GEOLOGY OF PART OF THE NORTHWESTERN APACHE MOUNTAINS, SOUTHEAST CULBERSON COUNTY, WEST TEXAS, U.S.A.

by

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ABSTRACT

GEOLOGY OF PART OF THE NORTHWESTERN APACHE MOUNTAINS, SOUTHEASTERN CULBERSON COUNTY, WEST TEXAS, U.S.A.

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Middle Permian marine (Bell Canyon Formation) strata along the southwestern margin of the Delaware Basin in southeastern Culberson County, Texas provide excellent exposures of basinal and slope strata, useful fossils for age dating, and a variety of interpretations of possible depositional environments. This work includes a detailed surficial geologic map of about a seven square kilometer area of the northwestern Apache Mountains, located along a portion of Texas Farm Road 2185, about 60 kilometers northeast of Van Horn, Texas. In addition to the map, a stratigraphic column is presented along with descriptions of a major subaqueous gravity flow in the map area and significant structural relationships recognized in the map area. Descriptions of the Upper Guadalupian Bell Canyon Formation and the overlying Lopingian Castile and Rustler Formations are presented to aid in providing a framework

for proposed biostratigraphic correlation with similar age strata in the Guadalupe Mountains, 70 km to the north-northeast of the map area. Analysis of one of the major, thick subaqueous gravity flows within the Bell Canyon Formation provides information about its clast lithology, fossil content, lateral extent, timing of emplacement and allochthonous debris origin.

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INTRODUCTION

1.1 Geographic Setting

The map area is located in central Culberson County, Texas approximately 60 kilometers (km) northeast of Van Horn, Texas in the northwestern part of the Apache Mountains (Figure 1.1) approximately eight km to the northwest of Seven Heart Gap, a well known geologic and geographic marker.

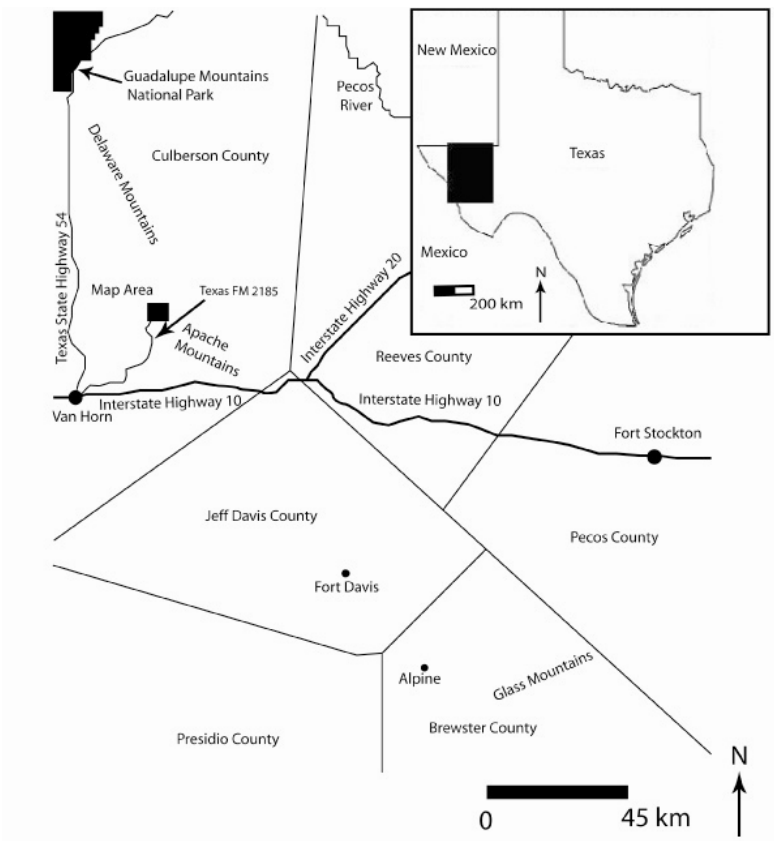


Figure 1.1. Geographic location of the map area. The map area lies approximately 60 km northeast of Van Horn, Texas along Texas Farm Road (FM) 2185.

The northeastern boundary of the study area is 31° 19′ 27" N latitude and 104° 31′ 45" W longitude. The southern boundary is Texas FM Highway 2185. The southwestern boundary is 104° 34′ 10″ W longitude and Texas FM 2185. The northern boundary lies along a line from 31° 19′ 27″ N latitude and 104° 34′ 10″ W longitude to 31° 19′ 15" N latitude and 104° 32″ 35" W longitude where it turns northeast, following a prominent drainage and ending at the northeast boundary 31° 19′ 27" N latitude and 104° 31′ 45" W (Figure 1.2).

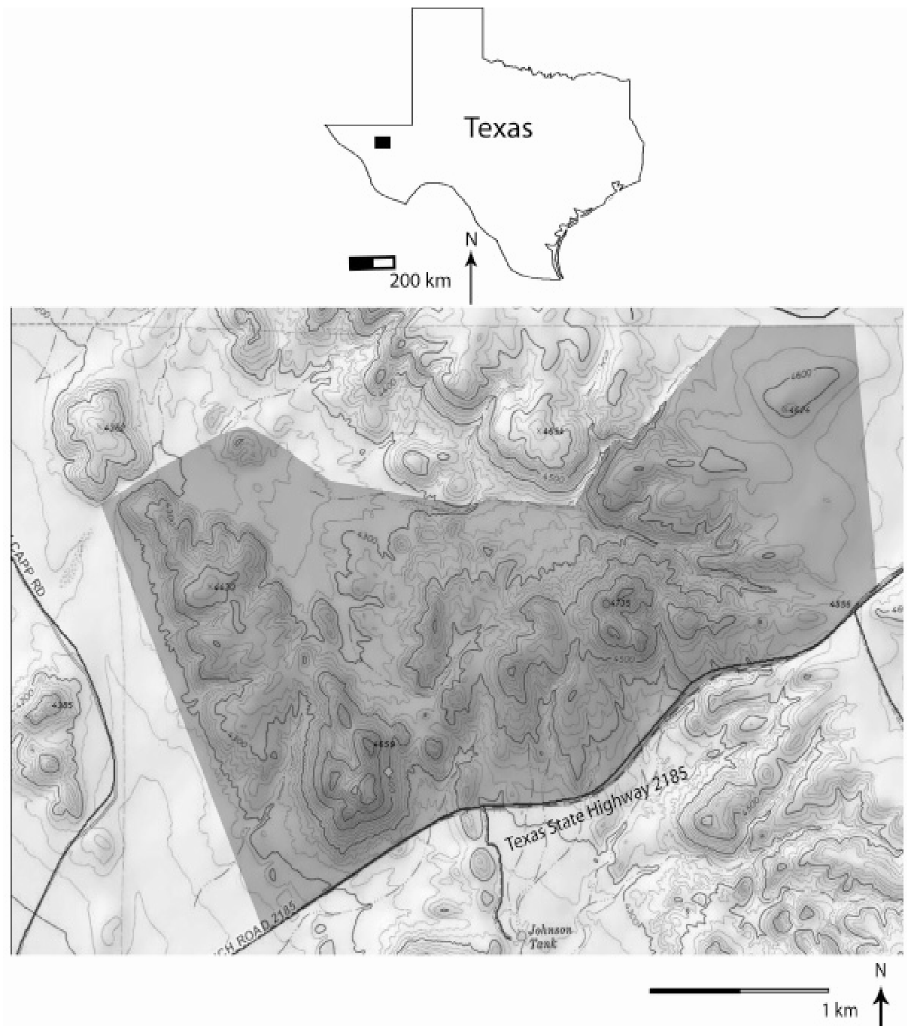


Figure 1.2. Geographic extent of the map area is shown by the shaded graphic below. The southern boundary of the map area is Texas FM 2185.

1.2 Previous Work-Regional and Map Area

Richardson (1904) did the first definitive geologic work in the northern Trans-Pecos region of Texas for the University of Texas Mineral Survey. He is credited for naming and describing many geologic units (such as the Castile and Rustler Formations) that occur in the map area. Richardson also collected many samples from the Guadalupe and Apache mountains that Girty (1908) described in his classic monograph "The Guadalupian Fauna" in which he described numerous brachiopod, sponge, gastropod, and pelecypod species (King, 1948; Wood, 1965). Baker (1920) first described the tectonic setting of the Trans-Pecos region. Lloyd (1929) proposed a reef origin for the Permian age Capitan Limestone in the Guadalupe Mountains. King (1948) published a comprehensive study of the strata in the Guadalupe Mountains and surrounding northern Trans-Pecos region as well as the first detailed geologic map of the region (King, 1948). King also refined basin-shelf margin-shelf correlations of strata in the Guadalupe Mountains region. Newell et al. (1953) further described the paleoecology and diagenesis of the Capitan Reef in the Guadalupe Mountains area. Newell et al. (1953) also interpreted silt and sandstones of the Bell Canyon Formation to have resulted from turbidity currents during low stands in relative sea level. Payne (1973) mapped and described the Upper Guadalupian Ramsey Sand, a sandy interval present below the Lamar Member of the Bell Canyon Formation. He interpreted the transportation of sand from the Delaware Basin margins into the deeper basin to be the result of fluid density currents and sediment suspension clouds.

McNutt (1948) mapped the Van Horn quadrangle between latitude 31° 10′ N and 31° 24′ N and between 104° 30′ W and 104° 40′ W as part of his doctoral dissertation at The University of Oklahoma. McNutt (1948) comments about the apparent absence of the Salado Formation in the area he studied. The Salado Formation is present between the Castile and Rustler Formations in the Delaware Mountains to the north of the map area. McNutt (1948) discusses Tertiary Basin and Range extensional faulting that produced the down-dropped block that constituted a large area roughly between the northern part of the Apache Mountains and the Southern Delaware Mountains surrounding the map area. He also makes note of north-northwest to northwest trending normal faults in the map area that often down-drop upper portions of strata of the Castile and Rustler Formations so that they are in contact with the what he called the Lamar Member of the Bell Canyon Formation. In a guidebook, DeFord et al. (1951) mentions that the Castile Formation is less thick in the Apache Mountains region relative to thicker areas south of the Guadalupe Mountains due to truncation by the Rustler deposits. He and others also mention downfaulted evaporites along the southern boundary of the map area of the Rustler and underlying Castile Formations, attributing the faulting to Tertiary uplift and extensional faulting. Owen (1951) discussed structural relationships in the Seven Heart Gap area to the east of the map area of this thesis and noted the way the Rustler Formation “draped” over the underlying Castile Formation. He also demonstrated that the lower part of the Rustler Formation can be traced from its type locality in the Rustler Hills (approximately 50 km to the northeast of the map area) to Seven Heart Gap. Newell et al. (1953) discussed Permian (Guadalupian) “submarine slide deposits” in Trew Canyon, approximately three km northwest of the map area and assigned them to the

Rader Member of the Bell Canyon Formation. Skinner and Wilde (1954) designated strata in the area of Seven Heart Gap to be Late Guadalupian (Lamar age) based on the occurrence of a fusulinacean *Paraboultonia splendens* in part because this species had also been documented in strata of the Lamar Member of the Bell Canyon Formation in road-cuts of Texas State Highway 180/62 on the north side of Bell Canyon drainage in northern Culberson County, Texas. Snider (1955) mapped and discussed Middle to Late Permian outcrops of the Seven Heart Quadrangle. He stated that the Castile Formation had been truncated during the Ochoan (Lopingian) prior to the deposition of the Rustler Formation in the Seven Heart Quadrangle area. He also made note that the Ochoan (Lopingian) Salado Formation that occurs between the Castile and Rustler Formations throughout the Delaware Basin is not present in the Seven Heart Quadrangle. Wood (1965) comprehensively mapped and described strata of the Apache Mountains to the southeast of the map area as part of his doctoral dissertation at the University of Texas at Austin. Wood (1965) described much of the strata of the Apache Mountains as coeval Capitan Reef equivalent facies. Not much work has been published on the strata in the map area, but in a guidebook, Silver (1968) noted some Permian age "submarine slide deposits" in the map area. In a recent paper, Lambert et al. (2002) described conodonts and foraminifers from Bell Canyon age strata along Texas FM 2185 on the east edge of the study area and noted that strata defining the upper boundary of the Middle Permian Guadalupian Series could be recognized by the presence of the conodont species *Clarkina postbitteri hongshuiensis* Henderson, Mei, and Wardlaw. The actual boundary of the Guadalupian Series and the overlying Lopingian Series is defined (GSSP) by the first occurrence of the conodont *Clarkina postbitteri postbitteri* Henderson, Mei, and Wardlaw, a species that has not been found in West Texas.

1.3 Scope of Current Study

Measured and described strata presented as stratigraphic columns of the Upper part of the Guadalupian Bell Canyon Formation, and to a lesser extent the Lopingian Castile and Rustler Formations exposed in the map area, comprise the main thrust of this work. The stratigraphic columns provide a framework for correlating faunas in the map area to similar age faunas in the Guadalupe and Delaware mountains to the north of the map area. The surficial geologic map in the present work displays the formations (i.e., Bell Canyon, Castile and Rustler) that crop out on the surface within the boundaries of the map area. The geologic map also displays “packages” of particular age strata as traced from measured sections where reliable age constraints were made possible by lithologic features. The use of the term “packages” is appropriate because the Bell Canyon member names used in the Guadalupe Mountains cannot be confidently lithologically recognized in the Apache Mountains, although there is confident enough biostratigraphic information in the conodont, foraminiferal, and radiolarian assemblages to make approximate time correlations. Age constraints for this work are largely based on current conodont, foraminiferal, and radiolarian analyses made possible by the work of Drs. Merlynd and Galina Nestell, Bruce Wardlaw, and others. Faults are placed on the geologic map as a result of relative displacement of strata (i.e., where strata of a particular age are adjacent to strata of a different age). Detailed structural analysis of the map area was not a priority of this study.

Analysis of one of the numerous thick sediment gravity flows of the Bell Canyon Formation in the map area provide information about its lithofacies, possible origin, fossil content, lateral extent and relative timing of emplacement.

Scant conclusions are drawn about the rheology and about the specific type of sediment gravity flow of the deposit. The location and extent of large clasts of reefal debris associated with a sediment gravity flow in the map area will also be described herein. Brief interpretations are given about the probable depositional environment and timing of emplacement of the reefal debris.

1.4 Regional Geologic Setting

The map area, comprised of the Upper Middle Permian (Upper Guadalupian) basinal deposits and Upper Permian (Lopingian) evaporites, lies along the southwestern flank of the Delaware Basin on a margin of the Diablo Platform (Figure 1.3.).

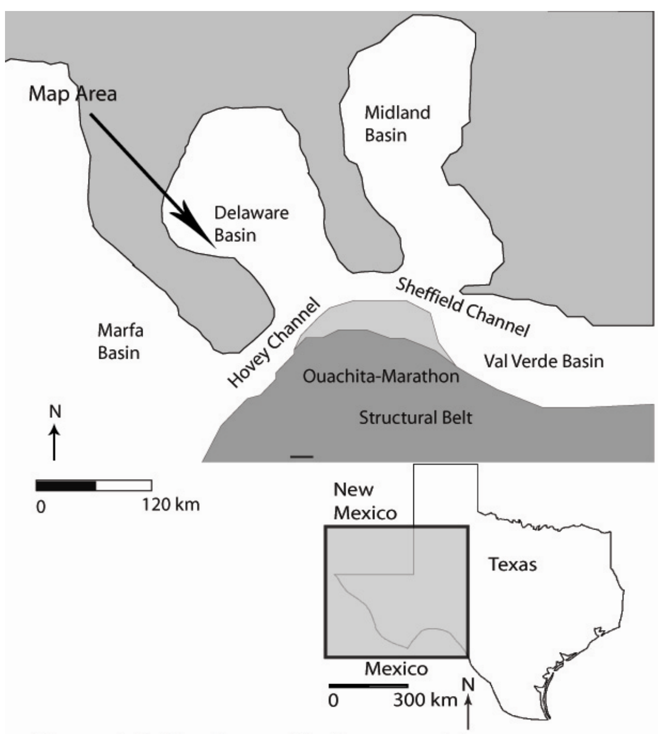


Figure 1.3. Physiographic features of the Permian Basin Region during Middle Permian time (modified from Ward et al., 1986).

The Delaware Basin is an ovoid-shaped, block-faulted, north-northeast trending structural depression in West Texas and southeastern New Mexico that is part of the southern portion of the larger Permian Basin. It is bordered on the east by the Central Basin Platform and on the west by the Diablo Platform (Figure 1.3). During Guadalupian time, the Delaware Basin is thought to be on the order of 300 to 500 meters deep (Williamson, 1979) and encompass an area of 33, 500 square km (Garber et al., 1989). The Hovey Channel at the southern portion of the Delaware Basin or possibly the Diablo Channel in the southwest of the basin connected it to the more open oceanic areas (Hill, 1999; Kirkland, 2000). The Delaware Basin is rimmed by a narrow carbonate belt that runs 600-700 km along the ancient shelf margin adjacent to and surrounding the major part of the basin. This belt is formed by the Capitan Reef Complex and crops out in the Guadalupe, Glass, and Apache mountains; elsewhere the reef is in the subsurface (Garber et al., 1989) (Figure 1.4).

During Permian time this belt was an equatorial shelf margin environment where carbonate rock was deposited in a shallow sea as a result of buildups of calcareous algae, *Archaeolithoporella* (which could be an alga or an inorganic precipitate), phylloid algae, sponges such as *Tubiphytes* (problematic alga), bryozoans and other constituents such as foraminifers (King, 1948; Newell et al. 1953). Carbonate reefs aggraded and prograded basinward throughout Middle Permian time in response to sea level fluctuations along the shelf margin.

1.4.1 Upper Middle Permian (Upper Guadalupian)

Deep water of the Delaware Basin was surrounded by carbonate shoals located along the shelf margins during the Late Guadalupian (Koss, 1977). Strata of the Upper part of the

Guadalupian present in the Delaware Basin are characterized by the coeval basinal Bell Canyon Formation (forereef), shelf margin Capitan Limestone (reef) and the Seven Rivers, Yates and Tansill Formations (from oldest to youngest) (backreef) (Figure 1.5).

