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Deposition and emplacement of Permian reefs in Sierra Plomosa, Chihuahua, Mexico

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ABSTRACT

Permian reefs in Sierra Plomosa, Chihuahua are well exposed and contain shallow-water faunas similar to the better-studied rocks of the Permian Reef Complex in Texas and New Mexico. The reefs are dominantly mudstones with subordinate algal boundstones, packstones, and grainstones. Fusulinids indicate the reefs are Late Wolfcampian through at least Early Leonardian. The reefs are found in complicated juxtaposition to basinal clastic rocks of the Plomosas Formation. Thrusting is clearly responsible for the structural association in the Sierra Santo Domingo at the east end of the range. Sliding of reefal blocks into adjacent deep water may have occurred. Reefal olistoliths of shallow water origin are embedded in deep marine terrigenous clastics.

Keywords: reef, microfacies analysis, olistolith, Permian, Mexico.

RESUMEN

Arrecifes del Pérmico en Sierra Plomosa, Chihuahua, están bien expuestos y contienen fauna de agua somera similar a las rocas mejor estudiadas del Complejo Arrecifal Pérmico en Texas y Nuevo México. Los arrecifes son dominantemente mudstones con boundstones, packstones y grainstones subordinados. Fufulínidos indican que los arrecifes son del Wolfcampiano tardío al Leonardiano temprano. Los arrecifes se encuentran en compleja yuxtaposición con rocas clásticas de cuenca de la Formación Plomosas. La asociación estructural en la Sierra Santo Domingo, en el extremo este de Sierra Plomosa, es claramente el resultado de cabalgamiento. Es probable que haya tenido lugar el deslizamiento de bloques arrecifales hacia aguas profundas adyacentes. Olistolitos arrecifales originados en agua somera se encuentran inmersos en clásticos terrígenos de mar profundo.

Keywords: arrecife, análisis de microfacies, olistolitos, Pérmico, México.

INTRODUCTION

Located in eastern Chihuahua, Sierra Plomosa (Figure 1) is one of several northwest–southeast trending sierras that extend across the east-central portion of the state. The Ordovician through Permian section near Mina Plomosa (Figure 2) is approximately 2,500 m thick as compared to 5,500 m in the Marathon Basin, Texas.

Sierra Plomosa is a window onto the Paleozoic basement in Chihuahua. At the southeastern end of the range, Pennsylvanian and Permian rocks of the Sierra Santo Domingo are thrust to the west. Several chaotic blocks, dominantly of Jurassic La Casita sandstone, are found in the valley between topographically higher Permian rocks to the east and west. The highly disturbed zone between is likely the product of contortion resulting from the east limb of the anticline (Sierra Santo Domingo) being folded and thrust to the west (Bridges, 1962).

Burrows (1910) described the pre-Cretaceous package of rocks as the Plomosas Formation. Spaulding (1955, mentioned by Bridges, 1962) recognized pre-Carboniferous rocks noting the presence of the Silurian coral *Halvaites* in a core taken by the mining company at Mina Plomosa. Bridges and DeFord (1961) described the Paleozoic rocks. In later publications, Bridges (1962, 1964, 1971, 1974) mapped the Paleozoic rocks and contributed to field guides for Chihuahua expounding on the geology of areas peripheral to Plomosa. Hawkins (1975) explored the microfacies of the Ordovician through Pennsylvanian rocks. Sheehan (1975a, 1975b) described Ordovician and Devonian brachiopods. The origin of the Permian algal limestone buildups was initially discussed by Montgomery (1987).

Significant discussion in this paper focuses on various reefs. The term "reef" will be employed as the carbonate buildups are definitely rigid biological constructions following the work of Flügel (1982) in his description of buildups composed of the encrusting organism *Tubiphytes* (the dominant component in the Plomosas carbonates) that form stratigraphic reefs.

