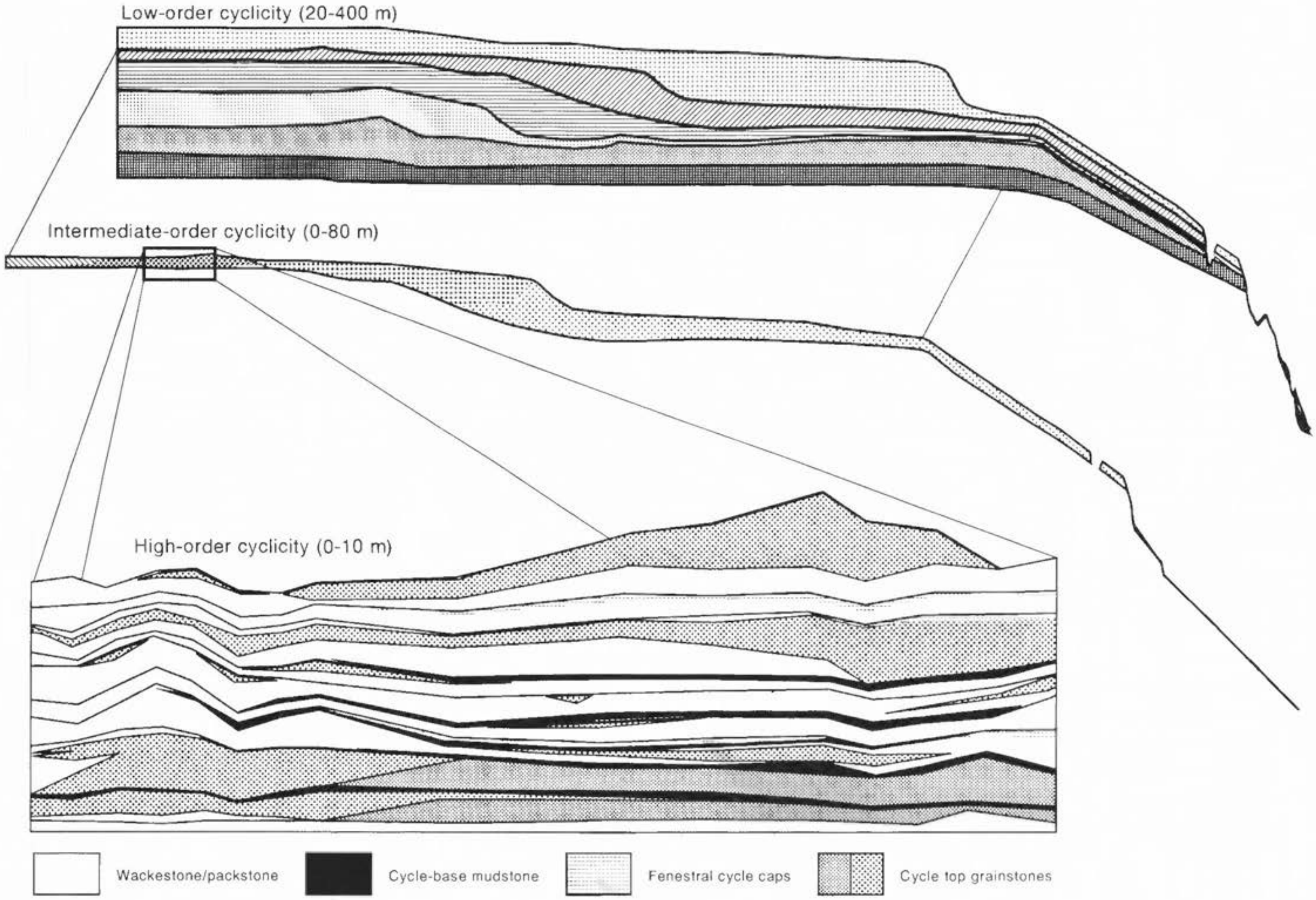

FIGURE 4. Schematic representation of scales of cyclicity in platform strata. Window showing high-order cyclicity includes all nine cycles that constitute the intermediate-order cycle in this 50 × 2500 ft window at the ramp crest.