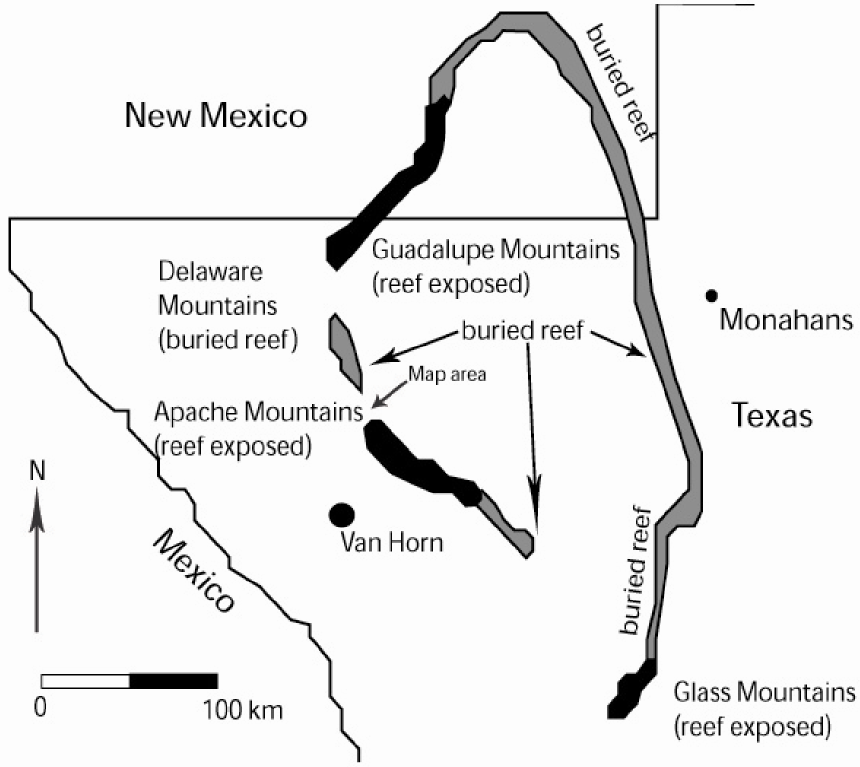


Figure 1.4. Map showing presently exposed and buried areas of the Capitan Reef Complex in west texas and New Mexico.

The Seven Rivers, Tansill, and Yates Formations formed along the continental shelf in a (backreef) lagoonal depositional environment composed of fine carbonate sand, algae, brachiopods, crinoids, and foraminifers. The Capitan Limestone formed along the shelf margin in a complex of fine carbonate mud and accumulations of algae, sponges, foraminifers, and bryozoans. Basinward of the Capitan Limestone, the Bell Canyon Formation consists mainly of subarkosic siltstone and fine-grained sandstone. In West Texas, in the Guadalupe Mountains area, the Bell Canyon Formation contains six distinct limestone members. From the base of the Bell Canyon Formation to the top (or from oldest to youngest) these members are the Hegler, Pinery, Rader, McCombs, Lamar and Reef Trail.

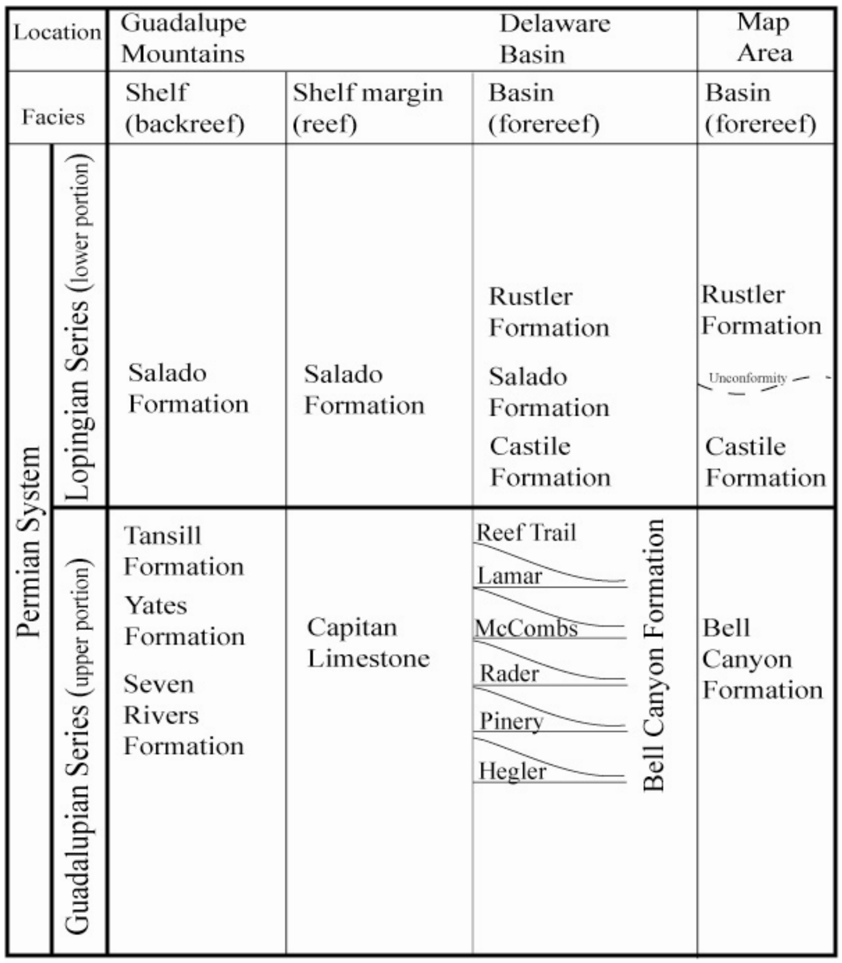


Figure 1.5. Permian lithologic units of the Guadalupe Mountains, Delaware Basin and the map area.

These forereef to basinal members have been used to correlate basinal strata with parts of the nearby reefal Capitan Limestone and corresponding backreef/shelf deposits (i.e., the Seven Rivers, Yates, and Tansill Formations) in the well studied Guadalupe Mountains region (King, 1948; Newell et al., 1953). The lower five basinal members, (excluding the Reef Trail Member), of the Bell Canyon Formation are composed of shallow water carbonate debris derived from the nearby Capitan Reef (Garber et al., 1989). Each of the lower five basinal members are wedge-shaped and as thick as 75 m near the shelf margin and thin to a few meters out in the deeper parts of the basin some 8-16 km basinward (Garber et al., 1989). Strata of the members often contain various fossil remains including brachiopods, algae, bryozoans, foraminifers and fusulinaceans. A particularly diagnostic large fusulinacean genus *Polydiexodina* is restricted to the Late Middle Permian (Middle Guadalupian) and occurs throughout the shelf margin and shelf deposits, but not above strata of the McCombs Member (and Yates Formation in massive Capitan strata). The fusulinacean *Yabeina texana* is likewise useful for determining the position of the Upper Guadalupian basal part of the Lamar Member of the Bell Canyon Formation (Nestell and Nestell, 2006a). Overlying the Lamar Member is the recently established Reef Trail Member (Wilde et al., 1999), the uppermost member of the Bell Canyon Formation in the Guadalupe Mountains. This member, containing siliciclastic and limestone intervals along with some debris flows, was described by King (1948) as the “post-Lamar beds” of the Bell Canyon Formation. Occurrence of the fusulinacean *Paraboultonia splendens* marks the lowermost extent of the Reef Trail Member.

1.4.2 Upper Permian (Lopingian)

A fall in sea level during Early Lopingian time combined with the Capitan Reef nearly encircling the Delaware Basin probably cut-off the basin’s circulation with open oceanic waters via the Hovey Channel (or possibly a channel to the southwest called the Diablo Channel (Hill, 1999) (Kirkland et al., 2000)). These changes in sea level and water circulation coupled with what was probably a very arid and hot environment at the time caused the salinity of the surface water in the Delaware Basin to become several times greater than that of the Middle Permian (Kirkland et al., 2000). Evaporitic precipitation began and deposited approximately one meter of laminated aragonitic mud in the map area during earliest Lopingian time. The aragonitic mud altered post-depositionally to the laminated limestone deposits that form the basal portion of the Castile Formation in the map area (Figure 1.6).

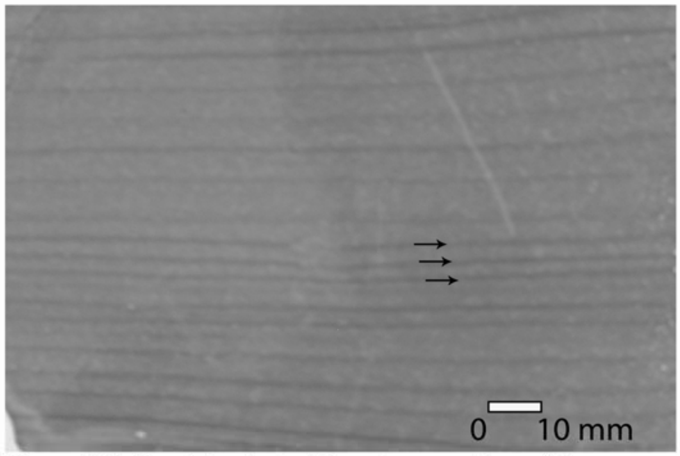


Figure 1.6. Basal laminated limestone portion of the Castile Formation. Arrows highlight darker laminations.

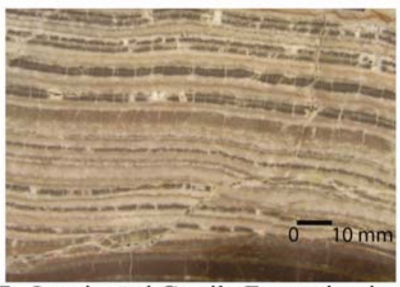


Figure 1.7. Laminated Castile Formation in the map area.

The laminated limestone is followed by younger, approximately one mm thick alterations of dark calcite and lighter colored anhydrite (as well as salt such as halite) repeating for approximately 45 m in the map area (Figure 1.7). In other places in the region, the Castile Formation reached a maximum thickness of 640 m (Kirkland et al., 2000). Capping the most prominent hills of the western and central portions of the map area, the Lopingian Rustler Formation unconformably overlies the Castile Formation. The Rustler Formation probably formed during similar conditions as that of the Castile Formation as suggested by fragmented evaporites of the basal Rustler Formation in the map area. Slight differences such as the presence of silt in the upper portions of the Rustler Formation may indicate a possible breech in the reef (Snider, 1955). In the map area, yellowish-brown dolomitic limestone with poorly sorted clasts that range in size from pebbles to cobbles dominate the majority of the strata of the Rustler Formation. Very finely bedded, dark brown colored intervals of subarkosic to arkosic sandstone is also present in the Rustler Formation.

1.5 Tectonic Setting

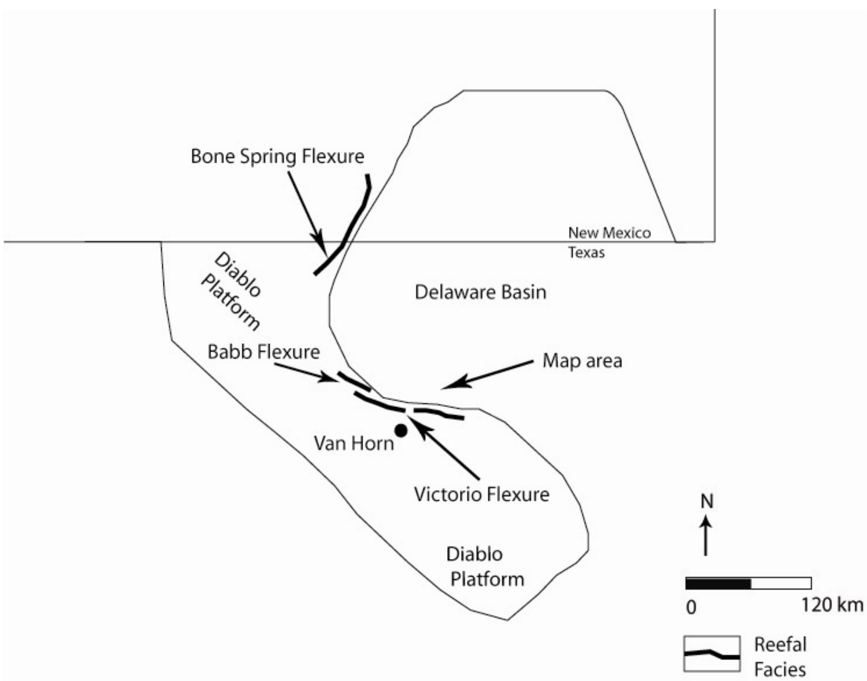


Figure 1.8. Approximate locations of Bone Spring, Babb and Victorio flexures along the Delaware Basin margin. Trend and location of selected Middle Permian reefal facies are shown with thicker lines (modified from King, 1948 and Ward et al., 1986).

Permian flexures such as the Bone Spring, Babb and Victorio formed during a period of regional subsidence (Figure 1.8). These monoclinal flexures developed along the subsiding basin margins effectively flexing strata downward, toward the center of the basin (King, 1948). The Delaware Basin deepened as reefs located along its margins grew upward and sediment accumulated along the basin margins (King, 1948). Ancient reef tracts located along and approximately parallel to flexures are common along the Delaware Basin margin (Figure 1.8). For example, the northeast trending Bone Spring flexure is overlain by northeast trending Goat Seep and Capitan reefs (King, 1948). In the Apache Mountains, a west-northwest trending reef zone of Capitan Limestone marks a likewise west-northwest trending monoclinal flexure, flexing strata downward toward the deeper Delaware Basin. The continuous regional subsidence allowed the accumulation of between 2,000 and 4,000 meters of Guadalupian and Lopingian terrigenous clastic, carbonate and evaporite strata to accumulate as the Delaware Basin deepened (McKee et al., 1967). Little structural deformation or deposition took place in the region during the Mesozoic (King, 1948).

Tertiary Basin and Range block faulting splintered the region into a complex system of uplifted and extensional faulted blocks. During Tertiary time the major mountain ranges (Guadalupe, Apache and Delaware) and their associated structural units in the region were uplifted to their present height (Wood, 1965). This uplift, known as the Delaware uplift, elevated a north-northwestward trending crustal block containing the Guadalupe, Delaware, and Apache mountains. This uplifted block is known as the Guadalupe-Delaware fault block (Wood, 1965). The western margin of the Guadalupe-Delaware fault block was uplifted extensively resulting in a 16 km wide belt of numerous, closely spaced, north-northwest trending high angle normal faults (known in the Guadalupe Mountains region as the Border Fault zone) (King, 1948).

This belt of faults stretches from the Brokeoff Mountains in southeast New Mexico, along the Delaware Mountain trend, to just north of the Apache Mountains in West Texas (King, 1948) (Figure 1.9). The uplift and associated extensional tension downfaulted strata to the west along the western basin margin and slightly tilted the Guadalupe-Delaware fault block as a whole toward the east (King, 1948).

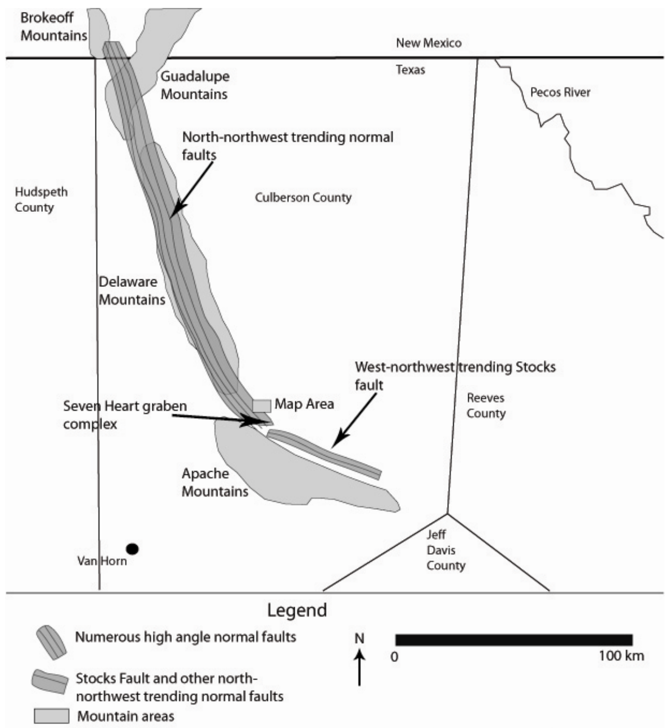


Figure 1.9. Geographic locations of Brokeoff, Guadaulupe, Delaware and Apache mountains relative to major normal fault trends (modified from King, 1949).

Numerous minor north-northwest trending faults break-up the western margin of the uplifted fault block (Figure 1.9). Displacement along faults is generally less than 1,200 m (King, 1948). North-northwest trending normal faults near the map area generally have displacements less than 135 m and are related to faulting forming the Border fault zone in the Guadalupe Mountains (Owen, 1951). The Seven Heart Graben Complex and the west-northwest trending Stocks fault separate the map area and the Guadalupe-Delaware fault block from that part of the Delaware uplift in the Apache Mountains, southeast of the map area (Figure 1.9). The Stocks fault does not extend into the Seven Heart Graben Complex (Owen, 1951; Wood, 1965). The west-northwest trending Stocks fault forms the northeastern boundary of the Apache Mountains and downthrows transitional basin-margin facies on the north side of the fault in the vicinity of the map area (Wood, 1965).

1.5.1 General Tectonic Setting of the Seven Heart Gap Area

The Seven Heart Graben Complex lies some 10 km to the southeast of the map area and vaguely divides the Apache Mountains to the southeast from the Delaware Mountains to the northwest. Wood (1965) studied the Seven Heart Graben Complex which is geographically the closest recently studied structural feature to the map area. This north-northwest trending Graben Complex is bound on the north by a northeast trending normal fault and displaces strata downward to the north. The Graben Complex is loosely bound on the south by west-northwest trending normal faults and on the southwest by north-northwest faults. The major north-northwest trending normal faults of the Seven Heart Graben Complex appear to be spaced a little over one km between each fault. Faults in the map area are normal with fault planes vertical or almost vertical, and trend approximately north-northwest or west-northwest. Major faults in the map area generally displace the Castile and Rustler Formations so that they are in contact with the Bell Canyon Formation.

CHAPTER 2

STRATIGRAPHY

2.1 Introduction

Basinal and forereef strata of Middle Permian Bell Canyon and Late Permian Castile and Rustler age in and around the map area in the Apache Mountains are similar to lithofacies found in basinal and forereef coeval strata and well documented in the nearby Guadalupe Mountains region to the north and northeast. Although the lithofacies of strata exposed in the map area are not precisely the same as in the Guadalupe Mountains, there are similarities that include interbedded siltstone/limestone intervals separated by debris flows or turbidites of varying thickness. The fossil content (foraminifers, radiolarians, and conodonts) of Bell Canyon age strata in the Apache Mountains provides fairly firm age correlation between the two areas and some Bell Canyon member names defined in the Guadalupe Mountains (such as Rader and Lamar) have been used in the Apache Mountains by previous authors (McNutt, 1948; DeFord et al., 1951; Owen, 1951; Newell et al., 1953; Skinner and Wilde, 1954; Snider, 1955; Wood, 1965; Lambert et al., 2002). One of the goals of this project was to map "packages" of similar lithofacies in order to ascertain possible usage of Bell Canyon member names in the Apache Mountains.

Some of the six members within the Bell Canyon Formation can be clearly correlated biostratigraphically based on conodonts (Lambert et al., 2002) from their respective type localities in the Guadalupe Mountains region to the Late Guadalupian age basinal and forereef deposits in the map area (Table 2.1 and Figure 2.1).