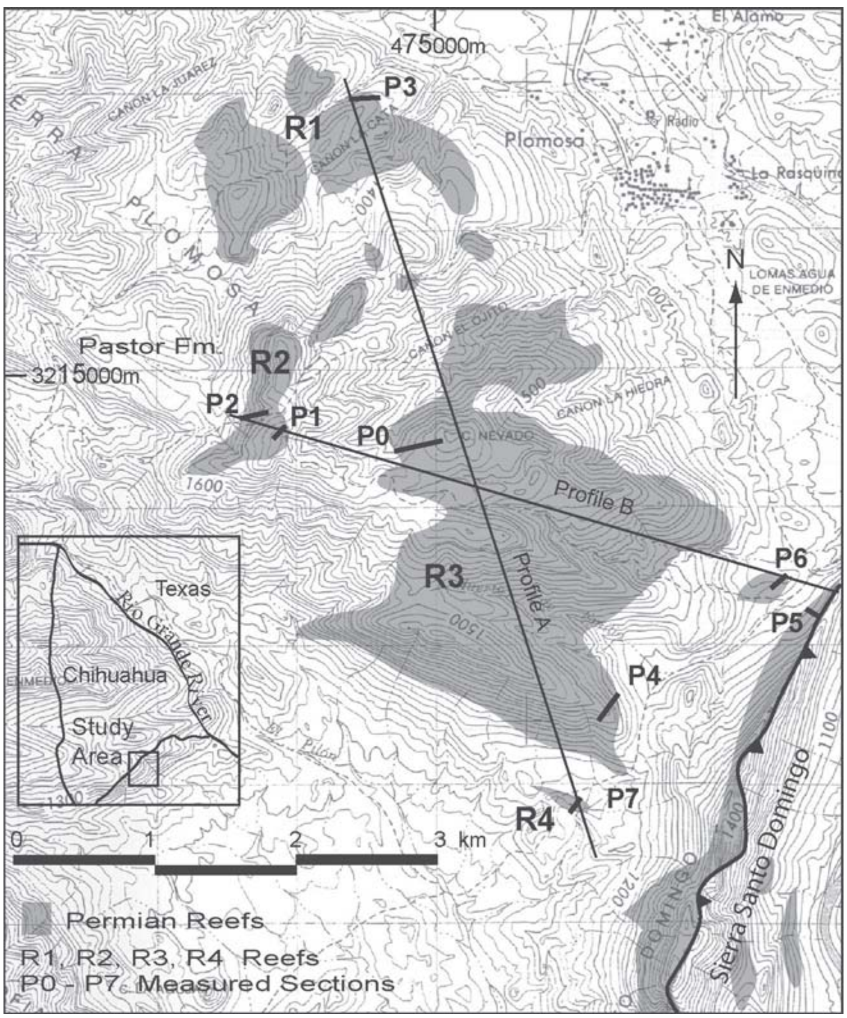

Figure 1. Location map with plan view of reefs (pattern) at Sierra Plomosa. P: sampling traverses; R: reef number designation. Modified from Bridges (1962).

STRATIGRAPHY OF THE PLOMOSAS FORMATION

Depending on stratigraphic interpretation, 1,060 m (Bridges, 1962) or up to 1,700 m (Montgomery, 1987) of Permian rocks belonging to the Plomosas Fm. are present in Sierra Plomosa. Permian reefs cap the east end of Sierra Plomosa extending to the east and southeast to the top of Sierra Santo Domingo (Figure 1). Reefs are present only in these areas. Rather than follow the idea of basically one reef, an idea with which Bridges (1962) seemed uncomfortable, it has been proposed that several reefs exist in Sierra Plomosa (Montgomery, 1987). The complex structural relationships produce a stratigraphy in which reef R1, the stratigraphically lowest reef on the northwest, is overlain by reef R2, reef R3, and ultimately reef R4 which is enclosed in rhythmic siltstone and shale (Figure 3). The stratigraphic position of the reefal rocks of Sierra Santo Domingo remains unclear due to structural complications (Figure 4).

The unconformities beneath the various reefs support this multi-reef view. On the northwest, reef R1 is underlain by a few meters of unfossiliferous red to gray shale that rests on massive crinoid grainstone of the Pastor Formation. Reef R2 rests with angular unconformity on a much thicker package (approximately 50 m) of gray-green siltstone that becomes more shaly upsection (Figure 4). Reef R1 appears to be a buildup enclosed in the terrigenous clastics on which reef R2 rests.

Separating reefs R2 and R3 is another package of similar siltstone, sandstone, and shale, that contains abundant conglomerate cropping out especially along the ridge east of Cerro Nevado (Figure 4). Dips in these clastics are chaotic; but there is little doubt that this package separates reefs R2 and R3.

At the base of section P4 (Figure 1), reef R3 is clearly resting with angular unconformity on siltstone and sandstone that are mostly sub- to immature quartz arenites to quartz wackes. The clastics are composed of varying amounts of feldspar and volcanic fragments both of which may be derived from the local Permian rhyolite and rare chert fragments of unknown origin. A rhyolite dated at 270 ± 30 Ma (de Cserna *et al.*, 1968) occurs in the clastic sequence stratigraphically above reef R2. Reef R3 is capped by two or three meters of conglomerate below approximately 150 meters of green to black, deep water, distal turbidite beds (Figure 3).

Reef R4 is enclosed in this apparent turbidite unit that ultimately grades into the informally named "green formation" above reef R4 (Figure 3). Located on the east end of Sierra Plomosa, the reef rocks of Sierra Santo Domingo may be part of or coeval with reef R3. The Permian section is capped by ridge-forming conglomerate (the "green formation") of unsubstantiated age(s).

Applying a model applicable to reef stratigraphy in the Permian Basin is not possible at Sierra Plomosa. The subreef rocks, where visible, are shale or sandstone and are almost uniformly nonfossiliferous. No characteristic dark, bioclastic, suprareef limestone has been discovered. No characteristic bioclastic talus deposits were discovered by Bridges (1962) nor were they in this study.