strata of the type San Andres Formation eastward and southeastward into the northern Guadalupe Mountain outcrops of southeastern New Mexico, where he recognized that the superb exposures of the Algerita Escarpment (his term) were composed of the San Andres Formation resting atop the Yeso Formation (Fig. 8). King (1942, 1948), working from the southern extremes of the Delaware Basin in the Sierra Diablo Mountains, identified the lowest cliff-forming units of the western escarpment of the Guadalupe Mountains as the Victorio Peak Formation and carried this unit as far north as Cutoff Mountains on the Texas—New Mexico state line (Figs. 8, 9). King (1948) and later workers (McDaniel and Pray, 1967; Kirkby, 1982) noted that the Victorio Peak Formation contained three subdivisions: lower and upper cliff-forming limestones and dolostones separated by recessive silt-rich dolostones.

Boyd's (1958) study of the Brokeoff Mountains (Fig. 9) was conducted in a critical area that would enable linkage of the type-section stratigraphy to the north and its Algerita Escarpment equivalent with King's (1948) classic southern Guadalupe Mountain framework (Fig. 8). Boyd (1958) noted a strong similarity between the Victorio Peak Formation of the Brokeoff Mountains and the lower portions of the San Andres Formation, both of which contain a more diverse and normal marine fauna than that of the remainder of the San Andres section. Boyd (1958) suggested that the lower portion of the San Andres and the upper portion of the Victorio Peak Formation were probably the same unit, but he kept the units separate on his geologic map.

The most recent attempts to integrate stratigraphy from the Algerita Escarpment, Brokeoff Mountain/Cutoff Mountain and Western Escarpment areas (Sarg and Lehmann, 1986; Wilde, 1986) used a sequence stratigraphic framework and fusulinid biostratigraphy to interpret the lower two-thirds of the San Andres Formation as lower Guadalupian (Roadian) rocks, the lower of two in the San Andres (Sarg and Lehmann, 1986) (Fig. 7). More recent lithostratigraphic (Fitchen, 1992) and integrated lithostratigraphic/biostratigraphic studies (Kerans et al., 1992a, b) have linked the siliciclastic-rich tidal-flat facies of the upper Yeso Formation on the Algerita Escarpment, through the West Dog Canyon and Cutoff Mountain sections of the Brokeoff Mountains, with the siliciclastic-rich middle division of the Victorio Peak gray member of the Bone Spring Formation of King (1948; now called Victorio Peak Formation). These correlations treat the upper division of the Victorio Peak (King, 1948) as equivalent to the faunally diverse lower San Andres subdivision of Sarg and Lehmann (1986). This interval contains two intermediate-order cycles (Leonardian 4 and 5; Figs. 7, 9, 10).

Biostratigraphic control for these correlations comes from conodont dates of the Lawyer Canyon section on the Algerita Escarpment, which demonstrate a Leonardian age for this portion of the San Andres Formation (Fig. 7) compared to fusulinid data of Wilde (1986). A Leonardian age is consistent with that inferred by correlation of the Algerita Escarpment section to the type section in the San Andres Mountains (Fig. 7). Conodont studies on the Western Escarpment show that the Leonardian-Guadalupian boundary occurs within the Cutoff Formation (Lambert, 1992; Lambert et al., in press), placing this key time line within the middle of the San Andres (our Guadalupian I HFS, Figs. 7, 9, 10) and supporting the tie between the Leonardian 4 and 5 HFS of this report and King's (1948) upper division of the Victorio Peak gray member of the Bone Spring Formation. These biostratigraphic

