MIDDLE PERMIAN (LATE GUADALUPIAN) BACK-REEF CARBONATE OF PANTHER CANYON, APACHE MOUNTAINS, TRANS-PECOS TEXAS

by

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March 8, 2018

DEDICATION

I dedicate this master thesis to my patient and loving wife,

Katy Moore.

ABSTRACT

In the Apache Mountains of West Texas, Middle Permian (Guadalupian) strata a portion of the Delaware Basin part of the Capitan Reef is well exposed in many canyons that cut through the northern escarpment in the eastern part of the mountains. In Panther Canyon, the massive part of the Capitan Reef is well exposed and overlain by a stratigraphic sequence of lagoonal carbonate deposits referred to the Yates and Tansill Formations. At the entrance to Panther Canyon, two sections of these stratified carbonate rocks have been measured and described: the PC7 section, 31.8 meters thick, with eight distinctive packages and the PC8 section, 86 meters thick, with 18 packages. Faunal assemblages consisting of algae, sponges, brachiopods, ostracodes, bryozoans, and foraminifers, are Capitanian (Late Guadalupian, Middle Permian) in age. Fusulinids present are *Codonofusiella extensa*, *Yabeina texana*, *Paradoxiella pratti*, and *Reichelina lamarensis* and the ranges of these genera enable these sections to be biostratigraphically correlated to extensively studied sections in the nearby Guadalupe Mountains to the north (Skinner and Wilde, 1955; Tyrrell, 1962; Nestell and Nestell, 2006; Wilde et al., 1999). Microfacies analysis has revealed the stratified carbonate rocks were generated within reef, proximal back-reef, and lagoon depositional environments. The environmental conditions were controlled by the eustatic condition during the time of deposition. Lagoonal rocks appear to contain two distinct microfacies: (1) Biomicrite containing dasycladacean green algal remains was deposited on the lagoon floor in calm, marine water. A barrier reef would disrupt any wave action and protect the lagoon allowing for the deposition of fine carbonate mud amongst the skeletal remains of the lagoonal inhabitants. (2) Bioclastic intrasparite was deposited in barrier wash-over fans generated by storm events. Large, storm generated, high energy waves could wash over the barrier reef and disturb the fine carbonate

lagoonal sediment and transport it out of the barrier inlets. Reef detritus generated by wave action can mechanically erode the fore-reef structure and be transported shoreward and deposited within the lagoon. The resultant allochemical composition of the rocks would be fore-reef derived carbonate intraclasts amongst lagoonal faunal and floral components.

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INTRODUCTION AND BACKGROUND

1.1 Geographic Setting

The Apache Mountains are located along the western margin of the Delaware Basin in southeast Culberson County, Texas (figure 1.1) where they form a west-northwest trending, linear escarpment approximately 18mi (21km) in length located along the southeastern margin of the Diablo Plateau. Several canyons transversely cut the range exposing Permian (Leonardian to Ochoan) strata. Panther Canyon, the study area, is located 2.86 miles due south of the Jobe ranch house on the northern side of the range at 31°10'46.52"N and 104°17'58.88"W. The

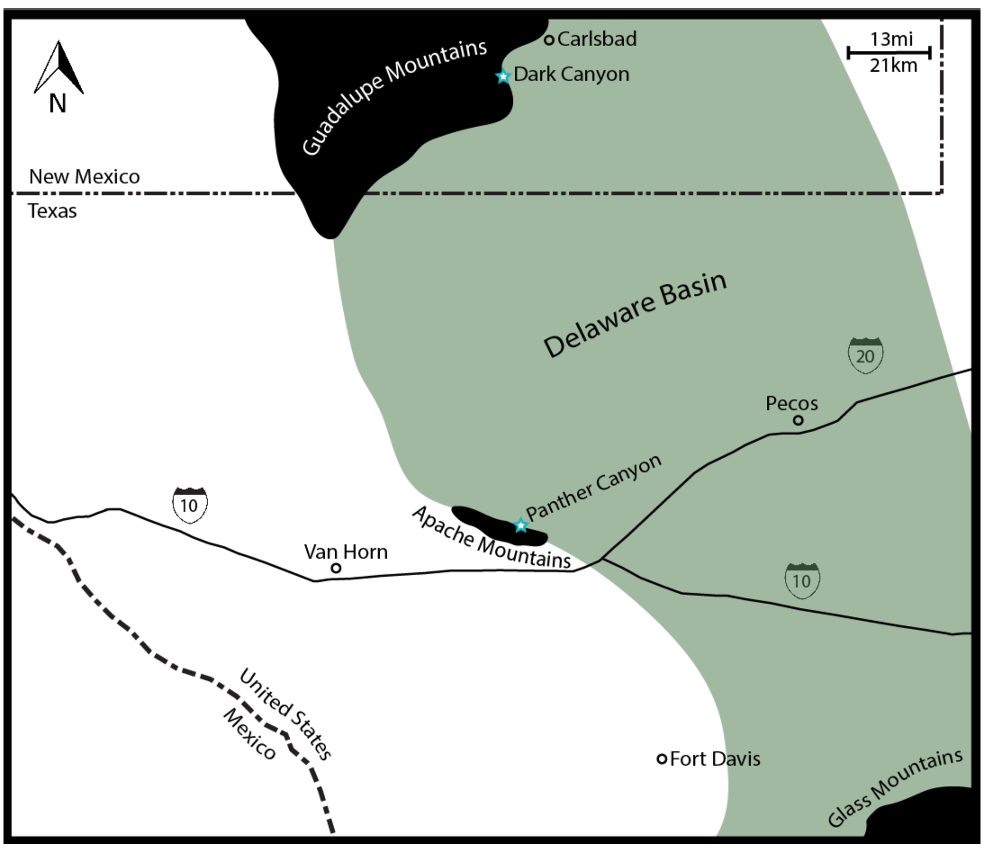

Figure 1.1 Regional map of Trans-Pecos Texas showing the geographic location of Panther Canyon and the Apache Mountains in relation to equivalent exposures fringing the Delaware Basin.

mountains are a part of the central part of the Texan Chihuahuan Desert ecoregion. Xerophyte vegetation, particularly *Agave lechugilla* and *Opuntia sp.*, are abundant and make trekking about the hills difficult. On one trip, the author had the tip of an *A. lechugilla* frond embedded in his leg for months before it finally worked its way out. The winters can be quite cold and the summers hot with frequent afternoon thundershowers which can lead to flash floods. The best time for field work is before opening day of deer-hunting season in the fall months when the weather is cool.

1.2 Previous Work

1.2.1 *Apache Mountains*

Little geological work has been conducted in the Apache Mountains since the 1960's because all of the land is privately owned and generally not accessible for geological research. The first survey of the Apaches was conducted by Richardson (1904, 1914) who produced a series of maps displaying the topography, geology, and selected geologic cross-sections of the Van Horn Quadrangle that included the western portion of the Apaches. Baker (1920) recognized the Trans-Pecos region of Texas to be structurally related to the Basin and Range Province of western North America. Lloyd (1929) was the first worker to propose the massive Capitan Limestone to be of reef origin in the Guadalupe Mountains, and Crandall (1929) agreed with Lloyd's analysis and correlated the Capitan Limestone Formation from the Guadalupes south to the Apaches. In his Ph.D. dissertation, McNutt (1948) described the geology of the southern part of the Delaware Mountains and the western sector of the Apaches. P. B. King (1949) included the Apaches in an aerial geologic map of Culberson and Hudspeth counties, which was the first to illustrate the structural features of the Apache Mountains area. DeFord (1951a, 1951b) interpreted the structural history of Trans-Pecos Texas and the Apache Mountains including a study of their tectonic history. The last published comprehensive geological study of the Apache Mountains was conducted by J.W. Wood (1965, 1968) who presented an overview of the regional geology and stratigraphy of the Apaches. He proposed that the stratigraphy was genetically equivalent in terms of its marginal relationship to the Delaware Basin to warrant applying the same nomenclature to the formations of the Apaches as those present in the Guadalupe Mountains. Such correlations are actually difficult because of different lithofacies complexes. However, some of the units can be biostratigraphically correlated. Wood presented a geologic map and two general cross-sections showing both the geographic position of each formation at the surface and the major structural elements of the Apache Mountains.

1.2.2 *Permian Back-reef*

The stratigraphic relationships and lithofacies of the Yates and Tansill back-reef strata have been studied extensively in the Guadalupe Mountains by several researchers, yet recognition of these equivalent units in the Apache Mountains has largely been neglected. The Yates Formation was defined and named by Gester and Hawley (1929) after the Yates oil field. DeFord and Riggs (1941) formally defined the Tansill Formation as the "post-Yates, pre-Salado limestone that had been recognized by many subsurface geologists". Tyrrell (1962, 1969) studied the time equivalent Tansill (back-reef) and Lamar (basin) carbonate strata in the Guadalupes and presented criteria for correlating them across the reef complex. Images of thin sections were included to illustrate the common carbonate fabrics present within both the back- and fore-reef provinces. He noted that the Tansill Formation was of lagoonal origin (Tyrrell, 1962) at Dark Canyon in the Guadalupes. Kendall (1969) illustrated several depositional systems, including shelf edge, apron, a barrier island and tidal flat complex, lagoons, and supratidal flats, that produced very specific lithofacies found in the Guadalupe Mountains area carbonate rocks. Later, Toomey and Cys (1977) described a west to east transverse across the Tansill-Capitan transitional zone at the mouth of Dark Canyon. They discussed the paleoecological and paleogeographical significance of the patterns present across the transition. They also concluded that the transition reflects a sequence of environmental facies belts which grade laterally from restricted carbonate depositional environments to increasingly more open marine environments. Newell et al. (1953) documented the environmental conditions and paleoecology of the Capitan reef complex and associated environments, recognizing three stratigraphic provinces: shelf, margin, and basin, and correlating time-equivalent formations across the three provinces. Hayes (1964) provided an in-depth monograph of geology of the southwest New Mexico portion of the Guadalupe Mountains. He notes that the Yates and Tansill Formations are laterally equivalent to the Capitan Limestone and grade into evaporite facies towards the shelfward direction opposite the Delaware Basin. Kerans and his colleagues (Kerans, 1995; Tinker, 1998; Kerans and Kempter, 2002; Rush and Kerans, 2010) have described the sequence stratigraphy of the Guadalupian carbonate platforms and established a hierarchy of third, fourth, and fifth order cycles which are identified by subaerial unconformities and/or karstification events.

1.2.3 *Back-reef Fauna*

The first extensive study of the West Texas Guadalupian fossil assemblage was published by Girty (1908). In his monograph Girty described and illustrated several hundred specimens of most marine invertebrate phyla. Johnson (1951) identified the presence of several forms of Permian calcareous algae including members of the families Codiaceae and Dasycladaceae collected from the Apache Mountains. Two equatorial sections of the small foraminiferal genus *Abadehella* Okimura and Ishii, 1975 were presented, but mistakenly assigned to the algal genus *Anthracoporella* Pia, 1920 by Johnson (Nestell and Nestell, 2006). Work on small foraminifers from the Permian of West Texas is sparse. Toomey and Cys (1977) listed a few genera found at the mouth of Dark Canyon including *Tetrataxis* Ehrenberg (mistakenly identified of the genus *Abadehella*, according to Nestell and Nestell, 2006), *Geinitzina* Spandel, *Globivalvulina* Schubert, and *Hemigordius* Schubert. Wilde (1999) noted the occurrence of *Abadehella* cf. *coniformis* Okimura and Ishii from the Reef Trail Member of the Bell Canyon Formation and from equivalent strata located at Seven Heart Gap in the Northwest Apache Mountains, and from the Altuda Formation from the western part of the Glass Mountains. In Lambert et al. (2002), Nestell and Nestell illustrated several genera of small foraminifers including *Pseudoammodiscus, Hemigordius, Rectocornuspira, Multidiscus, Calcitornella, Nodosaria, Ichthyolaria*, and *Abadehella.* Most recently, Nestell and Nestell (2006) described four new genera and sixteen new species of foraminifers from two Amoco cores taken from the north side of the mouth of Dark Canyon.

1.2.4 *Late Guadalupian Fusulinacea*

The fusulinacean distribution of the Permian of West Texas has been studied and documented by several workers over the years. Girty (1908) illustrated several large fusulinaceans from the Permian of West Texas. Dunbar and Skinner (1931) described three new genera including *Pseudofusulina, Parafusulina*, and *Polydiexodina.* Skinner and Wilde (1954) assigned six previously described genera including: *Boultonia* Lee (1927), *Minojapanella* Fujimoto and Kanuma (1953), *Codonofusiella* Dunbar and Skinner (1937), *Palaeofusulina* Deprat (1912), *Dunbarula* Ciry (1948), and *Gallowaiinella* Chen (1934) and one new genus, *Paraboultonia*, to the subfamily Boultoniinae. Subsequently, Skinner and Wilde (1955) presented and described four new fusulinacean species from the Guadalupe Mountains area including *Yabeina texana, Reichelina lamarensis, Codonofusiella extensa*, and *Paradoxiella pratti*. Tyrrell (1962, 1969) reported the presence of the species *Y. texana* Skinner and Wilde near the entrance of Dark Canyon. Wilde (1990) proposed that the top of the Guadalupian is marked by an interval containing *Paraboultonia*. Later he emended this claim (Wilde et al., 1999) by illustrating fusulinaceans from four Guadalupian fusulinacean zones: *Codonofusiella, Yabeina, Paradoxiella,* and *Reichelina,* and a fifth zone of *Paraboultonia* belonging entirely within the Lopingian (Upper Permian). Wilde and Lambert (!999) formally defined the post-Lamar strata of the Bell Canyon Formation as the Reef Trail Member, which is comprised of strata containing the *Yabeina, Paradoxiella,* and *Reichelina* zones. He then corroborated his fusulinacean zonation from the Altuda Formation in the Glass and Del Notre mountains between the towns of Alpine and Marathon, Texas (Wilde and Rudine, 2000). Nestell and Nestell (2006) point out that Wilde had been premature in assigning *Paraboultonia* zone to the Lopingian because the Guadalupian conodont succession had not been established. Lambert et al. (2002) documented the conodont succession that was missing in Wilde's conclusion from an outcrop in the western sector of the Apache Mountains and firmly established that the *Paraboultonia* zone is entirely Late Guadalupian in age. Currently, there are no known fusulinaceans of Lopingian age found in North America. Nestell, Nestell, and Wardlaw (personal communication, 2018) have a current manuscript on the Guadalupian fusulinacean, conodont and radiolarian zonations that has been submitted to an AAPG Memoir to be published in 2018.

1.3 Scope of the Current Study

The main thrust of the current study is to describe the depositional history of the back-reef (lagoonal) strata in two measured sections, PC7 and PC8, located on top of massive Capitan Reef strata at the mouth of Panther Canyon in the eastern sector of the Apache Mountains. Twenty six "packages" of carbonate lithofacies, 8 in PC7 and 18 in PC8, are described using Folk's Practical Petrographic Classification of Limestones (Folk, 1959). Each lithofacies is classified based on its allochemical modal percentage and composition as well as matrix composition, and is assigned to a specific depositional environment. The lithofacies evolution seen in each section is summarized and a depositional model is presented for the two sequences of strata. The term "package" is appropriate because the back-reef strata in the Apaches is difficult to confidently assign to any previously defined formation, although general lithofacies properties and faunal evidence, including fusulinacean and other small foraminiferal assemblages, provide biostratigraphic evidence for confident correlation to the Yates and Tansill Formations in the Guadalupe Mountains. However, each package in each of the two sections may itself contain distinct litho- and biofacies reflecting changes in depositional environmental conditions in that section through time. As mentioned previously, Wood (1968) argued that the same formational nomenclature could be applied in the Apaches as used in strata located 80km (50mi) to the North in the Guadalupe Mountains. The present study suggests that Delaware Basin marginal strata exposed on top of the massive Capitan Reef in the Apache Mountains area is lithologically and biostratigraphically similar to Yates and Tansill aged strata exposed in the Guadalupes. However, confident boundaries of these formations in the Apache Mountains are difficult to identify and prohibit the confident assignment of certain lithic packages in the Apaches to these two formations as defined in the Guadalupe Mountains.

1.4 Regional Geologic Setting

1.4.1 *West Texas Permian Reef*

Flexural subsidence of the crust north of the Ouachita thrust belt created the Permian Basin system located in West Texas and southeastern New Mexico. The northwestern lobe of the structurally complex Permian Basin is called the Delaware Basin (Figure 1.2). Three stratigraphic provinces are recognized: shelf, margin, and basin. Basinal strata are generally composed of thick sandstone beds with interbedded mudstone/siltstone and carbonate debris flows of varying thicknesses. Thick carbonate rock, both on the surface and subsurface, fringes the Delaware Basin margin representing a biologically productive reef complex with an array of associated carbonate depositional systems. Much of the reef extent is buried today, however, in the Guadalupe Mountains, Apache Mountains, and Glass Mountains reef rock is exposed on the surface (Figure 1.3). A broad shelf consisting of dolomite and terrigenous clastic strata is present a short distance behind the reef margin.

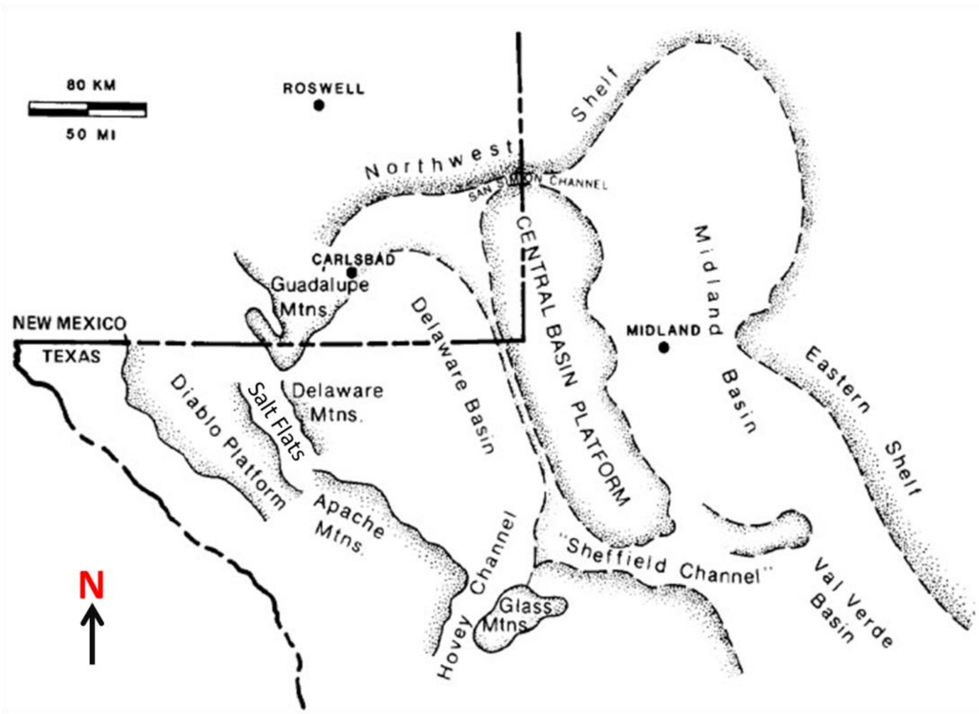

Figure 1.2 West Texas and southeast New Mexico Map of the Permian Basin showing the named structural elements including the Delaware Basin, the Guadalupe Mountains, and the Apache Mountains (After Ward et al., 1986)

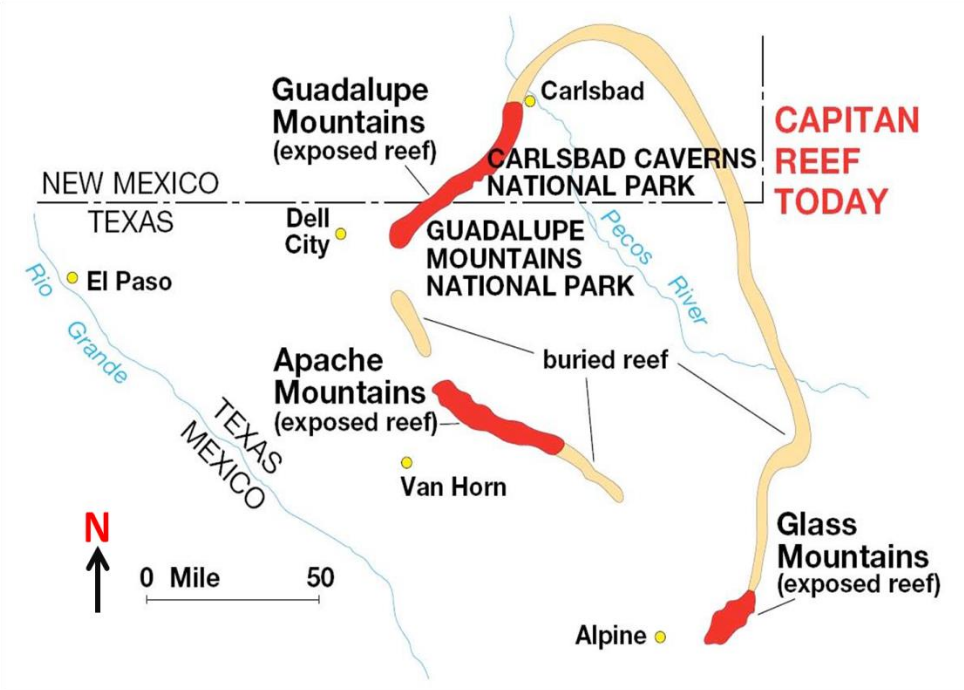

Figure 1.3 West Texas and southeast New Mexico map showing where the Capitan Reef is buried and exposed at the surface. (Image available from the Guadalupe Mountains National Park Service Website at: http://www.nps.gov/gumo/learn/nature/geologicformations.htm)

1.4.2 *Apache Mountains*

The Apache Mountains are a structurally distinct portion of the Cenozoic Delaware Uplift. Previous works considered the genetic relationship of the Apache segment of the uplift compared to the eastwardly tilted Guadalupe-Delaware tectonic block and determined that they are similar but separated from the main system by the Seven Heart graben complex in the western sector (Owen, 1951) and the west-northwest trending Stocks Fault to the north (Brand and DeFord, 1962). The positions of stratigraphically and environmentally equivalent rocks are situated about 600m (2000ft) lower in the Apache Mountains area than in the Guadalupe Mountains area (Wood, 1968). This discrepancy is explained by the gentle east-southeast dip of rock strata of the region.