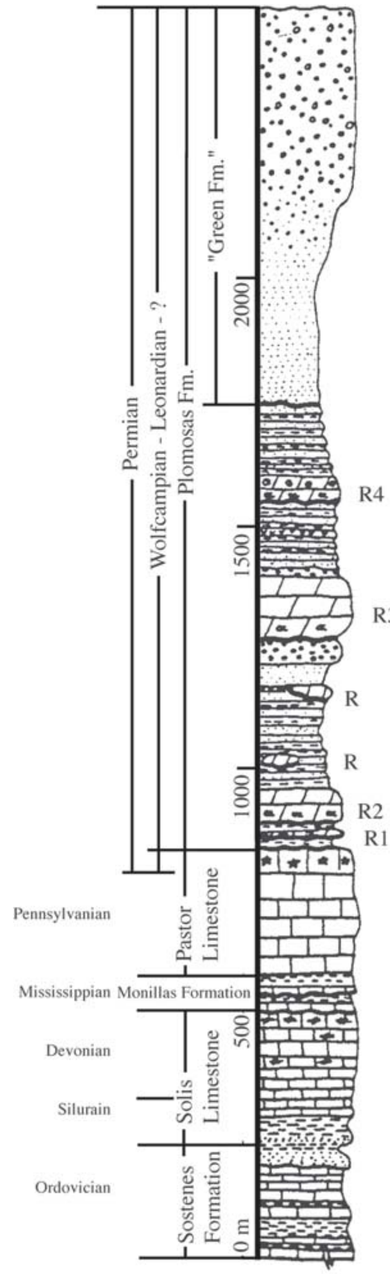

Figure 2. Composite stratigraphic column of Sierra Plomosa based on Bridges (1964) with the Permian being measured for this study.

Fossils

Aside from the fossils described in the limestone bodies, fossils in Sierra Plomosa are not abundant nor are they well-preserved due to extensive, hydrothermal mineralization and fresh water diagenesis.

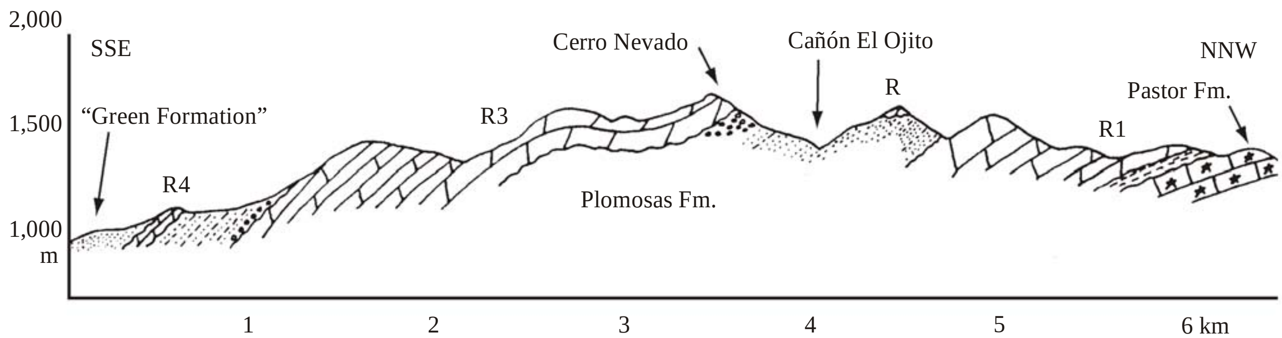

Figure 3. Cross section NNW-SSE through reefs at eastern end of Sierra Plomosa. Line of section in Figure 1.

The Pastor Formation ranges from Desmoinesian to Wolfcampian based on fusulinids and brachiopods (Bridges, 1962). The Plomosas Formation contains *in situ* fossils in the lower half of the section and they are found almost exclusively within the reef rocks. The reefs are Late Wolfcampian through at least Early Leonardian based on the presence of the fusulinids *Schwagerina* spp., *Triticites*, and *Parafusulina* and the sponge *Guadalupia* (Bridges, 1962). J.L. Wilson (personal communication, 1987) indicated Early Permian fusulinids have been found in lithic clasts and in the matrix of the clastic break in reef R3. The Early Leonardian ammonoid *Perrinites hilli* was collected from float (Bridges and DeFord, 1961). *Tubiphytes*, the seemingly omnipresent reefal organism at Plomosa, appeared in the Early Carboniferous and occurs through the Late Jurassic.

Microfacies analysis

Microfacies analysis of the reef rocks was accomplished by first collecting widely spaced traverses across the exposed reefs (P0-P7 in Figure 1). Four hundred small hand samples selected for allochem content visible with a 14x hand lens were taken at approximately two-meter intervals of stratigraphic thickness through each reef. Numerous additional samples were also collected from rocks enclosing each reef.