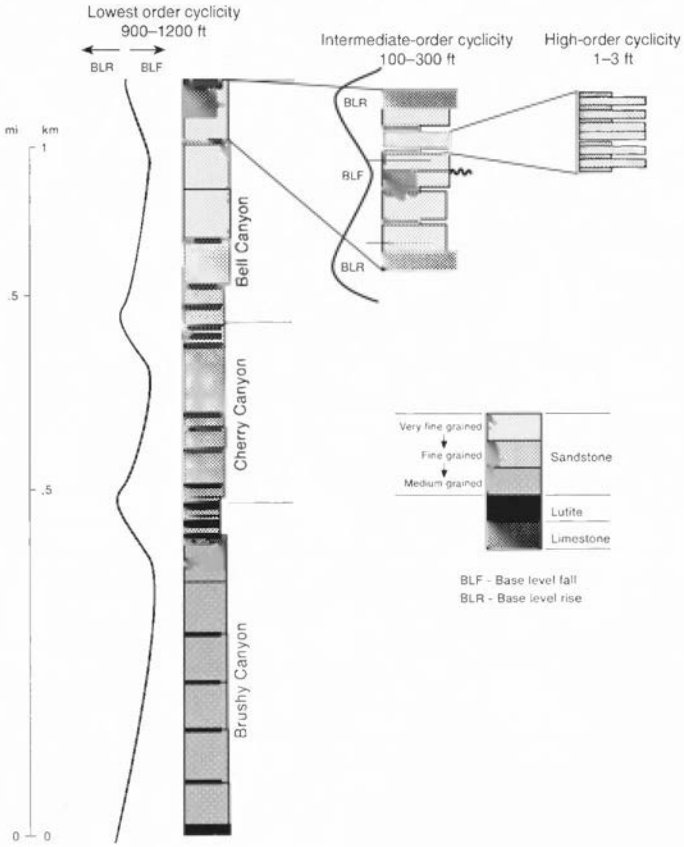

FIGURE 5. Simplified representation of cyclicity in basinal strata using a comparable low, intermediate, high ranking. From Kerans et al. (1992b).

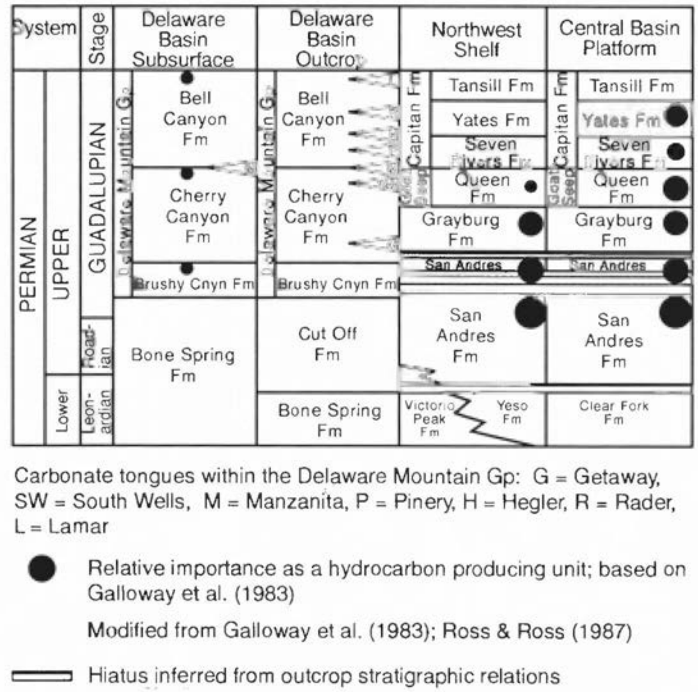

FIGURE 6. Stratigraphic nomenclature of the Delaware Basin and surrounding shelves. The focus of this report is on Leonardian and lower portions of the Guadalupian sections. Terms for the Northwest Shelf include both outcrop and subsurface usages.

relationships also support the equivalence of lower San Andres strata with the upper Bone Spring Formation as this term is used in the subsurface (King, 1948; Newell et al., 1953; Tyrrell, 1964; Meissner, 1972). Lambert (1992) has shown that uppermost Bone Spring limestones resting directly beneath the Pipeline Shale in outcrop are actually correlative with the Cutoff Formation, as originally proposed by Newell et al. (1953). Lambert (1992) derived a Guadalupian age for these uppermost Cutoff/Bone Spring strata, making a portion of this unit equivalent to our Guadalupian 1-4 HFS on the Algerita Escarpment.

BRUSHY CANYON–SAN ANDRES RELATIONS

Despite 80 years of research in the Guadalupe Mountains, a definitive tie between the Brushy Canyon Formation, the lowest unit of the Delaware Mountain Group and its platform equivalent, the San Andres Formation, has never been documented. Our research suggests that the entire Brushy Canyon Formation, up to 1500 ft of sandstone and siltstone, was transported across the exposed carbonate shelves of the San Andres Formation, leaving only local remnants as evidence. Whether this bypass occurred through as yet undocumented channel systems or as eolian dune complexes reworked by the subsequent transgression is one of the frequently revisited debates of Delaware Basin geology (Harms, 1974; Gardner, 1992). Did the bypass occur across a single surface on the platform or were multiple bypass surfaces involved? Are the bypass surfaces of the Brushy Canyon and Cherry Canyon Formations amalgamated within the Lovington sandstones as proposed by Meissner (1972) or are they distinct and separate surfaces?