The northeastern bounding feature of the Apache Mountains is the normally displaced Stocks Fault (Brand and DeFord, 1962). It extends from somewhere near Seven Heart Gap to approximately 30mi southeastward towards Lake Levinson (Figure 1.4). The northern block is downthrown in excess of 335m (1100ft) near Panther Canyon and is diminished to 150m (500ft) of displacement to the east (Brand and DeFord, 1962). Wood (1968) interpreted the extent of the fault based on aerial photographs and field observations. Three lines of evidence are presented by Wood to illustrate the fault: (1) small hills of Cretaceous aged limestone beds located less than 1000 feet north of the escarpment are positioned at the same elevation as older Permian rocks indicating that they were downthrown to their current position, (2) a sharp lineation near the base of the escarpment just west of the mouth of Panther Canyon can be seen in aerial photographs (as well as in Google Earth satellite images) (Figure 1.4), and (3) a mile west of Hurd Canyon (located nearby and to the east of Panther Canyon), a block of massive Permian limestone is positioned less than 100ft from Cretaceous sandstone and limestone.

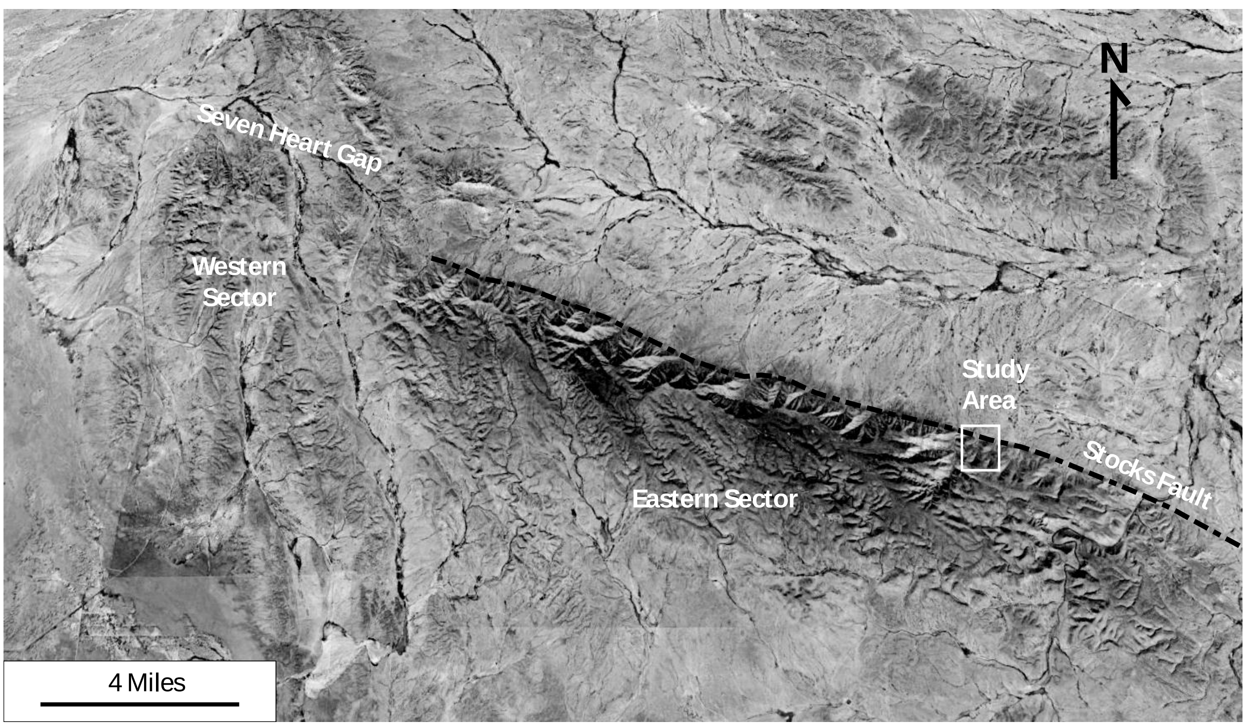

Figure 1.4 Google Earth image of the Apache Mountains showing the eastern and western sectors, after Wood (1968), as well as Stocks Fault, the northern bounding feature of the eastern sector.

Wood (1968) divided the Apaches into two sub-provinces: the western sector and the remaining two-thirds he called the eastern sector (Figure 1.4). The structure of the western sector is dominated by north-northwesterly trending horst-and-graben structures associated with the Late Oligocene Basin and Range tectonism. The structure in the east is controlled by the faulted Apache Anticline which plunges 76 feet per mile towards the southeast (Freeman, 1950). The anticline has a core consisting of a massive carbonate reef complex and is flanked by younger back-reef strata.

1.4.3 *Panther Canyon*

Since the Oligocene (25 Ma) meteoric water has weathered and eroded several canyons through the Apache Mountains perpendicular its strike. Panther Canyon is located in the northern face in the eastern sector, a close neighbor to Hurd Canyon to the east (Wood, 1968) (Figure 1.5). The length of Panther Canyon is approximately 3650m (12000 ft) from highest point on the spine of the ridge to the mouth of the canyon. Two separate drainage systems converge at the mouth of Panther Canyon. The base of the eastern wall slopes gently and becomes more inclined towards the top. Contact of the Yates/Tansill related strata with the massive Capitan Reef strata exposure is generally difficult to locate because of erosion and vegetation. The bottom two thirds of the canyon wall is massive Capitan Reef limestone (Wood, 1968). The remaining strata forming the top third of the canyon wall are layered beds of limestone and dolostone with a diverse array of litho- and biofacies (Wood, 1968).

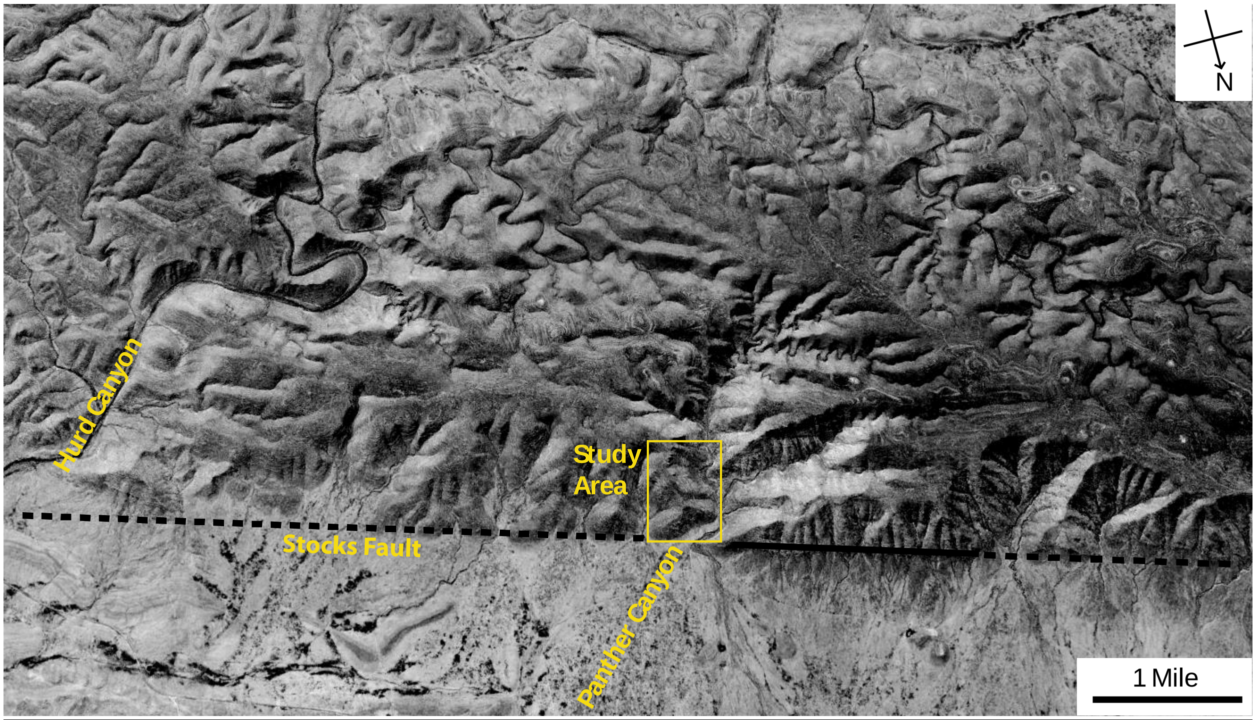

Figure 1.5 Google Earth image of Panther Canyon and neighboring Hurd Canyon which both cut into the northern escarpment of the Apache Mountains.

1.5 Tectonic History

Horak (1985) neatly summarized the tectonic history of the Permian Basin in which seven phases were recognized from the Late Precambrian to the present: (1) passive margin phase (Late Precambrian-Pennsylvanian), (2) collision of Gondwana and Laurentia (Middle Pennsylvanian-Middle Permian), (3) Permian Basin subsidence (Middle Permian-Middle Triassic), (4) stable platform (Middle Triassic-Late Cretaceous), (5) Laramide Orogeny (Late Cretaceous-Late Eocene), (6) regional volcanism (Late Eocene-Late Oligocene), and (7) Basin and Range extension (Horak, 1985). The Apache Mountain uplift to their current position first occurred during the Laramide Orogeny, halted during the Eocene/Oligocene volcanism, and continues to the present as a result of the Basin and Range tectonism.

1.6 Depositional Environment Indicators

1.6.1 *Introduction*

Interpretation of the paleoenvironments present during the time of sediment deposition and carbonate precipitation is based upon certain criteria related to the environmental conditions influencing the types of rocks that were formed. Water depth, topography, wave energy, water chemistry, meteorological events, climate, and faunal and floral influences, are only a few of the potential factors that can have a large impact on the lithofacies of rocks generated within carbonate producing environments. With careful observation of minute details preserved within the texture of the rock, an interpretation can be made to detail the environmental conditions responsible for generating the carbonate rocks found at Panther Canyon.

1.6.2 *Fossil Indicators*

The presence of in situ fossil remains can be a useful indicator for determining the depositional environment present during the time of formation of the rocks. Modern analogs of these constituents, both floral and faunal, can be used to make assumptions about the habitat conditions in which fossil organisms preferred to live.

1.6.2.1 *Mizzia sp.*

Kirkland and Chapman (1990) compared the fossil dasycladacean algal genus *Mizzia* Schubert, 1907 to the extant genus *Cymopolia* Lamouroux, 1916 with respect to morphology and geographic occurrence. Both genera are comprised of perforate balls forming branched stalks which attach to a muddy, sandy, or solid substrate. Both occur at latitudes between 30˚ North and South in warm, tropical to subtropical marine habitats. The paleohabitat of *Mizzia* has been interpreted from Late Permian tectonic reconstructions (Flügel, 1985). Also, a distinct decrease in faunal diversity when *Mizzia* is present is interpreted to mean they preferred to live in environments with very high salinity, which is consistent with the occurrence of the extant genus *Cymopolia*. Kirkland and Chapman (1990) concluded that these similarities warrant the interpretation of *Cymopolia* as a modern analog to *Mizzia*. Therefore, strata containing *Mizzia* can be interpreted to be formed in a warm, restricted lagoon with little wave agitation with a depositional environment likely below the fair-weather wave base in hypersaline water.

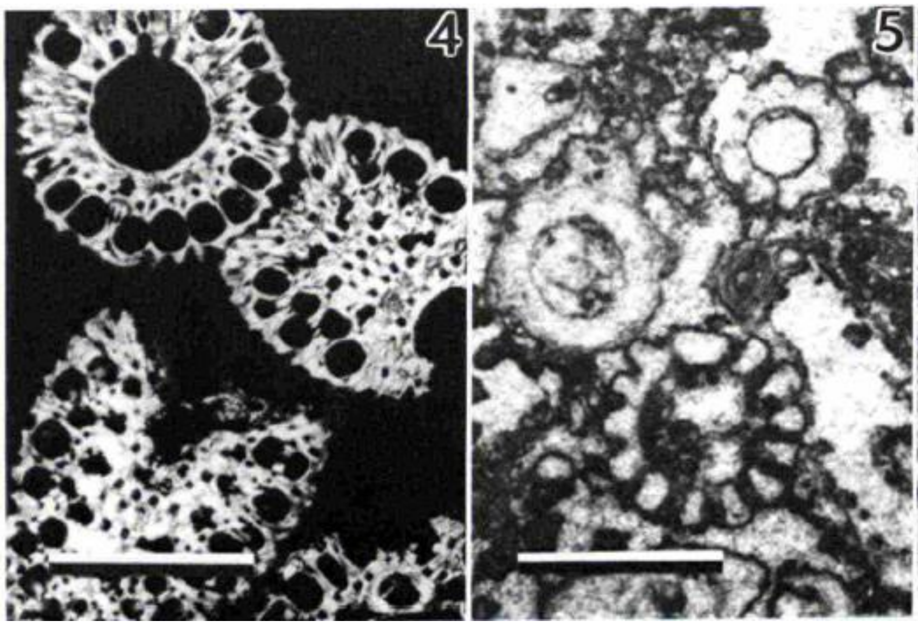

Figure 1.6 Photomicrographs showing morphologic similarities between (4) Cymopolia and (5) Mizzia (from Kirkland and Chapman, 1990). Scale bars = 1 mm.

1.6.3 *Petrologic Indicators*

Petrologic factors influencing depositional environment interpretation include allochemical composition, be it fossiliferous, intraclastic, peloidal, or oolitic, as well at the allochem frequency compared to the percentage of intergranular matrix and its composition (Folk, 1959; Dunham, 1962).

Fossils are the evidence of formerly living organisms preserved in the rock record and can be found in rock deposited within the habitat where the organism lived or they can be allochthonous. If the fossils travelled some distance before deposition, a significant proportion of broken skeletal fragments can be found amongst the allochem assemblage. If the fossils are largely intact, or the fossil lived a sedentary, colonial life habit (such as corals or bryozoans) the rock containing the fossils was likely deposited within the habitat where the organism lived (Kidwell et al., 1996)

Intraclasts (e.g., carbonate fragments) are pieces of consolidated materials eroded from sea-bottom beds and redeposited within the same basin from whence they were eroded. In general, significant energy is required to generate intraclasts such as a severe weather event or subaqueous gravity flows (Folk, 1959). Pellets are small, indiscriminate, smooth, carbonate spheres or ellipsoids lacking any internal structure, range in size from 0.03 to 0.15 mm in diameter, and tend to be extremely uniform and well sorted. Often, they are considered to be the fecal remains of marine invertebrates or fish (Folk, 1959). .

Ooids are small (< 2 mm), smooth carbonate spheres or ellipsoids that contain a small grain or fragment as a nucleus that is coated by a radial or concentric pattern of calcite layers. They are rare in modern seas but have been more common in the past (Opdyke and Wilkinson, 1990). Modern ooids are found in warm, tropical to subtropical waters such as in the Bahamas, Persian Gulf, and in the Mediterranean. Conditions promoting the formation of ooids include warm water, the presence of supersaturated solution where calcium carbonate can favorably precipitate out of suspension, the presence of abundant nuclei, be it quartz sand grains or broken skeletal fragments, to act as an initial place for the calcite to coat, gentle wave agitation where the ooids can roll about agglutinating chemical calcite from the water column, shallow water depth above the wave base, and the presence of microbes to aid in mineral precipitation.

The presence of a microcrystalline calcite ooze matrix indicates a low energy environment incapable of releasing the mud into suspension within the water column. Sparry calcite cement between carbonate grains indicates an environment with sufficient energy to wash away any fine-grained material leaving only the larger carbonate grains in contact with each other. These factors can be difficult to distinguish in a hand sample but are readily observable in thin section.

1.7 Field and Laboratory Methods

1.7.1 *Field Work*

Four separate field trips were conducted to the study location in Panther Canyon, on the northern escarpment of the Apace Mountains. The first trip was for reconnaissance to locate potential stratigraphic sections and targeted for study the stratified back-reef, lagoonal carbonate rock located at the mouth of Panther Canyon. These strata clearly show a transition from massive reef carbonate to stratified back-reef carbonate that occurs two thirds of the way up the first eastern hill at the mouth of the canyon. The first task was to locate this transition which proved to be more difficult than anticipated because the northern part of the area is largely covered by modern alluvium and desert flora, including grasses, scrub brushes, and cacti, and outcrops are often sparse and incomplete. Another problem was that the back-reef strata subtly grades into the massive reef complex proximal to the reef front and layering can be inconspicuous. Two sections were selected to measure: PC7 and PC8 (figure 1.6). The base of each section was taken at what was interpreted to be at or below the reef/back-reef transition.

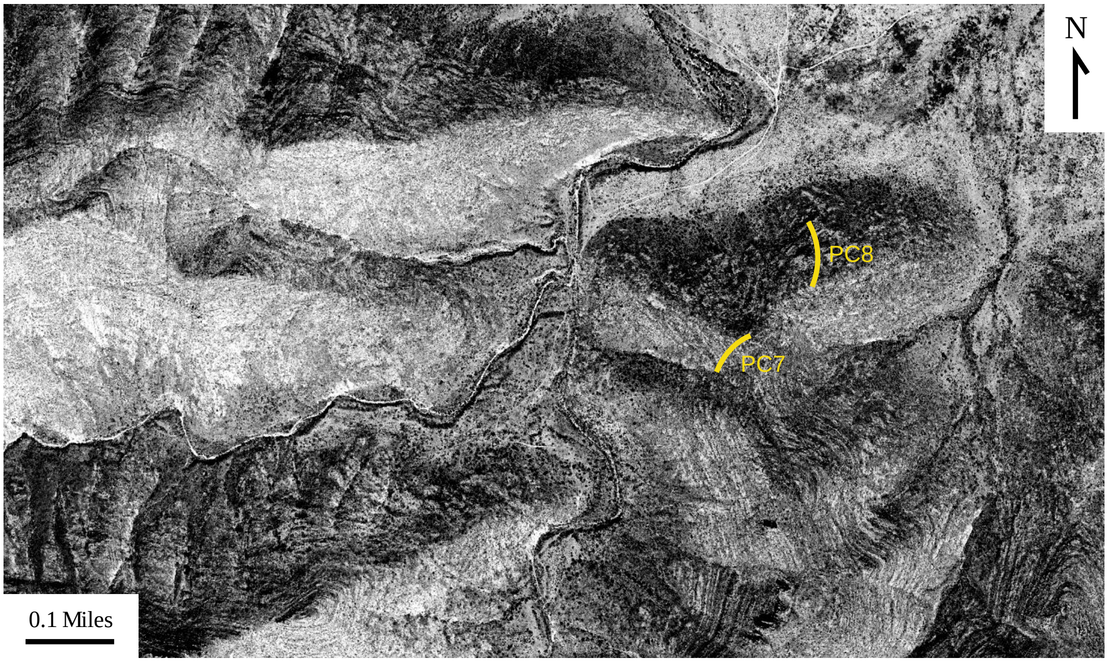

Figure 1.7 Google Earth image of the study location showing the position of the two measured sections: PC7 and PC8.

The second trip was to measure both sections using a Jacob's Staff and take samples at an interval of five meters for both lithologic and biostratigraphic analysis. The first section, PC7, contains eight packages of reef and back-reef carbonate strata. The second section, PC8, contains eighteen packages of reef and back-reef carbonate strata. Two kilogram sized samples were collected to be processed for lithological and paleontological analysis.

The third trip was intended to increase the sampling frequency to better resolve the depositional history of each section. Inclement weather, however, hampered the productivity of the trip and a fourth was deemed necessary.

The fourth and final trip was designed to resample both sections with a higher sampling interval frequency, 1.5 to 2 meters, where possible, to gain more data required to understand the depositional history of both sections and to construct a depositional model.

1.7.2 *Thin Section Processing*

Samples were processed in the thin section laboratory at the Department of Earth and Environmental Sciences, University of Texas at Arlington. One-centimeter thick slabs of rock were cut into one inch by three inch billets and polished. Each was then double mounted using epoxy to adhere the billets to two glass microscope slides. The double mounts were sliced down the middle between the two pieces of glass using a thin section machine creating two specimens per billet. These sections were then ground to an approximate thickness of thirty micrometers and polished using a plate of frosted glass and 1000 grit aluminum oxide abrasive powder. Once the appropriate thickness was achieved, the thin sections were cleaned and cover slips were applied using Canada balsam for adhesion.

1.7.3 Sample Photography and Microscopy

Samples were digitally scanned using Pacific Image Electronics Co.'s Sciscan 10,000 DPI microscope slide scanner. The scanner's resolution was satisfactory to visualize the microfacies present in each sample. SciView was the computer software used to interface with the scanner. Adobe Photoshop was used to edit and clarify and produce figures depicting the microfacies of each sample. When higher resolution was necessary, visualizing micron scale dolomite rhombs for example, Motic's BA310 Pol polarizing, petrographic light microscope with binocular 10x/20 eyepieces and 4x, 10x, 40x, and 60x objectives was used. Observing the matrix of carbonate rocks under crossed nicols with a rotating stage is a useful tool for differentiating calcite spar from micrite. Sparite crystals show uniform extinction when the stage is turned whereas micrite appears to show no extinction whatsoever.