Table 2.1. Information including age, origional author(s) and type locality locations for the six members of the Bell Canyon Formation (Guadalupian). Information is quoted or paraphrased from Lys et al., (1976).

[1] “Reference to unpublished manuscript naming Rader Limestone as a unit of the Delaware Mountain Group.”

MEMBER NAME	HEGLER	PINERY	RADER	MCCOMBS	LAMAR	REEF TRAIL
AGE	Late Guadalupian					
RELATIVE AGE	(OLDEST)	→	→	→	→	(YOUNGEST)
ORIGIONAL AUTHOR(S)	King (1948)	King (1942)	King in Miller and Furnish (1940)[1]	Newell et al., (1953)	Lang (1937)	Wilde et al., (1999)
TYPE LOCALITY	“East of Rader Ridge, near the Hegler Ranch”	Slope above spring at Pine Spring, four km east of Guadalupe Peak, Northwest Culberson County, Texas	Located at Rader Ridge approximately 9.7 km east-northeast of Guadalupe Peak in northwest Culberson County, Texas	“McCombs Ranch, approximately 9.7 km northeast of Guadalupe Peak in northwest Culberson County, Texas”	“Escarpment north of Lamar Canyon where the canyon is crossed by the El Paso Natural Gas pipeline”	Exposures on a hillside near the Permian Reef Geology Trail, northeast of the mouth of McKittrick Canyon, Guadalupe Mountains National Park, Texas

Another goal of this project was to attempt to establish a chronological order of Late Guadalupian age lithofacies that are exposed and structurally complicated by faulting in the map area. Eight successive road-cuts are present on Texas FM 2185 (that forms the east-southeast boundary of the map area) of which six expose Bell Canyon (Late Guadalupian) age strata. Two of these road-cuts expose (M and E-F sections) the transition from Latest Guadalupian to Earliest Lopingian age strata. In this work, strata in these road-cuts are described and assigned a letter or letters (Figure 2.2). The two road-cuts that are not named expose strata of the Rustler Formation. A generalized measured section, divided into packages of similar lithologies, is given below for each named road-cut along Texas FM 2185. These sections provide a framework for correlation to similar age strata in the map area. Several Bell Canyon age subaqueous gravity flows (debris flows or turbidites) occur throughout the map area. Process based interpretations were only made for one major, thick, subaqueous gravity flow in the lower portion of the B-section (Figure 2.3).

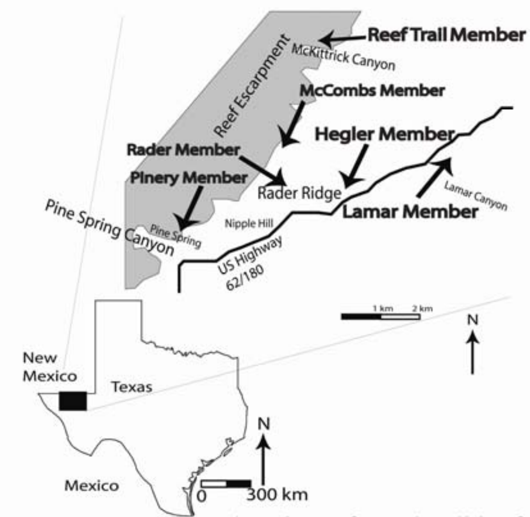


Figure 2.1. Approximate locations of type localities for the six members of the Bell Canyon Formation in and around the Guadalupe Mountains of West Texas, U.S.A.

All strata considered as being “debris flows” or “turbidites” occurring in the designated road-cuts will herein be termed “gravites” after Gani (2004) to avoid using process based terminology where analysis has not been undertaken. The gravite forming a large portion of the lower part of the B-section road-cut is herein termed a densite after Gani (2004) for a deposit that has characteristics in its lower portion of a debris flow and characteristics of a turbidite in its upper part.

2.2 Bell Canyon Formation B, A, G, E-F and M-Sections

2.2.1 B-Section

The oldest portion of the Bell Canyon Formation exposed along Texas FM 2185 occurs in the lowermost part of the B-section road-cut, approximately 2.75 km from the southwestern boundary of the map area. The series of road-cuts begins with the topographically lower B-section (southeast side of the road in a gulley) and continues up section through the A and G-sections as one proceeds northeast along Texas FM 2185 (Figure 2.2).

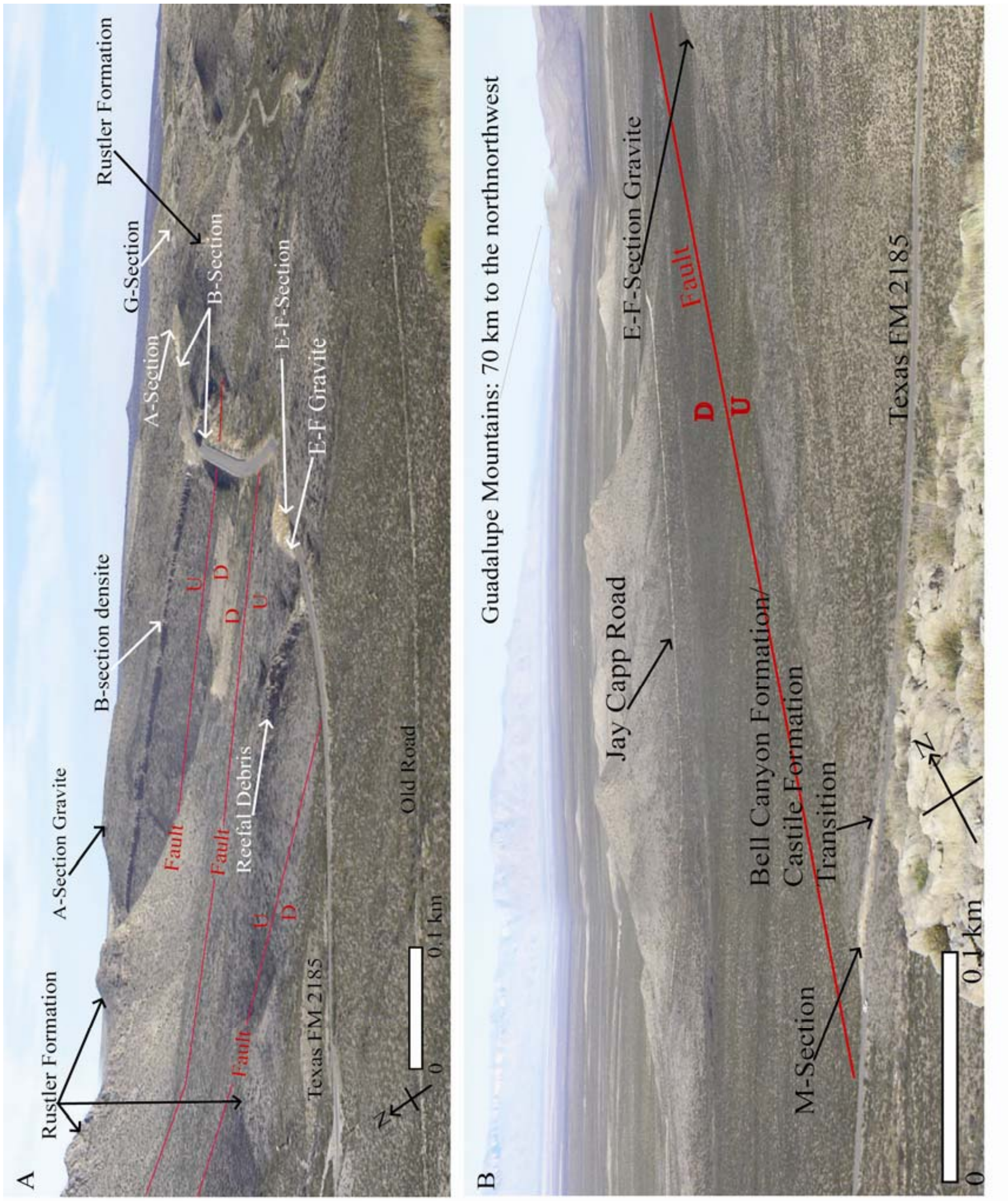


Figure 2.2. (A) Panoramic view looking northeast. E-F, B, A and G-sections labeled along with gravites (if visable). (B) Panoramic view looking northwest. M-section labeled as well as E-F gravite. Faults labeled with relative displacement shown as U=up and D=down.

The B, A, and G-sections are composed of basinal facies that are periodically interrupted by gravites composed of more shallow water, forereef and reefal facies (Figure 2.3).

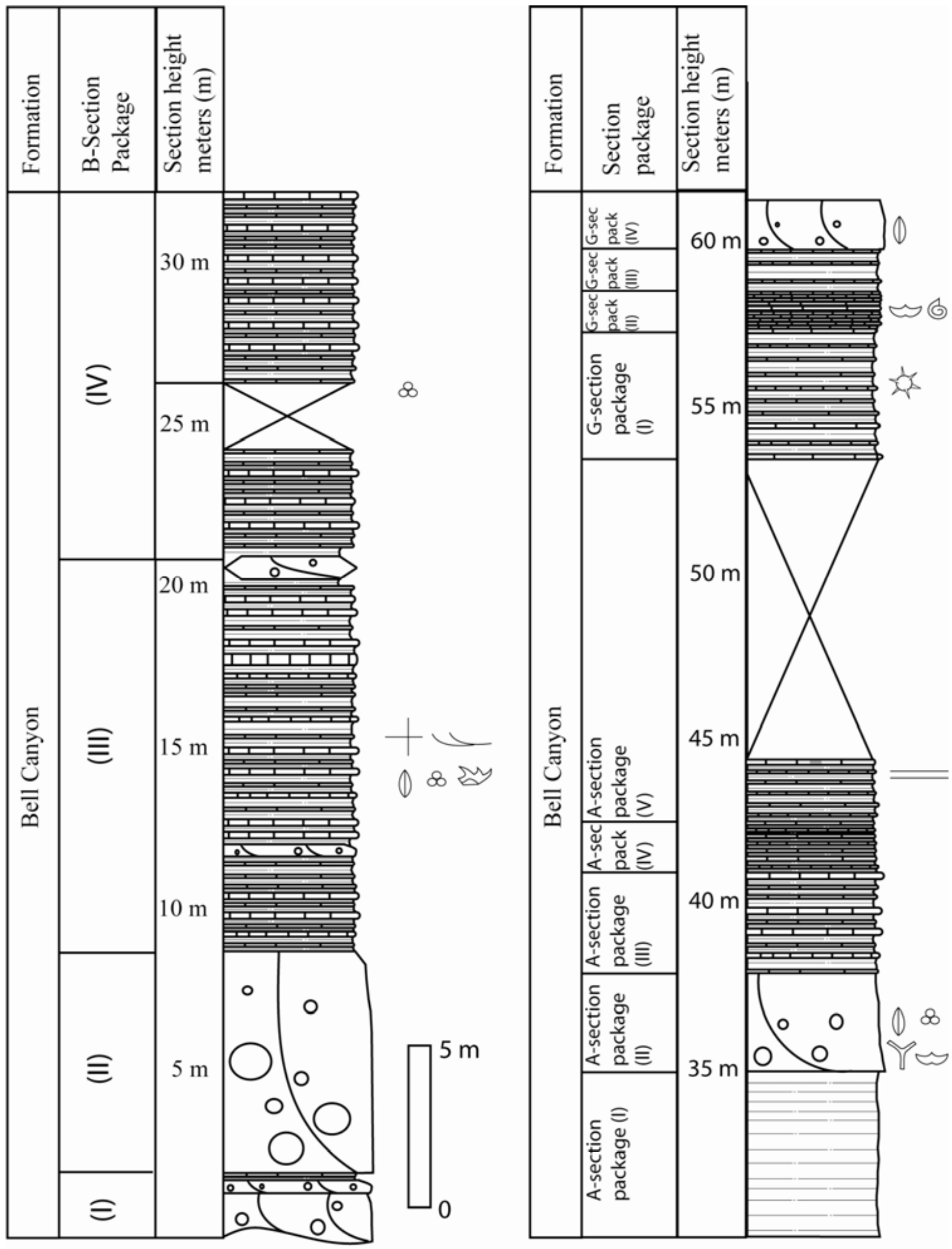


Figure 2.3. B, A and G-sections measured in road-cuts along Texas FM 2185. The B, A and G-section strata are divided into packages (sections modified after Nestell et al., 2006c). Paleontological symbols are given for each package. Paleontological and lithologic symbols are displayed on Figure 2.8.

The B-section itself is 33 m thick. Package (I) of the B-section road-cut exposes a few meters of medium to thickly bedded gravites overlain by a densite (Figure 2.3). The densite is overlain by approximately 17 m of thin to thickly bedded limestone interbedded with thin bedded brown siltstone. Within package (III) of the B-section are very thin beds of gypsum that occur interbedded with brown siltstone (Figure 2.3). Some limestone beds, approximately 11 m from the top of the densite in the B-section package (III) have well developed asymmetric ripples (Figure 2.3). Abundant fossils in the B-section include radiolarians, small foraminifers and the fusulinacean genus *Polydiexodina* (Figure 2.3). A conodont identified as *Jinogondolella* "*granti*" Mei and Wardlaw of latest Wordian age occurs in the upper portion of the B-section making this section at least in part biostratigraphically equivalent to the Hegler or Pinery members of the Bell Canyon Formation in the Guadalupe Mountain region (Lambert et al., 2002). However, this identification has recently come into question and the conodont assemblage present is currently being studied by Wardlaw and Nestell (personal communication, 2007), but they consider that the Hegler/Pinery call is still correct.

2.2.1.1 B-Section Package (I)

The base of the B-section (base of B-section package (I)) is exposed on the north side of the southwestern part of the B-section road-cut where between two and four meters of very thickly bedded gravites occur interbedded with minor amounts of brown siltstone and medium-bedded limestone (Figure 2.3). Thickness measurements vary from location to location in the B-section package (I) because of the lenticular shape of the gravites. Gravites exposed in the B-section package (I) are composed of a lower portion of pebble-sized clasts and typically grade upward into fine packstone or wackestone. The lowermost part of the gravite in the B-section package (I) contains small cobble-sized clasts and likewise grades into a packstone near its top.

2.2.1.2 B-Section Package (II)

The B-section package (I) is overlain by a massive 6.7 m thick densite forming B-section package (II). This densite is mapped as the primary B-section gravite by using a black line on Map I (Appendix) and will be discussed in detail in the following chapter of this work.

2.2.1.3 B-Section Package (III)

Above the densite, and forming the majority of B-section package (III) is approximately 12.3 m of thin to medium-bedded carbonate mudstone and wackestone interbedded with brown siltstone (Figure 2.3). Approximately three meters above the densite is a small gravite that is less than one meter thick. It grades from a coarse carbonate breccia at its base to a carbonate mudstone near its top. Another gravite, approximately 0.8 m thick with an undulating base occurs approximately 11.5 m from the top of the densite. This gravite is composed of a basal carbonate breccia with subrounded pebble to cobble sized clasts of limestone and some brown siltstone (Figure 2.4). The middle portion of the gravite grades into a packstone. The upper twenty centimeters of the gravite contain scattered light gray subrounded limestone cobbles (Figure 2.4 (B)). Above this, the gravite grades into a packstone with abundant small foraminifers and the fusulinacean genus *Polydiexodina*. When traced laterally to the east and west this gravite pinches out completely (Figure 2.4 (A)).

2.2.1.4 B-Section Package (IV)

The B-section package (IV) is 12 m thick, includes two meters of covered section, and is composed of a sequence of thin to very thinly-bedded light brown siltstone alternating with thin to medium-bedded limestone (Figure 2.3).

Figure 2.4. Photographs taken of north wall of B-section road-cut along Texas FM 2185. (A) Lens shapped gravite forming top of B-section package (III). (B) Upper portion of gravite pictured above with large light gray limestone clasts in the upper 20 cm.

Wackestone in lower portions of B-section package (IV) contain abundant small foraminifers and occasional pelloids. A carbonate mudstone contains small ammonoids approximately 2.5 m from the base of B-section package (IV).

2.2.2 A-Section

The basal portion of the 14.5 m thick A-section overlies the B-section and is composed of approximately five meters of light brown, poorly indurated, nodular siltstone (Figure 2.3). A three meter thick gravite comprises A-section package (II) (the

A-section gravite) overlies the light brown nodular siltstone. This gravite has abundant brachiopods, bryozoans, fusulinaceans, and small foraminifers. Clasts in the A-section gravite range in size from pebble to cobble at the base and the unit grades into a packstone in the top half meter. Above the A-section gravite is approximately 6.5 m of thin bedded limestone interbedded with varying amounts of brown siltstone. Some of the limestone beds contain abundant fusulinaceans such as *Polydiexodina*.

2.2.2.1 A-Section Package (I)

Five meters of light brown, poorly indurated nodular siltstone with calcite cement lie at the base of the A-section. These siltstones show visible layering in some places and not in others. This five meter interval of light brown siltstone can be recognized throughout the map area below the A-section gravite.

2.2.2.2 A-Section Package (II)

The A-section package (II) consists of the A-section gravite. This 3 meter thick gravite is mapped and generally crops out above the B-section densite. Its lower portions are composed of pebble to cobble sized clasts, the unit grades into a packstone in the upper 50 cm. Clasts within the gravite are rounded to subrounded. Cobble sized wackestone clasts next to smaller clasts with bryozoans and easily recognizable brachiopods are characteristic of the base of the A-section gravite (Figure 2.5). The fusulinacean *Polydiexodina* is a very abundant constituent of both the clasts in the lower portions of the gravite as well as the packstone in its upper portion. The lower and middle portions of the A-section gravite often contain sparry calcite cementing smaller clasts together. This is a unique feature of the A-section gravite and serves as a diagnostic property used to identify it in the map area.

2.2.2.3 A-Section Package (III)

Above the A-section gravite is three meters of thin bedded limestone interbedded with brown siltstone.

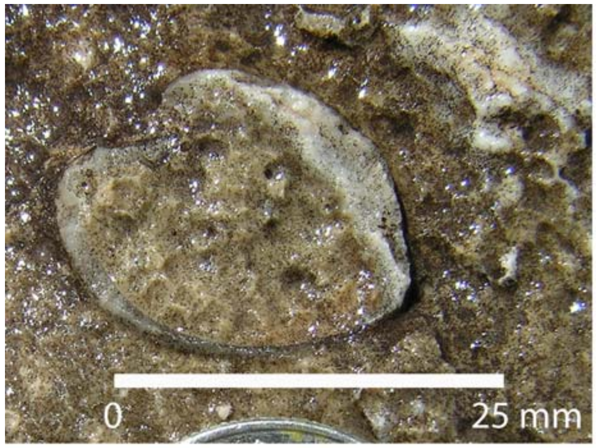


Figure 2.5. Brachiopod shell within A-section package (II) or "A-section gravite." Geopetal structure indicates up direction that is almost opposite to the present up direction.