Erosion associated with Brushy Canyon Formation bypass truncates the Cutoff Formation and its contained Leonardian-Guadalupian boundary and thus the bypass surface on the platform must occur above this surface (above the Guadalupian intermediate-order cycle of Fig. 7). The Cherry Canyon tongue of the Cherry Canyon Formation, which interfingers with the upper San Andres Formation of the Brokeoff Mountains and Last Chance Canyon areas (Boyd, 1958; Hayes, 1964; Sarg and Lehmann, 1986; Sonnenfeld, 1991b; Fitchen, 1992), defines an upper limit for Brushy Canyon bypass. Fitchen (1992, this volume) in the Brokeoff Mountains and Sonnenfeld (1991 b) in Last Chance Canyon have recognized the presence of sandstone units within the Cutoff Formation, distinct from the Cherry Canyon tongue sandstones, indicating that the Brushy Canyon Formation and the Cherry Canyon Tongue of the Cherry Canyon Formation bypassed across separate surfaces.

Both Fitchen (1992, this volume) and Kerans et al. (1992a, b) correlate this lower Brushy Canyon equivalent sandstone to a laterally extensive karstic zone in the San Andres Formation that defines the top of the Guadalupian 4 intermediate-order cycle. This karst surface can be traced laterally in a dip direction for 7 mi and displays karst breccias up to 40 ft thick below its surface. A basinward shift in the critical ramp crest facies tract of approximately 5 mi occurs above this karst-modified sequence boundary. Although further detailed mapping of this relationship will be required to unequivocally demonstrate a tie between the Brushy Canyon Formation and its time-equivalent surface and/or strata on the San Andres ramp, our model (Figs. 3, 7, 9, 10) supports the contention that this surface is not equivalent to the Lovington sandstone interval (Fig. 10). Rather, as described above, we believe that the Lovington sandstones can be correlated with the Cherry Canyon Tongue and represents a distinctly younger surface. The recognition of two major bypass surfaces (one for Brushy Canyon and one for Cherry Canyon), rather than the single Lovington sandstone surface equivalent to both the Brushy Canyon Formation and Cherry Canyon Tongue, diverges from earlier views (Meissner, 1972; Sarg and Lehmann, 1986).

CONCLUSIONS

Refinement of the uppermost Leonardian through Guadalupian sequence rocks is presented here to serve as a model for aiding future petroleum exploration and development in the Permian Basin. Three levels of stratigraphic cyclicity include low-order, intermediate-order and high-order cycles equating to depositional or composite sequences, high-frequency sequences and cycles, respectively. Some 29 high-fre-