CHAPTER 2

STRATIGRAPHY

2.1 Introduction

Three distinct provinces exist associated with the Delaware Basin system: shelf, margin, and basin. The shelf consists of a succession reef to shore of (1) calcarenite containing reef-derived bioclastic detritus, (2) pisolite, (3) fine-grained dolomite, (4) evaporites, (5) red beds (fine-grained sandstone and siltsone containing iron cement), and sandstone and gypsum 30 miles from the reef-front (Newell et al., 1953). The shelf margin is marked by a massive carbonate reef system as thick as 2000 m (6560 ft). The dominant reef-building faunas include sponges, bryozoans, and algae. Reef talus extends onto the slope toward the basin. Basinal strata are predominantly composed of thick sandstone units containing interbedded limestone and shale. Within the general study area, strata from the outer shelf and reef margin are present, but, the lithology in the sections studied is nearly all limestone with dolostone towards the top.

Wood (1968) suggested the Permian age rocks in the Apache Mountains relate to named strata along the Northwestern Shelf of the Delaware Basin sufficiently enough to warrant the use of the same formation and member names. In the present work, Wood's suggestion is followed by using the formational names of Capitan, Yates, and Tansill. Much work has been done in equivalent back-reef and reef margin strata to the north in the Guadalupe Mountains and to the southeast in the Glass Mountains to better constrain the overall Delaware Basin margin stratigraphic system since Wood conducted his study (Tyrrell et al., 1978; Wilde, 1990; Wardlaw and Rudine, 2000; Wilde, 2000l; Wilde and Rudine, 2000; Lambert et al., 2002; Nestell and Nestell, 2006). New evidence in the current study will aid better delineation of formation boundaries in the back-reef setting within the Apache Mountains.

Three formations are recognized in the study area: Capitan, Yates, and Tansill. The Yates and

Tansill, the upper two formations of the Artesia Group, can be found in the back-reef, outer-shelf province (Figure 2.1). The Capitan Formation represents the reef margin province.

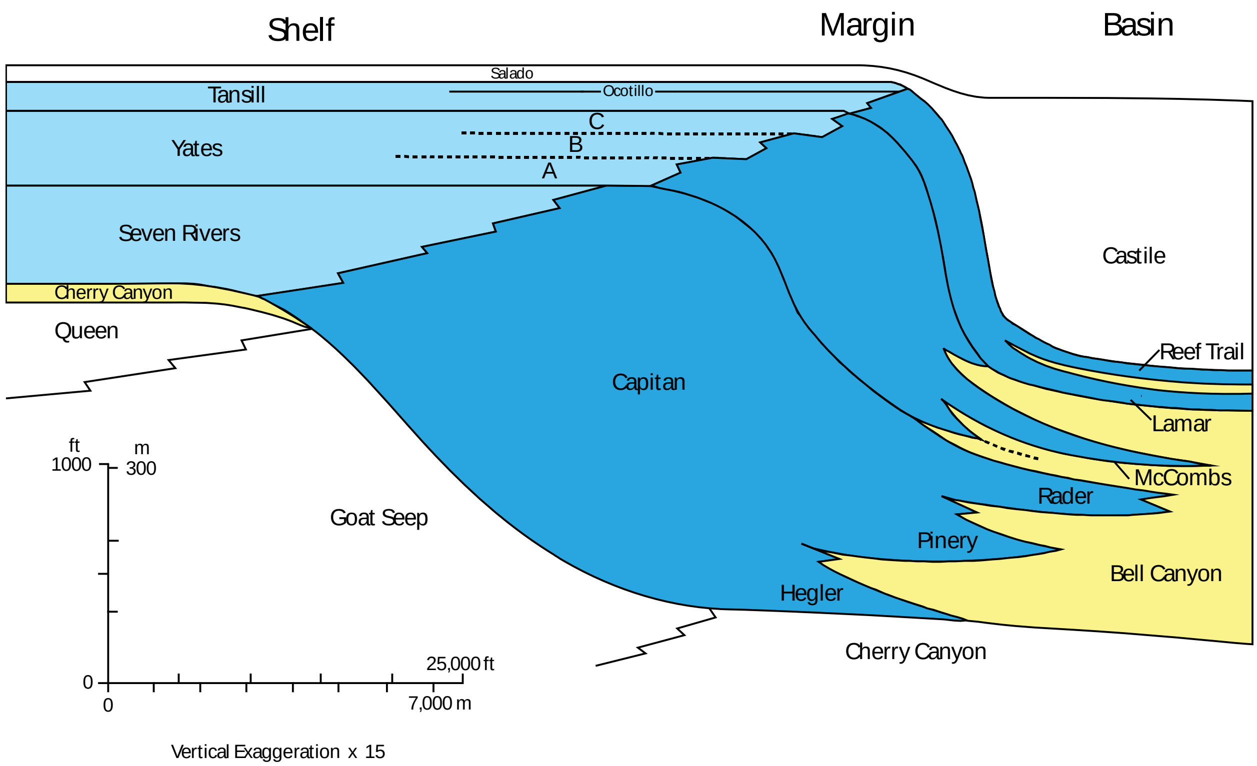

Figure 2.1 Shelf—margin–basin transect in the Guadalupe mountains area showing stratal relationships (modified from Garber et al., 1989; Tyrrell, 2002; Rush and Kerans, 2010)

The onset of Capitan Formation deposition occurred around the same time as the end of the Grayburg Formation deposition and the beginning of the Queen Formation deposition. Capitan deposition continued contemporaneous with that of the Seven Rivers, Yates, and Tansill Formations. Each of the back-reef formations grade from evaporites and terrigenous clastics into carbonate proximal to the reef margin and merge with the massive reef structure at the margin (Newell et al., 1953).

2.2 Capitan Formation

2.2.1 *Definition and Distribution*

The famous Capitan Reef fringes the entire rim of the Delaware Basin except for gaps across the Hovey Channel to the Southwest and the Sheffield Channel to the Southeast. Many researchers from across the globe studyied the Capitan Reef, which is one of the best examples of an exhumed ancient carbonate reef complexes in the world (Lloyd, 1929; Newell et al., 1953; Hayes; 1964; Toomey and Cys, 1977; Kirkland-George, 1992). The Capitan Formation was first described from the Guadalupe Mountains and named after El Capitan, the southernmost peak of the range (Richardson, 1904).

Two formations have been recognized which make up the reef, the Goat Seep Formation (middle Wordian) and the younger Capitan Formation (upper Wordian–Capitanian). Both formations consist of two parts: a thick, massive carbonate reef unit which grades into an approximately 35˚ dipping slope of talus basin-ward. Reef construction began during the deposition of the Wolfcampian as small patch reefs that eventually grew with time into massive barrier reefs during the Guadalupian that restricted marine circulation and sedimentation between the back-reef lagoon and the open ocean (Newell et al., 1953). The talus facies consist of aprons of reef derived detritus stretching far into the basin. Within the Apache Mountains, strata equivalaent to the Goat Seep Formation is not represented at the surface, so the Capitan Formation will be the focus of this section.

The most striking characteristic of the Capitan Formation is the massive, seemingly unbedded nature of strata of the formation which is resultant from the continuous labor of reef-building organisms which secrete carbonate for the construction of the hard parts of their bodies.

The thickness of the reef in the Guadalupe Mountains ranges from 400-1200 feet and the width perpendicular to the long axis ranges from 2.5 to 3.5 miles wide (Newell et al., 1953). Loci of reef buildup migrated forwards and backwards within this range as a function of the changing eustatic conditions during deposition. The boundaries of the reef, and its back-reef and fore-reef counterparts, are generally ill-defined as they are comprised of reef derived bioclastic rocks and detritus. The primary delineation of reef and back-reef is marked be the onset of bedding between layers in the back-reef zone.

The Capitan Limestone laterally grades in the back-reef zone into the Seven Rivers, Yates, and Tansill Formations, the upper formations of the Artesia Group. In the fore-reef, reef talus grades into large sandstone wedges and the named limestone members of the basinal Bell Canyon Formation. Strata overlying the Capitan Formation belongs to the Castile and Rustler Formations which represent a longstanding lowstand where sea eventually evaporated and left behind thick sequences of evaporite minerals such as gypsum, anhydrite, and salt. Where the Capitan reef is exposed to the surface in the Guadalupe and Apache mountains most of these evaporite deposits are eroded away.

Wood (1968) refers to the Capitan Formation as the core of the Apache Mountains. The base of the Capitan Formation lies below the surface in the Eastern Sector of the range. Back-reef strata of the Seven Rivers Formation in the South and Yates Formation on the north side of the mountains directly overly the reef due to reef migration related to the eustatic condition through time. At the mouth of Panther Canyon, the thickness from where the massive reef facies break through the desert surface to the onset of bedded strata is 250 feet and the Capitan strata transition vertically to the Yates. In Hurd Canyon to the east, thickly bedded Seven Rivers strata merge northward into 500 feet of Capitan dolostone containing no semblance of the original texture or structure due to dolomitization (Wood, 1968). Beyond Hurd Canyon towards the east the Capitan Formation is below the surface due to the plunge of the Apache Anticline.

The western sector of the Apache Mountains contains both the massive reef facies as well as the reef talus, strata of which slope towards the basin. In the northern portion of the Apaches south of Seven Heart Gap, a contact can be seen between the two facies which marks the transition from reef to fore-reef talus (Wood, 1968).

2.2.2 *Lithology and Fossils*

From the Guadalupe Mountains Newell et al. (1953, page 38) describe the massive Capitan lithology as "fine-grained-to-aphanitic, white, calcite limestone, with conchoidal-to-splintery fracture, containing abundant sycon sponges, stromatolites, coralline algae, brachiopods, bryozoans, and vugs filled with fibrous calcite."

Reef-dwelling foraminifers including many fusulinaceans are common, particularly the large, elongate *Polydiexodina capitanensis* Dunbar and Skinner, 1931 and *P. shumardi* Dunbar and Skinner, 1931 within the middle portion of the reef. Populations of *Polydiexodina* are often found with their tests aligned parallel to the paleo-current direction. *Rauserella erratica* Dunbar, 1944 is also common.

Reef-building faunas from the massive facies were cemented *in situ* as opposed to the reef talus where constituent grains were transported to their final locations in much deeper water by vigorous wave action or turbidity currents. The talus facies vary widely in texture from medium-grained grainstone to bolder-sized breccia, and the allochems tend to be more fractured than in the reef (Newell et. al., 1953). They can be composed of dolomite or limestone with no specific or regular distribution. Diagenesis effects are conspicuously absent, likely attributable to the great water depth of their deposition. The primary texture is usually well preserved (Newell et al., 1953).

The Capitan Formation in the Apache Mountains is composed of very light gray fossiliferous limestone in some areas and darker gray crystalline dolomite in others. Dolomitization varies widely from the rock fabric being completely devoid of any relict structure or texture to only slightly altered in others. Diagenetic dolomite tends to be very patchy and inconsistent due to the heterogeneity of porosity throughout the unit.

The 250-foot Panther Canyon section of the Capitan contains a fine-grained dolomite in the upper and lower portions that can vary from intraclastic, pelletiferous, to fossiliferous dolomicrite containing dasycladacean algae, fusulinaceans, and other small benthic foraminifers. The middle interval is limestone ranging from fusulinid biosparite, fossiliferous intrasparite, and foraminifer-algal biomicrite to a dolomitized bryozoan biolithite (Wood, 1968).

2.2.3 *Age*

The Capitan Formation deposition began during the middle part of the Wordian Stage of the Guadalupian Series (approximately 255 MA) and continued to the end of the Capitanian Stage of the Guadalupian (approximately 251 MA) based on fusulinacean and conodont zonation (Nestell and Nestell, 2006; Glenister et al., 1992, 1999; Wilde, 2000; Wardlaw, 2004). The base of the Capitan Formation occurs within the *Jinogondolella asserata* conodont zone which marks the base of the Wordian Stage. Within the lower part of the Capitan Formation, a zone of *J. postserrata* occurs marking the beginning of the Capitanian Stage. The next conodont zone, *Clarkina postbitteri postbitteri,* marks the base of the Lopingian Series. No *C. postbitteri postbitteri* zone occurs in the Capitan Formation in West Texas, indicating that the deposition of the formation ceased near the end of the Guadalupian. The youngest occurrence of the fusulinacean genus *Parafusulina* is Wordian in age and below the base of the Capitan Formation. The genus *Polydiexodina* begins in the Hegler Member of the Bell Canyon Formation in the base of the Capitan Formation and persists into McCombs Member of the Bell Canyon Formation. After the extinction of *Polydiexodina*, a small, ellipsoidal, Tethyan fusulinid genus *Yabeina* occurs towards in the Yates – Tansill transitional interval (Wardlaw, 2004; Nestell and Nestell, 2006.)

2.3 Yates Formation

2.3.1 *Definition and Distribution*

The original definition of the Yates Formation was made by Gester and Hawley (1929). It was named after the acclaimed rancher, store proprietor, oil man, and landowner of the Yates Oil field, Ira Griffith Yates, Jr. The formation was redefined by Mean and Yarbrough (1961) to include the entire section between the Seven Rivers and Tansill Formations. Sumrall's Douglas well No. 5 within the Yates field was designated the type section. In the Delaware Basin area, the Yates Formation conformably overlies the Seven Rivers formation and is truncated conformably by the Tansill Formation.

Surface exposures of Yates strata are located along the Northwestern Shelf of the Delaware Basin in West Texas and southeastern New Mexico within several deep canyons that cut through the Southeastern escarpment of the Guadalupe Mountains, most notably in McKittrick Canyon. Newell et al. (1953, page 132) noted "three distinctive beds of dolomite (A, B, and C) separated by persistent beds of quartz sandstone." The thickness ranges from 240 feet shelfward to 350 near the reef (DeFord and Riggs, 1941). The Eastern shelf of the Basin, the

Central Basin Platform, also contains Yates Formation but only in the subsurface. In the Glass Mountains to the South, Yates equivalent strata are assigned to the middle part of the Altuda Formation (Wilde and Rudine, 2000).

The Yates Formation is the most extensively exposed formation within the Eastern sector of the Apache Mountains. Wood (1968, page 15) describes the Yates Formation in the Apaches as a "sequence of thinly-bedded and medium-bedded alternating siltstone or very fine sandstone and dolomite." At Hurd Canyon to the east of the study area, the Yates strata consists of 120 ft of siltstone and silty carbonate (Wood, 1968). Further to the South, away from the reef at Hurd Draw the Yates beds reach 150 ft and contain siltstone, dolostone, and very fine sandstone. Near the reef the beds are 100 ft thick and are predominantly dolostone and limestone. The formation shows a thinning trend as it approaches the reef margin. This thinning is due to the pinching out of terrigenous clastics and the merging of the back-reef carbonate with the reef structure (Motts, 1972).

2.3.2 *Lithology and Fossils*

Three zones representing the inner, middle and outer shelf have been distinguished in the Yates Formation by lateral lithologic variation (Mean and Yarbrough, 1961). The inner shelf is predominantly red siltstone with interbedded red sandstone and sabkha evaporites. The middle shelf contains sandstone and more evaporites. The outer shelf proximal to the reef margin is predominately carbonate with fine-grained sandstone stringers. Each zone contains frosted sand sized quartz grains among their constituents (Mean and Yarbrough, 1961).

The siltstone redbeds of the inner shelf form a broad, 90-100-mile-wide belt parallel to the reef margin with beds ranging in thickness from 150-200 feet. Lithologically they consist of red siltstone, fine-grained red sandstone, and 10-foot-thick anhydrite beds which can be traced for miles. The grains are commonly cemented by halite or anhydrite. These beds pinch out where they were bounded by continental deposits located distally from the reef and they grade into sandstone in the middle shelf. (Newell et al., 1953)

The sandstone facies of the middle shelf have historically been one of the most productive intervals in terms of oil and gas production within the Central Basin Platform. They consist of a 5-7-mile-wide strip of gray to red fine-grained sandstone parallel to the reef margin with thickness ranging from 240-340 feet. Medium- to coarse-grained frosted quartz clasts float in the fine-grained sand matrix making this interval lithologically distinct and recognizable. The sandstone is quite permeable in places where it lacks cementation and is quite impermeable where the grains are cemented by anhydrite or dolomite. The sandstone facies also contain thin, laterally discontinuous beds of red and green shale, pink to gray dolomite, and white anhydrite (Mean and Yarbrough, 1961).

The outer shelf is dominantly carbonate often exceeding 300 feet thick and forms a band 2-4 miles wide proximal and parallel to the reef margin (Newell et al., 1953). Dolomite is the dominant lithology of the formation, but local limestone beds are common, particularly near reef strata of the Capitan Formation. Texturally the limestone beds tend to be allochemically abundant, packstone to grainstone, composed of intraclasts and fossils grains. Wood (1968) suggests the intraclasts represent reef detritus deposited in shallow, highly agitated near-reef shoals in the back-reef area. Algal bioherms developed in places with limited wave action.

Sandstone stringers can be interbedded within the outer shelf carbonate and often extend into the reef margin. They are very fine-grained, gray or red in color, and cemented by dolomite.

The inner and middle-shelf belts lack significant fossil populations (Mean and Yarbrough, 1961). The outer shelf, in contrast, was a highly productive ecosystem, the evidence of which was preserved in the rock. Fusulinaceans are common throughout the Yates carbonate facies. *Polydiexodina* Dunbar and Skinner is abundantly represented ranging from the Seven Rivers Formation to the middle part (Unit B) of the Yates Formation (Newell et al., 1953). At the study location, *Polydiexodina* is found only within the Capitan Formation in strata time correlative with Unit B of the Yates Formation. The preserved orientation of these elongate fusulinid tests are aligned parallel to the paleo-current direction during the time of deposition. *Codonofusiella extensa* Skinner and Wilde can be found ranging from the upper part (Unit C) of the Yates Formation and continues into the lower part of the Tansill Formation. *Reichelina?* sp. and *Rauserella bengeensis* Wilde and Rudine were noted by Nestell and Nestell (2006) within the upper part of the Yates Formation. Other small benthic foraminifers are present within the Yates carbonate facies (Nestell and Nestell, 2006).

2.3.3 *Age*

Based on the results of many workers and using the fusulinid and conodont zonation, the deposition of the Yates Formation occurred during the middle part of the Capitanian of the late Guadalupian, roughly 265.9-262.4 m.a. (Wilde, 1990; Glenister et al., 1992, 1999; Wilde and Rudine, 2000; Yang and Yancey, 2000; Wardlaw, 2004).

2.4 Tansill Formation

2.4.1 *Definition and Distribution*

The post-Yates, pre-Salado strata was widely recognized by subsurface geologists though its type section was only formally defined in 1941 by DeFord and Riggs at an outcrop along the bank of the Pecos River on U.S. Highway 285, 3.7 miles from the Eddy County Courthouse in Carlsbad, New Mexico. The Tansill Formation is defined as "a body of limestone, silt, and anhydrite that forms a widespread layer of the earth's crust in southeastern New Mexico and West Texas." (DeFord and Riggs, 1941, page 1715) The limestone portion is located around the rim of the Delaware Basin where its strata can often be seen grading into strata of the Capitan Formation. The silt and anhydrite are distributed shelf-ward. At the type locality, the formation is 123.5 feet thick and is composed mostly of limestone with interbedded fine-grained sandstone and siltstone. A prominent 13.5-foot-thick silty sandstone towards the top of the type section was designated as the Ocotillo Member of the Tansill Formation (DeFord and Riggs, 1941). They reported the Ocotillo Member is traceable for over 100 miles in the subsurface. The type section is 4 miles shelf-ward of the reef margin and is considerably thinner than equivalent horizons nearer to the reef. In Dark Canyon, adjacent to the reef, Tansill beds are up to 350 feet thick and the Ocotillo Member stretches to 40 feet (Tyrrell, 1962).

Tansill strata, like the Yates below, are distributed along the paleo-shelf parallel to the Capitan reef trend within the Guadalupe and Apache Mountains. Equivalent strata in the Glass Mountains to the south belong to the upper part of the Altuda Formation. Along the Central

Basin Platform in the eastern margin of the Delaware Basin the Tansill strata are in the subsurface below the Castile evaporite deposits of Lopingian age.

Time-equivalent stratigraphic horizons across the shelf, margin, and basin transect can be correlated using fusulinid occurrences (Tyrrell, 1962, 1969). The pre-Ocotillo carbonate of the Tansill Formation was deposited penecontemporaneous to the basinal Lamar Member of the Bell Canyon Formation. The small, round "Tethyan-type" fusulinid *Yabeina texana* Skinner and Wilde is restricted to the lower 10 feet of both the Tansill and Lamar beds. An even smaller genus of fusulinid, *Reichelina* Erk, 1942, is common in the middle part of the Tansill Formation below strata of the Ocotillo Member, and in the middle and upper parts of the Lamar Member, indicating the two are time-correlatable. The post-Ocotillo Tansill beds and strata of the Reef Trail Member of the basinal Bell Canyon Formation (Wilde et. al., 1999) contain the fusulinid *Paraboultonia splendens* Skinner and Wilde indicating the two units are time-equivalent (Pinar, 2013).

Tansill strata crop out in only the eastern third of the Apache Mountain escarpment. To the west the Tansill Formation strata would have been positioned structurally higher due to the eastward plunge of the Apache anticline and thus was eroded. Wood (1968, page 17) reported the strata of the Tansill Formation is "characteristically a thick-bedded very finely crystalline dolomite, though somewhat thinner bedded above the basal thicker bedded, cliff forming part." Part of the current study is to assess the validity of the Wood's claim that the base of the Tansill Formation within the Apache Mountains section is marked by the cliff forming dolomite.