Boundstones and bioclastic packstones composed of encrusting organisms dominate the samples analyzed. Encrusting algae predominate in abundance and generic diversity. *Tubiphytes* is the dominant binder and is present throughout the reefs both *in situ* and as detrital grains. Some of the largest and best-developed *Tubiphytes* were found on the southeast side of reef R1. The encrusting alga *Sphaerocodium* (=*Coactilum*) was discovered in reefs R1 and R3. Platy algae are abundant occurring in reef R1. Dasycladacean algae, mostly *Mizzia*, are abundant grainstone components in certain horizons of reef R3. The calcareous red algae *Solenopora texana* was found encrusting the cryptostome bryozoan *Acanthocladia guadalupensis* in reef R3. *Girvanella*? lumps were found in reef R3. Endolithic algal coats are present throughout the reefs. Oncoids are present in hand sample near the stratigraphic top of reef R3.

Other important biological components of the reefs, many of which are binders, include foraminifera, bryozoans,

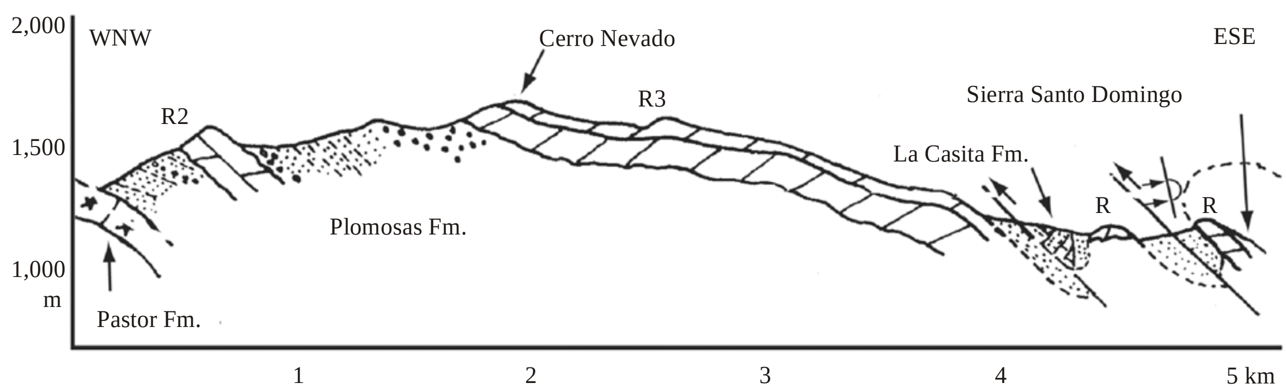

Figure 4. Cross section ESE-WNW through southeastern end of Sierra Plomosa to Sierra Santo Domingo. Line of section in Figure 1.

and rarer calcisponges. Foraminifera were common in all reefs. Bryozoans occur in buildup R1. Calcisponges are not abundant, but were found in reef R1. Large gastropods were found in the rocks of traverse P4. Various thin-sections include spicules. Quartz grains are sporadically present. Multiple phases of cementation are apparent within the reefs.

The dominance of facies-diagnostic foram, algal, and other binders as well as stromatactic fabric and oncoids and only rare fusulinids argues for deposition in shallow water of perhaps only a few meters depth with partial restriction from open marine circulation. Cortoids are common in many of the thin-sections especially in reef R4. The value of this presumed endolithic algae as an indicator of shallow water depths has been stressed by numerous authors. As summarized by Flügel (1982), too many difficulties exist to summarily assume cortoids are indicators of shallow water. This caution has been respected.

The thin-sections of traverses P0 and P1 (Figure 1) are difficult to interpret due to severe recrystallization. *Tubiphytes* ghosts are present in many thin-sections, but are only vaguely identifiable with the enhancement of an overlain kaolin slide.

Along traverse P2 (Table 1) foraminiferal and echinodermal packstone changes to *Tubiphytes* then to *Tubiphytes* and encrusting algal boundstone upsection. The limestone in the upper portion of the Pastor Limestone is clearly of encrusting algal origin. Many of the samples from traverse P2 are badly recrystallized making other paleoenvironmental conclusions difficult.

Examination of the thin sections of traverse P3 (Table 2) indicates a paleoenvironmental shift occurred in buildup R1. At the base of the reef, higher energy currents in open circulating lagoonal waters accumulated fusulinids and echinoderms. Following a small clastic break in carbonate sedimentation, accumulation of spicules ensued. The final phase of reef growth was marked by bryozoan development occurring perhaps along the proximal forereef margin. The upsection trend is transgressional from lagoon to forereef.

Tubiphytes packstones are most abundant throughout traverse P4 (Table 3). The *Tubiphytes* bindstones are differentiated from the packstones on the subjective basis of cohesiveness or the relative degree of attachment to other particles. Spicules are present in the lower part of section P4, but are not found with the dasycladaceans in the upper part of the section. Foraminifera and megafossils occur (in low percentages) in the uppermost part of this section.

Spicule-rich rocks on the Permian shelf are characteristically found near algal mounds (Wilson, 1975). The spicule-rich rocks lower in section P4 were likely deposited directly adjacent to a mound. Dasycladacean algae are lagoonal organisms that are occasionally moved and concentrated by currents in the backreef area (Flügel, 1982). The dasycladacean algae of the packstones and grainstones of the upper third of section P4 originated in protected lagoonal environments and collected in a high energy, backreef area. This southeastern area of buildup R3 exhibits a paleoenvironmental shift from lower energy, lagoonal, mound deposits to possibly higher energy dasycladacean backreef conditions.