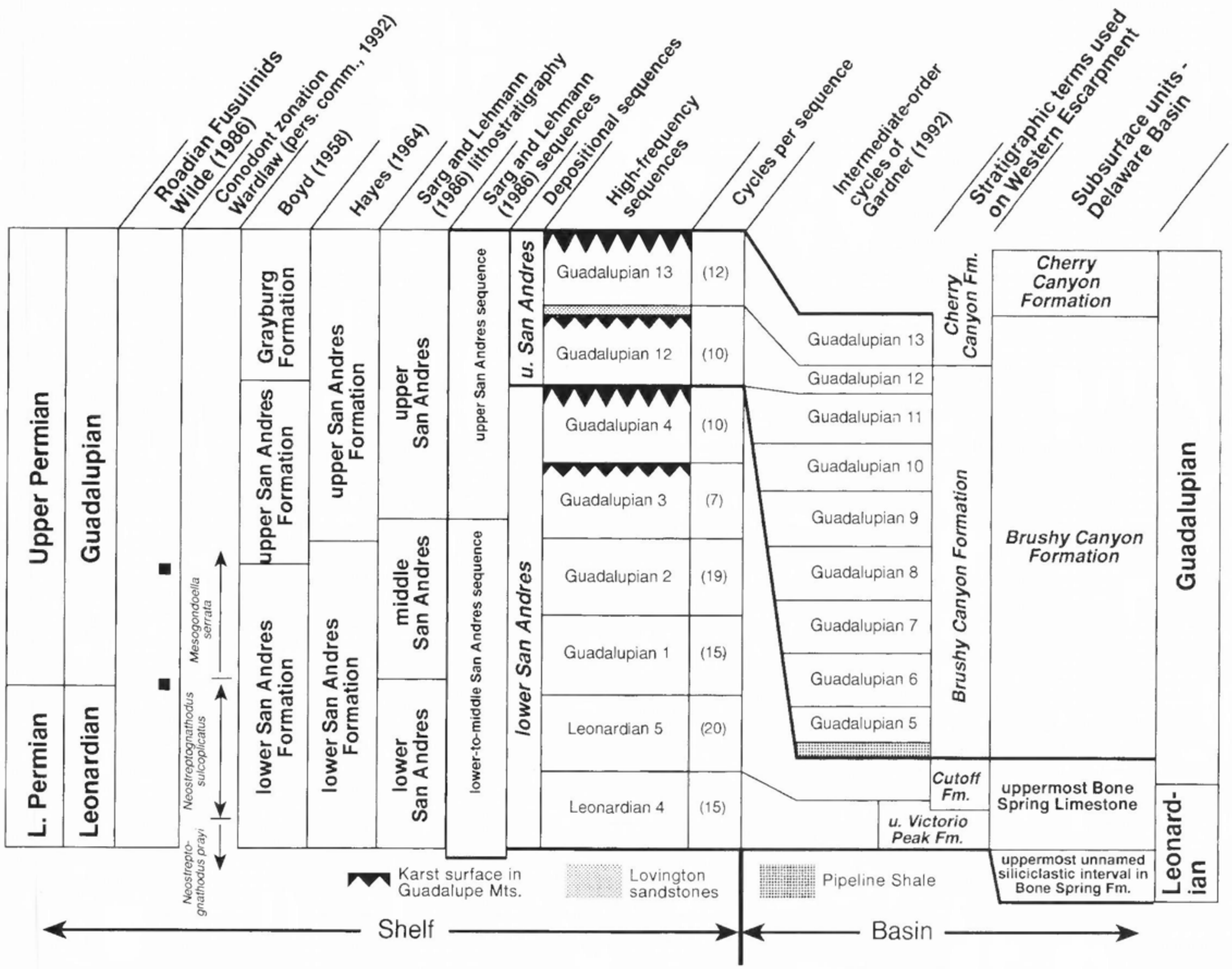

FIGURE 7. Evolution of stratigraphic nomenclature in the San Andres Formation and equivalents in the Delaware Mountain outcrop and subsurface. Note that the Leonardian-Guadalupian boundary occurs within the Cutoff Formation and within the uppermost Bone Spring Formation.

quency sequences are recognized in the San Andres—Bone Spring through Tansill—Bell Canyon succession.

Recently acquired biostratigraphic and lithostratigraphic data support original interpretations of Lee and Girty (1909), Newell et al. (1953) and Kottlowski et al. (1956), who among others suggested that the lower San Andres Formation is Leonardian and is partly equivalent to the upper division of the Victorio Peak as defined by King (1948) and to the uppermost Leonardian Bone Spring Formation of the subsurface. The recognition that the lower two San Andres high-frequency sequences (Leonardian 4 and 5) and the upper division of the Victorio Peak defined by King (1948) on the Western Escarpment are the same unit represents an important departure from previous studies. The position of the Brushy Canyon bypass surface within the San Andres platform stratigraphy is shown to occur atop the first widespread karstic surface within the San Andres Formation, at the top of the Guadalupian intermediate-order cycle.