2.2.2.4 A-Section Package (IV)

A 1.5 m thick sequence of thin bedded carbonate mudstone interbedded with very minor amounts of brown siltstone overly package (III) in the A-section.

2.2.2.5 A-Section Package (V)

Approximately 1.75 m of thin bedded carbonate mudstone interbedded with brown siltstone occurs at the top of the A-section. In places the carbonate mudstone is laminated. Approximately nine meters of covered section lie between the A and G-sections.

2.2.3 G-Section

The G-section is a 7.5 meter thick sequence of very thin to thin bedded carbonate mudstone interbedded with varying amounts of brown siltstone (Figure 2.3).

Approximately nine meters of covered section lie between the stratigraphically lower A-section and the stratigraphically higher G-section. The carbonate in the G-section contains radiolarians, small brachiopods and foraminifers such as *Polydiexodina*. The G-section is capped by the G-section gravite which is mapped using a white line on Map I (Appendix) and can also be traced to the east of the map area. The G-section gravite is approximately 1.5 m thick with clasts ranging in size from large cobble to pebble. The upper portions of the gravite contain limestone blocks with very abundant *Polydiexodina* fusulinaceans reminiscent of the "Rader slide" in the Guadalupe Mountain region (Nestell et al., 2006b). The strata of the G-section are possibly equivalent in age to the strata of the McCombs Member of the Bell Canyon Formation in the Guadalupe Mountain region. Approximately 55 meters of the Bell Canyon Formation is present on a hill to the northeast of the G-section (outside of the map area) on the east side of FM 2185. Lithostratigraphic correlation between the portion of the Bell Canyon Formation occurring above the G-section and the lowermost portion of the youngest part of the Bell Canyon Formation (E-F-Section) along Texas FM 2185 is not possible because the section is not complete or continuous. Biostratigraphic correlation based on conodonts places the portion of the Bell Canyon Formation occurring above the G-section beneath the basal part of the E-F-section. Precisely how this correlation works is yet an open problem and is presently being investigated (Nestell and Nestell, personal communication, 2007).

2.2.3.1 G-Section Package (I)

Package (I) of the lowermost G-section is composed of 3.75 m of thin bedded laminated carbonate mudstone interbedded with brown siltstone. Carbonate mudstone in package (I) contains radiolarians.

2.2.3.2 G-Section Package (II)

Above package (I) of the G-section is approximately one meter of thin to very thinly bedded laminated carbonate mudstone. This carbonate mudstone is interbedded with very thin beds of brown siltstone, and contains small brachiopods and ammonoids (Pseudogastrioceratidae) (Figure 2.6).

Figure 2.6. Small ammonoid in G-section package (II).

2.2.3.3 G-Section Package (III)

Package (III) contains 1.25 m of mostly brown siltstone interbedded with thin to very thin beds of carbonate mudstone. Limestone beds in package (III) pinch and swell laterally.

2.2.3.4 G-Section Package (IV)

The 1.5 m thick G-section gravite grades from large cobble to pebble sized clasts near its base. Large packstone blocks containing abundant *Polydiexodina* fusulinaceans are present.

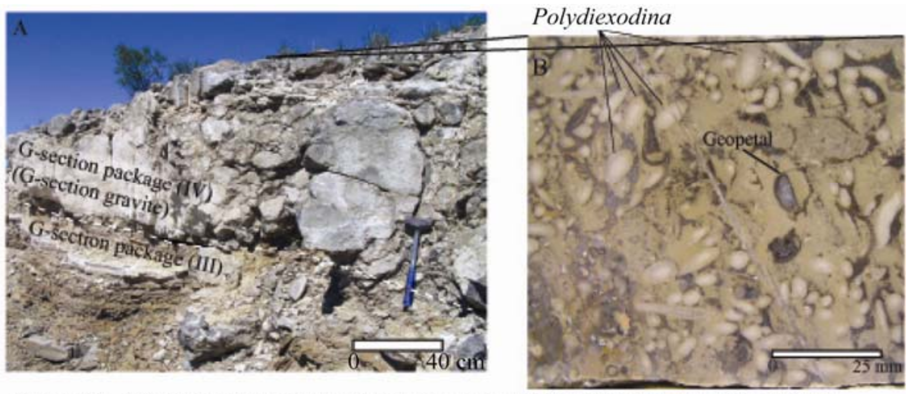


Figure 2.7. (A) White stippled line shown above divides G-section package (III) from G-section package (IV). Large cobble and boulder sized clasts are clearly visable in the G-section gravite. (B) A few of the very abundant fusulinacean genus *Polydiexodina* from upper portions of the G-section gravite shown above. Geopetal structure indicates a paleo up direction that differs from the present up direction.

The very abundant *Polydiexodina* fusulinaceans are a diagnostic feature of this gravite making it possible to accurately trace it laterally (Figure 2.7).

2.2.4 E-F-Section

The E-F-section is a 25.9 m thick sequence of basinal facies exposed in a road-cut approximately 1.2 km from the southwest corner of the map area along Texas FM 2185 (Figures 2.2 and 2.8). This section on the northwest end of the road-cut exposes the transition from the uppermost strata of the Bell Canyon Formation (Guadalupian) to the lowermost strata of the Castile Formation (Lopingian). The transition zone is a mappable package (E-F-section package (VIII)), approximately one meter thick with the basal unit a thickly bedded, laminated limestone and below the typical looking strata of the Castile Formation. The transition zone also has a diagnostic pinkish, thin bed of limestone containing scarce specimens of the conodont *Clarkina postbitteri hongshuiensis*

Henderson, Mei, and Wardlaw (Nestell et al., 2007) that is capped by another laminated limestone. The transition zone is mapped with a pink color on Map I (Appendix).

The lower portion of the E-F-section exposes over 13 meters (E-F-section packages (I-III) of a fining upward gravite. The unit is mapped as the E-F-section gravite using a light yellow color on Map I (Appendix) and contains limestone clasts within it as large as 10 cm across as well as one exceptionally large block exposed on the south wall of the west end of the road-cut at road level that is 1.4 m thick and approximately two meters in length. This block consists of thin beds of limestone and brown siltstone. A few of these limestone beds contain radiolarians, small foraminifers and conodonts such as *Jinogondolella altudaensis* and *Jinogondolella xuanhanensis* Mei and Wardlaw (Lambert et al., 2002). These conodont species indicate that the block contained in the gravite located along the southwest side of the E-F-section is equivalent in age to the Lamar Limestone Member of the Bell Canyon Formation in the Guadalupe Mountain region. Clasts within the E-F-section gravite contain fusulinacean genera such as *Polydiexodina*, *Paraboultonia*, and *Codonofusiella*. All strata occurring in the map area below the E-F-section gravite but above the strata above the G-section is mapped using a light shade of green on Map I (Appendix). Toward the uppermost portion of the E-F-section, 25 m from the base of the section, the E-F-section package (VI) contains the fusulinacean *Paraboultonia splendens* and is therefore equivalent in age to the Reef Trail Member of the Bell Canyon Formation in the Guadalupe Mountain region (Nestell et al., 2006c). The Reef Trail Member is Late Capitanian (Late Guadalupian). The E-F-section packages (IV-VII) are mapped as the Upper Bell Canyon Formation using a dark green color on Map I.

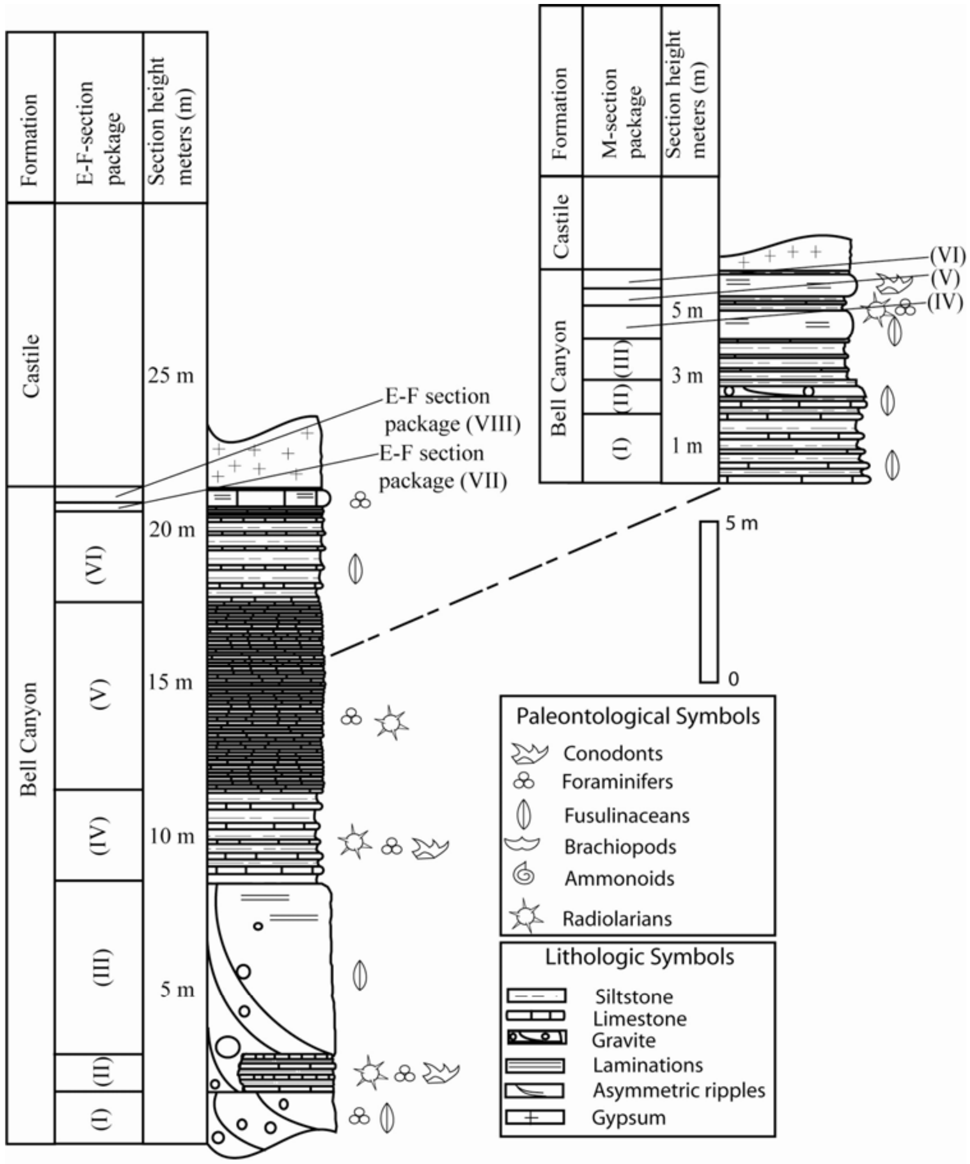


Figure 2.8. E-F and M-sections measured in road-cuts along Texas FM 2185. The M-section is equivalent to the upper portion of the E-F-section. Paleontological symbols are given for each package (Packages modified after Lambert et al., 2002; Nestell et al., 2006c).

2.2.4.1 E-F-Section Package (I)

A 1.8 meter thick gravite deposit forms the base of the southwest end of the E-F-section (Figure 2.9). This gravite is composed of pebble and less common small cobble sized carbonate clasts containing fusulinaceans and small foraminifers.

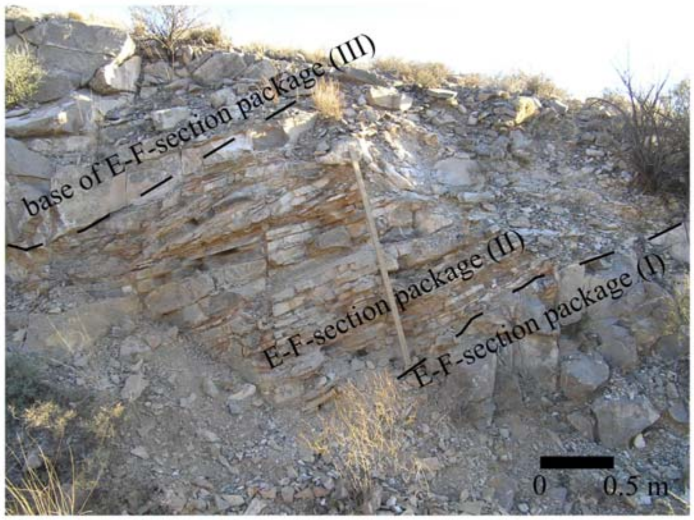


Figure 2.9. Picture taken of the south wall of the western part of the E-F-section road-cut along Texas FM 2185. E-F-section packages (I), (II) and (III) are labeled above. E-F-section package (II) is equivalent in age to the Lamar Member of the Bell Canyon Formation in the Guadalupe Mountain region.

2.2.4.2 E-F-Section Package (II)

The bottom of a 1.4 m thick block of thin bedded limestone interbedded with brown siltstone abruptly contacts the top of E-F-package (I) (Figure 2.9). Limestone from the E-F-section package (II) contains radiolarians, small foraminifers and conodonts such as *Jinogondolella altudaensis* and *Jinogondolella xuanhanensis* Mei and Wardlaw (Lambert et al., 2002). The E-F-section package (II) dips toward the northeast at a steeper angle (by ten degrees) than the 12.7 meters of interbedded, layered limestone and siltstone above it in the E-F-section. The difference in dip angle of E-F-section package (II) to the dip angle of the rest of the E-F-section as well as the abrupt contact between the underlying E-F-section package (I) and E-F-section package (III) suggest that E-F-section package (II) was ripped-up and incorporated into the gravite comprising the surrounding E-F-section packages (I) and (III) during its formation. However, due to the small size of E-F-section package (II), poor exposure on both the north and south side of

Texas FM 2185 in the E-F-section and faulting in the area it is difficult to conclusively interpret E-F-section package (II) as an incorporated block in a gravite. It may simply represent a period of "normal" basinal deposition sandwiched between gravites.

2.2.4.3 E-F-Section Package (III)

Package (III) is a five meter thick carbonate gravite. The graded gravite has large cobble to pebble sized fossiliferous limestone clasts in its base with less common clasts of brown siltstone, much like the siltstone in E-F-section package (II). Common fusulinaceans in limestone clasts include *Polydiexodina*, *Paraboultonia*, and *Codonofusiella* (Nestell et al., 2006c). The upper two meters of the gravite grade into a carbonate mudstone. Within the upper two meters of the gravite there is a laminated, very fine grained carbonate packstone that appears to be a carbonate mudstone. This laminated part of the section is overlain by a fine grained carbonate mudstone that conformably contacts the overlying basinal strata of E-F-section package (IV) (Figure 2.10).

2.2.4.4 E-F-Section Package (IV)

The E-F-section package (IV) is mostly brown siltstone with about five thin carbonate mudstone/wackestone beds. Package (IV) is 2.9 m thick and has a 15 cm thick characteristic limestone bed 40 cm from the top of the package that pinches and swells slightly where exposed in the E-F-section road-cut. These limestone beds contain radiolarians, small foraminifers, and conodonts *Jinogondolella altudaensis* and *J. xuanhanensis* (Nestell et al., 2006c).

2.2.4.5 E-F-Section Package (V)

E-F-section package (V) is 6.4 meters of thin to medium bedded carbonate wackestone with small foraminifers and radiolarians (Figure 2.11).

Figure 2.10. Laminations in the upper 1.7 meters of the E-F-section gravite.

This thick sequence of carbonate mudstone is mappable and forms characteristic gentle slopes of small gray rectangular carbonate mudstone rock fragments when traced laterally throughout the map area.

2.2.4.6 E-F-Section Package (VI)

E-F-section package (VI) is 2.5 meters thick. This package is composed of brown siltstone interbedded with thin beds of carbonate wackestone/packstone (Figure 2.11 and 2.12). A limestone bed at the base of the E-F-section package (VI) contains the fusulinacean *Paraboultonia splendens* Skinner and Wilde, which correlates with the Reef Trail Member of the Bell Canyon Formation in the region of the Guadalupe Mountains.

2.2.4.7 E-F-Section Package (VII)

Three limestone beds interbedded with about five centimeters of brown siltstone form the 0.3 m thick E-F-section package (VII).

Figure 2.11. North wall of E-F-section along Texas FM 2185. E-F-section packages (V-VIII) labeled above. E-F-section packages (VI, VII and VIII) are equivalent to the Reef Trail Member of the Bell Canyon Formation in the Guadalupe Mountains region.

The lowermost limestone bed is slightly laminated and contains *Paraboultonia splendens* Skinner and Wilde. The overlying limestone beds contain radiolarians and small foraminifers (Figure 2.12).

Figure 2.12. Top of the south wall of the E-F-section along Texas FM 2185. E-F-section packages (VI-VIII) are labeled above.

2.2.4.8 E-F-Section Package (VIII)

E-F-section package (VIII) is mapped as the transition between the underlying Bell Canyon Formation (Guadalupian) and overlying Castile Formation (Lopingian). The package itself is a 0.6 m thick dark gray laminated limestone and easily mappable on both sides of Texas FM 2185 (Figure 2.12). The diagnostic pinkish limestone part of E-F-section package (VIII) is exposed on the northwest side of Texas FM 2185 very near the E-F-section road-cut (Figure 2.8 and 2.13). Strata of the Castile Formation crops out further to the north and northeast of the E-F-section road-cut.

Figure 2.13. Pink limestone in uppermost E-F-section package (VIII). This pink limestone occurs just below strata of the Castile Formation.

2.2.5 M-Section

The M-section lies very near the southwest corner of the map area along Texas FM 2185 (Figure 2.2 B). The 6.35 m thick M-section is equivalent in age to the upper portions of package (V) and packages (VI-VIII) of the E-F-section (Figure 2.8). Lithologically, the M-section is very similar to the E-F-section and biostratigraphically they are very similar. The M-section is shown on Map I (Appendix) using the same colors as the E-F-section. Strata occurring above the E-F gravite are colored dark green and strata beneath the E-F gravite (E-F-section package III) are colored a lighter shade of green on Map I (Appendix) (Figure 2.8). Also on Map I (Appendix), the transition beds between the underlying Bell Canyon Formation and the Castile Formation are colored pink (Figure 2.13).

2.2.5.1 M-Section Package (I)

The base of the M-section package (I) is exposed at the southwest end of the M-section road-cut. The M-section package (I) is a two meter thick sequence of thin bedded carbonate wackestone interbedded with brown siltstone. Limestone within upper portions of M-section package (I) contain the fusulinacean *Paraboultonia splendens* Skinner and Wilde in several beds that appear to be miniature “debris flows” (Nestell et al., 2006c). M-section package (I) is equivalent in age to the upper portions of the E-F-section package (V) (Figure 2.8).

2.2.5.2 M-Section Package (II)

The M-section package (II) is a one meter thick sequence of thin to medium beds of limestone and brown siltstone. Approximately 30 cm from the top of M-section package (II) is a 40 cm thick graded gravite. This relatively thin gravite contains abundant *Paraboultonia splendens* Skinner and Wilde (Nestell et al., 2006c). Upper portions of this gravite are laminated.