The samples of traverse P5 are in very poor condition due to recrystallization, but *Tubiphytes* ghosts are present. Considerable searching was done in the field in an effort to locate less altered samples, but mineralization is widespread in the deformed rocks of Sierra Santo Domingo.

The small reef fragment collected as traverse P6 (Table 4) has not been assigned a reef number due to possible involvement in the Sierra Santo Domingo thrust. The reef is dominantly algal packstone to boundstone. Algae and fusulinids dominate.

Algal/foraminiferal packstone dominates reef R4 (Figure 3). Fusulinids are present throughout section P7 (Table 5) indicating better open marine circulation occurred during the deposition of reef R4 than with any of the other Plomosa reefs. The percentages of dasycladaceans, fusulinids, and small arenaceous foraminifera in these thin-sections are fairly constant throughout reef R4. The rocks of traverse P7 were probably deposited in backreef conditions. No clear intrareef bathymetric or environmental changes are indicated.

Thin-sections from reefs R1 (traverse P3) and R3 (traverse P4) suggest a transgressive trend during the formation of these reef rocks. There is no strong suggestion of any trend from the thin sections of the other Plomosa reefs.

The nearest, well-studied, *Tubiphytes* reefs are in the Finlay Mountains, Texas, the anatomy of which was described by Myers (1972). The lithologically and faunally diagnostic bounding strata that are present in each reef include: (1) a bioclastic base beneath the entire reef consisting of several horizons of calcirudite and/or fusulinids; (2) coarse, circumferential, talus deposits grading into fusulinid calcirudite; and (3) dark bioclastic, suprareef limestone with scattered bioclasts. The thicknesses and areal extent of the bounding units are variable, increasing in magnitude and scope with increasing buildup size. Utilizing the Permian Kemnitz field in New Mexico as a paleoecologic model (Malek-Aslani, 1970), *Tubiphytes* may be found almost exclusively in forereef to reef wall environments with bryozoans in the forereef. Dasycladacean algae occur mainly in the backreef area. Thus, distinct spatial facies arrangements define a clear paleogeographic polarity in Permian reefs of the Permian Basin.

Determination of polarity (shoreward- *vs.* seaward-facing margins) for the reefs at Sierra Plomosa is rendered difficult due to the lack of the distinct facies arrangement of the reefal bounding units of the Finlay Mountains reefs. There is no field evidence in Plomosa for an *in situ* reef wall, and no forereef talus has been discovered. Only one thin-section (in Traverse P2) exhibits the forereef talus-characteristic of subrounded lithoclast calcirudite in black micrite matrix.

Table 1. Microfacies data of traverse P2. Sample interval is 2 m of true thickness.

Microfacies analysis		**Location: Sierra Plomosa, Chihuahua; Traverse P2**																			
Thin section	**Classification**	**Allochems (percent)**																			**Other grains (percent)**
		Total Forams	Encrusting Forams	Arenaceous Forams	Tubular Forams	Fusulinids	Sponges	Spicules	Corals	Bryozoans	Mollusks	Echinoderms	Total Algae	Blue-green Algae	Dasycladacean Algae	Phylloid Algae	Tubiphytes	Calcispheres	Peloids	Aggregates	
P50	P	80				80						20									
P51	P	75	5			70						25									
P52	P	80				80															
P53	D											20									
P54	P	70				70						30									
P55	P	20				20						20	50				50				10
P56	P	5	5										60				60				35
P58	C																				
P68																					
P72	C																				
P73	C																				
P74	C																				
P76	W							70					30				30				
P77	BN												95				95				5
P78																					REXTL
P79	P												70				70		30		
P80	BN										5		85	50			35		10		
P81	BN?/D							3				10	85	55			30		2		
P82	D																				REXTL
P83	D																				REXTL
P84	BN											10	90				90				
P85	W												95				95				5
P86	BN/D											25	75				75				
P87	W/D												90				90				10
P88	W/D												90				90				10
P89	D																				REXTL
P90	D																				REXTL
P91	BN?/D												30				70				
P92	P?/D											90					90				10
P93	D																				REXTL
P94	R																				
P95	D/BN?																				REXTL
P96	D																				REXTL
P97	BN?/D												70				20				10
P99	BN?/D												70				20				10
P100	BN?/D												75				20				5

Note. W: Wackestone; P: Packstone; R: Rudstone; BN: Bindstone; D: Dolomite; C: Clastic; REXTL: Recrystallized.