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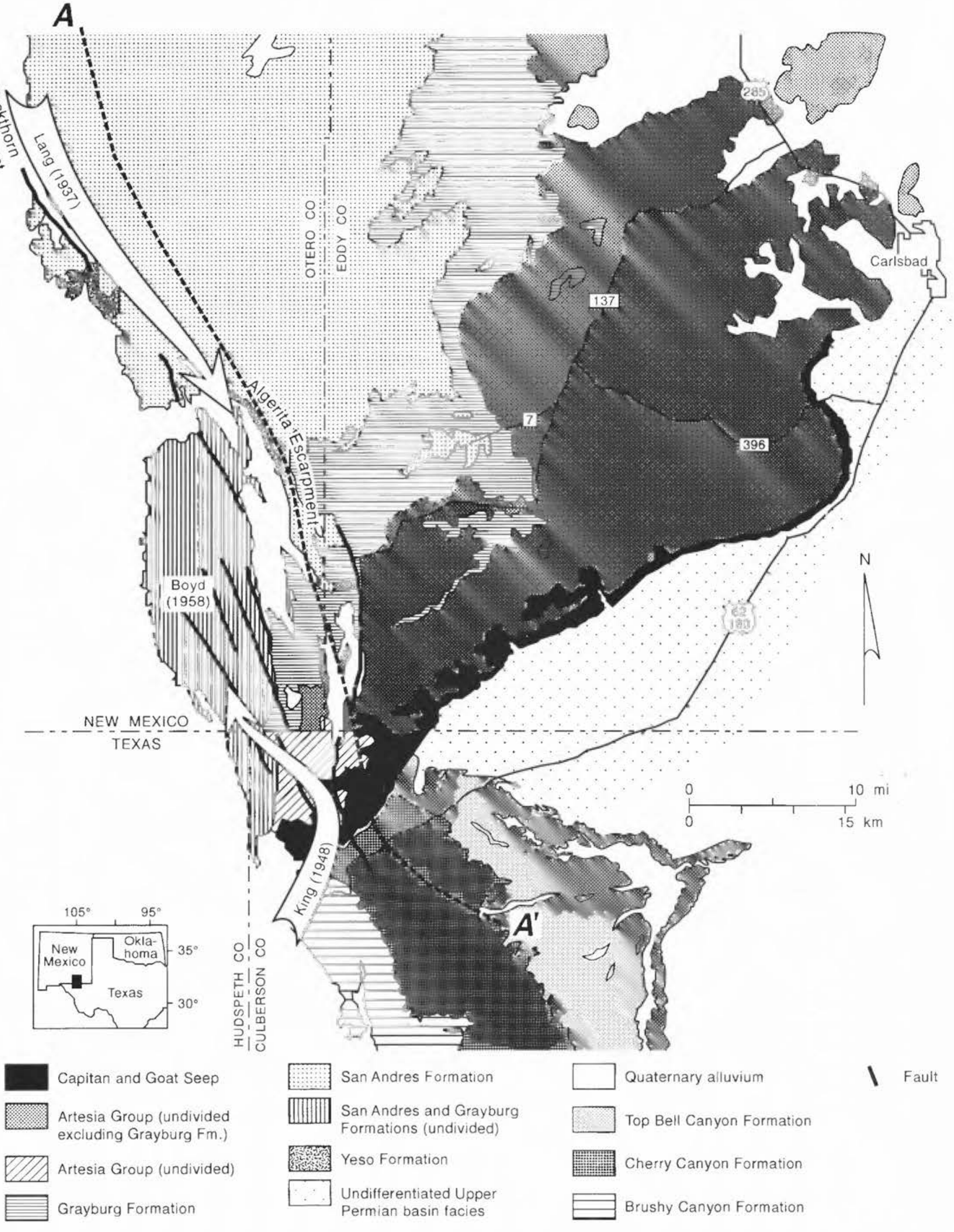
FIGURE 8. Geologic map of the Guadalupe Mountains after King (1948) and Hayes (1964) showing geographic disparity of three key studies, those of Lang (1937), Boyd (1958) and King (1948). Problems in correlation across the Texas—New Mexico state line hindered recognition of the equivalence of the lower San Andres Formation on the Algerita Escarpment with the upper division of the Victorio Peak gray member of King (1948) or upper Victorio Peak Formation or Kirkby (1982).