2.4.2 *Lithology and Fossils*

Like the Yates Formation below, the Tansill lithology varies laterally in wide bands parallel to the reef trend (Newell et al., 1953). These bands make up the inner shelf proximal to the continent, the middle shelf, and the outer shelf near the reef margin of the Delaware Basin. The inner shelf is composed of siltstone and claystone. The middle shelf is made up mostly of evaporite deposits, largely anhydrite in composition. The outer shelf is lithologically dolostone and limestone with an array of microfacies depending on where they are in relation to the reef margin. Tyrrell (1962) described four major near reef Tansill microfacies including (1) Skeletal—lump calcarenite or dolarenite, (2) Lump—pelletoid calcarenite or dolarenite, (3) Pelletoid—oolitic dolarenite, and (4) Microgranular dolomite. He also noted the dolomite was likely the result of dolomitization of originally calcareous sediments apart from the microgranular dolomite. Skeletal grains including calcareous algal remains, foraminiferal tests, and mollusk valves were originally composed of calcite and underwent chemical diagenetic replacement to dolomite after deposition and lithification. Also, there are significant amounts of sparry calcite filling vugs, molds, and intergranular spaces that is believed to have occurred post-dolomitization (Tyrrell, 1962).

In the Apache Mountains, most Tansill lithology consists of microgranular dolomite containing anhydrite cementation and few fossils with an exception along the northern margin (Wood, 1968) where the microfacies changes to skeletal—lump calcarenite (to use the terminology of Tyrrell, 1962). Intraclasts, small foraminifers, fusulinaceans, brachiopod valve fragments, calcareous algae, sponges, and bryozoans make up the allochem constituents of the near reef limestone. One thin section from Wood's (1968, page 17) study is described as an "algal biosparite containing dasycladacean algae (*Mizzia* sp.), fusulinid fragments, bryozoans, and corals? (*Chaetetes?* sp.).” Corals are present, but generally scarce in West Texas Permian strata. Towards the top of the near reef strata dolostone becomes more common, often highly dolomitized. Allochem recognition becomes impossible, making interpretation of the rock’s depositional history problematic.

2.4.3 *Age*

The Tansill Formation is firmly established by many workers to have been deposited during the latest Capitanian of the latest Guadalupian Series of the Permian, approximately 262.7-260.4 m.a. based on fusulinid and conodont research (Wilde, 1990; Glenister et al., 1992, 1999; Wilde and Rudine, 2000; Yang and Yancey, 2000; Lambert et al., 2002; Wardlaw, 2004).

CHAPTER 3

YATES AND TANSILL MICROFACIES ANALYSIS, SEQUENCE STRATIGRAPHY, AND DEPOSITIONAL MODEL

3.1 Introduction

Microfacies analysis of carbonate rocks is the most useful method for interpreting the depositional environment of a carbonate rock sample (Flügel, 2010). *In situ* characteristics preserved within the microfacies structure can reveal the nature of important environmental factors responsible for generating the rock. Considering the individual depositional environments represented by the characteristics of each rock specimen within the two measured and described sections of the Yates/Tansill Formations, a depositional model can be constructed to interpret their depositional history.

Presented in this chapter are lithologic descriptions of packages of carbonate rocks sampled from two stratigraphic sequences on top of the Capitan reef at the entrance to Panther Canyon. The term "package" is used herein to describe a layer of rocks that can be composed of a one or several lithofacies indicating environmental changes during deposition. Each package can be divided into a series of microfacies that may be repeated multiple times within different stratigraphic horizons throughout the sections. Each microfacies is named based upon a combination of the lithologic properties of the rock and the depositional environment possibly generating them.

Two measured sections of well bedded carbonate strata, Panther Canyon 7 (PC7) and Panther Canyon 8 (PC8), are illustrated and described in the first part of this chapter. The lower portion of PC7 is interpreted herein to be representative of the uppermost part of the Yates

Formation proximal to the reef margin and the remainder of the PC7 section is interpreted to represent the lower and middle parts of the Tansill Formation. Section PC8 is interpreted to entirely represent the middle part of the Tansill Formation and is considered to be stratigraphically younger than the upper portion of the section PC7. All lithologies from both sections are composed of bedded limestone, but a considerable amount of dolostone is present in the lower part of the PC8 section.

Carbonate textures for the current study are described using the common carbonate rock classification schemes: Dunham (1962) and Folk (1959, 1962). Dunham's scheme is useful for identifying the energy conditions present during deposition, whereas Folk's scheme factors emphasize the allochemical composition, supplying more clues about the nature of the depositional environment. Both schemes are useful for facies interpretation and depositional model generation. In the second part of this chapter a depositional model is presented for generating the Yates/Tansill stratigraphic sequence located at the mouth of Panther Canyon.

3.2 PC7 Section

The base of the PC7 section is located in the upper part of the first nose of the eastern hill at the mouth of Panther Canyon (31˚ 10' 32.5092" N, 104˚ 18' 5.1068" W; figure 3.1). The first objective of this study was to locate the first contact of bedded strata overlying the massive reef material of the Capitan Formation which was difficult because of weathering and ground cover at the study locality. The first section PC7 was selected to begin measuring and sampling based on the confidence of what appeared to be clear bedding, however, more covered bedded strata may exist below the first bed. Measurements and sampling were conducted from the first chosen package to the top of the hill making the PC7 section a total of 31.8 meters containing eight packages of rocks. The bed exposure was poor to moderate with limited lateral exposure (figure 3.2)

Figure 3.1 Photograph looking across a shallow ravine at the PC7 section. Section measured diagonally from lower left to upper right in center part of picture.

Figure 3.2 Photograph showing an outcrop within the PC7 section illustrating an example of the exposure quality.

3.2.1 *PC7 Package (I) – Lagoonal Bioclastic Intrasparite*

Description

Package (I) (sample PC7-1) of the PC7 (figure 3.3) section is composed of dark colored, fine-grained limestine with carbonate intraclasts amidst a predominantly sparry calcite cement matrix. Limy mud is present but is less than 1/3 of the total composition. The intraclasts appear rather opaque containing smaller, lighter colored, unrecognizable inclusions. Grain sorting is poor. Fossils make up a significant proportion of the total allochemical assemblage of the sample. Small foraminifers such as *Globivalvulina, Abadehella,* and *Pseudoammodiscus* are common along with possible fusulinaceans of the genus *Reichelina*. Also uncommon are disarticulated remains of dasycladacean green algae. Brachiopod and gastropod shells are common.

Interpretation

Intraclasts are pieces of consolidated or semi-consolidated rock that have been weathered and eroded from a source rock, transported, and incorporated into sediments which subsequently become consolidated to form another rock (Folk, 1959). High energy is required to initiate the process. A likely energy source capable of mechanically weathering and eroding the intraclasts from their source is a strong storm, such as a hurricane. The quantity of intraclasts present in sample PC7-1 indicates they came from an area where storms were frequent and powerful. Dasycladacean algal remains in the sample are a strong indicator that the depositional environment was lagoonal. The intraclasts were likely sourced from a barrier reef/island system and the storms caused waves to overtop and erode the barrier and transported these sediments into the lagoon. According to Dunham classification (1962), the rock is a packstone due to the small amount of micrite present in the matrix along with the thick coating of carbonate grains. The rock should be classified as a bioclastic intrasparite under Folk's classification (Folk, 1959).

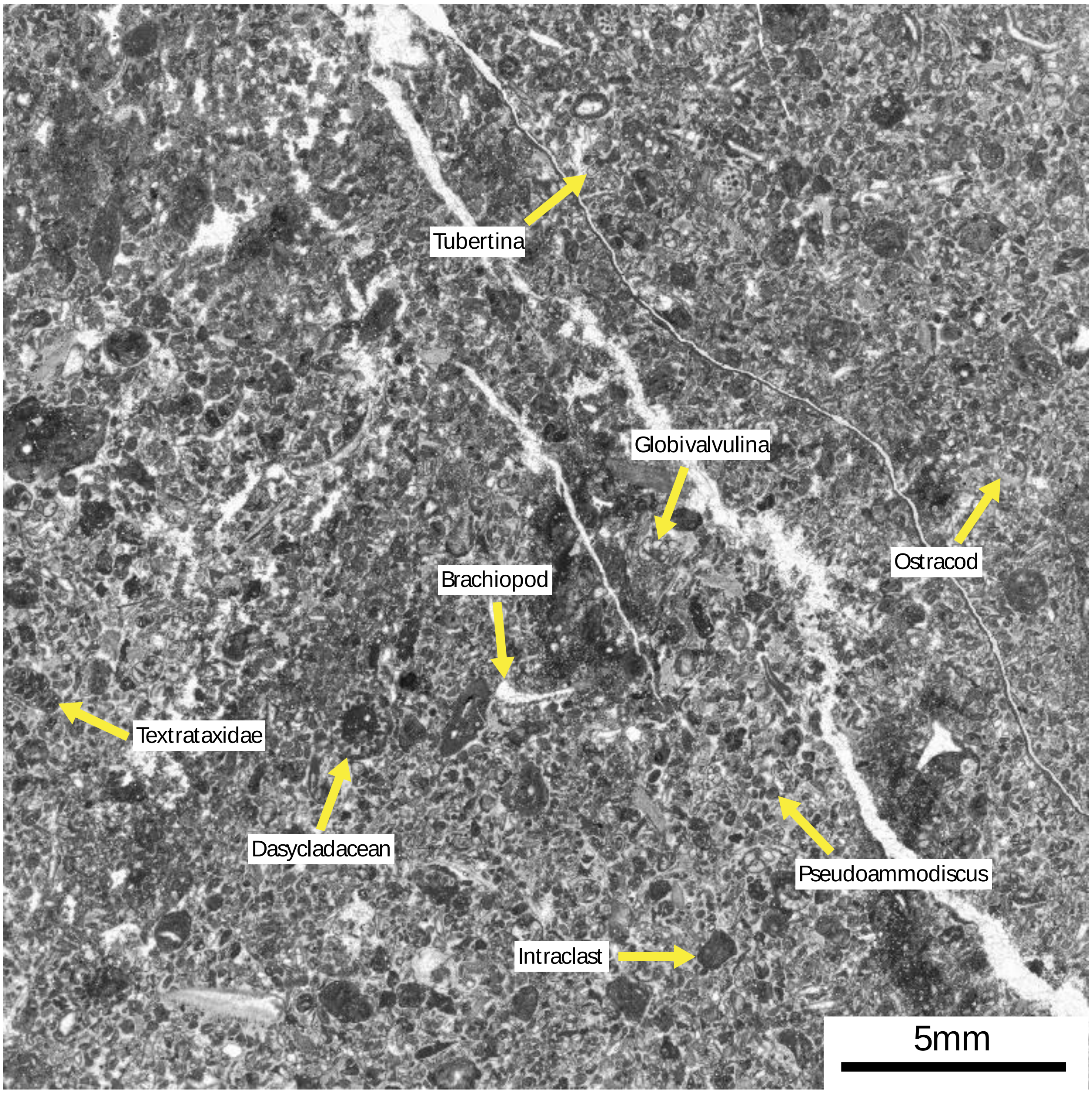

Figure 3.3 Photomicrograph depicting the microfacies of package (I) of section PC7 (sample PC7-1): lagoonal bioclastic intrasparite containing dasycladacean algae, brachiopod fragments, ostracods, foraminifers and intraclasts.

3.2.2 *PC7 Package (II) – Lagoonal Poorly Washed Bioclastic Intrasparite*

Description

Two samples were taken from package (II): PC7-2A (Figure 3.4), from the base of the package, and PC7-2B (figure 3.5) from the top. Sample PC7-2A has a mixture of sparry calcite cement and micrite in approximately equal proportions. The same type of dark, fine-grained intraclasts as in package (I) are present. Small foraminifers present include *Agathammina, Crescentia*, *Globivalvulina*, *Palaeonubecularia*(?) and *Abadehella* along with disarticulated dasycladacean remains. The marine invertebrate macrofauna is more abundant than in package (I) and includes punctate and impunctate brachiopods, gastropods, bryozoans, crinoids, echinoid spines, and ostracod valves. Sorting is poor to moderate.

The upper sample, PC7-2B, of package (II) is very similarly textured at the base to sample PC7-2A. The matrix composition is sparry calcite and predominant allochems are dark, fine-grained intraclasts like those of package (I). The faunal assemblage is congruous to the base of the package with the notable addition of calcareous sponges.

Interpretation

Package (II) is very similar in texture to package (I) except for the addition of fossils made by typical reef-building fauna such as sponges and bryozoans. These allochems were likely sourced from a reef environment. Along with the numerous intraclasts present amidst the allochem assemblage, these reef fossils were probably transported by the same storm mechanism as the constituents in the previous package. The disarticulated dasycladacean algal remains present were deposited within a back-reef lagoonal depositional setting. Do to the presence of carbonate mud within the microfacies Dunham would regard package (II) as a packstone.

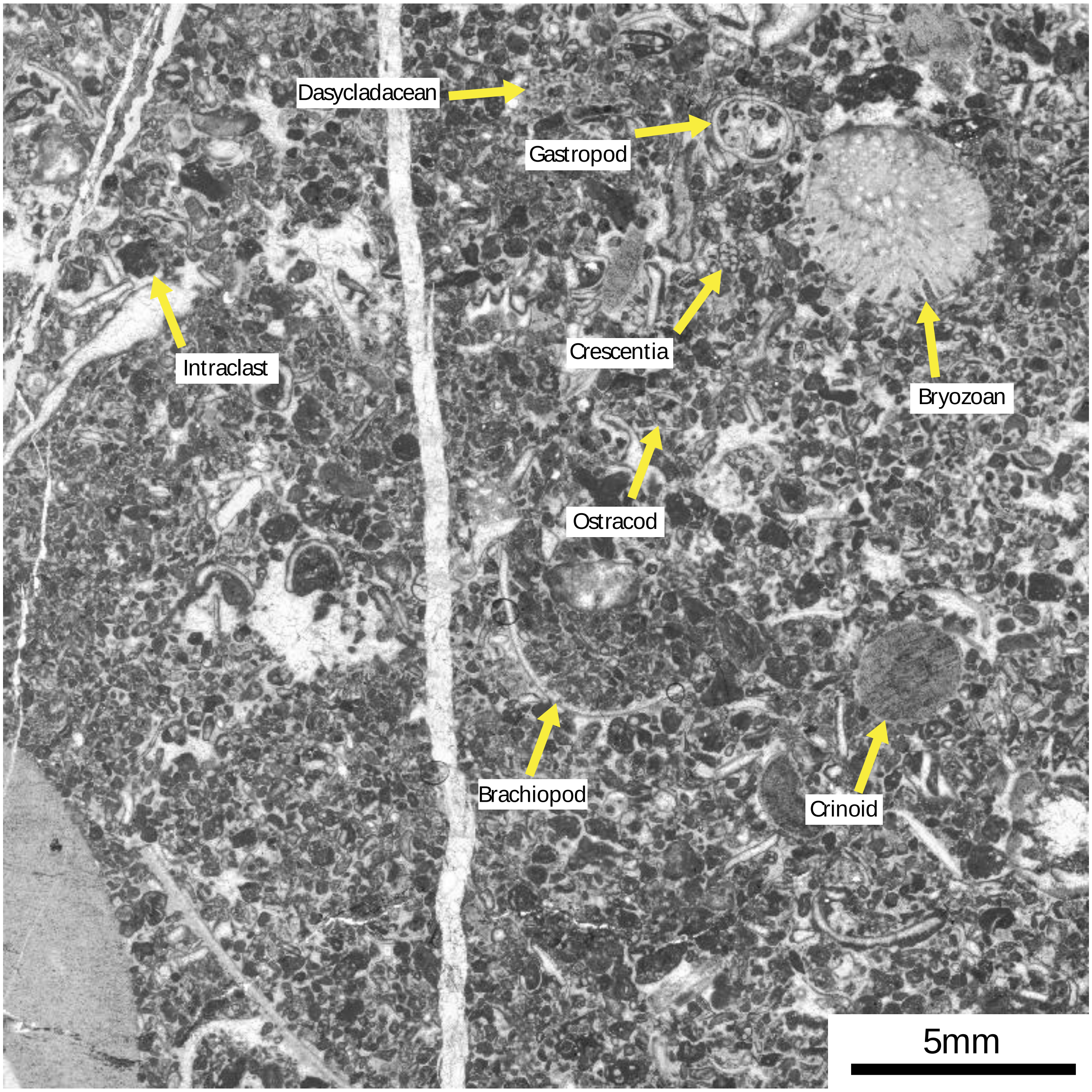

Figure 3.4 Photomicrograph depicting the microfacies of the base of package (II) of section PC7 (sample PC7-2A): lagoonal poorly washed bioclastic intrasparite containing dasycladacean algae, crinoids, brachiopods, bryozoans, gastropods, ostracods, foraminifers, and intraclasts.

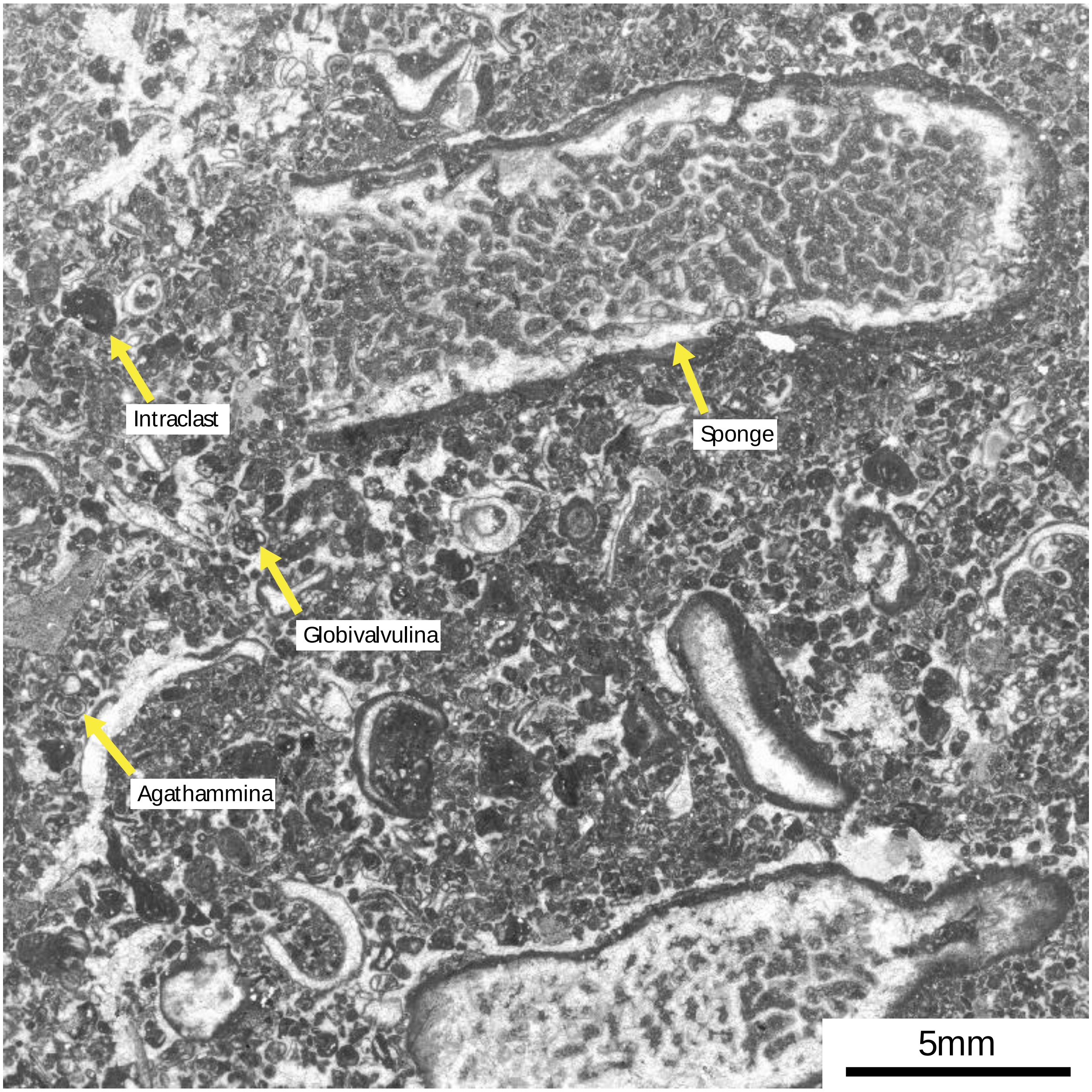

Figure 3.5 Photomicrograph depicting the microfacies at the top of package (II) of section PC7 (Sample PC7-2B): lagoonal poorly washed bioclastic intrasparite containing sponges, foraminifers, and intraclasts.

3.2.3 *PC7 Package (III) – Lagoonal? Aphanocrystalline Biogenic Dolostone*

Description

Package (III) (sample PC7-3) (figure 3.6) is composed of secondary replacement dolomite with an aphanocrystalline, “sugary” texture. Fossil allochem ghosts are present, yet are generally unrecognizable. With some creativity, layered growth of some variety of a stromatoloid fauna appears to be present throughout the sample, possibly of the problematic genus *Archaeolithoporella* which is common in Yates Formation equivalent Capitan Formation reef limestone in the Guadalupe Mountains (Mazzulo and Cys, 1978). The package contains many vugs which are open or filled with equant calcite sparry cement. Based on the relict fossil population a reasonable assumption can be made concerning the original limestone texture. The rock is either a bioclastic packstone or a bioclastic grainstone, according to Dunham (1962).

Interpretation

Fossil allochem alteration indicates dolomitization occurred after deposition. Therefore, the presence of dolomite provides little evidence for interpretation of the depositional environment responsible for creating the original texture of package (III). The stromatoloid fauna indicates relatively calm water likely a protected lagoon.