Olistoliths

Compelling stratigraphic, paleontologic, and sedimentologic evidence exists in the Sierra Plomosa and Sierra Santo Domingo for an allochthonous origin of several of the algal reefs (especially R1, R2, R4). The Plomosa reefs are largely algal boundstone not unlike many in west Texas and New Mexico (Malek-Aslani, 1970; Myers, 1972). In terms of environment of origin, the reefs are discordant with the enclosing deep-water clastic turbidites. A clastic lens within buildup R3 (traverse P4) is of striking difference in lithology and texture from the clastics stratigraphically above and below buildup R3. The clastics above and below the reefs at Plomosa, while unlike the largely euxinic basinal rocks of the Permian Basin, are similar to basinal rocks in Chihuahua at Sierra del Cuervo (75 km to the W). An important difference between the deep-water rocks of the Permian Basin and those of Plomosa are the sporadically rich content of displaced, shallow water fossils in the Permian Basin. The clastic rocks of Plomosa and Ahumada are fossil-poor (Bridges, 1962; this study) lacking *in situ* and displaced shallow water fossils.

Table 2. Microfacies data of traverse P3. Sample interval is 2 m of true thickness.

Microfacies analysis		Location: Sierra Plomosa, Chihuahua; Traverse P3																			
Thin section	Classification	Allochems (percent)																			Other grains (percent)
		Total Forams	Encrusting Forams	Arenaceous Forams	Tubular Forams	Fusulinids	Sponges	Spicules	Bryozoans	Mollusks	Echinoderms	Total Algae	Blue-green Algae	Dasycladacean Algae	Phylloid Algae	Tubiphytes	Calcispheres	Peloids	Aggregates	Intraclasts	
P150	G	15				15				5	10	70				70					
P151	G	2				2					98										
P152	P	2				2					98										
P154	P	90				90					10										
P155	G										98										2
P156	P	5		5					5		50										40
P157	P	5				5					80	15				15					10
P158		20		5		15					80										
P159	P	15		5		15					50										35
P164	C																				
P165	C																				
P166	C																				
P167	C																				
P168	C																				
P169	C																				
P171	C																				
P172	C																				
P175	R																			95	5
P176	BN/D										10	90		45		45					
P177	BN/D										5	95		45		50					
P178	P	30				30					70										
P179	R										10									90	
P180	C																				
P181	P							10	10		5	75				75					
P182	P	10	10									70				70		20			
P183	P?							10			10	80				80					
P184	P							30				40						30			
P185	P							15			5	60				60		20			
P186	BN?							30				40				40		30			
P187	P							20			5	40				40		35			
P188	P	15	15					5		5		55				55		15			5
P189	BN	5	5					5				25				25		10		60	
P190	W																				REXTL
P191	BN/D								10			50				50					40, REXTL
P192	P																				REXTL
P193	W																				REXTL
P194	R							15	5		15	15				15		15		20	15
P195	BN						10		15			75				75					
P196	P/BN?	10						15	10			50				50		15			
P197	BN	5						10	10			65				65		10			
P198	P	20							15		5	60	20			40					
P199	P	20							20			60	60								
P200	P	20										10	10						60		10

Note. G: Grainstone; W: Wackestone; P: Packstone; R: Rudstone; BN: Bindstone; D: Dolomite; C: Clastic; REXTL: Recrystallized.

Any model of the Plomosa area must account for the repetitive and abrupt superposition of shallow water reefs in deep water clastics. Bridges (1962) suggested the Sierra Santo Domingo (and thus these reef rocks as well) was thrust into position. I concur with this assessment. Bridges (1962) also suggested reef R3 may have been thrust to the west. This second thrust is theoretically possible, but remains unconfirmed. The origin (emplacement) of reefs R1, R2, and R4 can better be explained by invoking tectonically induced, gravity sliding of reef blocks into deep water.

Table 3. Microfacies data of traverse P4. Sample interval is 2 m of true thickness.

Microfacies analysis		**Location: Sierra Plomosa, Chihuahua; Traverse P4**																				
Thin section	**Classification**	**Allochems (percent)**																				**Other grains (percent)**
		Total Forams	Encrusting Forams	Arenaceous Forams	Tubular Forams	Fusulinids	Sponges	Spicules	Corals	Bryozoans	Mollusks	Echinoderms	Total Algae	Blue-green Algae	Dasycladacean Algae	Phylloid Algae	Tubiphytes	Calcispheres	Peloids	Aggregates	Intraclasts	
P311	P	2						15			3		40				30		30			10
P312	W							20					60		10		50		20			
P313	M												95				95					5
P314	C																					
P315	W												98	8			90					2
P316	W											5	95	10			85					
P320	BN	2						10		4			74	24			50		10			
P321	BN												95	10			85					5
P322	M/D												95	10			85					5
P324	P							30		7			30				30	3	30			
P325	P/BN	5											75	20			53	2				20
P326	M/D																					REXTL
P327	P							15					70	30			40		15			
P328	P							5		20			70			50	20		5			
P329	BN							15					70	40			30		10			5
P331	BN							10					75	15			60		10			5
P332	BN							10					70	20			50		10			10
P333	P							20		15			35	5			30		20			10
P334	BN							15					80	5			75		5			
P335	BN												70				70		20			10
P336	W	5								3	7	1	40				40					44
P337	G									1	20		69	9	40	5	15					10
P338	G												98	98								2
P339	P	10						5		5	5	10	65		35	5	25					
P340	P/D												95		75		20					5
P341	P/D												80		60		20		20			
P342	P/D												95		55		40					5
P343	BN/D												98	98								2
P344	P/D	20				20							20				20					60
P345	P	15											30		30							55
P346	BN	10											70	30			40					20
P347	BN	5									5		90	35	15		40					
P348	BN	10									5		85	10	5		70					

Note. G: Grainstone; M: Mudstone; W: Wackestone; P: Packstone; BN: Bindstone; D: Dolomite; C: Clastic; REXTL: Recrystallized.