2.2.5.3 M-Section Package (III)

The M-section package (III) is a 1.3 m sequence of alternating brown siltstone with very thin beds of carbonate mudstone. This package is lithologically very similar to package (VI) of the E-F-section.

2.2.5.4 M-Section Package (IV)

The M-section package (IV) is a 90 cm thick laminated limestone. The basal few centimeters of this limestone contain *Paraboultonia splendens* Skinner and Wilde (Nestell et al., 2006c) as does the basal part of package (VII) in the EF-section.

2.2.5.5 M-Section Package (V)

The M-section package (V) is approximately 45 cm of light brown siltstone with interbedded lenses of limestone. Some of these lenses thicken to as much as 30 cm and contain small foraminifers and radiolarians.

2.2.5.6 M-Section Package (VI)

The M-section package (VI) is 70 cm thick. This dark gray laminated limestone forms the top of the M-section. The diagnostic pink limestone with *Clarkina postbitteri hongshuiensis* Henderson, Mei and Wardlaw is exposed sporadically toward the north of the road-cut along the northwest-southeast trending low hills providing the relief for the road-cut.

2.2.6 Large Scale Reefal Debris

Sporadically throughout the map area, below the lowermost E-F and equivalent M-sections (mapped using a dark green color on Map I (Appendix)) are very thick accumulations of reefal debris (mapped using a dark blue color on Map I (Appendix)). Very large clasts of reefal debris occur along with typical clasts of the E-F-section gravite as discussed in section 2.2.4.3 of this work as a mix of both types of clasts (Figure 2.14). Due to this mix of reefal and more typical E-F-section gravite clasts, it is impossible to differentiate between the two for the purposes of establishing temporal constraints as far as which clast type came first during emplacement. In many places, reefal debris is not present, only the E-F-section gravite and the strata of the Bell Canyon Formation above and below. Reefal debris will be discussed more rigorously in chapter 4 of this work.

Figure 2.14. Point of pencil pointing to a block of reefal material (*Archaeolithoporella*). Handle end of hammer pointing at an outlined area of clasts typical within the E-F-section gravite regardless if reefal blocks are present or otherwise.

2.3 Bell Canyon Formation Correlated Sections

Two other sections of Bell Canyon Formation strata, other than the B, A, G, E-F and M-sections along Texas FM 2185 were chosen for measurement and description. These remote exposures were selected in order to create a more complete stratigraphic section in the map area by correlating these remote sections to the sections along Texas FM 2185. The oldest section measured occurs directly below the B-section on the east-southeast side of FM 2185 in a deep ravine. The other measured section occurs below the E-F-section gravite approximately 1.8 km north-northwest of the M-section and on private property.

2.3.1 Correlated Section below B-Section (BDB2)

A northeast-southwest trending drainage on the east-southeast side of FM 2185 and less than 50 m to the south of the B-section road-cut exposes another seven meters of the Bell Canyon Formation below those strata exposed in the B-section road-cut. The exposure of Bell Canyon Formation strata in the drainage is truncated at its base against a prominent fault trending almost perpendicular to Texas FM 2185. Down-dropped strata of the Castile Formation (Lopingian) to the south and west of the fault abuts against the lowermost strata of the Bell Canyon Formation (exposed immediately surrounding the map area) lying to the east-northeast in the drainage. The correlated section below the B-section (BDB2) is composed of mostly thin limestone interbedded with brown siltstone. Limestone beds thicken toward upper portions of BDB2 (Figure 2.15).

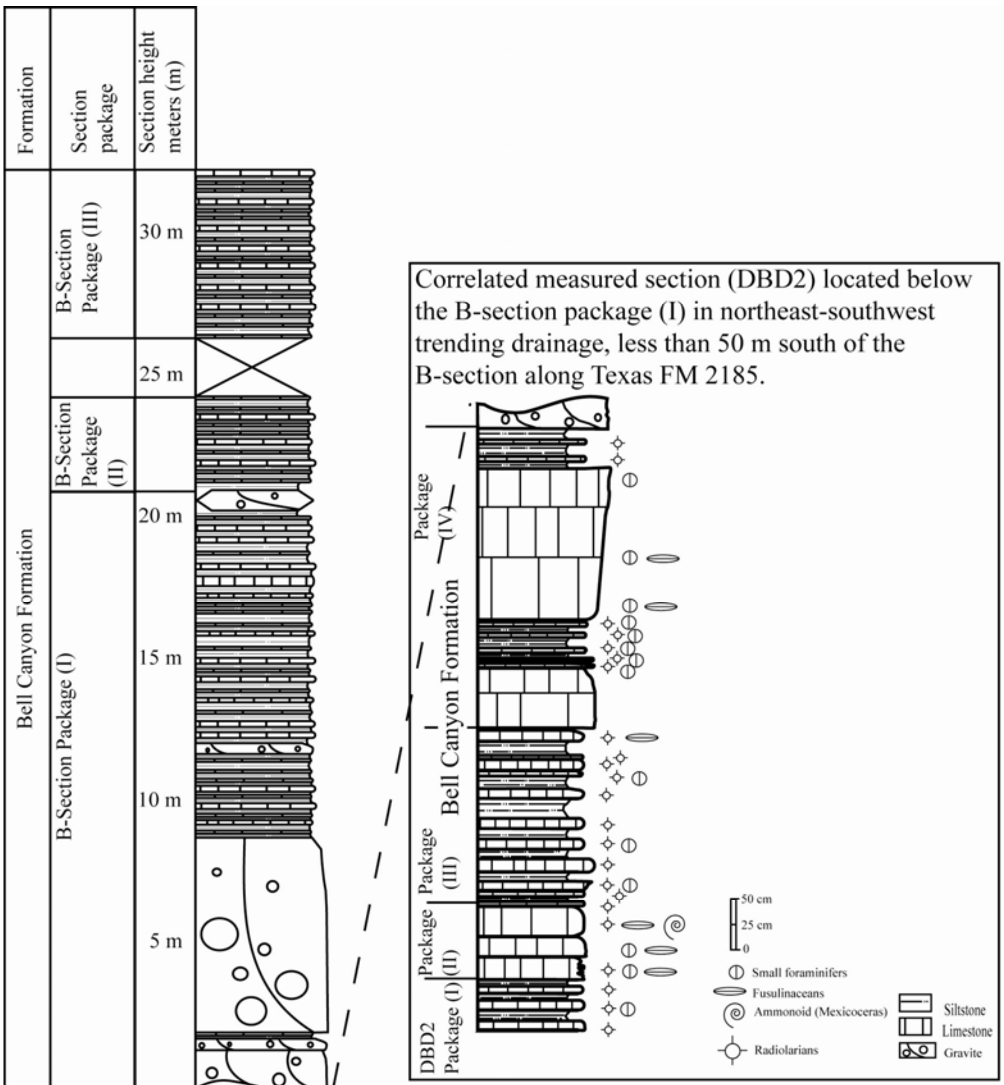


Figure 2.15. B-section measured in the road-cut along Texas FM 2185. Correlated section BDB2 contains ammonoid *Mexicoceras*.

Strata of BDB2 were divided into packages for organizational purposes. About a meter from the base of the exposure (and the fault) in the drainage is a relatively thick limestone bed in strata of the lowermost Bell Canyon Formation containing the large ammoniod *Mexicoceras (?).* Preliminary conodont analysis verifies that BDB2 is the oldest section in the immediate region of the map area. *Jinogondolella sp. A* of late Wordian age (Nestell and Wardlaw, personal communication, 2007) occurs in this section.

Another exposure (north of the north-central boundary of the map area) approximately 1.85 km north-northwest of the E-F-section along Texas FM 2185 does expose strata below the B-section (and underlying BDB2-section) along Texas FM 2185. This remote section contains strata older than that in the B-section (and is located well below the B-section densite) and consists of approximately 45 meters of light brown, poorly indurated siltstone interbedded with a few thin beds of silty limestone. This section is capped by a two or three meter thick carbonate breccia containing the fusulinacean *Polydiexodina.* A measured section made for this exposure was not included in this work because reliable biostratigraphic control using fossils other than conodonts was not possible at the time of writing.

2.3.1.1 Correlated Section below B-Section (BDB2-Package (I))

BDB2-package (I) is 0.75 meter thick (Figure 2.15). It consists of thinly bedded carbonate wackestone interbedded with brown siltstone. Carbonate packstone/wackestone in the BDB2-package (I) contain radiolarians, small foraminifers and fusulinaceans.

2.3.1.2 BDB2-Package (II)

BDB2-package (II) is 0.55 meter thick and consists of three thinly bedded limestone interbedded with minor amounts of brown siltstone. The carbonate packstone/wackestone contains radiolarians, small foraminifers and fusulinaceans. The uppermost limestone bed contains the ammonoid genus *Mexicoceras (?).*

2.3.1.3 BDB2-Package (III)

BDB2-package (III) is 1.87 meters thick and composed of thin bedded carbonate packstone/wackestone alternating with brown siltstone. Carbonate packstone/wackestone beds contain radiolarians and small foraminifers. The uppermost limestone bed in BDB2-package (III) contains radiolarians as well as fusulinaceans.

2.3.1.4 BDB2-Package (IV)

BDB2-package (IV) is three meters thick. Thin to medium bedded limestone interbedded with minor amounts of brown siltstone form the top portions of BDB2. Limestone beds in this package are thicker and vary from thin carbonate packstone/wackestone to coarse packstone with large fusulinaceans (*Polydiexodina*) and small foraminifers. Dark red chert stringers occur throughout the thickest limestone beds of BDB2-package (IV). Above BDB2-package (IV) are a few meters of gravites that pinch and swell beneath the main B-section gravite.

2.3.2 Correlated Section below E-F-Section Gravite (NMW)

An east-west trending drainage approximately 1.2 km from the M-section along Texas FM 2185 exposes 14 meters of basinal facies below the E-F-section gravite. This measured section, herein referred to as “NMW,” mainly consists of light brown, poorly indurated, very thinly bedded siltstone interbedded with occasional thin beds of limey siltstone and limestone (Figure 2.16). Strata of NMW-section were divided into packages for organizational purposes. Other places in the map area expose strata very similar to the strata of NMW-section but these localities do not have the thickness that the NMW-section provides. Exactly how the NMW-section correlates to the portion of the Bell Canyon Formation occurring above the G-section is not clear as conodont information is not yet available. Preliminary identification of the conodonts present in several beds of this section shows that *Jinogondolella postserrata* is present which puts this section biostratigraphically in the Pinery-Lamar interval in the Guadalupe Mountains equivalent age sections. The stratigraphic position immediately below thick gravites and large blocks of reefal debris equivalent to those in the very base of the E-F-section, suggests that this stratigraphic sequence is probably of Late Lamar age. Lithologically, the strata of the NMW-section are unlike any portion of the Bell Canyon Formation occurring above the G-section, other than the poorly indurated light brown siltstone, so a lithostratigraphic correlation is not possible at this time.

However, future analysis of radiolarians and conodonts may make biostratigraphic correlation of the NMW-section to strata above the G-section possible. At the NMW section there are 28 meters of reefal debris above the sandstone/siltstone interval mixed with typical debris of the E-F-section gravite as observed in the E-F-section along Texas FM 2185. This reefal debris section is 21 meters thicker than in the E-F-section gravite where the basal large blocks of reefal debris are not a component of the measurement thickness of the deposit. Six meters of strata of the upper part of the Bell Canyon Formation overly the debris portion of the section, and are roughly equivalent in age (based on conodonts) to strata in the upper part of the E-F-section and also to strata of the Reef Trail Member in the Guadalupe Mountains region. The sequence is also overlain by the Castile/Bell Canyon Formation transition zone (present in E-F-section package (VIII) and M-section package (VI)).

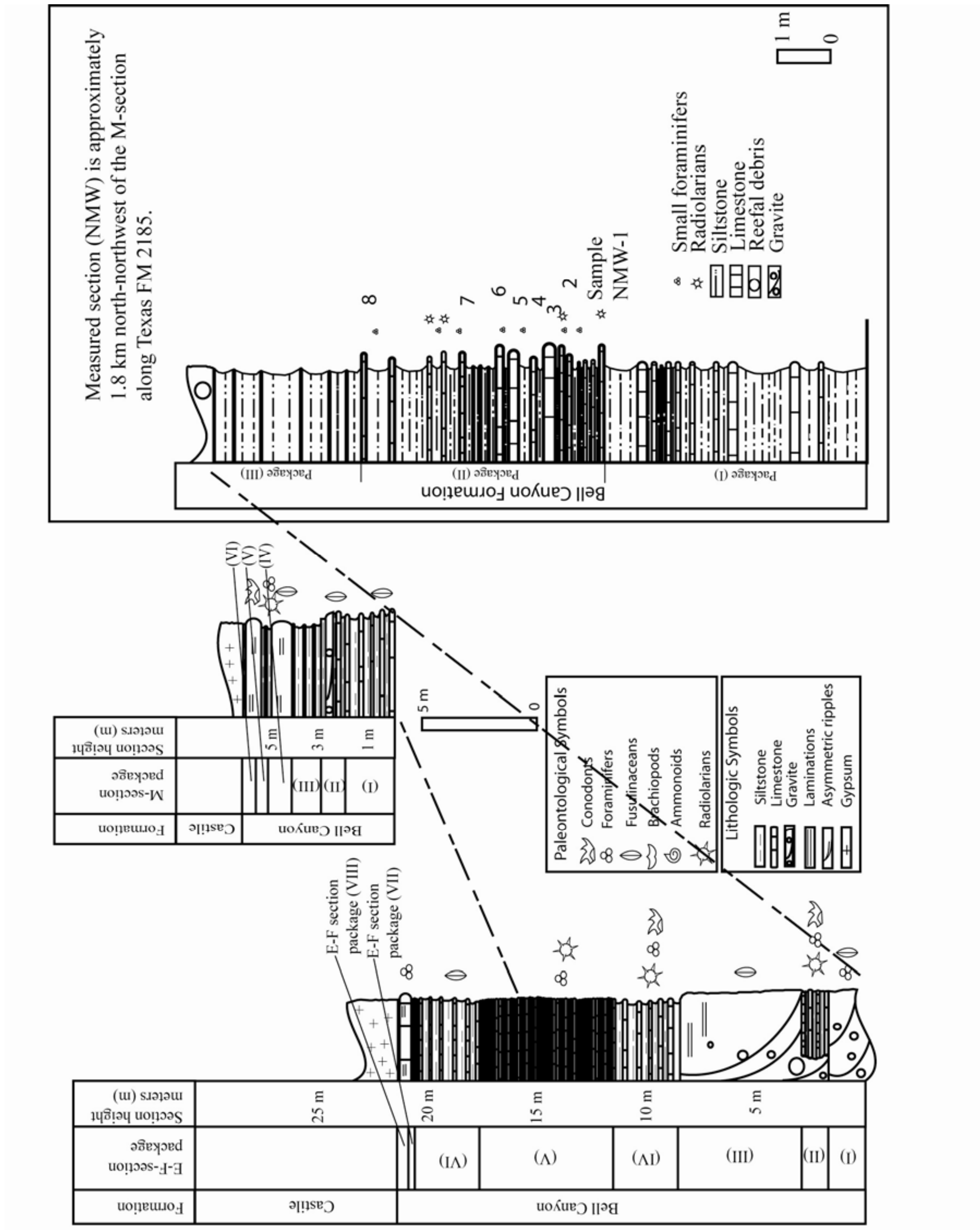


Figure 2.16. E-F and M-sections measured in road-cuts along Texas FM 2185. The M-section is equivalent to the upper portion of the E-F-section. The correlated section (NMW) is located below the reefal debris associated with lower portions of the E-F-section gravite.

2.3.2.1 Correlated Section below the E-F-Section Gravite (NMW) Package (I)

NMW-package (I) consists of approximately 5.5 meters of poorly indurated light brown siltstone interrupted by a few thin beds of protruding limey siltstone.

Digenetic gypsum is commonly found in the poorly indurated light brown siltstone.

2.3.2.2 Correlated Section below E-F-Section Gravite NMW-Package (II)

NMW-package (II) consists of five meters of thin beds of limey siltstone, carbonate mudstone, wackestone and packstone. A few of the limestone beds grade from coarse packstone at their base to wackestone at their tops. Some limestone in NMW-package (II) is very dark gray which differs from most all other limestone in the map area. Fossils observed in NMW-package (II) include a few bryozoans, fusulinaceans, abundant radiolarians and small foraminifers.

2.3.2.3 Correlated Section below E-F-Section Gravite NMW-Package (III)

NMW-package (III) consists of 3.5 meters of poorly indurated light brown siltstone occasionally interrupted by thin beds of limey siltstone. Above this package is the basal reefal debris portion of the E-F-section gravite.

2.4 Upper Permian (Lopingian) Castile and Rustler Formations

2.4.1 *Castile Formation*

Strata of the Castile Formation in the map area conformably overly strata of the Bell Canyon Formation above an interval that is mapped herein as the transition between the Castile and the Bell Canyon formations. Approximately, one meter of laminated dark gray limestone forms the basal portion of the Castile Formation in the map area above the diagnostic pink limestone of the transition zone between the Castile and the Bell Canyon formations (Figure 2.17). This limestone forming the basal Castile Formation is a laminated gypsum/carbonate mudstone containing no fossils. Above this laminated gypsum/carbonate mudstone is approximately 22.5 meters of a sequence of alternating dark calcite and lighter anhydrite beds less than one millimeter apart. The Castile

Figure 2.17. Boundary between the Castile Formation and the uppermost transition zone (E-F-section package (VIII) and equivalent M-section package (VI)).

Formation seems to vary in thickness by as much as 20 meters depending on where it is measured. Some of this variation may be explained by the disconformity between the top of the Castile Formation and the basal Rustler Formation in the map area. Solution of the upper portion of the Castile Formation caused the overlying Rustler Formation to slump downward onto the Castile Formation making it thinner in places and thicker in others. Portions of the Castile Formation in the map area are lithologically very much like the Castile in the Guadalupe Mountain region. The classic sequence of roughly parallel, paper-thin, alternating light and dark laminations is very apparent throughout the map area where the Castile Formation is exposed. Strata of the Castile Formation near overlying strata of the Rustler Formation is broken up and brecciated. It appears as though the lighter colored anhydrite (or gypsum depending on hydration) became fluid-like or expansive post-depositionally and contorted and rearranged the otherwise continuous succession of parallel, light and dark, paper-thin layers of the Castile

Formation (Figure 2.18). A peculiarity within the Castile Formation in the map area is the presence of pebble to boulder sized clasts of brown, clastic, fine-grained sandstone intermittently occurring within this brecciated part of the strata of the Castile Formation. These brown sandstone clasts appear to be in place and occur throughout strata of the Castile Formation very near strata of the basal Rustler Formation in the map area.