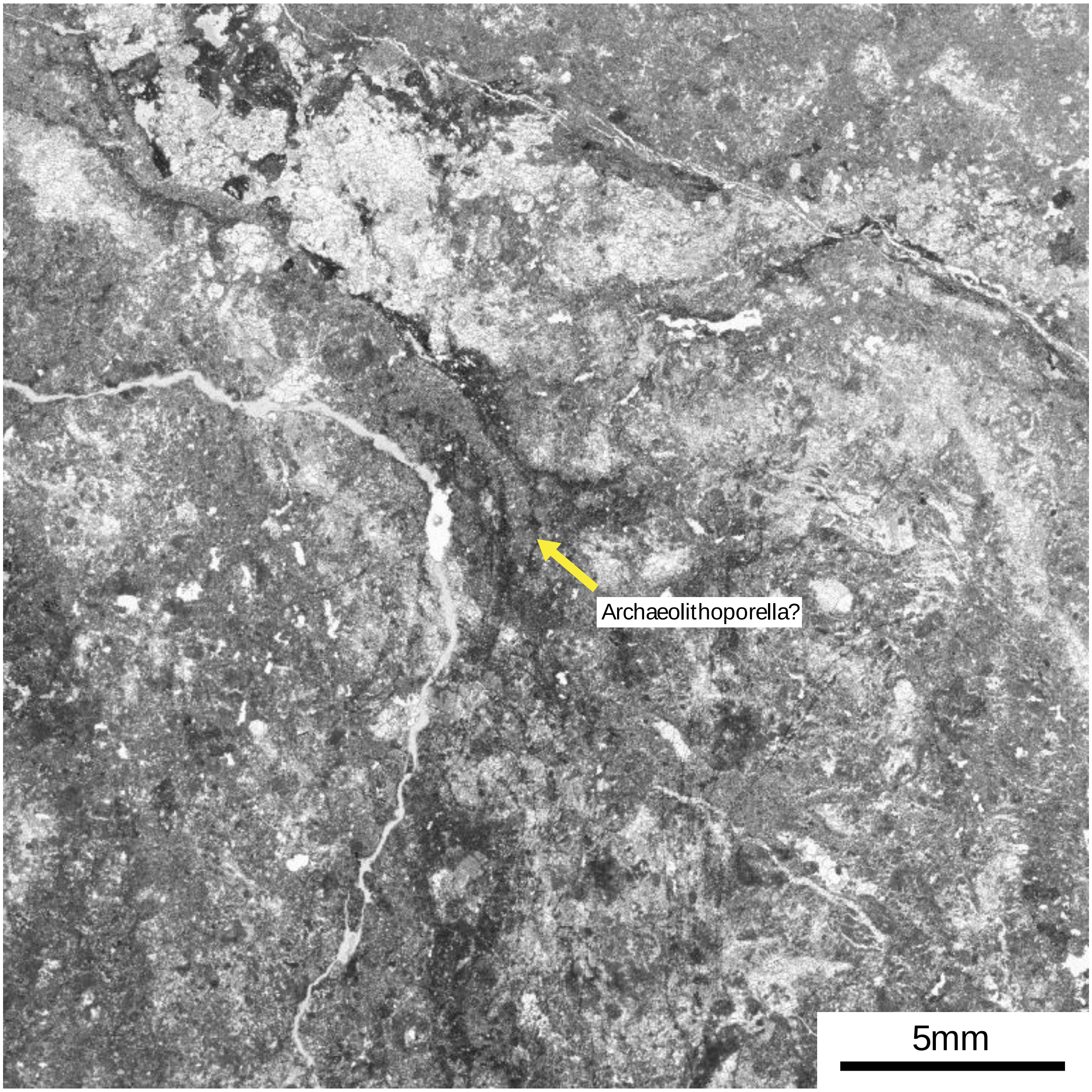

Figure 3.6 Photomicrograph depicting the microfacies of package (III) of section PC7 (sample PC7-3): lagoonal? aphanocrystalline biogenic dolostone possibly containing the problematic genus Archaeolithoporella.

3.2.4 *PC7 Package (IV) – Reefal Sponge Calcirudite with Micrite Matrix*

Description

Package (IV) (sample PC7-4) (figure 3.7) contains several macrofaunal fossils including cylostome bryozoans and calcareous sponges encrusted with microconchid worm tubes. The space between these fossils is a wackestone containing calcareous sponge spicules and small foraminifers including *Crescentia*. The micritic matrix comprises approximately 60% of the total mass of the wackestone. The allochems are very poorly sorted. The overall texture of the rock is classified as a sponge calcirudite with a micrite matrix after Folk (1962).

Interpretation

The diverse, reef-building macrofauna present in package (IV) clearly indicate a reefal depositional environment generated the lithofacies. The laterally the strata are covered at the sample location, so the extent of the reef facies remains a mystery. The proximity of the sample location to the Capitan reef front could indicate a short lived transgressive cycle which migrated the reef front shelfward. The other possibility is that the water chemistry and the climactic conditions were right to promote reef-building fauna to form patch reefs in the back-reef zone. With the limited data available, either case is possible, but the present author leans towards the patch reef scenario.

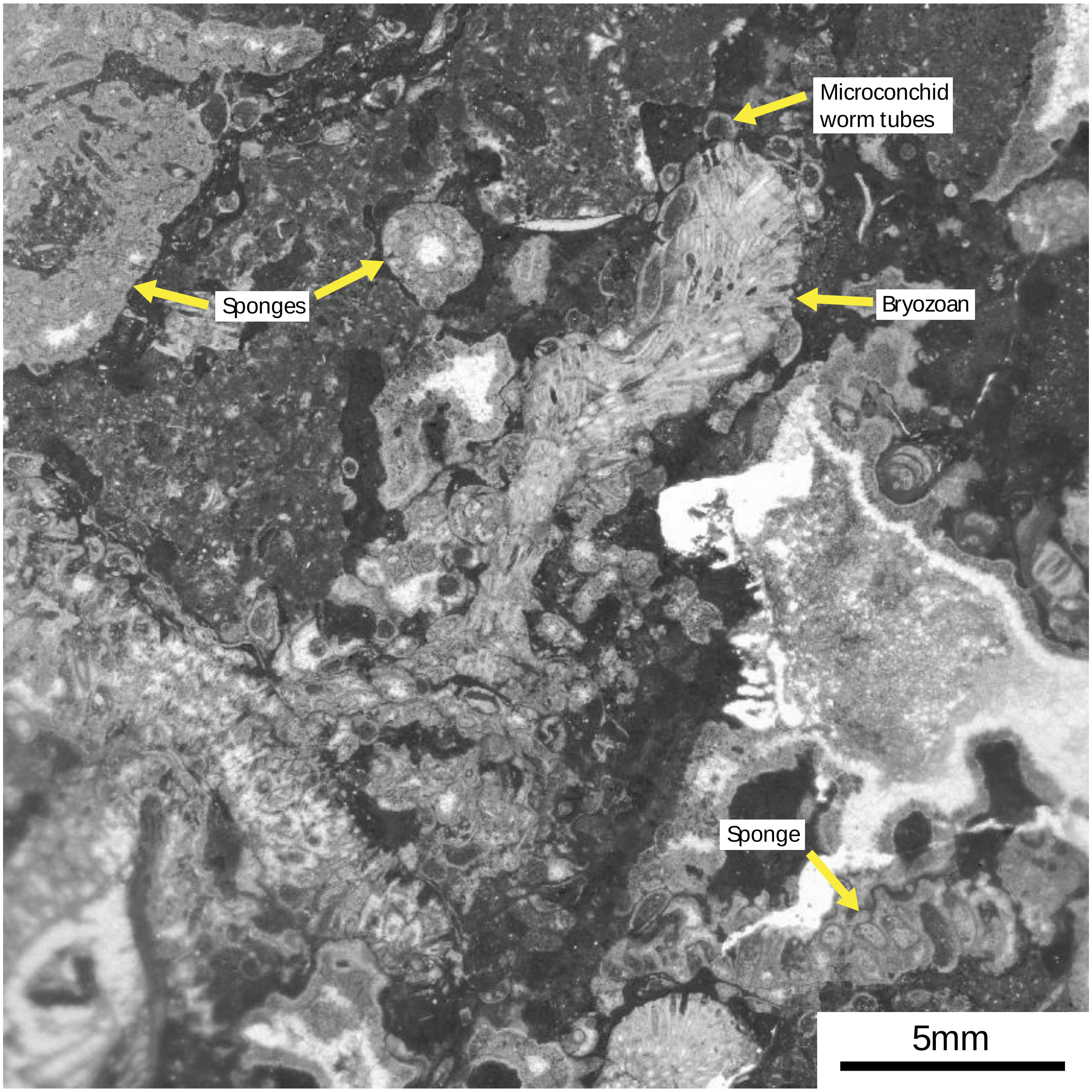

Figure 3.7 Photomicrograph depicting the microfacies of package (IV) of section PC7 (sample PC7-4): reefal sponge calcirudite containing sponges, bryozoans, and encrusting microconchid worm tubes.

3.2.5 *Package (V) –Back-reefal Codonofusiella Biosparite, Lagoonal Bioclastic Intramicrite Description*

Four samples were collected from package (V). The package is 4.2 meters thick and the frequency of sampling was one per meter and two cycles of microfacies development occurred. The first and third samples have similar microfacies different from the second and fourth, which are also similar.

The first sample, PC7-5A (figure 3.8), represents the base of package (V). The matrix between allochems in this sample shows at least two stages of sparry calcite cementation. The first is a thick rind of isopachous cement on the surface of the grains. The second stage is represented by drusy, blocky white calcite crystals filling the remainder of the intragranular space. These two stages are characteristic of phreatic zone meteoric diagenesis (Scholle and Ulmer-Scholle, 2003). Allochemical composition of sample PC7-5A is dominated by numerous fusulinacean tests of the genus *Codonofusiella*, likely of the species *Codonofusiella extensa* Skinner and Wilde. Brachiopods, gastropods, crinoids, and other unidentified small fusulinaceans contribute to the remaining fossil allochemical component. Intraclasts are also present but contribute little to the modal percentage of the allochem population and are darker in color than the others, thus far described from the section. Grains are poorly sorted. The rock is classified as *Codonofusiella* biosparite according to Folk (1962).

The next sample is PC7-5B (figure 3.9). The matrix is composed of micrite with a small proportion of calcite spar in places where the grains contain larger gaps between them. Sorting is poor. The predominant allochems are comprised of very fine-grained intraclasts dark in color and generally well rounded. Larger intraclasts are distributed throughout the fabric of the rock,

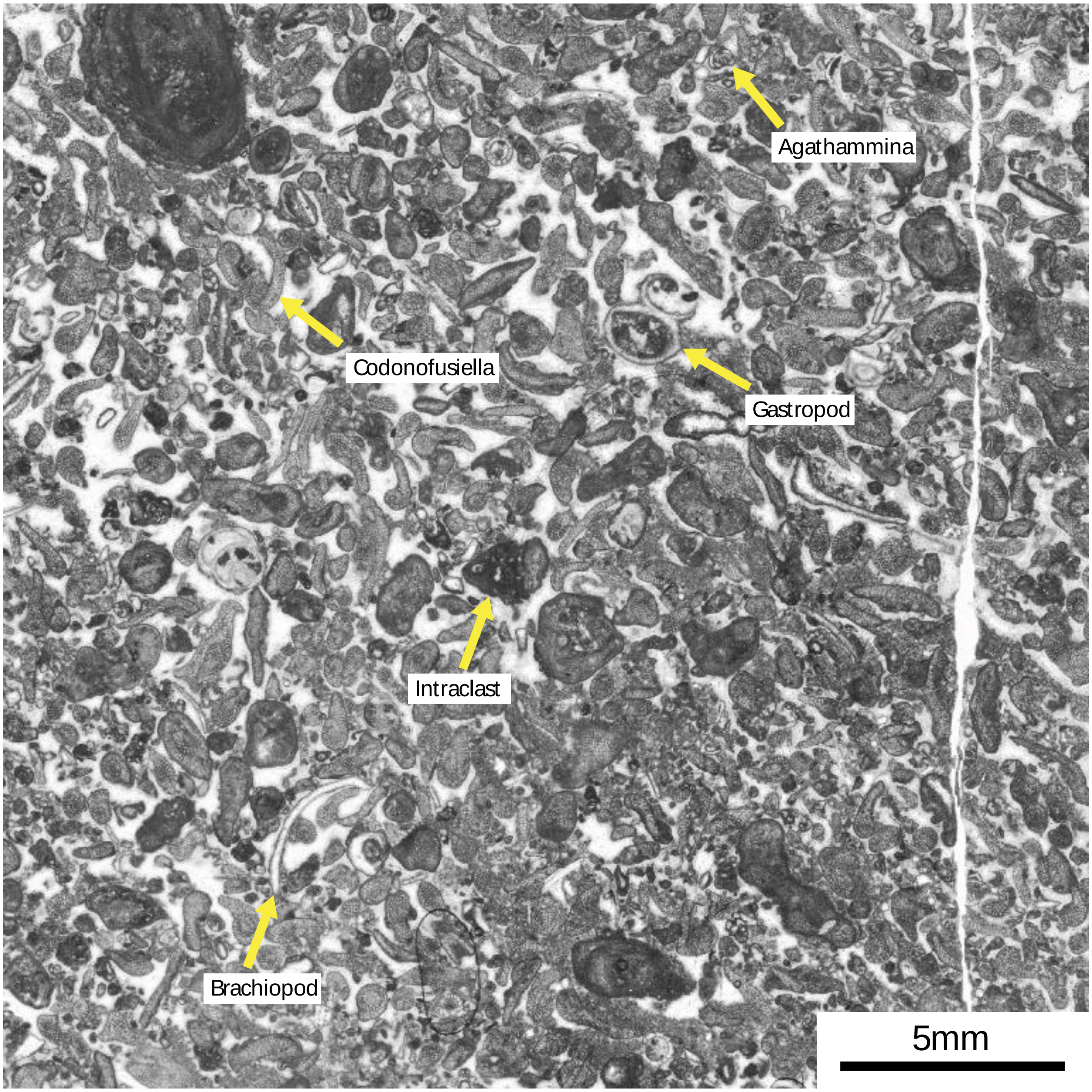

Figure 3.8 Photomicrograph depicting the microfacies at the base of package (V) of section PC7 (sample PC7-5A): back-reefal Codonofusiella biosparite containing Codonofusiella, gastropods, brachiopods, and intraclasts.

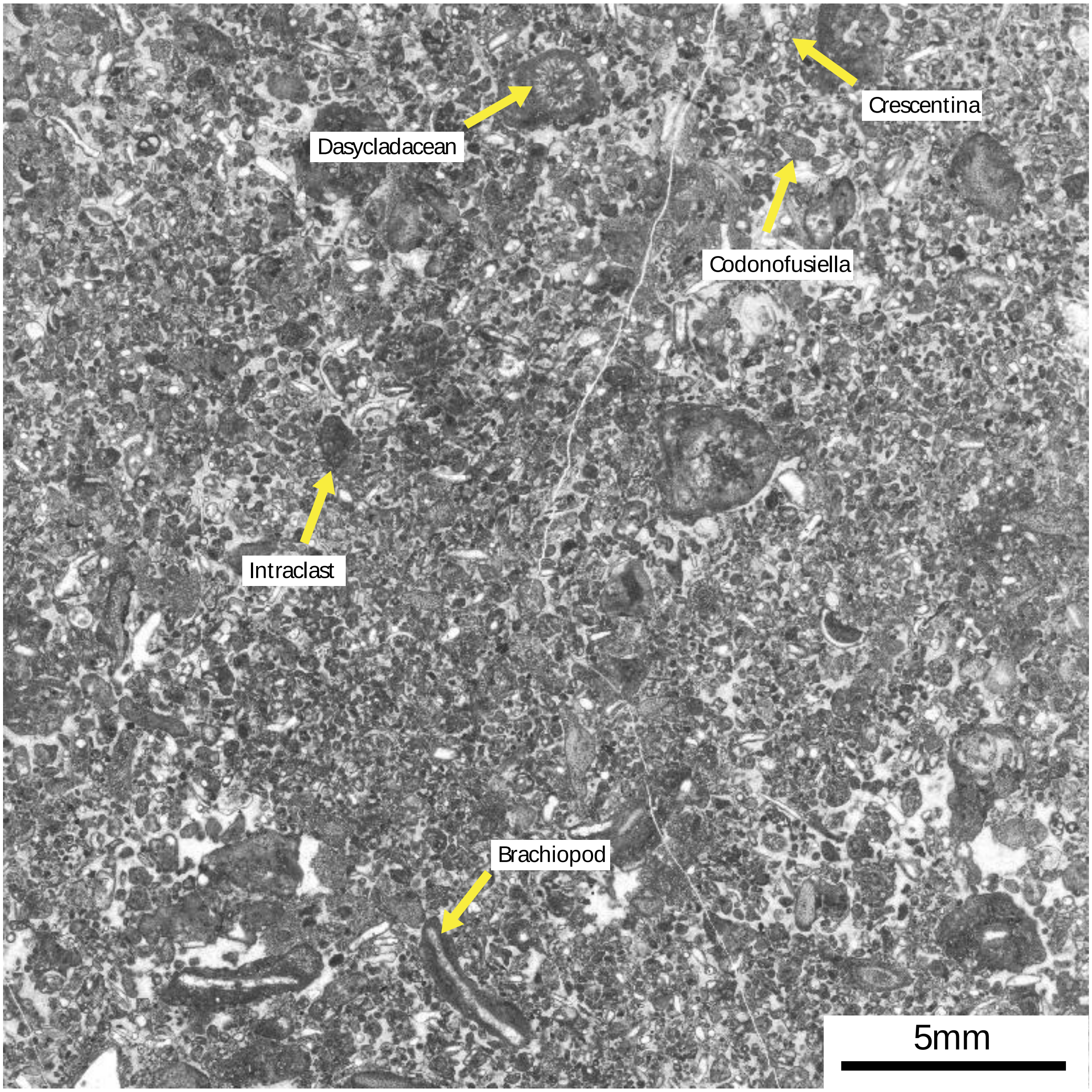

Figure 3.9 Photomicrograph depicting the microfacies in the lower-middle part of package (V) of section PC7 (sample PC7-5B): lagoonal bioclastic intramicrite containing dasycladacean algae, brachiopods, Codonofusiella, and small foraminifers.

often displaying an internal texture. *Codonofusiella* is still present, but in smaller numbers. Brachiopods, gastropods, disarticulated dasycladacean algae parts, and small foraminifers including *Crescentia* and *Abadehella* contribute to the remaining fossil allochem population. The rock is classified as a bioclastic intramicrite under Folk's classification and a packstone, according to Dunham's criteria.

The third sample, PC7-5C (figure 3.10), is a repetition of the *Codonofusiella* biosparite represented at the base of the package, sample PC7-5A. The *Codonofusiella* are even more abundant in this sample than in PC7-5A. Small foraminifers including *Pseudoammodiscus* and *Agathammina* are sparsely present. Notably, the dasycladacean algae persist from the previous sample that are not represented in PC7-5A. The intraclasts also persist though are less numerous.

The top of package (V), sample PC7-5D (figure 3.11), is another representation of a bioclastic intramicrite similar to sample PC7-5B, except for the addition of sparse, smooth ostracod valves observed in sample PC7-5D. The total percentage of intraclast allochems appears to be higher compared to sample PC7-5B.

Interpretation

The depositional environments which produced the rocks of samples PC7-5A and PC7-5C were quite similar and were likely situated along a shallow carbonate platform in the back-reef setting. Water conditions were clear, warm, and productive with abundant nutrients to support the large *Codonofusiella* population. Wave energy was high enough to winnow away any carbonate mud, but not so high as to disrupt the life habit of the *Codonofusiella*. Samples PC7-5B and PC7-5D contain numerous intraclasts unlike the other two parts of the package. The

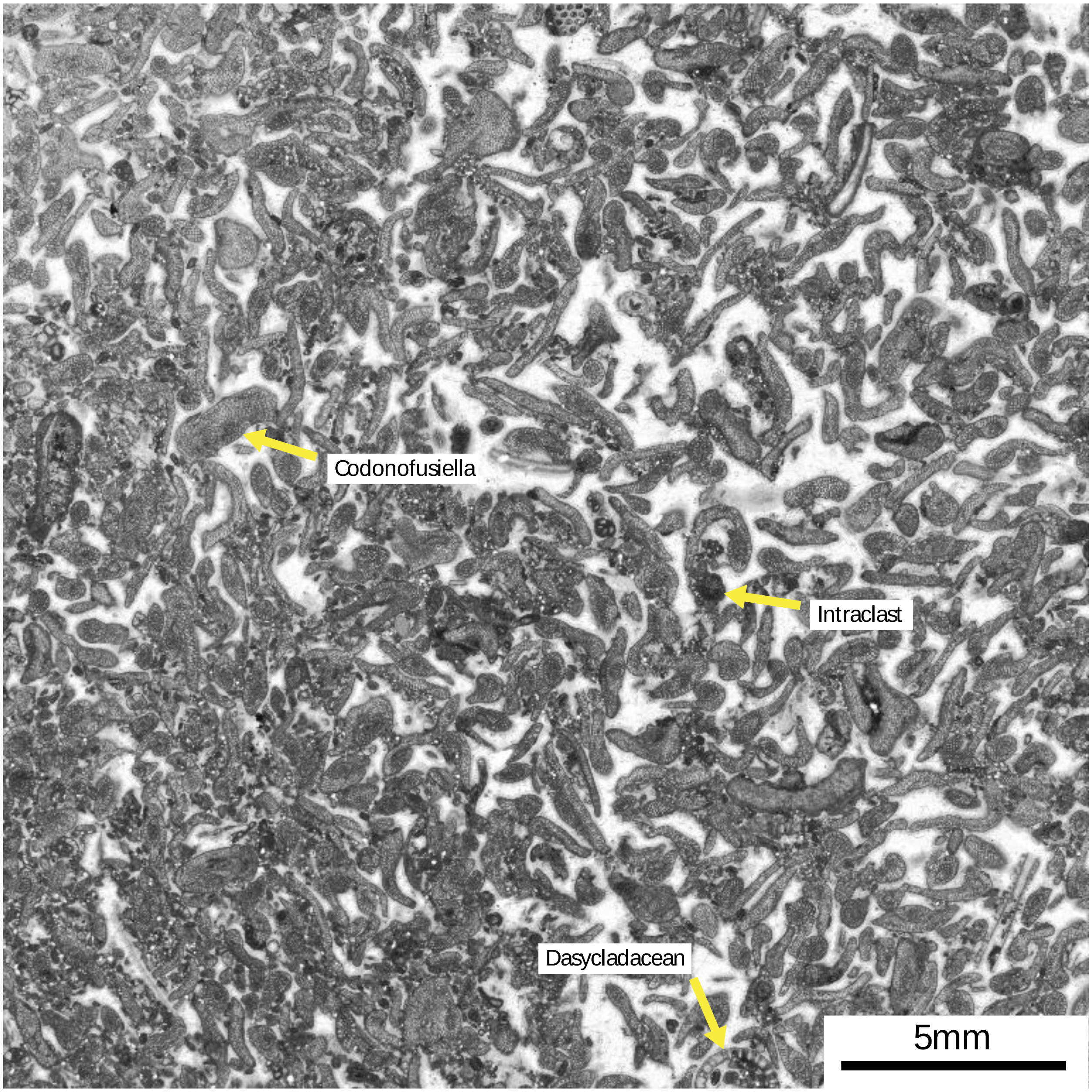

Figure 3.10 Photomicrograph depicting the microfacies in the upper-middle part of package (V) of section PC7 (sample PC7-5C): back-reefal Codonofusiella biosparite containing Codonofusiella, dasycladacean algae, and intraclasts.