A
Buckthorn Escarpment
Lang (1937)
OTERO CO
EDDY CO
Algerita Escarpment
285
Carlsbad
137
7
396
Boyd (1958)
N
62
180
NEW MEXICO
TEXAS
0 10 mi
0 15 km
King (1948)
A'
105°
95°
New Mexico
Okla-homa
35°
Texas
30°
HUDSPETH CO
CULBERSON CO
Capitan and Goat Seep
Artesia Group (undivided excluding Grayburg Fm.)
Artesia Group (undivided)
Grayburg Formation
San Andres Formation
San Andres and Grayburg Formations (undivided)
Yeso Formation
Undifferentiated Upper Permian basin facies
Quaternary alluvium
Top Bell Canyon Formation
Cherry Canyon Formation
Brushy Canyon Formation
Fault

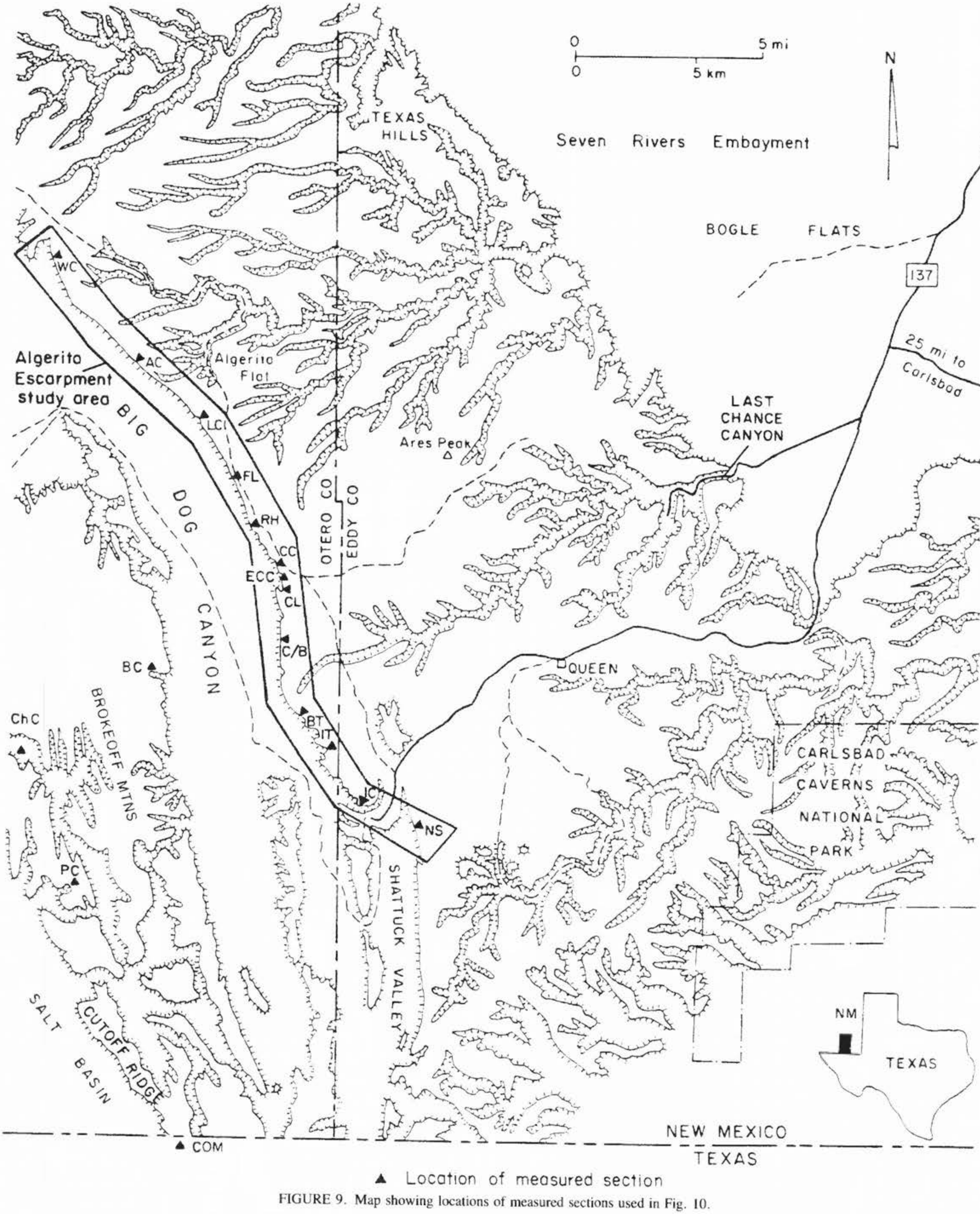


FIGURE 9. Map showing locations of measured sections used in Fig. 10.