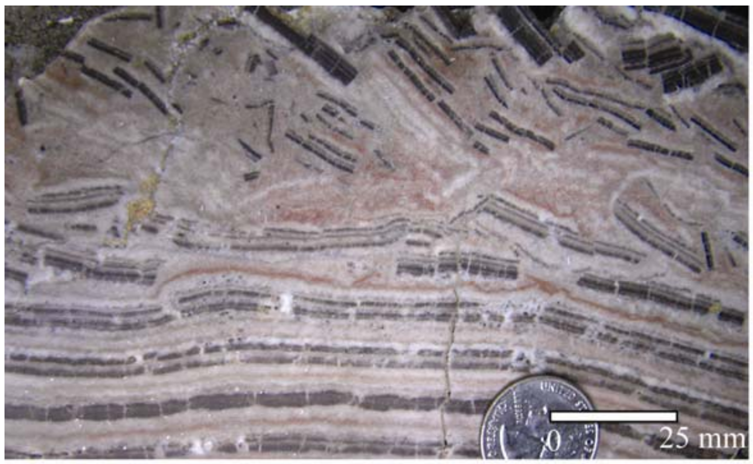


Figure 2.18. Laminations of dark calcite and lighter anhydrite in strata of the Castile Formation located just above the top of the E-F-section in road-cut in the map area.

Brecciated portions of strata of the Castile Formation in the map area exhibit typical looking laminated clasts of the Castile Formation occurring in a matrix of anhydrite and calcite (Figure 2.19). In places the calcite fills fractures within strata of the Castile Formation and forms sparry dogtooth calcite. Brecciation and the presence of thin sandstone intervals in the Castile Formation may indicate that erosion truncated portions of the Castile Formation in the map area producing the unconformity between the Castile and Rustler Formations instead of solution as thought by previous authors working in the area. The Castile Formation is mapped with a light blue color on Map I (Appendix).

2.4.2 Rustler Formation

The Rustler Formation is approximately 15 meters thick and unconformably overlies the Castile Formation in the map area. Thickness of the Rustler Formation varies somewhat

Figure 2.19. Upper portions of the Castile Formation are commonly brecciated and eroded. Clasts of laminated Castile Formation as well as fine-grained clastics are typical of upper portions of the Castile Formation in the map area.

based on the extent of erosion of particular hills because strata of the Rustler Formation cap Castile strata exposed on the hills in the map area. Strata of the Rustler Formation are composed of a basal sandstone unit that sporadically crops out in the map area where it has not weathered away (Figure 2.20). To the authors' knowledge, this lower sandstone unit has not been examined in the vicinity of the map area other than to mention its presence. Where the sandstone crops out, it consists of approximately three meters of very thin beds of dark brown, medium-fine grained arkose-subarkose sandstone. Grains within the sandstone are rounded to subrounded and consist largely of quartz (majority), and minor amounts of feldspar (orthoclase), lithics and heavy minerals set in a carbonate matrix. Plagioclase feldspar within the sandstone has largely been altered to clay suggesting large volumes of fluid have been transported through the sandstone since Upper Permian time.

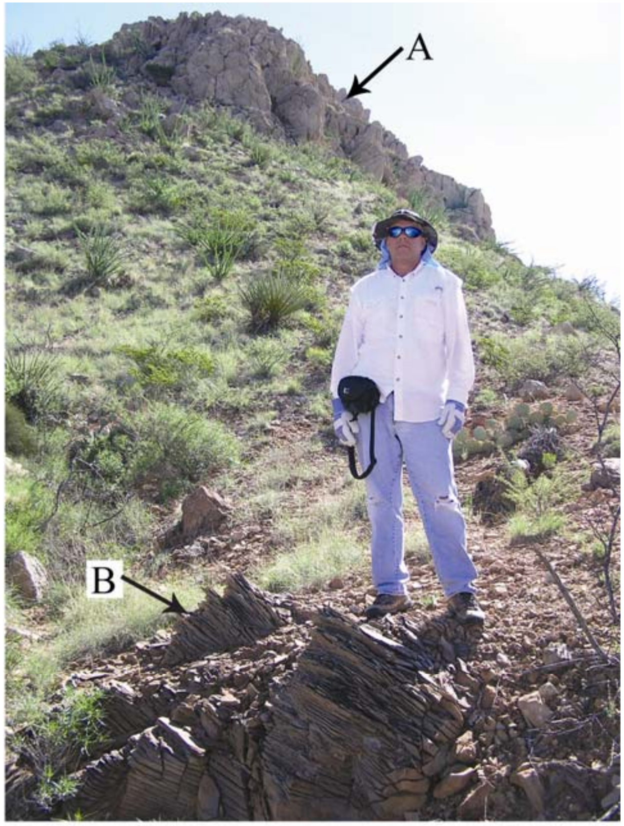


Figure 2.20. (A) Rustler Formation capping hill in map area. (B) Basal sandstone of the Rustler Formation. Field assistant Charles Kennedy for scale. Photograph taken at approximately N 31° 18' 32" latitude and W 104° 33' 23" longitude.

The remaining and more common strata of the Rustler Formation in the map area consist of a distinctive yellowish-brown, dolomitic pebble conglomerate or breccia (Figure 2.21). No fossils were observed anywhere in strata of the Rustler Formation. The contact between the underlying Castile and overlying Rustler Formations was drawn based on the appearance of yellow-gray or brown dolomitic limestone or dolomite. The Rustler Formation is mapped using a brown color on Map I (Appendix). The basal sandstone of the Rustler Formation occurred so sporadically that it was not diagnostic for mapping purposes.

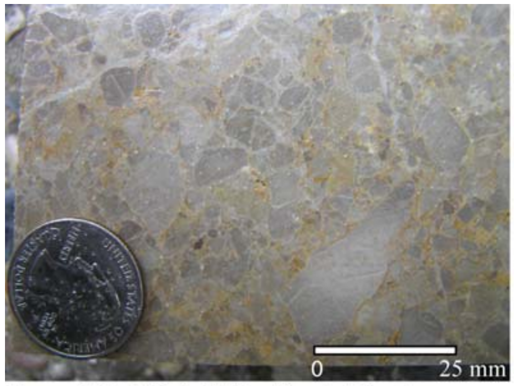


Figure 2.21. Polished slab of typical Rustler Formation strata in the map area. The polished slab of typical Rustler Formation strata was collected at approximately N 31° 18' 55" latitude and W 104° 32' 21" longitude.

CHAPTER 3

SUBAQUEOUS GRAVITY SLIDES (GRAVITES)

3.1 Gravites in and around the Map Area

Gravite is a term used herein to describe all deposits resulting from down slope movements of sediment under the action of gravity (Gani, 2004). This term is used herein to avoid using a genetic term that implies specific depositional processes. Middle Permian gravites are common along the western Delaware basin shelf-margin and have been noted, interpreted and described by many authors (King, 1948; Newell et al., 1953; Silver, 1968; Koss, 1977; Harms and Williamson, 1988; Lawson, 1989). Relative to the present project, Newell at al. (1953, p. 71) comment:

> The most extensive and most interesting of the Permian slide deposits is comparable in volume to great modern landslides. It is exposed along both sides of Trew Canyon at the extreme southern margin of the Delaware Mountains, near the Apache Mountains. The deposit forms a vertical cliff about 40 feet high for many miles at the canyon rim and belongs to part of the Rader member.

Extraordinary, Middle Permian gravites very similar to those described by Newell et al. (1953) are viewable via the Jay Capp Road which is approximately 1.5 km from the southwest corner of the map area (Figure 3.1). This road passes through Ed Ray Canyon and Trew Gap for approximately 14.2 km before returning to Texas FM 2185 just two km northeast of the map area. Land along Jay Capp Road and Texas FM 2185 is privately owned and trespassing is not permitted.

Figure 3.1. Arrows point to gravites forming prominent cliffs along hillsides. Photograph taken of the west wall of Ed Ray Canyon along the Jay Capp Road approximately 6.5 km from its southwest intersection with Texas FM 2185.

3.2 Gravites in the Map Area

The Bell Canyon Formation of Late Guadalupian age in the northwestern part of the Apache Mountains contains four major carbonate gravites and a number of thinner, minor gravites that all dip the southeast, in an approximately 80 meter thick stratigraphic sequence in the map area. These four major and numerous minor gravites are transected by Texas FM 2185 in the M, E-F, B, A and G-section road-cuts. The road-cut's corresponding section letter or letters will be used to designate the location of major gravites along Texas FM 2185 and serve as a name for each mapped gravite in this work. For example, the major gravite occurring in the B-section is herein referred to as the B-section gravite.

Relatively thicker bedded gravites within the Bell Canyon Formation are easily recognized and traceable for several kilometers to the west and northwest from Texas FM 2185 where they form prominent cliffs along hills and erosion resistant ledges in drainages. They are easily distinguished from surrounding Bell Canyon Formation strata because they are composed of conglomerate or larger sized allochthonous clasts. These allochthonous clasts were derived from nearby shelf edge (reef and to a lesser extent backreef) and basin slope (forereef) carbonate facies. A discussion of the rheology, flow type and the dominant sediment support mechanism of one of these thicker gravites exposed in the lower part of the B-section road-cut will be given in a later section of this chapter.

3.2.1 Mapped Gravites

Three major gravites other than the B-section gravite occur in the map area. Two major gravites occur along Texas FM 2185 stratigraphically above the B-section in the A and G-sections. These two gravites are mapped using a dark gray and gray color respectively on Map I (Appendix). In contrast to the average thickness of six meters of the gravite in the lower part of the B-section, the A and G-section gravites vary in thickness from less than two meters to as much as three. These measurements vary somewhat depending on where the measurements are made. All gravite thickness measurements given in this work were made in the road-cuts along Texas FM 2185. The A and G-section gravites are composed of coarse, poorly sorted clasts at their base and grade into packstone and wackestone in their upper 50 centimeters. Brachiopod shells, bryozoans, abundant fusulinaceans and small foraminifers occur in small cobble-sized clasts in the A-section gravite. The G-section gravite is composed of rounded, cobble to boulder-size clasts throughout the lower 1.2 m. The upper 20 cm of the G-section gravite contains blocks of very abundant fragmented and intact fusulinaceans of the genus *Polydiexodina*. The third major gravite in the map area occurs in the E-F-section just eight meters beneath the Castile Formation (Lower Lopingian). In the E-F-section road-cut, the E-F gravite is 7.2 m thick. The thickness of this gravite includes a 1.8 m thick thin bedded limestone and brown siltstone occurring 1.4 m from its base, but does not include the very large blocks of reefal debris found just ten meters to the southwest of the

E-F-section road-cut, because the reefal debris occurs sporadically throughout the map area. Large scale reefal debris is mapped as a separate component of the E-F gravite and discussed further in Chapter 4. The lower 1.8 m of the E-F section gravite contains pebble to small cobble-size fossiliferous carbonate clasts. This lowermost portion of the gravite abruptly contacts a conspicuous 1.4 m thick block of thinly bedded limestone and brown siltstone sandwiched between gravites (possibly Lamar age equivalent block discussed in Chapter two). Cobble size pieces of the underlying brown siltstone are present between 3.3 and 3.5 meters from the base of the E-F gravite and are surrounded by carbonate pebble to cobble-size clasts comprising the majority of the gravite. The remaining five meters of the gravite are a spectacular example of an upwardly fining sedimentary deposit. The basal 5.3 m of the gravite are composed of pebble to cobble-size clasts that fine upward into a coarse packstone. Fossils within the gravite include fragments of bryozoans, sponges, small foraminifers, the fusulinaceans *Polydiexodina* and *Paraboultonia splendens.* Within the top two meters of the gravite, the packstone grades into a very fine grained, laminated carbonate wackestone/packstone. This laminated carbonate mudstone is easily recognized in the upper 1.7 m of the gravite. This gravite is traceable for many hundreds of meters east and west of the highway and mapped on Map I (Appendix) using a light yellow color.

3.3 B-Section Gravite Introduction

The B-section gravite is very prominent in the map area due to its coarse basal material (many clasts are larger than 0.5 meter in longest exposed dimension) and traceability for kilometers to the west-northwest across the map area (Figure 3.2). Minor gravites, less than one meter thick, that thicken and thin laterally are interbedded

Figure 3.2. Large clasts of the B-section gravite outlined in stippled white lines. Photograph taken from the north side of the lower part of the B-section along Texas FM 2185 of the south wall.

with thin beds of brown siltstone and abruptly contact the base of the extremely coarse B-section gravite. The B-section gravite is an exceptional example of a fining upward sequence with the exception of a few noticeable, outsized "floating clasts" surrounded by smaller clasts in the lower two-thirds of the gravite (Figure 3.3). The upper third of the gravite grades from a packstone to a wackestone. Fine-grained carbonate strata of the upper third of the gravite conformably contact overlying thinly bedded, brown siltstone and limestone.

3.3.1 B-Section Gravite

3.3.1.1 Lower Contact

A very poorly sorted carbonate megabreccia containing clasts ranging in size from pebble to boulder lies above a one to two centimeter thick, poorly sorted, coarse-grained wackestone containing clasts and bioclasts as large as one to two centimeters across. The transition from the very thin bedded underlying wackestone to the extremely coarse carbonate megabreccia of the B-section gravite is not clear because sampling in

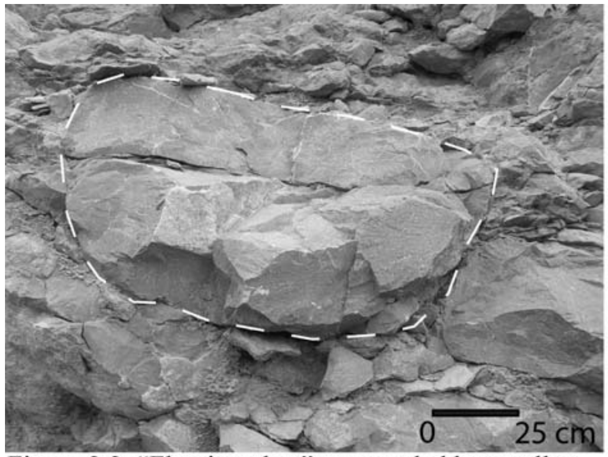


Figure 3.3. “Floating clast” surrounded by smaller clasts of the B-section gravite. Photograph taken of the lower 2.5 m of the B-section gravite on the north wall of the B-section road-cut along Texas FM 2185.

this part of the gravite yields only boulder to cobble size clasts with minor amounts of brown silt or clay between them (Figure 3.4).

Figure 3.4. B-section gravite is above black stippled line. Below stippled line are thin to medium-bedded, fine-grained limestones.

The base of the wackestone forms an erosive contact between the overlying gravite and an underlying fine-grained laminated packstone (Figure 3.5). The basal contact of the gravite with the strata below is sharp and irregular. Along the surface of the contact the underlying laminated packstone and the overlying gravite undulates as much as four centimeters forming shallow crests and troughs. Cross-sectional analysis of the strata at the lower contact reveals that the wackestone thickens at crests and disappears at troughs.

Laminations within the upper five centimeters of the underlying packstone truncate against the poorly sorted, coarse-grained wackestone directly under crests along the contact (Figure 3.5). Tracing a particular limestone underlying the gravite is difficult because the beds thicken and thin (often by many decimeters) and occasionally pinch-out completely.

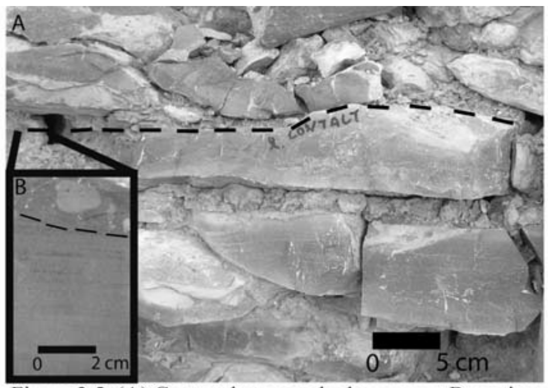


Figure 3.5. (A) Contact between the lowermost B-section gravite and the underlying medium bedded limestone and siltstone of the Bell Canyon Formation. (B) Polished slab showing the contact between the underlying laminated packstone and the overlying poorly sorted wackestone of the lowermost B-section gravite. Contact traced in stippled line in both A and B.

3.3.1.2 Gravite Zones

The B-section gravite is herein divided into three zones. The lower 2.5 meter zone (I) contains very large clasts that are roughly the same size. The middle 2.5 meter zone (II) contains smaller clasts embedded in a slurry-like deposit of carbonate mud. The third and uppermost 1.7 meter zone (III) records a rapid change from clasts over five centimeters across to clasts less than one centimeter in longest exposed dimension. The upper half meter of this uppermost zone is massive packstone and wackestone. Zones (I), (II) and (III) of the B-section gravite are measured along the north wall of the B-section along Texas FM 2185 and it should be noted that the thickness of these zones varies somewhat depending on where measurements are taken. For example, the gravites often form prominent cliffs along hills in the map area that are often thinner than measurements made in road-cuts. Thickness differences are partly due to the upper fine-grained portion of the gravite being less resistant to erosion than the megabreccia forming the lower portions of the gravite. Figure 3.6 shows the zones of the gravite, where each sample described herein was taken and provides thin section pictures of clasts taken from zones (I) and (II) of the B-section gravite.

3.3.1.3 Lower 2.5 Meter Zone (I)

The lower 2.5 meters of the gravite consists of a massive, dark gray, very poorly sorted carbonate megabreccia. Subrounded carbonate clasts comprising the megabreccia range in size from half a meter (one as large as 9.5 m in longest exposed dimension) to clasts that are less than five centimeters in longest dimension. Commonly, clasts range in size from 0.25 to 0.5 m across in zone (I). Noticeably larger clasts commonly rest upon smaller clasts throughout zone (I). Individual clasts that exhibit grading from coarse to fine are randomly oriented in zone (I). Clasts within zone (I) are mainly biopelmicrites or biopelsparites containing abundant pelloids, recrystallized pelloids and coated grains. Bioclasts include small foraminifers, fusulinaceans such as *Polydiexodina,* gastropods, algae, *Tubiphytes* and bryozoans. Small foraminifers occurring in zone (I) are illustrated on plate 1. Mud content varies from clast to clast in zone (I) from around 10 percent to over 50 percent. Sparry calcite cement varies from clast to clast and is most common in between larger bioclasts and pelloids.