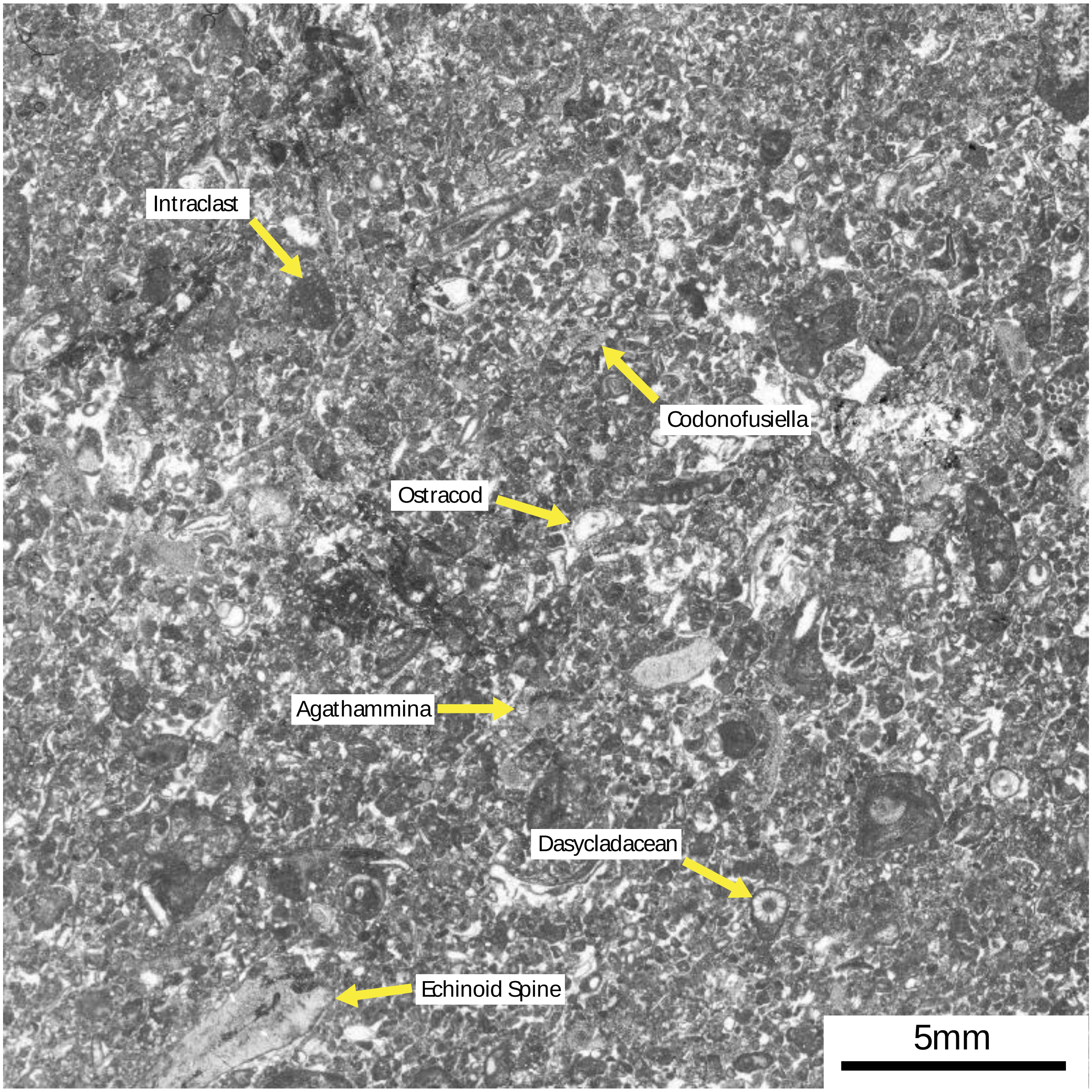

Figure 3.11 Photomicrograph depicting the microfacies in the top of package (V) of section PC7: lagoonal bioclastic intrasparite containing dasycladacean algae, echinoids, ostracods, Codonofusiella, foraminifers, and intraclasts.

intraclasts of the first two noted were likely generated by storm events and transported into a back-reef lagoon setting.

The cyclical nature of package (V) shows the environment underwent periods of prolonged quiescence between storm events. If continuously bombarded by wave action, the *Codonofusiella* tests would not be deposited as large population groups as observed in samples PC7-5A and PC7-5C. The individual tests would become entrained and distributed throughout the lagoon before they became consolidated into rock. Package (V) shows two such periods of quiescence disrupted by two distinct periods of storming.

3.2.6 *Package (VI) – Lagoonal* Dasycladacean *Intrasparite*

Description

Two samples of package (VI) were collected, one from the base, PC7-6A (figure 3.12), and another, PC7-6B (figure 3.13), from the top of the unit. Although the thickness of the package spans 2.5 meters, the microfacies changes only slightly. Both samples have similar allochemical compositions consisting of sub-angular to sub-rounded intraclasts supplemented by a bioclast population of disarticulated dasycladacean algal remains, sparse brachiopod fragments, and gastropods. The intraclasts consist of poorly sorted, sand-sized particles composed of carbonate with an array of internal textures. Allochems are held within a matrix consisting of two stages of calcite sparry cement. The first stage is represented by isopachous bladed spar covering the outside of the grains. Blocky, equant calcite crystals filling in the remaining space between the allochems display the second stage. These two stages are indicative of phreatic zone diagenesis. Often, some portion of the equant spar has been dissolved or otherwise removed from the rock leaving behind approximately 15% porosity.

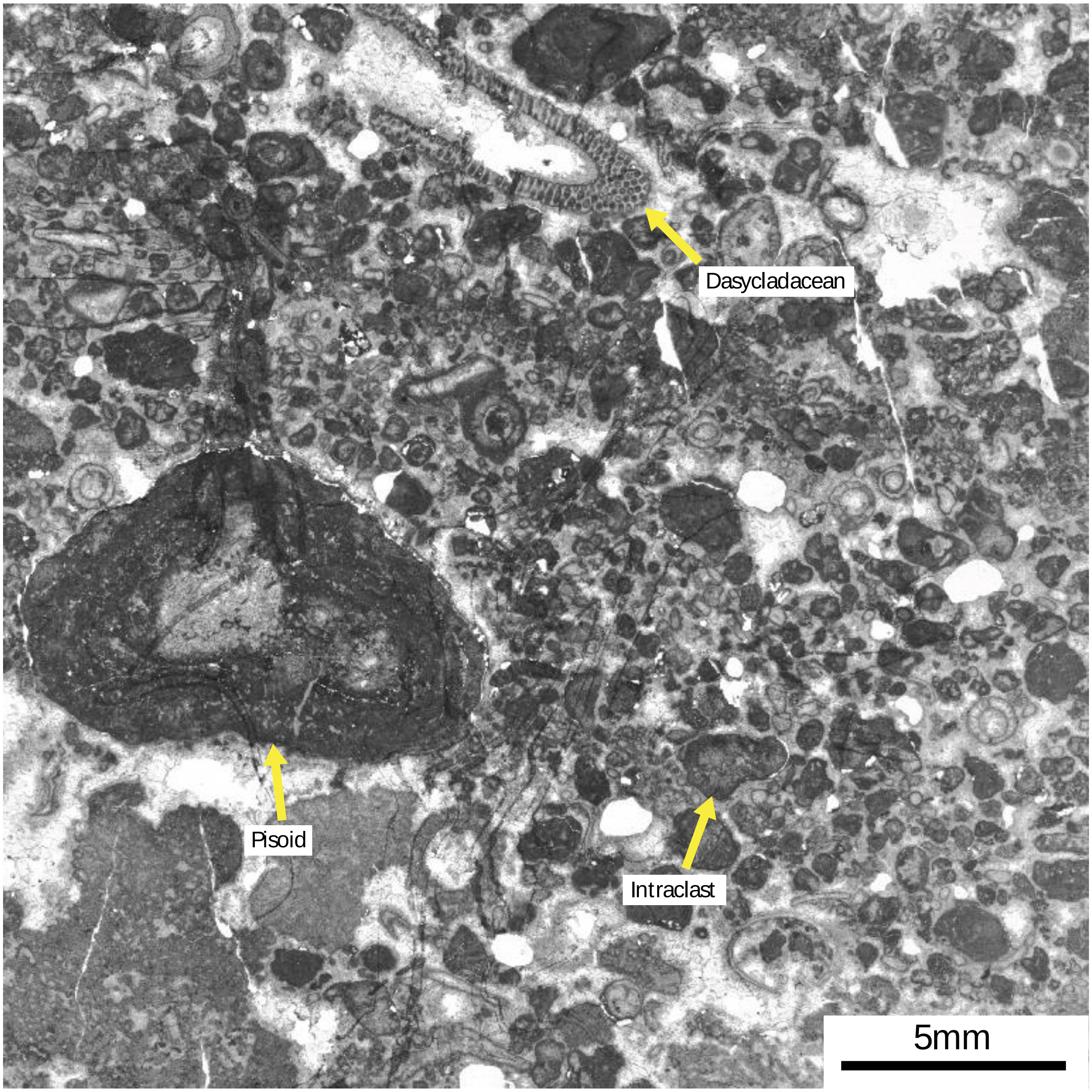

Figure 3.12 Photomicrograph depicting the microfacies in the base of package (VI) of section PC7 (sample PC7-6A): lagoonal dasycladacean intrasparite containing dasycladacean algae, intraclasts, and sporadic oncoids.

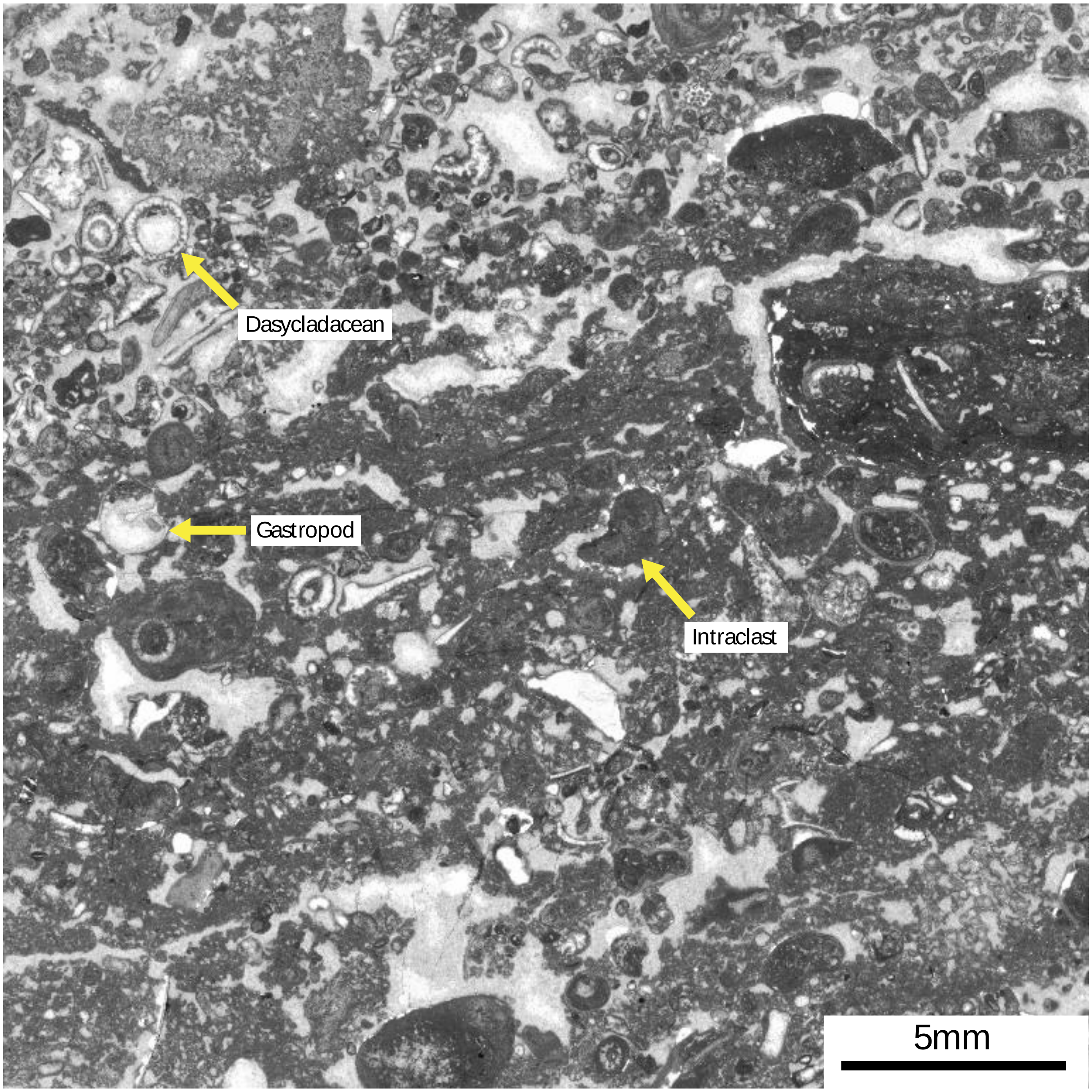

Figure 3.13 Photomicrograph depicting the microfacies in the top of package (VI) of section PC7 (sample PC7-6B): lagoonal dasycladacean intrasparite containing dasycladacean algae, gastropods, and intraclasts.

Interpretation

Dasycladacean algae is indicative of a lagoonal depositional environment. The intraclast population was likely mechanically weathered, eroded, and transported from a reef source by storm generated waves and deposited within a lagoon. Fine lagoonal sediments were winnowed by the wave action and transported out of the basin by the recessing storm surge through barrier inlets leaving behind clean dasycladacean grainstone.

3.2.7 *Package (VII) – Back-reefal Yabeina Intrasparite, Lagoonal Bioclastic Intrasparite, Lagoonal Pelmicritic Boundstone*

Description

Package (VII) is 9.4 meters thick from the base to the top. Five samples were collected with a frequency of approximately one sample per every two meters. The rock at the base of the package, sample PC7-7A (figure 3.14), is limestone containing very fine-grained intraclasts. Larger aggregate intraclast grains, or grapestones, are distributed throughout the fabric. Amidst these intraclasts are skeletal grains including fusulinid tests of the genera *Yabeina* and *Codonofusiella*. Notably, *Yabeina texana* Skinner and Wilde, only known in the Permian shelf of West Texas, is the only verbeekinid found in North America apart from exotic terrane localities in the Pacific Northwest (Nestell and Nestell, 2006). Other small foraminifers including *Agathammina*, *Globivalvulina*, and *Abadehella* are present. Dasycladacean algae is present yet rare. Small gastropod shells, brachiopod fragments, and ostracods are present. The matrix is composed of sparry calcite cement and is classified as a grainstone.

The second sample, PC7-7B (figure 3.15), is also limestone. Coated grapestones, often referred to as botryoidal grapestones (Dana, 1947) are the predominant allochems that make up

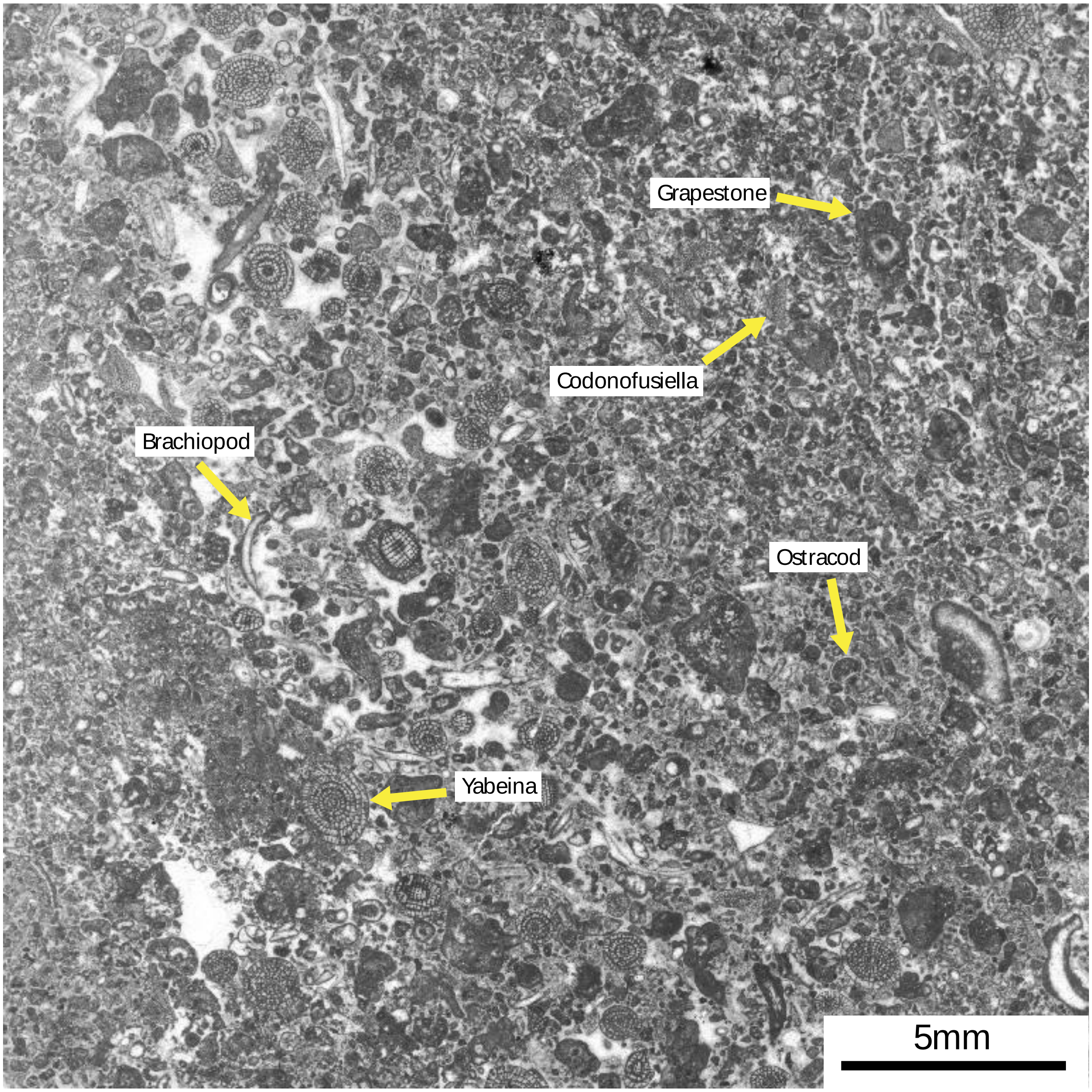

Figure 3.14 Photomicrograph depicting the microfacies in the base of package (VII) of section PC7 (sample PC7-7A): back-reefal Yabeina intrasparite containing Yabeina, sparse Codonofusiella, brachiopods, ostracods, and grapestone intraclasts.