Allochthonous blocks up to a kilometer in length were documented in the Nubrigyn algal reefs of eastern Australia (Conaghan *et al.*, 1976). In California, olistoliths up to two kilometers in length were reported by Eastoe *et al.* (1987). In the Permian Basin, great volumes of displaced rocks exist (Rigby, 1958), the largest block being a 14.5 km by 25.5 km slab that was displaced 11 km (Guinan, 1971). Rohr *et al*. (2002) described both older on younger reef block stratigraphy and erosion along a carbonate margin as an emplacement mechanism.

Steep margins existed around the Permian Basin and at least along the northern margin of the Pedregosa Basin (Ross, 1967). Sedimentation in the Plomosa area was likely controlled by a steep, by-pass type of margin allowing emplacement of large carbonate blocks in deep-water, turbidite sediments. According to Enos and Moore (1983) large transported blocks originally described as *in situ* reefs may be found in fore-reef slope deposits. A crucial piece of evidence for such a scenario is finding older exotic blocks within younger enclosing rocks. This situation exists in Plomosa. Bridges (1962) reported fusulinids in conglomerate below the reef in the southern Sierra Santo Domingo (south of section P5) to be younger than fusulinds in the southeast part of reef R3.

Based on the presence of these reefs as exotic blocks, the following paleogeographic setting is envisioned. During the Early Permian the Plomosa algal reefs developed in shallow water accumulating adjacent to a steep margin

Table 4. Microfacies data of traverse P6. Sample interval is 2 m of true thickness.

Microfacies analysis		Location: Sierra Plomosa, Chihuahua; Traverse P6																				
Thin section	Classification	Allochems (percent)																				Other grains (percent)
		Total Forams	Encrusting Forams	Arenaceous Forams	Tubular Forams	Fusulinids	Sponges	Spicules	Corals	Bryozoans	Mollusks	Ostracods	Echinoderms	Total Algae	Blue-green Algae	Dasycladacean Algae	Phylloid Algae	Tubiphytes	Calcispheres	Peloids	Aggregates	Intraclasts	
P5-4	G	25				25								75	10	35		30					
P5-5	P	5	5											95	30	40		25					
P5-6	P/D																						REXTL
P5-7	P	20				20								65	5	35		25		15			
P5-8	BN											5		95	25			70					REXTL
P5-9	W	40				40																	60, REXTL
P5-10	BN	35				35						10		50	25	25				5			
P5-11																							REXTL

Note. G: Grainstone; W: Wackestone; P: Packstone; BN: Bindstone; D: Dolomite; REXTL: Recrystallized.

(Figure 5). Tectonic activity aided the periodic collapse of the undercut reefs. Detached reefs (probably R1, R2, R4, and perhaps R3) slid into the adjacent basin coming to rest with angular unconformity in and environmental discordance with the enclosing clastic sediments. There remains the possibility that reef R3, which outcrops over approximately five square km, and the reef rocks of Sierra Santo Domingo, were thrust into position (Bridges, 1962). A concerted effort was undertaken during this study to locate thrust diagnostic fault breccias associated with reef R3, but none were found. The unconformable stratigraphic stacking of reefs R1, R2, and R4 in deep water clastic sediments is

Table 5. Microfacies data of traverse P7. Sample interval is 2 m of true thickness.

Microfacies analysis		Location: Sierra Plomosa, Chihuahua; Traverse P7																			
Thin section	Classification	Allochems (percent)																			Other grains (percent)
		Total Forams	Encrusting Forams	Arenaceous Forams	Tubular Forams	Fusulinids	Sponges	Spicules	Corals	Bryozoans	Mollusks	Echinoderms	Total Algae	Blue-green Algae	Dasycladacean Algae	Phylloid Algae	Tubiphytes	Calcispheres	Peloids	Aggregates	Intraclasts	
P400	G/P	15				10				5			50	30			20		30			
P401	P	35		10		25							45	15	20		10		18			2
P402	BN/P	5											80	60	15		5		10			5
P403	W/P	5				5				2			83	15	8		60		10			
P404	W/P									10			80	60	10		10					10
P405	G	10											65	10	30		25		25			
P406																						
P407	P/G	15				5					2		68	35	8		25		15			
P408	P	20		20									60	20	15		25		20			
P409	P	40				40							60	10	30		20					
P410	P/G	35		20		15							50	25	10		15		15			
P411	P	70		45		25							30	20			10					
P412		30		30															65			5
P413	P	30		15		15							70	35	10		25					
P414	G	25											75	35	15		25					
P415																						
P416	BN	15								5			65	45			20					15