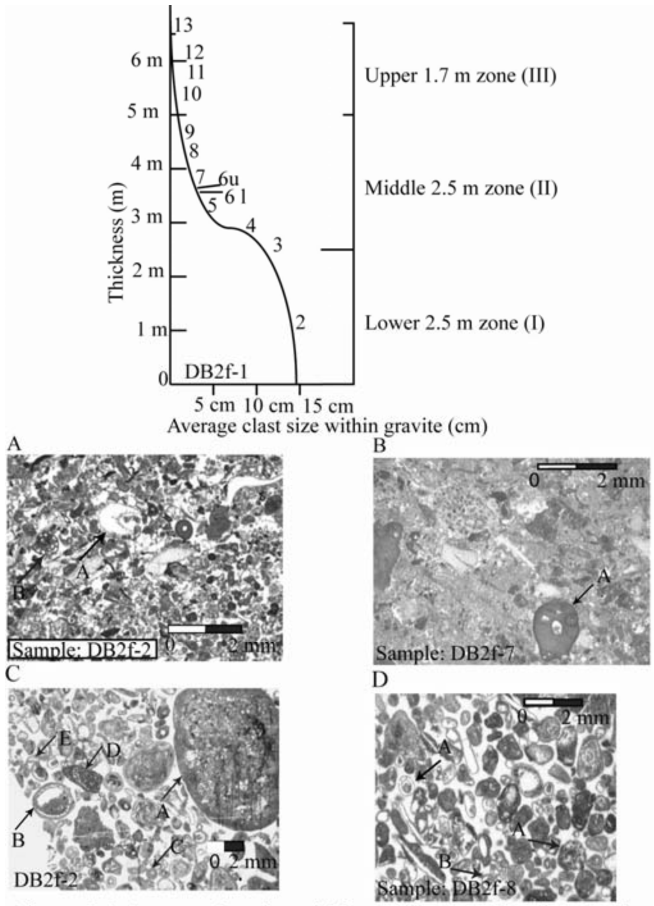


Figure 3.6. Average clast size within gravite plotted against gravite thickness. Clasts smaller than one cm are distributed throughout the deposit but are not included in the average. Sample locations DB2f-1 through DB2f-13 are given to the right of the curve. A. Biomicrite containing (A) Algae and (B) Fusulinaceans in the lower 2.5 meter zone (I). B. Biomicrite in the middle 2.5 m zone (II) of the gravite deposit containing (A) *Tubiphytes*. C. Biosparite in the middle 2.5 m zone (II) containing (A) large rounded grains and (B) geopetal structure in algal grain, (C) coated grains, (D) fragmented fusulinacean and (E) algal fragment. D. Biosparite in the middle 2.5 m zone (II) containing (A) large rounded grains (B) geopetal in algal grain, (C) coated grains, (D) fragmented fusulinacean and (E) algal fragment.

3.3.1.4 Middle 2.5 Meter Zone (II)

The middle 2.5 meters of the gravite is composed of a massive, gray, poorly sorted carbonate breccia. Interlocking clasts within the carbonate breccia are smaller and more angular than in zone (II) of the gravite. Clasts range from 15 centimeters to less than a centimeter in longest dimension. Clasts generally decrease in size within zone (II) with the larger clasts being 10-15 cm in longest dimension at the base of zone (II) to less than one cm near the top of zone (II). In places, clasts tend to be approximately aligned, with their long axis parallel with the upper and lower contacts of the gravite and surrounding strata (Figure 3.7).

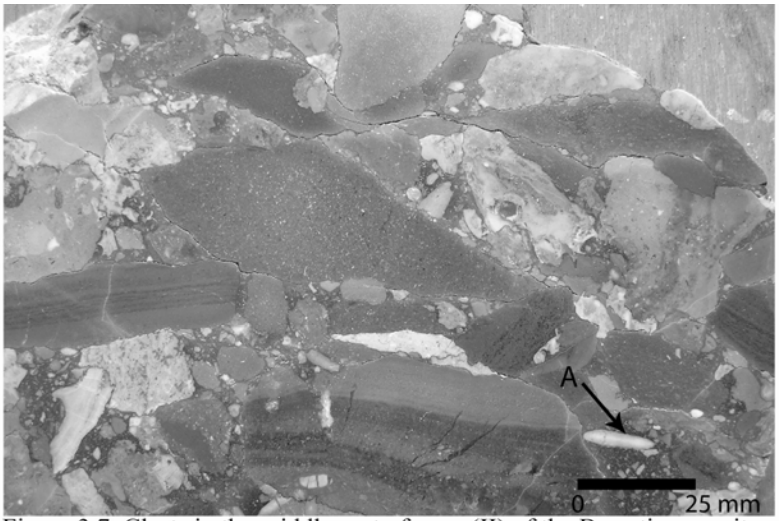


Figure 3.7. Clasts in the middle part of zone (II) of the B-section gravite. The long axis of some clasts are approximately aligned with each other in this zone. (A) Fusulinacean genus *Polydiexodina*.

Less than five percent of the total volume of zone (II) is a buff colored micritic matrix occurring between biomicrite or biosparite clasts. The clasts in zone (II) contain pelloids, and occasional ooids (Figure 3.6). Bioclasts include small foraminifers, fragmented and intact fusulinaceans such as *Polydiexodina,* gastropods, algae, brachiopod fragments, *Tubiphytes,* and bryozoans (Figure 3.8).

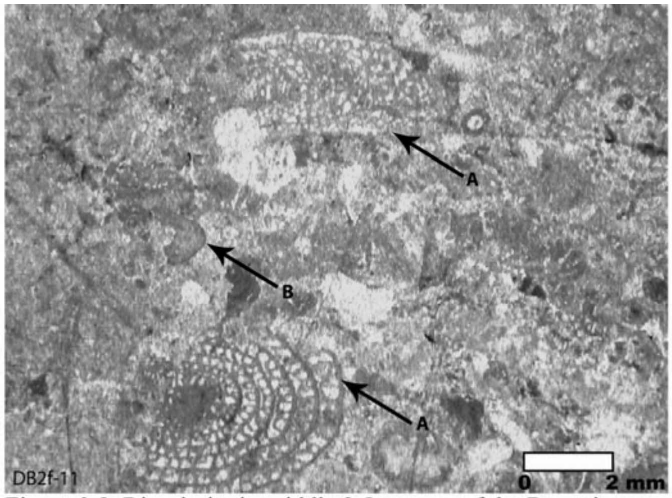


Figure 3.8. Biomicrite in middle 2.5 m zone of the B-section gravite containing fragmented (A) fusulinaceans (*Polydiexodina*) and (B) *Tubiphytes*.

Small foraminifers occurring in zones (II) are illustrated on plate 1. In zone (II) mud content varies from less than five percent to more than 30 percent within clasts. Sparry calcite cement within clasts ranges from five to 15 percent in zone (II).

3.3.1.5 Upper 1.7 Meter Zone (III)

The upper 1.7 meters of the gravite are composed of massive, light gray carbonate mudstone, wackestone and packstone. Larger clasts within a finer matrix that are common less than half a meter below decrease in size to less than half a centimeter and become less and less abundant toward the top of the gravite until only wackestone and carbonate mudstone remain (Figure 3.9). In general, the upper 1.7 meter zone grades from packstone to wackestone to a carbonate mudstone from the base of the zone to the top. Pelloids, mud and bioclasts such as small foraminifers comprise most of this top zone. Small foraminifers occurring in zones (III) are illustrated on plate 1. The upper 0.25 m is a fine-grained biomicrite (Figure 3.9).

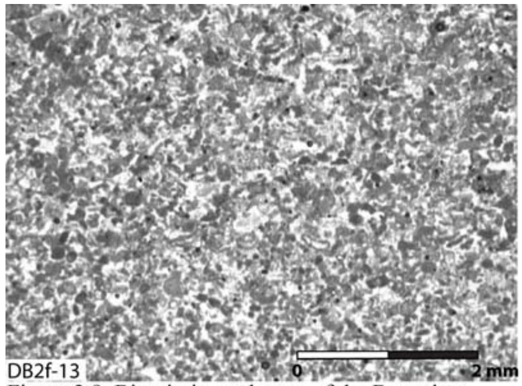


Figure 3.9. Biomicrite at the top of the B-section gravite deposit (upper 1.7 m zone (III)).

3.3.1.6 Upper Contact

The upper contact between the gravite and the overlying brown siltstone is sharp, flat and roughly parallel with its basal contact. An abrupt change from the underlying massive gray carbonate wackestone/mudstone to an overlying, poorly indurated brown siltstone characterizes the upper contact. Throughout the map area, this contact appears to vary little.

3.3.2 Lateral Extent

On the north side of Texas FM 2185, the B-section gravite forms a prominent north-northwest trending cliff about half-way up the west exposure of the hill that Texas FM 2185 cuts. The cliff itself is generally between five and ten meters thick from its base to its top, although it lenticularly thickens in places to over 15 meters. This cliff line is traceable for about 350 m to the north from Texas FM 2185 in the B-section road-cut. From this point the cliff line is obscured due to an east-southeast trending fault which downwardly displaces (relative to the cliff line closest to the highway) the cliff line an estimated 10 or 15 meters. Beyond this to the north, the gravite is recognizable again about 400 meters to the northwest in an east-southeast trending drainage where it forms a prominent erosion resistant, very thickly bedded (three to four meters) carbonate megabreccia. The gravite again forms a prominent cliff a little over half-way up the hills that form the east-southeast trending drainage that forms the northern boundary of the map area. The B-section gravite is mapped with a black line on Map I (Appendix).

3.4 Source of B-Section Gravite Debris

The B-section gravite is unlike the medium to thin bedded alternating siltstone and limestone beds that typify the basinal facies in the map area. The B-section gravite has clasts within it characteristic of reefal and backreef lagoonal facies. Fauna assigned to the Capitan Limestone (reef) and equivalent backreef facies by Wood (1965) in the Apache Mountains to the south of the map area includes faunal elements recognized in the B-section gravite in this work. In the Capitan Limestone, Wood (1965) commonly recognized brachiopods, gastropods, crinoids, *Tubiphytes* and algae (*Mizzia* sp.). Wood (1965) also recognized ooids, coated grains and pellets in backreef facies in the Apache Mountains. Occasionally coated grains, pelloids and ooids occur quite abundantly in clasts within zones (I) and (II) of the B-section gravite. These clasts may be interpreted as a more lagoonal or backreef facies relative to the other clasts observed in the B-section gravite. In contrast to the gravites, basinal strata in between the gravites exposed in the map area typically contain siltstone interbedded with thin limestone containing radiolarians, conodonts and small foraminifers.

Due to the similarity of faunal elements occurring in reefal strata in the Apache Mountains to those observed in clasts of the B-section gravite it is reasonable to interpret that material was transported downslope subaqueously from the shallow-water shelf under the action of gravity to deeper basinal environments. The very large clasts within the B-section gravite indicate that they did not travel a great distance down slope into the

Delaware Basin from its probable source along the reef to the south. Newell et al. (1953) notes that deposits very similar to the B-section gravite in Trew Canyon (or Trew Gap) thin in a basinward direction or toward the north, suggesting that the main reef was located to the south or southwest of the map area during Guadalupian time. However, it is important to note that the gravite demonstrates characteristics indicative of matrix strength and fluid turbulence as discussed below. These characteristics are not indicative of reef talus simply accumulating in talus fans at the foot of reef scarps. The B-section gravite is an exceptional deposit of reefal and backreef facies occurring in a reworked slurry far out into the Delaware Basin.

3.5 Age

Reworking and abrasion of fusulinaceans is evident throughout the B-section gravite deposit (Figure 3.8). Reworking complicates the matter of determining the age of the gravite deposit precisely since faunal assemblages used for biostratigraphic control in the region are mixed. *Polydiexodina* is the youngest fusulinacean genus in the gravite. Preliminary conodont analysis of limestone beds in the upper part of the B-section above the B-section gravite yielded *Jinogondolella aserrata* and *J. postserrata* (Personal communication, Wardlaw and Nestell, 2007). These conodont species mark the transition between Late Wordian and Early Capitanian time.

3.6 Rheological Interpretations

The B-section gravite shows evidence of having a composite rheology of both non-Newtonian Bingham Plastic (i.e., debrite) and Newtonian fluids (i.e., turbidite). This transitional deposit between non-Newtonian and Newtonian rheologies is termed a densite by Gani (2004). Outsized clasts resting on smaller clasts in the lower 2.5 meters zone (I) of the densite and clay content over about five percent between clasts indicate yield strength and cohesiveness of the lower five meters of the flow. Hampton (1975) demonstrated that as little as 2-4% clay (by volume) can generate yield strength in sediment gravity flows. Yield strength and cohesiveness are characteristics of non-Newtonian Bingham plastic rheology generated from a type of flow that is mostly laminar and debris flow-like. The interlocking nature of the clasts with each other, combined with outsized clasts “floating clasts” and poor sorting, indicate that matrix strength is the dominant sediment support mechanism for the lower five meters of the B-section gravite. Matrix strength is the dominant sediment support mechanism in debris flow deposits. Clasts in the upper portion of the middle 2.5 meters zone (II) tend to be approximately aligned with their long axis parallel with the base and top of the gravite. This alignment indicates that these clasts were deposited in an environment of decreasing energy relative to the clasts below. Well sorted, normal distribution grading and clasts of fine-grained wackestone and packstone indicate that the dominant sediment support mechanism was fluid turbulence for the upper 1.7 meter zone (III). Fluid turbulence is characteristic of Newtonian fluids and appears to characterize zone (III). A gravite with Newtonian rheology is called a turbidite by Gani (2004). Zone (III) can be designated as a turbidite (Gani, 2004). Gani (2004) defines a hybrid gravite deposit composed of a lower debrite and an upper turbidity current without a bedding plane in between as a densite (Gani, 2004). Because no bedding plane between these two deposits is apparent and due to conclusions reached above, the author calls this B-section gravite a densite.

CHAPTER 4

REEFAL DEBRIS

4.1 Large Scale Reefal Debris in the Map Area

Allochthonous debris occurring stratigraphically just below the E-F-section gravite contains clasts typical of gravites in the map area, that is, rounded carbonate clasts of mudstone, wackestone or packstone as well as very large, sometimes several meter-scale clasts of fossiliferous boundstone that may best be described as reefal debris. Where reefal debris does crop out in the map area, it forms rounded, light brown cliffs on hills. Large scale reefal debris only occurs in two places in the map area. The most extensive exposures of the large scale reefal debris are mapped using a dark blue color on Map I (Appendix) and occurs most prevalently in the northwest part of the map area north and west of the M-section. A small exposure also occurs just west of and at the base of the E-F-section in the road-cut along Texas FM 2185. Large scale reefal debris in the map area is not distributed continuously the way as other trends of gravites (such as B, A, and G gravites) in the map area. Other gravites in the map area appear to have spread more or less evenly out across the basin floor. The continuity of the gravites is only interrupted by faulting in the map area. The reefal debris present at the base of the E-F-section gravite appears to be confined and isolated in nature suggesting that channels may have confined reefal debris (Figure 4.1).

4.2 Description of Reefal Debris

Large scale reefal debris occurs in the form of large, dolomitic or carbonate, rounded, fossiliferous boundstone clasts, some larger than five meters in longest exposed

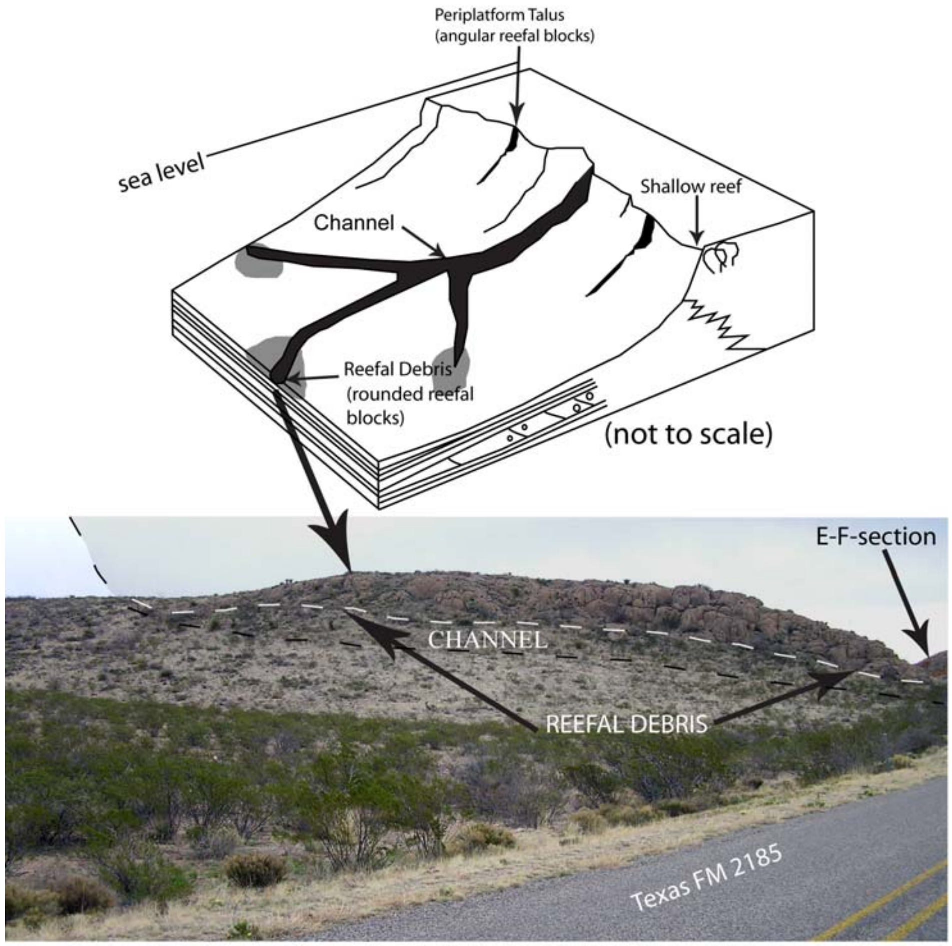


Figure 4.1. Lower picture showing localized nature of reefal debris. Reefal debris caps hills in the map area and is associated with the E-F-section gravite (where reefal debris occurs). Reefal debris is shown above the white stippled line. Cartoon above shows one interpretation for the localized nature of the reefal debris. Channel margins outlined in black stippled line in lower photograph.

dimension. Most of these rounded clasts are less than two meters in longest exposed dimension (Figure 4.2 A-C). Between the large reefal clasts are often smaller reefal clasts or clasts of carbonate mudstone, wackestone or packstone (Figure 2.1 A, B). Reefal clasts are cemented together with a brownish gray, mud or silt in between pebble or sand sized

Figure 4.2. Reefal debris in lower E-F-section gravite. Larger, individual clasts of reefal debris are outlined in stippled black line. A and B shows large clasts of reefal debris surrounded with debris typical of the E-F-section gravite. C demonstrates a typical exposure of reefal debris on top of a hill in the northwest part of the map area.

carbonate grains. It is common for reddish chert to outline the inside perimeter of reefal clasts making the larger clasts stand out more apparently (Figure 4.2 A). Five to six mm thick, light gray calcite veins commonly cross-cut outcrops of reefal debris. Light gray sparry calcite also commonly fills voids within and between clasts of reefal debris. On the tops of hills in the map area where reefal debris crops out, between large reefal clasts, are eight to ten cm wide crevices, some lined with gray calcite.