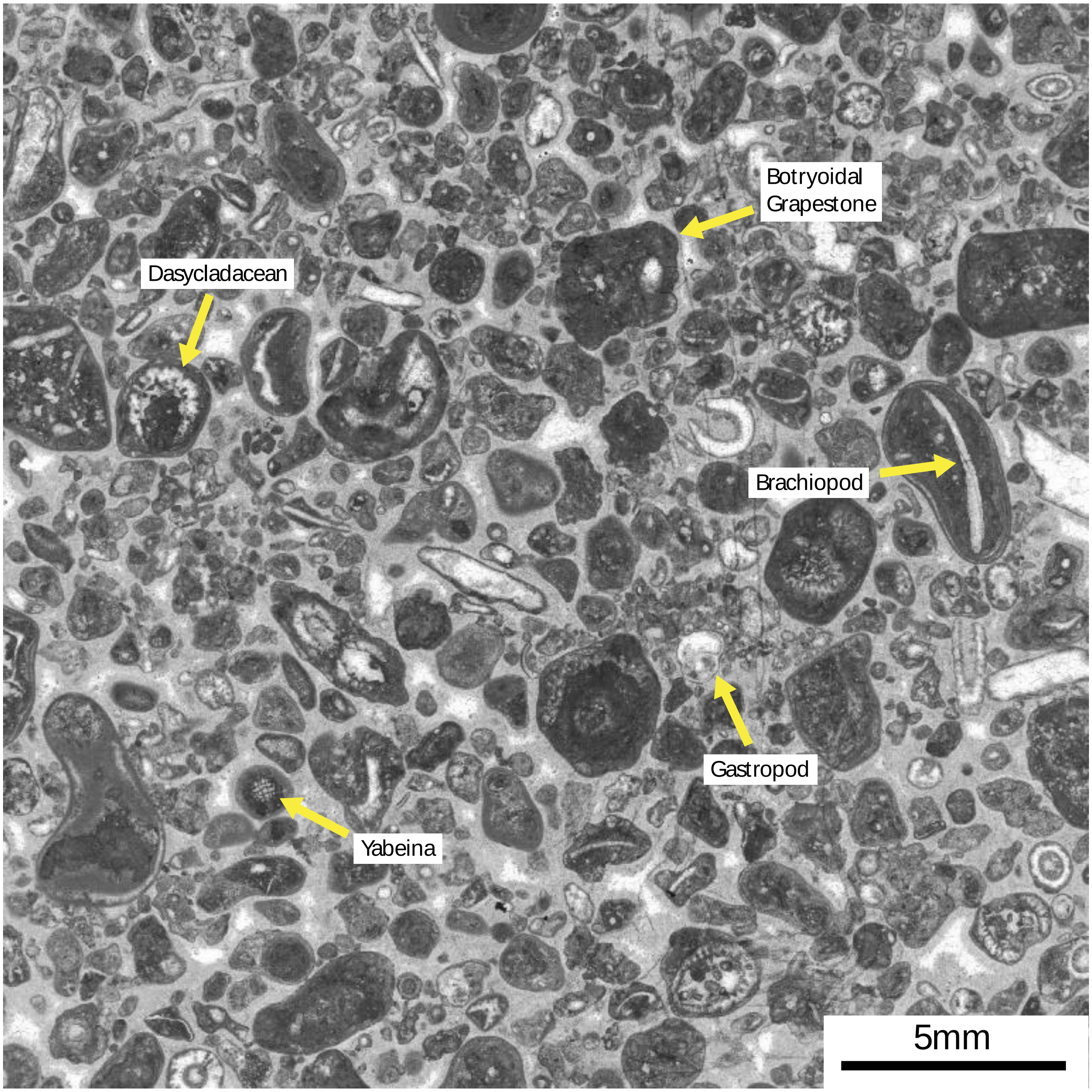

Figure 3.15 Photomicrograph depicting the microfacies in the lower-middle part of package (VII) of section PC7 (sample PC7-7B): lagoonal bioclastic intrasparite containing dasycladacean algae, sparse Yabeina, gastropods, and botryoidal grapestone intraclasts.

the rock. These grapestones are a type of intraclast that began as individual carbonate grains deposited and partially cemented together before some sudden increase in energy, such as a storm event, ripped them from the sea floor and deposited them elsewhere. They were subsequently coated with layered carbonate by a similar process to that which generates oolites. Fossils are present including the fusulinacean *Yabeina*, ostracods, gastropods, brachiopods, and dasycladacean algae. The matrix is composed of sparry calcite cement and is a grainstone.

Sample three from package (VII) of the PC7 section, PC7-7C (figure 3.16), is limestone containing what appears in thin section to show low-angle cross bedding. The matrix is composed of more micrite than most of the samples of package (VII) and is a packstone. Micrite in places lacking in allochem support is often replaced by sparry calcite cement. These places show there was original fenestral porosity. The predominant allochems from the sample are very small, irregularly shaped, yet uniformly sized peloids. Brachiopod fragments and ostracods supplement the peloids. Fine sediments are observed deposited on discontinuity surfaces creating a geopetal fabric which illustrates the original depositional orientation of the sediments. Some surfaces show the layered growth of stromatolites often trapping peloids within the stromatolitic structure. The grains are well sorted apart from the brachiopod fragments and ostracod valves.

Sample four of package (VII), PC7-7D (figure 3.17), is composed of limestone with a clean, blocky calcite spar matrix. Dunham would consider the sample a grainstone. The allochems consist of small, coated intraclasts amidst botryoidal grapestone intraclasts like those of sample PC7-7B. The sorting of the intraclasts is poor. Fossils are abundant including dasycladacean algae, small gastropods, brachiopod spines, and small foraminifers including *Abadehella*, *Vachardella*, and *Globivalvulina*. The fusulinacean *Codonofusiella* is also present.

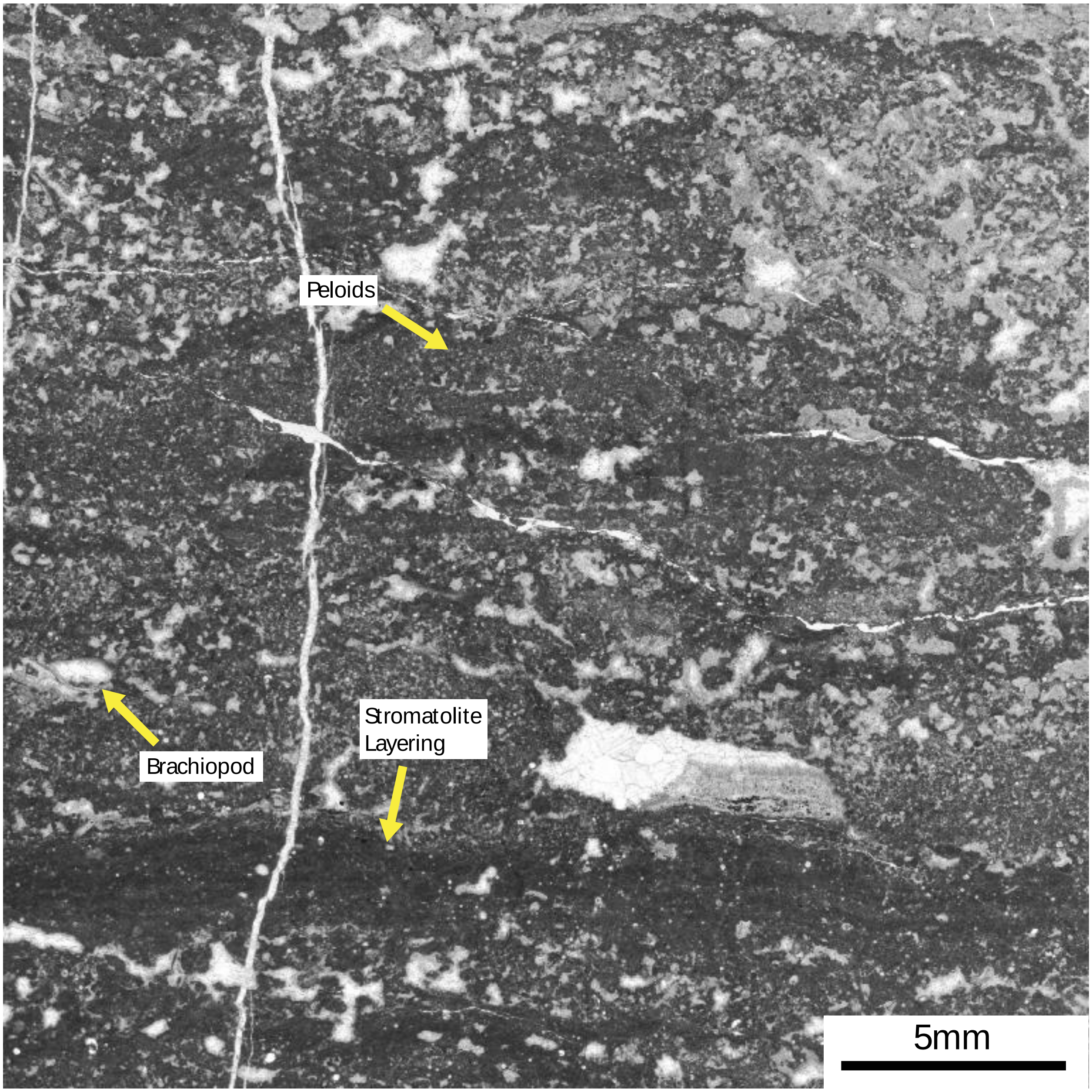

Figure 3.16 Photomicrograph depicting the microfacies in the middle part of package (VII) of section PC7 (sample PC7-7C): lagoonal pelmicritic boundstone containing stromatolite layering peloids, and sparse brachiopod fragments.

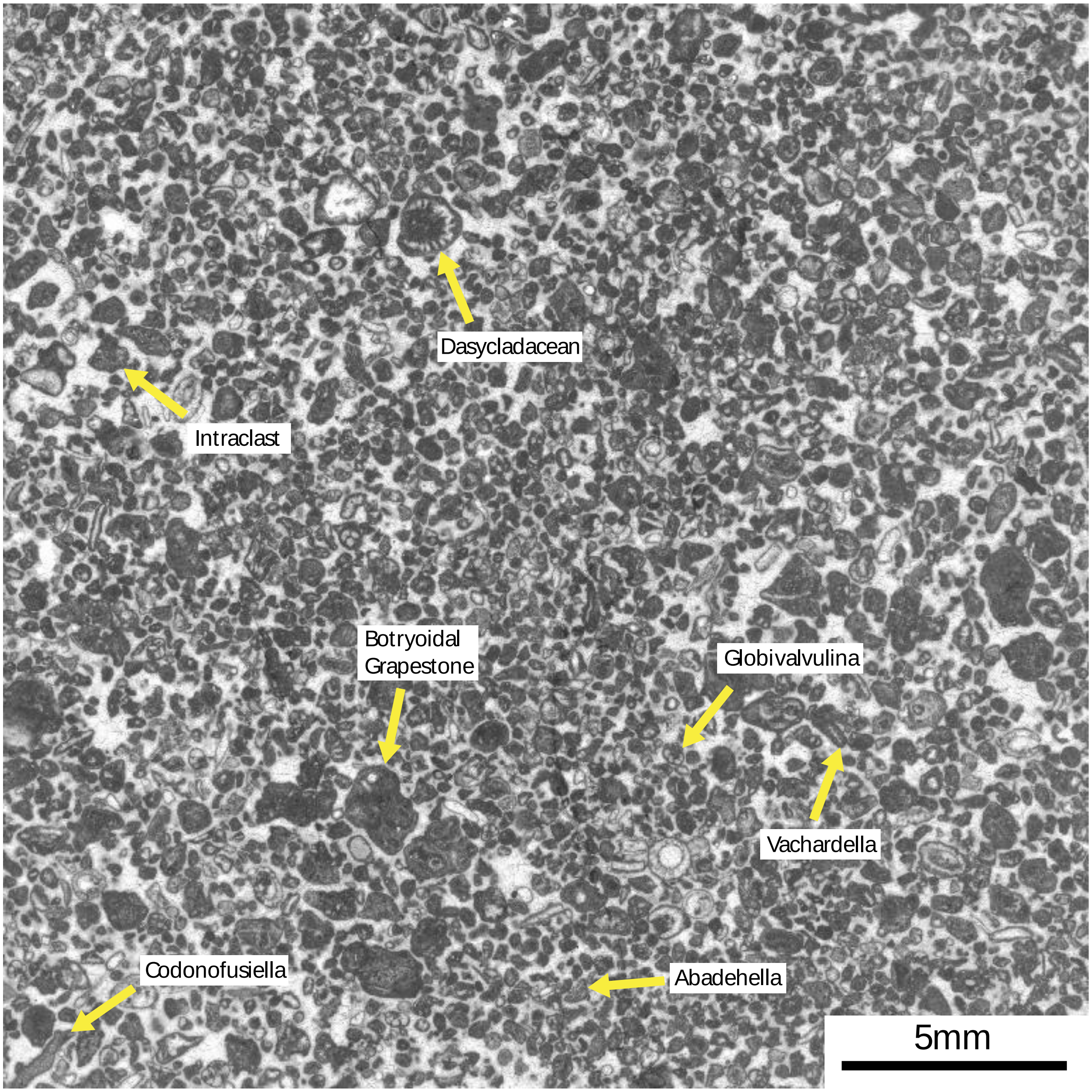

Figure 3.17 Photomicrograph depicting the microfacies in the upper-middle part of package (VII) of section PC7 (sample PC7-7D): lagoonal bioclastic intrasparite containing dasycladacean algae, foraminifers, botryoidal grapestone intraclasts, and individual intraclasts.

The rock at the top of package (VII) of PC7, sample PC7-7E (figure 3.18), is a botryoidal grapestone intrasparite in the manner of the previous samples from package (VII). The intraclasts have a familiar internal texture unlike that of the lower packages containing grapestones. They are full of small, irregular peloids reminiscent of those found in sample PC7-7C. Possibly the provenance of these intraclasts is a similar environment. Blocky calcite sparry cement fills most of the void space between the grains of the rock. The original porosity was around 40% of the rock, considerably greater than the previous samples of package (VII), The character of the porosity is fenestral nature, possibly generated by degassing of decaying organic material or the drying out of cyanobacterial mats (Flügel, 2010). Small carbonate particles suspended in micrite line the bottom of the fenestral cavities providing a convenient indicator of the original depositional orientation. Bioclasts in the rock include brachiopod fragments and disarticulated dasycladacean algal parts as well as sparse gastropods. The sample is a grainstone.

Interpretation

Package (VII) represents a back-reef lagoon that was frequently bombarded with storm generated high energy events. These events lead to the winnowing of fine-grained lagoonal sediments and the generation of various types on intraclastic allochems, such as botryoidal grapestones, ordinary grapestones, and individual, fine-grained intraclasts. During fair-weather conditions, dasycladacean algae and potentially other colonial, lagoonal dwelling faunal elements, whose structural support would be destroyed during high energy events, could rebuild protected from high energy waves and currents by the fringing barrier reef. Low energy conditions promoted fine carbonate sediments to settle out of suspension and deposit on the sea floor.

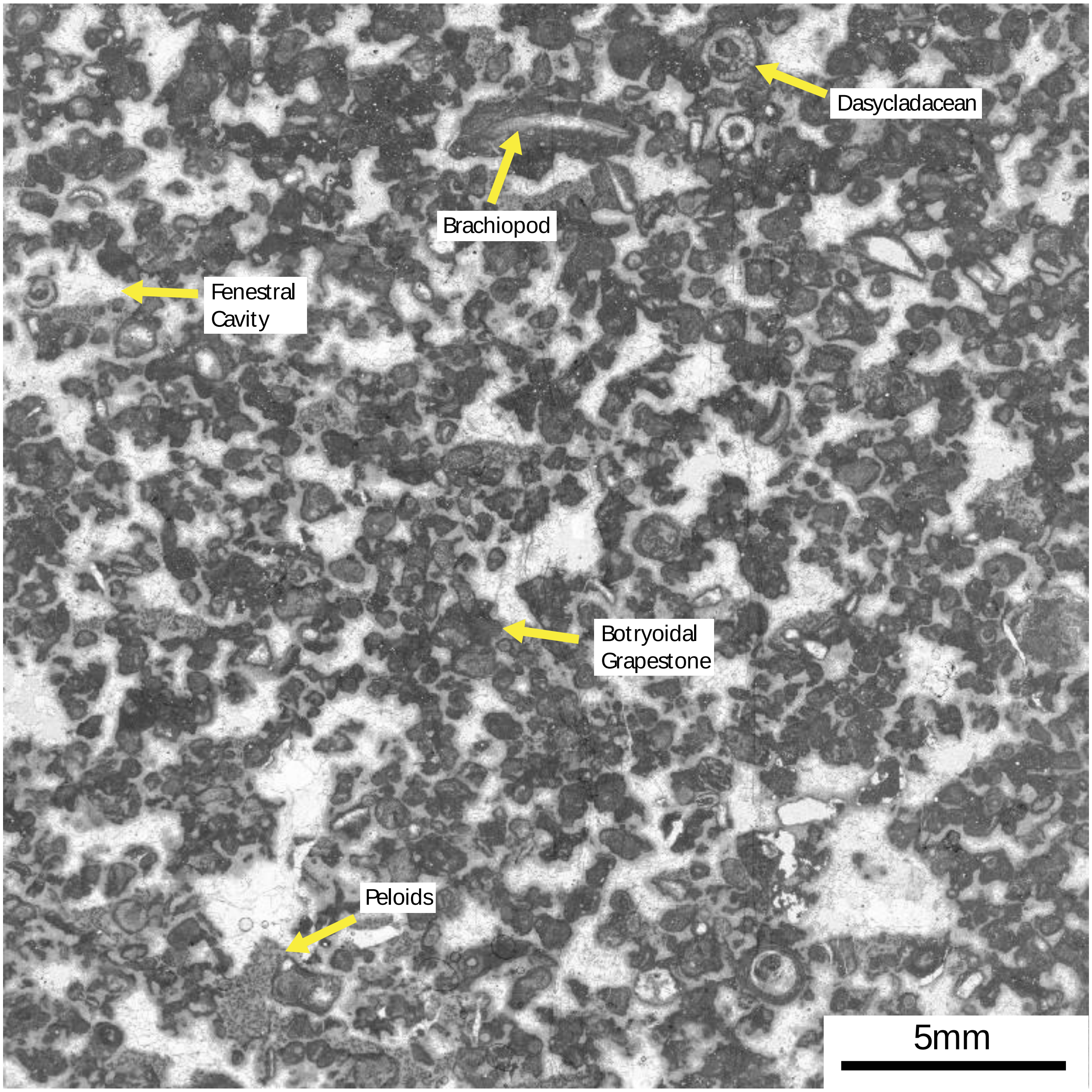

Figure 3.18 Photomicrograph depicting the microfacies in the top of package (VII) of section PC7 (sample PC7-7E): lagoonal bioclastic intrasparite containing dasycladacean algae, brachiopods, peloids, botryoidal grapestones, and individual intraclasts.

Li et al. (1997) described three depositional stages of a tropical carbonate lagoonal environment with frequent storm influence from the east coast of Grand Cayman, British West Indies. The depositional conditions are: (1) storm approach stage; (2) storm waning stage, and (3) fair-weather inter-storm stage. During the approach stage, fine lagoonal sediments are perturbed and entrained into the water column by large waves. These waves overtop the barrier reef, mechanically weathering and eroding reef sediments and transporting them shoreward. Grains generated in the fore-reef can also be transported by the same overtopping waves. The authors noted in their lagoonal samples the presence of foraminiferal tests made by species endemic to fore-reef environments. During the storm waning stage, the reef and fore-reef derived sediments are deposited within the lagoon and the fine lagoonal derived sediments suspended in the water column are preferentially transported out of the lagoon through tidal channels as the storm surge drains. Once buried and lithified, the resultant limestone matrix would be a clean, sparry calcite. The lagoon is protected by the barrier reef during fair-weather inter-storm conditions. The energy level is sufficiently low to allow fine sediments to be deposited on the sea floor and lagoonal colonial fauna is permitted to thrive without being negatively affected by strong wave forces.

The basal facies of package (VII), sample PC7-7A, represents a shallow subtidal back-reef zone influenced by a storm generated moderately high energy event. The fine-grained intraclasts were created by strong waves mechanically weathering and eroding existing consolidated or semi-consolidated carbonate sediments and redepositing them back into the lagoonal basin. Any carbonate mud was winnowed by the event and transported out of the environment. Sediments were rapidly buried before the reinfiltration of mud and could occur during fair-weather conditions. The substantial number of fusulinacean tests could maintain their close proximity to each other because energy levels were inadequate to entrain the tests into the water column and disperse them throughout the lagoon.

Sediments of sample PC7-7B, the second of package (VII), were deposited in calmer water compared to the PC7-7A. The allochem association is generally the same: small intraclasts, grapestones, and bioclasts. Yet in sample PC7-7B, a thin layer of oolitic or microbial carbonate film usually covers the allochems. Botryoidal grapestones are often described in association with calm, restricted lagoonal environments where microbial organisms can build up carbonate rinds on the grain surfaces without being perturbed by strong wave action. Any agitation was likely gentle. The expected matrix composition of rocks deposited in a calm, fair-weather lagoon environments is micrite; however, the matrix of sample PC7-7B is spar. A possible explanation is that the sediments were transported during stormy conditions with energy sufficient to winnow the carbonate mud. After the storm abated the sediments could have been deposited too deep in the sediment column for mud to reinfiltrate the intragranular space during fair-weather conditions. Then, microorganisms could biogenically deposit the calcite rinds on the grapestone surface.

Calm water is also required to produce the microfacies of sample three (PC7-7C) from package (VII). The interpretation for the depositional environment is a calm, shallow lagoon. The micrite matrix indicates there was insufficient energy to agitate the fine carbonate material and wash it from the sediments. The peloids being irregularly shaped indicates their origin was possibly algal. They were unlikely to have been of fecal origin because those tend to be rounded and elongate in nature. The appearance of stromatolites in the sample suggests the water depth was shallow, as most stromatolitic organisms require sunlight for photosynthesis.

Sample four, PC7-7D, of package (VII) was deposited in a calm, back-reef lagoonal environment. The sample is very like sample PC7-7B in that the matrix is composed of sparry calcite with an allochemical composition of botryoidal grapestone intraclasts and small fossil bioclasts. The primary difference between the two samples is the grain sorting. There are considerably smaller sized intraclasts in PC7-7D compared to PC7-7B, indicating they were likely deposited in a deeper water depth. In addition, the grain coating is thinner in PC7-7D and less well developed compared to PC7-7B indicating conditions were not quite as favorable for surficial carbonate precipitation. Storm events winnowed the mud from the sediments allowing a clean, sparry calcite grainstone to deposit in an otherwise calm lagoon.

Sediments comprising the rock at the top of package (VII) (sample PC7-7E) were deposited in a back-reef lagoonal setting during a high energy storm event. The sediments were originally deposited within the lagoon itself based on the fine-grained allochems, and micrite seen within the grapestone bound intraclasts of the sample. These grains have very similar qualities to overall texture present in sample PC7-7C lower in the package and were likely deposited under similar conditions. The fossil assemblage likely originated in a barrier reef environment and was violently eroded from the reef structure as most of the preserved faunal structural components are broken.