Note. G: Grainstone; W: Wackestone; P: Packstone; BN: Bindstone.

more complicated than can be adequately explained by thrusting. The lack of the typical *in-situ* strata surrounding Permian reefs, the absence of structural complications (especially with reefs R1, R2, and R4), and the diversity of the Plomosa reefs with respect to allochem content and bounding rocks support reef sliding. Thrusting would include reef bounding strata, probably would generate breccia, would present structural discontinuities, and would show repetition of similar packages of rock. Difficulty remains with the origin of R3 and whether the partly enclosing conglomerate indicates changing sea level or is a byproduct of thrusting. More detailed observations of the contact of reef R3 with the rocks beneath it might provide information that would help solve the reef emplacement problem.

CONCLUSIONS

Although not particularly fossiliferous, reefs in the Sierra Plomosa, Chihuahua are similar in faunal composition to other Permian buildups of the Permian Basin to the north. Unlike the typical reefs of the Permian Basin, the reefs of Plomosa are not underlain, overlain, or surrounded by the expected bioclastic deposits common to reefs of the Permian Basin. No breccia or other evidence of thrusting was discovered beneath the small reefs. The discovery of fauna in the clastics that is younger than overlying reef block argues for thrusting or sliding emplacement.

The suggestion is made that the Plomosa reef blocks are similar to others described in the Permian Basin as being allochthonous. Reef blocks R1, R2, R4, and possibly R3 may have detached from an undercut margin and subsequently slid into adjacent basinal clastics.

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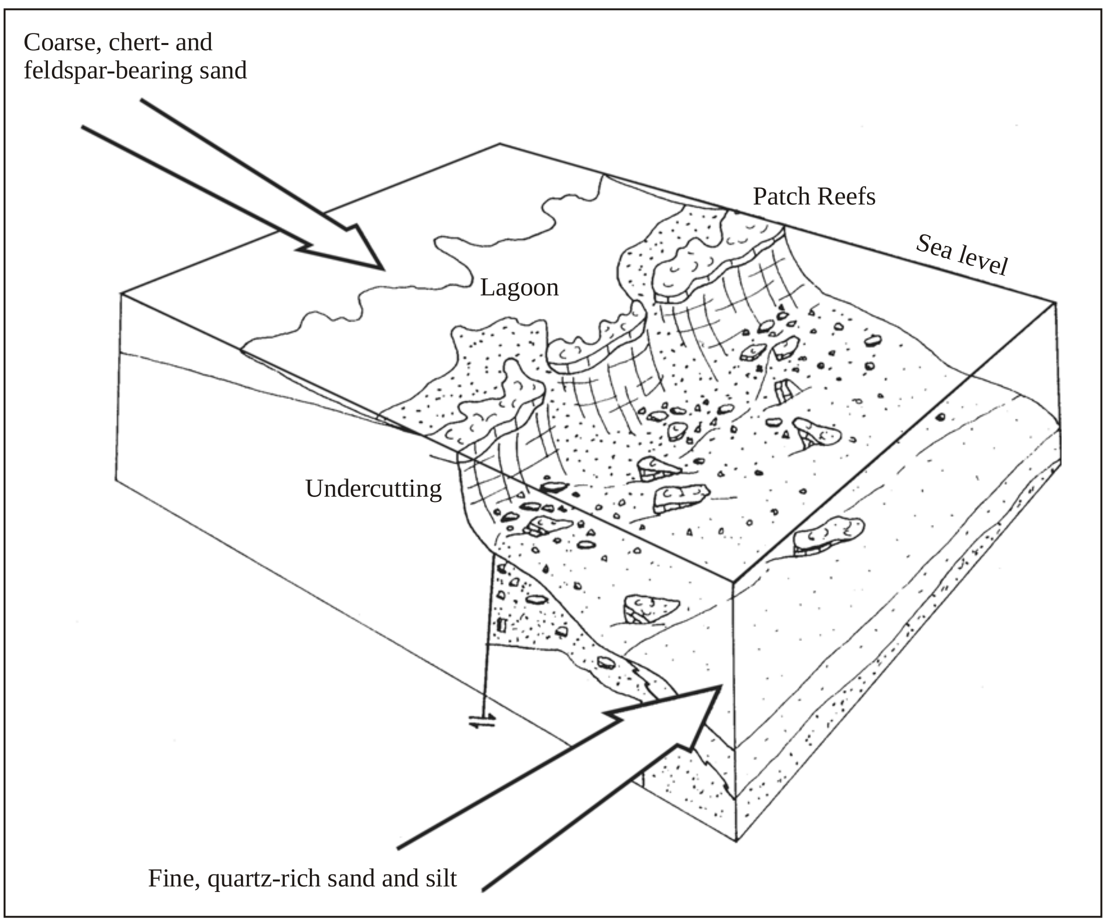

Figure 5. Proposed model for Sierra Plomosa reef formation and emplacement.

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