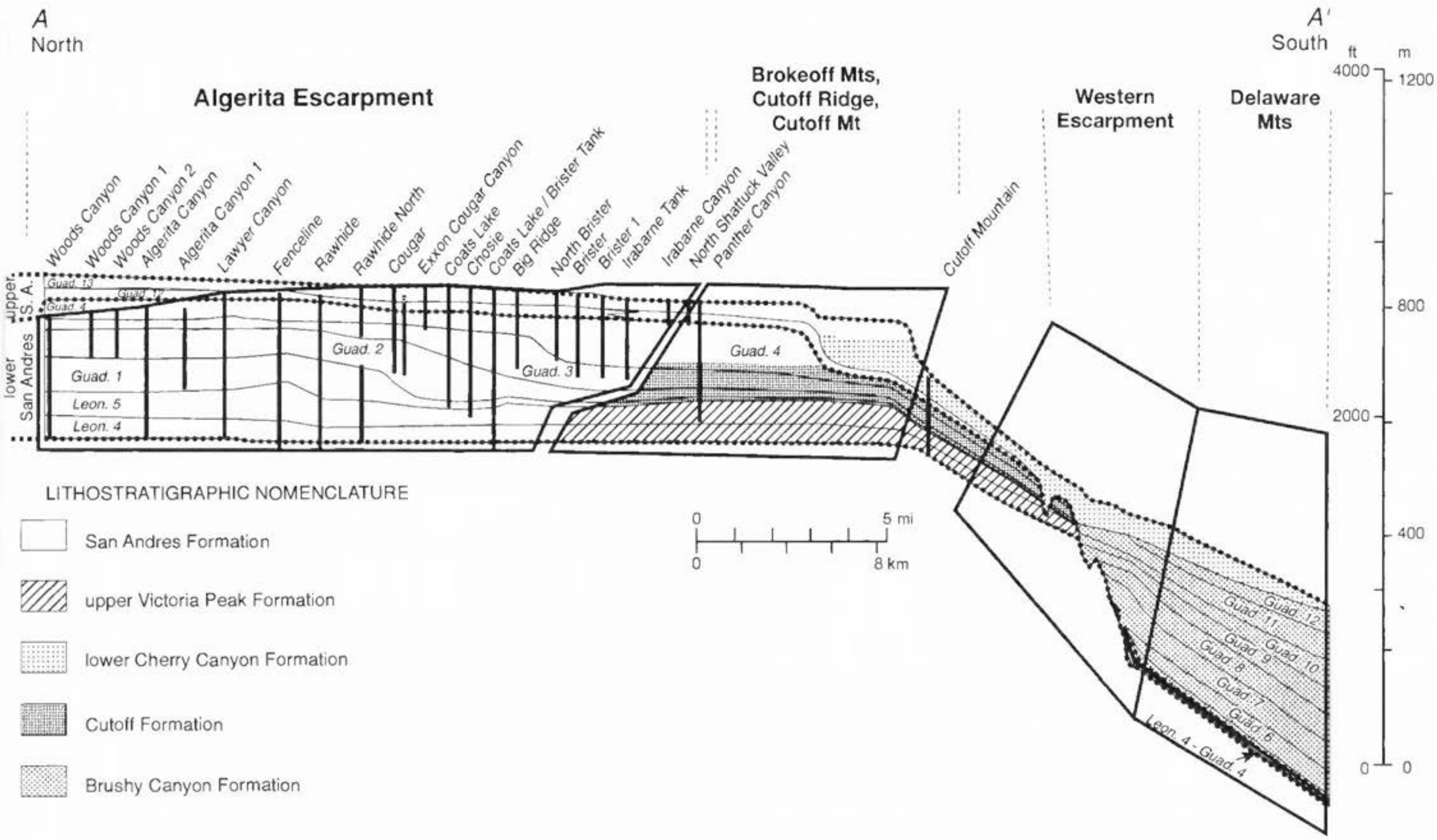


FIGURE 10. Cross section of San Andres Formation and its partial equivalents, the upper Victorio Peak, Cutoff, Brushy Canyon and Cherry Canyon Formations. The middle heavy stippled line separating the lower and upper San Andres depositional sequence, is the Brushy Canyon bypass surface. The Lovington sandstones are found at the base of the next higher HFS boundary between the Lawyer Canyon and West Dog Canyon areas.

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