4.2.1 Fossils within Reefal Debris

Abundant fossils occur in the allochthonous blocks of the reefal debris. *Archaeolithoporella* is very nicely exposed on faces of large blocks of reefal debris along with other large fossils including brachiopods, sponges, algae, and bryozoans. Smaller fossils occurring in the reefal debris blocks include *Tubiphytes,* and fusulinaceans such as *Codonofusiella*, (*Lantschichites*), and *Polydiexodina*. Figure 4.3 A and B illustrate common fossils in the reefal debris along with their associated depositional environments. Fossils within the reefal debris are not indicative of basinal facies and therefore their enclosing blocks were transported to deeper water from shallow waters by submarine gravity flow or flows.

4.3 Reefal Debris Source

The source for the reefal debris is likely the nearby reefal facies of the Capitan Limestone that forms the core of the Apache Mountains approximately six km to the southwest. The blocks of previously lithified reefal debris were part of the reef prior to being incorporated into the E-F-section gravite that transported the blocks out into the basin (Figure 4.3 A, B). Geopetal structures within reefal blocks indicate up directions that are different than the block’s present orientation. This orientation implies that the blocks have been independently rotated prior to coming to rest along the margins of the Delaware basin. Rounding indicates the reefal blocks were abraded during transport from updip reef platform to deeper portions of the basin. Blocks of rounded debris rule out the possibility that the reefal debris simply accumulated at the base of the reef platform, having traveled only a short distance.

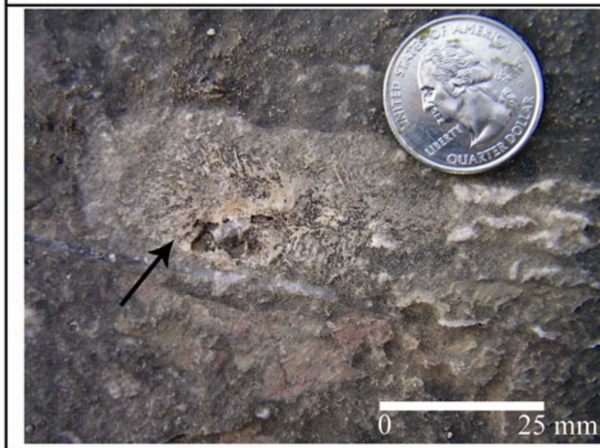
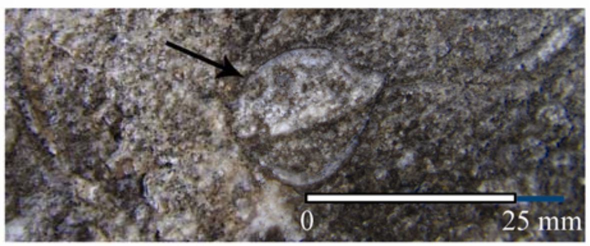
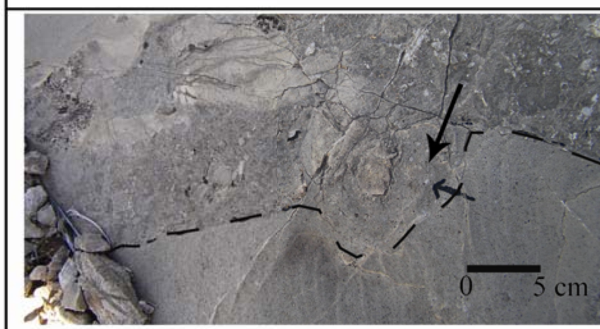
FOSSIL	FOSSIL NAME /DESCRIPTION	ENVIRONMENT
	Arrow pointing to a sponge	Continental shelf
	Brachiopod indicated by arrow. Note geopetal filling of mud in brachiopod cavity indicating the up direction. Up direction is different that present up direction.	Continental shelf
	Arrow points to fusulinacean genus *Polydiexodina*. Other fusulinaceans present in clasts nearby include *Paraboultonia*. (Stippled line marks lower and upper margins of two clasts. The upper clast is much coarser grained than lower clast.	Reef and back-reef (lagoon)

Figure 4.3 Fossils contained within clasts of large scale reefal debris. The depositional environment associated with each fossil is given below.

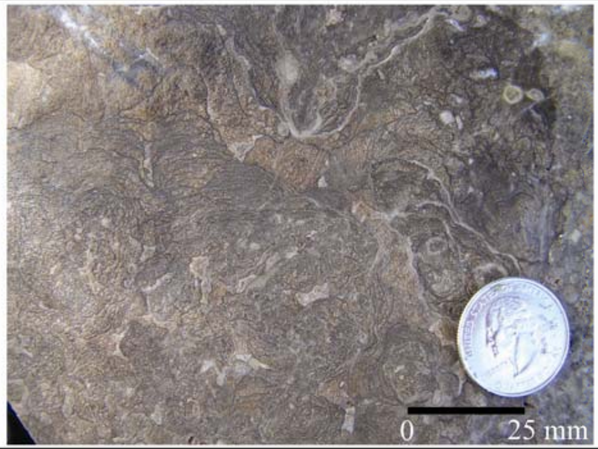
FOSSIL	FOSSIL NAME /DESCRIPTION	ENVIRONMENT
	Alga (*Archaeolithoporella*)	(A) Reef/shallow continental shelf
	(A) Bryozoa (B) Brachiopod Note geopetal filling of mud in brachiopod cavity indicating the up direction. Up direction is different that present up direction.	(A and B) Continental shelf and reef
	Silicified sponge	Continental shelf

Figure 4.4. Fossils contained within clasts of large scale reefal debris. The depositional environment associated with each fossil is given below.

CHAPTER 5

CONCLUSIONS

Basinal and forereef strata of the Middle Permian Bell Canyon Formation in the Northwestern Apache Mountains and in the map area are somewhat similar in lithofacies to those strata found in the basinal and forereef Bell Canyon Formation in the Guadalupe Mountains to the north and northeast of the map area. Although the lithofacies of strata exposed in the map area are not precisely the same as those in the Guadalupe Mountains, fossil content (foraminifers, radiolarians, and conodonts) of Bell Canyon age strata provide fairly firm age correlation between the two areas so that the names of members of the Bell Canyon Formation in the Guadalupe Mountains may be at least be loosely used in a chronologic sense. The oldest strata in the map area are exposed in and below the B-section and are of Late Wordian age (Hegler or Pinery equivalent). The remaining strata of the Bell Canyon Formation exposed in the map area, stratigraphically above the B-section are of Capitanian age (Rader, McCombs, Lamar, Reef Trail equivalent). Although previous authors working in the Apache Mountains have applied Bell Canyon member names, such as Rader and Lamar, to coeval strata exposed in the Apache Mountains, it should be noted that most member names of the Bell Canyon Formation used for strata exposed in the Guadalupe Mountains cannot be easily extended to the Apache Mountains. Bell Canyon member names should only be used informally for strata exposed in the Apache Mountains to establish their chronological equivalency to coeval strata in the Guadalupe Mountains.

The use of the Castile and Rustler formational names in the Apache Mountain should also be done with reservation as these strata are not the precise lithological equivalents of coeval strata in the Guadalupe Mountains area. The terms Castile and Rustler are used informally in this work to loosely indicate the extent of Lopingian age strata in the map area and a thorough discussion of the use of these latter two names in the Apache Mountains area is beyond the scope of this work.

Subaqueous gravity slides or gravites (densites) occurred throughout the map area during Bell Canyon time. These mass wasting events transported shallow water facies into deeper parts of the Delaware Basin and the map area. One particularly thick gravite (in the B-section) examined in the map area in this work has characteristics of a debris flow in its lower part and a turbidite in its upper part. All of the debris flows exposed in the Apache Mountains area should probably be examined in more precise detail to aid in the interpretation of the depositional processes that resulted in their emplacement.

Blocks of chaotically oriented large scale reefal debris forming the base of fining upward sequences of debris flows occur in isolated patches in the map area, especially related to the E-F-section gravite. It is not clear whether or not the large blocks of reefal debris preceded more typical, non-reefal clasts of the E-F-section gravite. The isolated nature of exposures of reefal debris in the map area may indicate that reefal debris clasts, being larger than more typical clasts of the E-F-section gravite, possibly were the basal portion of a channeled subaqueous gravity slide. These gravites also need additional study to determine their possible origin and mechanism of emplacement.

APPENDIX A

PLATE 1

SEE SUPPLEMENTARY FILE

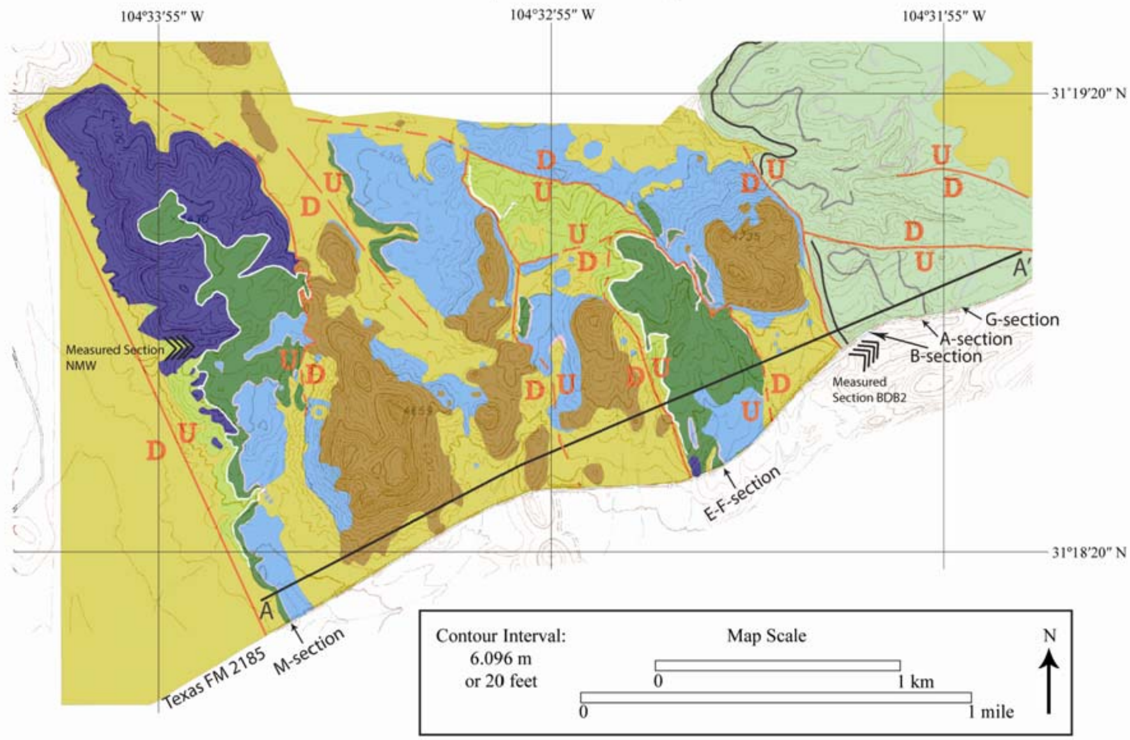
APPENDIX B

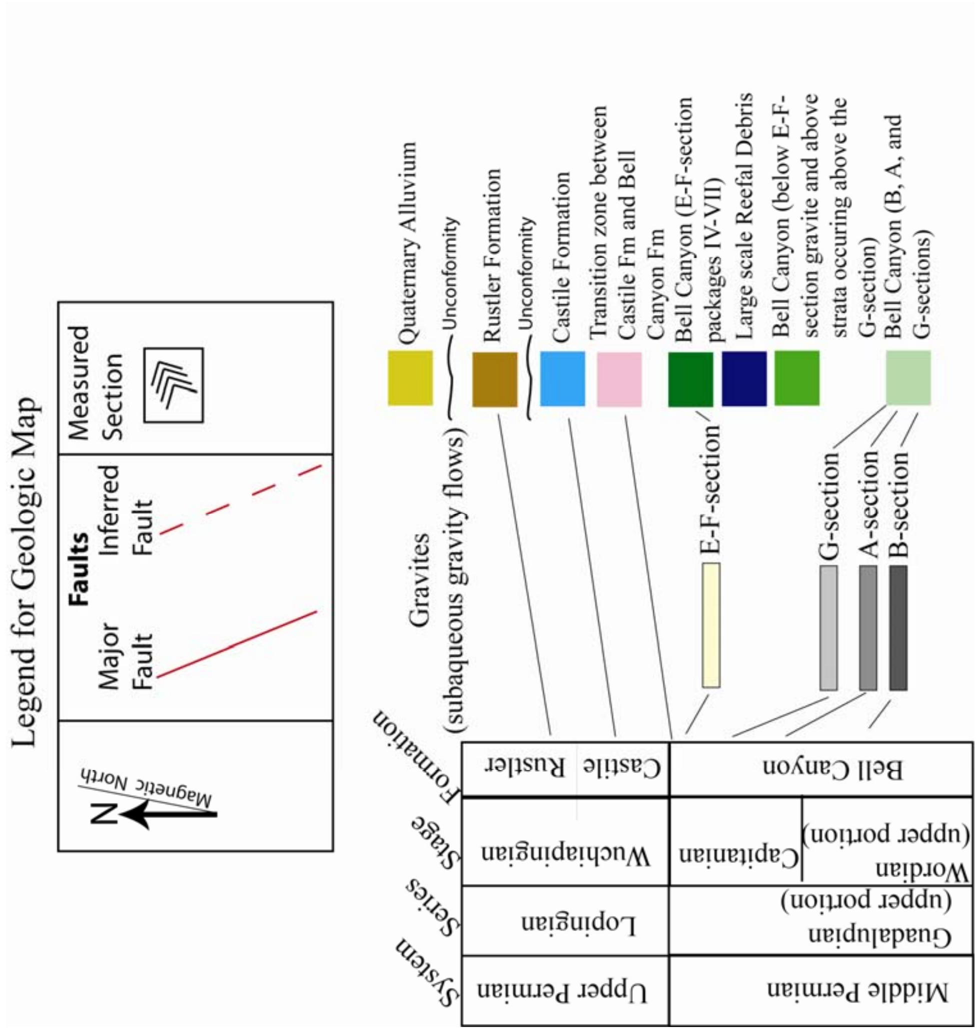
GEOLOGIC MAP AND CROSS SECTION OF A PORTION OF THE NORTHWEST APACHE MOUNTAINS, SOUTHEAST CULBERSON COUNTY, TEXAS, U.S.A.

SEE ALSO SUPPLEMENTARY FILE

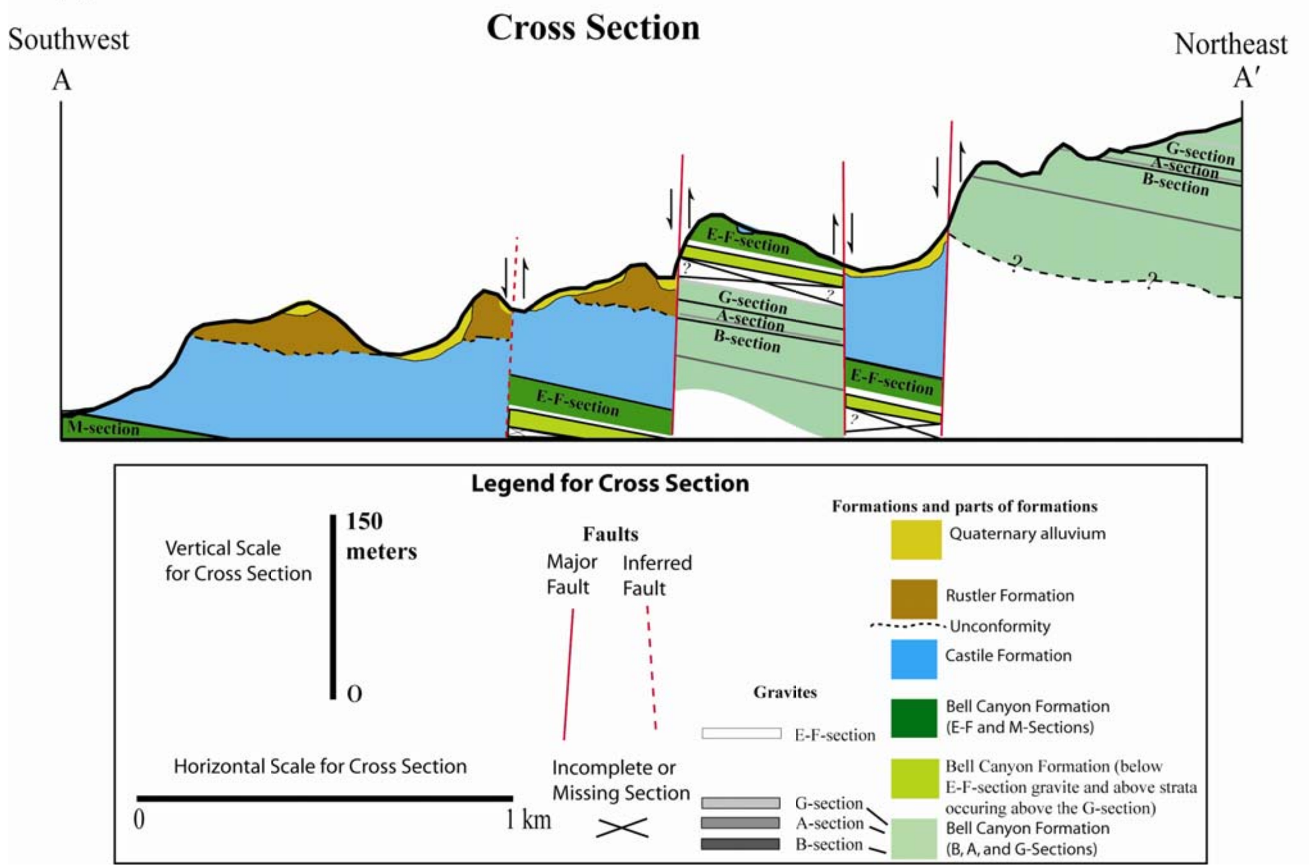
Map (l)

Geologic Map of a Portion of the Northwest Apache Mountains, Southeast Culberson County, Texas, U.S.A.
Walter L. Kennedy
2007
The University of Texas at Arlington




Legend for Geologic Map
Magnetic North
N
Faults
Major Fault
Inferred Fault
Measured Section
Quaternary Alluvium
Unconformity
Rustler Formation
Unconformity
Castile Formation
Transition zone between Castile Fm and Bell Canyon Fm
Bell Canyon (E-F-section packages IV-VII)
Large scale Reefal Debris
Bell Canyon (below E-F-section gravite and above strata occuring above the G-section)
Bell Canyon (B, A, and G-sections)
Gravites (subaqueous gravity flows)
E-F-section
G-section
A-section
B-section
System
Series
Stage
Formation
Upper Permian
Lopingian
Wuchiapingian
Castile
Rustler
Middle Permian
Guadalupian (upper portion)
Capitanian
Wordian (upper portion)
Bell Canyon

Map (I) - *Continued*



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Walter Kennedy began studying at the University of Texas at Arlington in 2000. He earned his B. S. in Geology in 2005 and began work on his Master’s degree later the same year. He will begin working at Chesapeake Energy Corporation as an associate geologist in Oklahoma City in early 2008.