3.2.8 *Package (VIII) – Lagoonal Bioclastic Intrasparite, Lagoonal Intrabiosparite, Beach? Aphanocrystalline Oolitic Dolostone*

Description

The final package from the PC7 section, package (VIII), is 9.0 meters thick and was sampled four times with a sampling interval of approximately one per every two meters. The package is a prominent ledge forming interval that caps the eastern hill at the mouth of Panther Canyon. Sample one, PC7-8A (figure 3.19), is a limestone with a sparry calcite cement matrix displaying a fine, equant crystal habit. The allochems are dominantly very fine-grained intraclasts amidst grapestone intraclasts of a darker shade. Bioclasts are present, sparsely distributed, and include brachiopod fragments, dasycladacean algae, ostracods, and, most rarely, fusulinaceans. Positive identification of these fusulinid bioclasts is problematic due to their sparse distribution and because the orientation of their tests in the thin section was inadequate to identify them. However, these forms appear to belong to the species *Codonofusiella altudensis* Wilde and Rudine. The primary intraclast grains are well sorted and sub-rounded. The darker grapestones are considerably larger than the other intraclasts in the sample and contain an internal micrite matrix.

The next sample, PC7-8B (figure 3.20), from package (VII) is limestone containing two predominant allochem types generally in volumetrically equal proportions: fusulinid bioclasts and peloid grapestone intraclasts. The fusulinaceans belong to at least two different genera, *Paradoxiella* and *Codonofusiella*, and are often coated with a thin rind of dark calcite. Identification of the fusulinaceans is problematic due to the unfortunate test orientation in the sample, however, one looks similar to a specimen *Paradoxiella pratti*? illustrated by Wilde and Rudine (2000, plate 15-7, figure 8). Other bioclasts present include dasycladacean algae, gastropods, and small foraminifers including *Agathammina* and *Abadehella*. The intraclasts found in the sample are usually grapestones containing peloid aggregates with occasional incorporated bioclasts. Very-fine peloids are often seen suspended within the space between larger allochems and the sorting is poor. Micrite tends to be the main cement binding the peloids and bioclasts together whereas calcite spar is the predominant matrix material of the rest of the

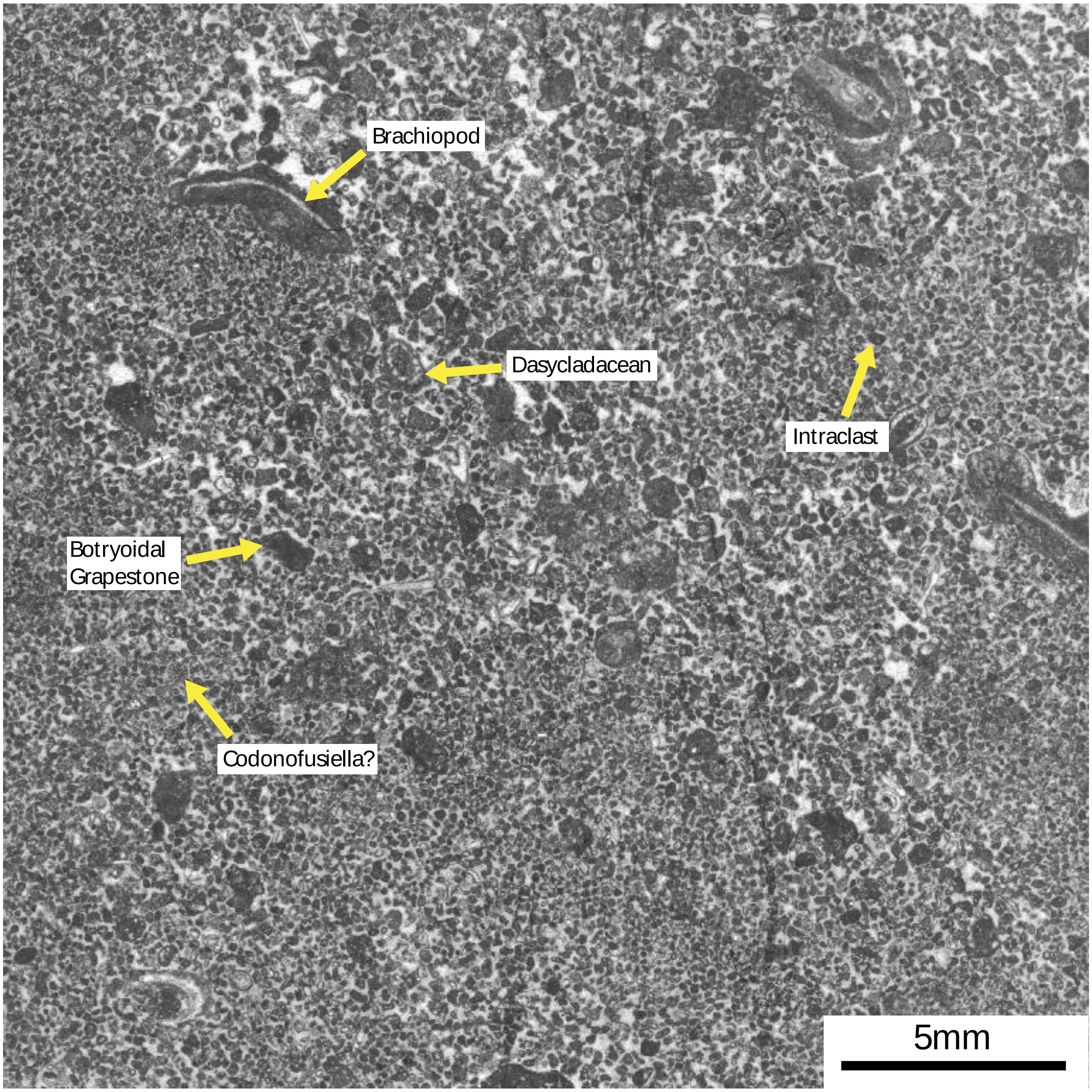

Figure 3.19 Photomicrograph depicting the microfacies in the base of package (VIII) of section PC7 (sample PC7-8A): lagoonal bioclastic intrasparite containing dasycladacean algae, brachiopods, botryoidal grapestones, and numerous intraclasts.

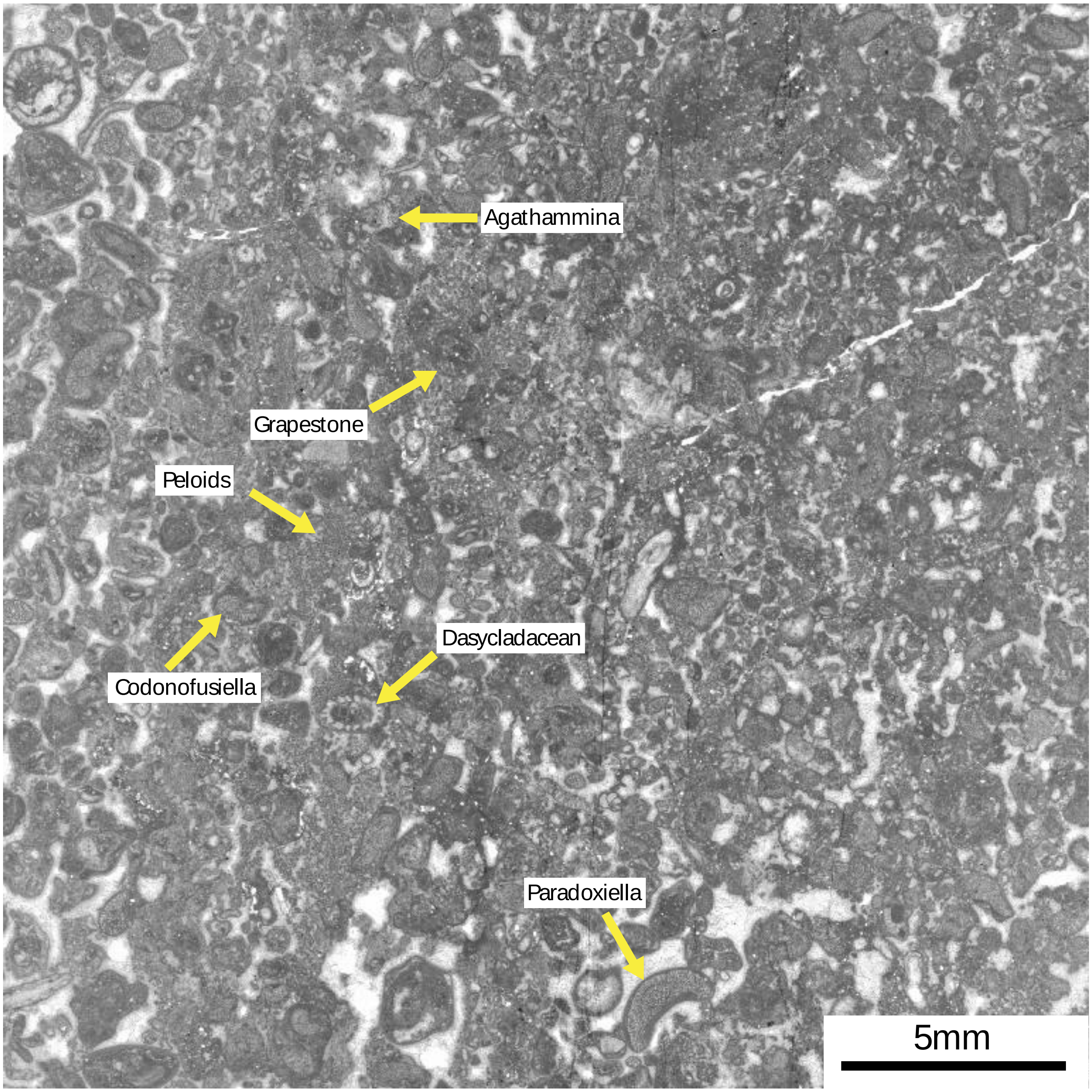

Figure 3.20 Photomicrograph depicting the microfacies lower-middle part of package (VIII) of section PC7 (sample PC7-8B): lagoonal intrabiosparite containing dasycladacean algae, reicheliella, Codonofusiella, small foraminifers, peloids, grapestones, and intraclasts.

fabric. The spar is formed in two stages typical of phreatic zone diagenesis. There is a thin rind of bladed isopachous cement on the surface of the allochems which formed rapidly after deposition. Beyond these blades slow forming blocky, equant calcite spar fills the remaining volume of the rock.

The third sample from package (VII), PC7-8C (figure 3.21), is composed of limestone displaying striking normal grading with large, gravel-sized allochems at the bottom of the sample transitioning into moderately coarse-grained allochems towards the top. In hand sample, the grains appear to be pisolitic in nature, but in thin section they are obviously large intraclasts. A few of the larger grains are coated by layered calcite and can be classified as pisoids. However, the nuclei of these pisoid grains are sufficiently large to identify them as intraclasts containing dasycladacean algae, fusulinaceans, and other small bioclasts embedded in a micritic matrix. The smaller grains consist of other intraclasts including grapestones and individual grains, as well as bioclasts such as fusulinaceans, dasycladacean algae, as well as a few ostracods and the foraminifer *Globivalvulina*. The fusulinaceans are difficult to identify, but are likely belonging to the genera *Codonofusiella* and possibly *Paradoxiella*. Binding these allochems together are several stages of sparry calcite cement. Most of the grains have a thin rind of smooth, dark calcite coating their exterior. Beyond this coating is a thick, bladed isopachous layer of calcite spar. Towards the top of the sample where the grains are smaller, the isopachous layer around the grains meets the isopachous layer from neighboring grains and completely fills the intergranular space. The larger grains in the lower portion of the sample are separated by a gap and the space is filled by blocky, euhedral calcite spar.

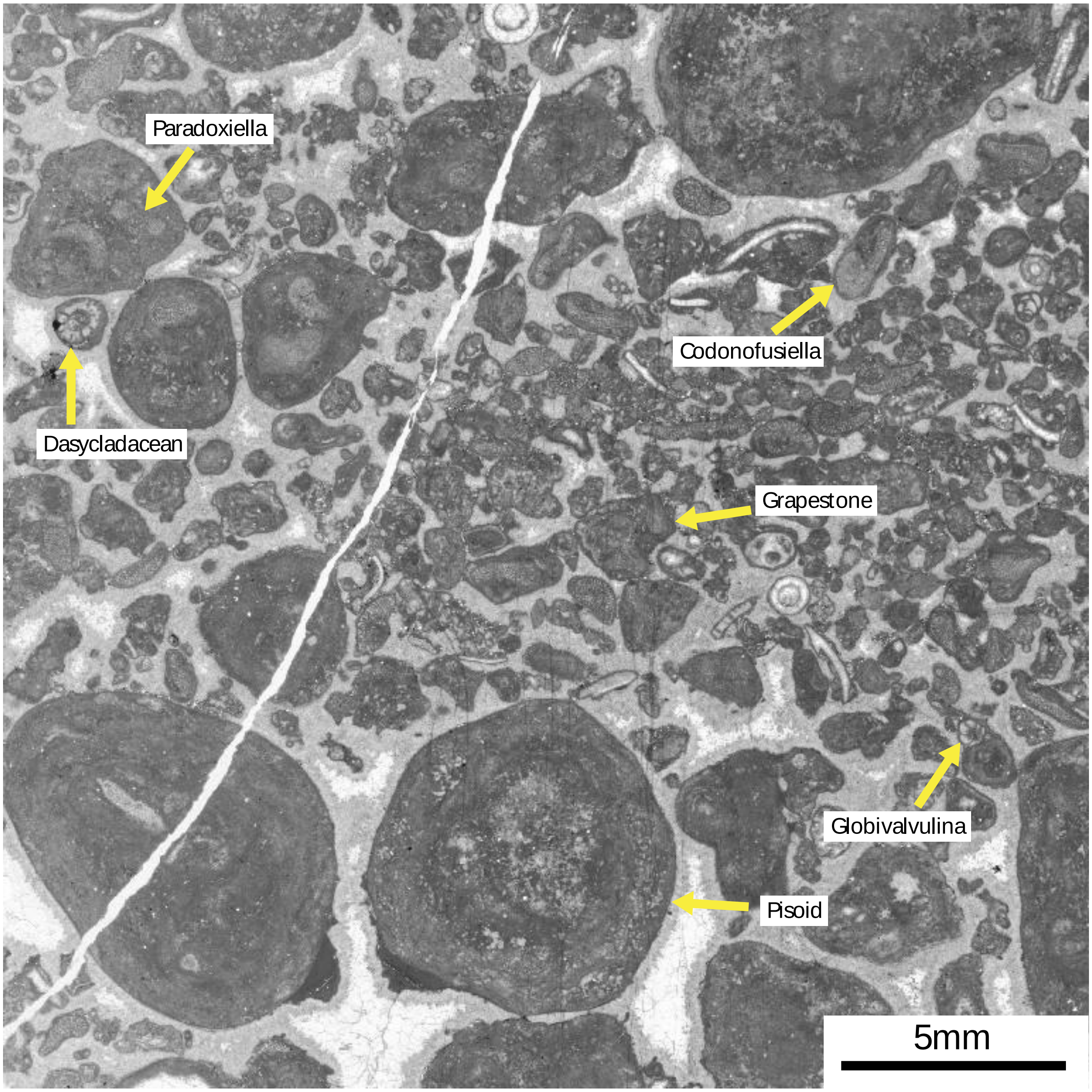

Figure 3.21 Photomicrograph depicting the microfacies in the upper-middle part of package (VIII) of section PC7 (sample PC7-8C): lagoonal bioclastic intrasparite containing dasycladacean algae, Paradoxiella, Codonofusiella, small foraminifers, grapestones, and pisoids.

The sample from the top of the section, PC7-8D (figure 3.22), originally was a limestone that has been entirely replaced by dolomite. Little can be said concerning the original texture of the rock. However, one presumption can be made based upon numerous spherical to ellipsoid-shaped cavities present in the rock. It is plausible these cavities are casts created by the dissolution of ooids based on their shape. Most of the cavities have been filled by calcite sparry cement, but many are totally filled by dolomicrite where only the faint outline of the original ooid shape remains. Some of the ooid casts contain a small thickened deposit of material in the bottom of the cavity that could represent insoluble material previously present within the nucleus of the ooid or incorporated within the concentric carbonate laminae of the ooid structure. These deposits on the cavity floors provides a convenient geopetal structure useful for determining the depositional orientation of the rock.

Interpretation

Sample PC7-8A was likely deposited in a back-reef lagoonal environment more distal from the barrier reef compared to the rocks of package (VII). The sediment grain size in sample PC7-8A is considerably smaller, very-fine compared to package (VII). The smaller grains remained suspended in the water column longer and traveled further away from the sediment source during a storm event. When the energy level weakened sufficiently to prevent the grains to remain entrained, they fell onto the sea floor of the lagoon. The grapestones were partially consolidated carbonate grains that were ripped up during the storm and were deposited alongside the smaller bioclasts and intraclasts.

Sample PC7-8B is poorly sorted with grain sizes ranging from coarse-silt to fine-sand indicating the energy level was low enough to allow the finer particles to settle out of suspension. These sediments were possibly deposited during the tail end of a barrier washover after larger particles

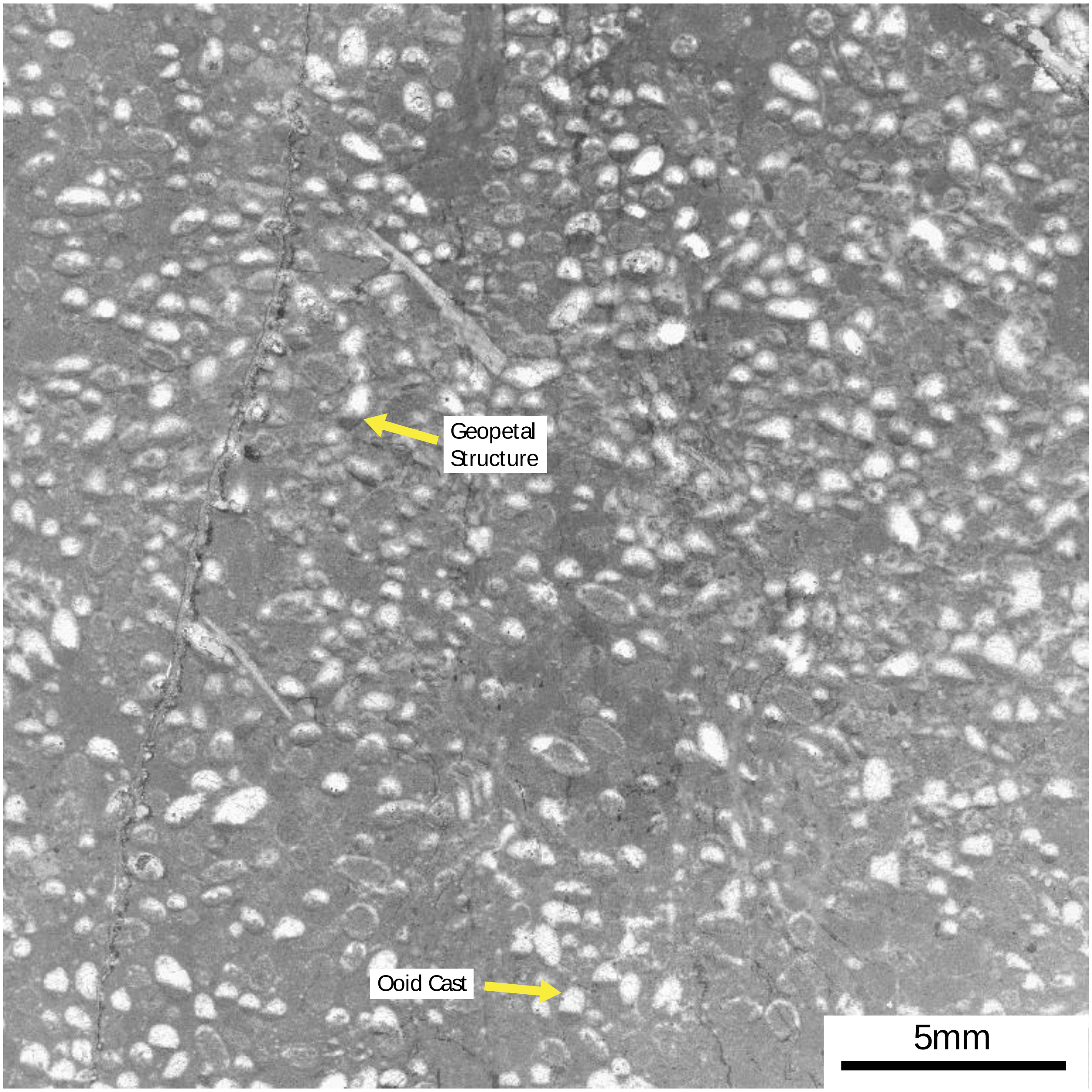

Figure 3.22 Photomicrograph depicting the microfacies in the upper part of package (VIII) of section PC7 (sample PC7-8D): Beach? aphanocrystalline oolitic dolomite containing ooid casts often partially filled showing geopetal structures.

had already settled onto the sea floor. The implication is that storm generated sediments settled after the storm abates showing a normal regime grain-sized gradient with larger particles at the base of a washover deposit fining upwards. The dasycladacean algae indicate the sample was positioned in a back-reef lagoonal setting.

Sediment grading of sample PC7-8C corroborates the settling implications from the previous sample. The base of the sample contains centimeter-sized intraclasts which grade into fine-grained intraclasts and fusulinid bioclasts towards the top. Leatherman and Williams (1983) showed that normal grading is the typical grain size distribution of modern storm generated barrier island washover fans. When particle densities and shape are uniform and spherical, settling velocities are governed by Stokes' Law. That is, a linear relationship of particle size and settling velocity exists which results in larger particles settings out of suspension before smaller particles creating a normal gradient of grain sizes. Sediments from the sample, being composed of calcium carbonate, maintain relatively uniform densities, however, the particle shapes vary widely. Smooth grain surfaces promote laminar flow around the particle as it falls allowing for an even decent. Rough surfaces promote turbid flow around the particle and slow their decent. Most of the grains from the sample have a thin coating of calcite, likely biogenetically precipitated, which smoothed the particle surfaces and allowed for the sediment deposition to behave consistent with Stokes' Law.

Dolomitization renders confident depositional environment interpretation of sample PC7-8D problematic. The presence of the dissolved ooid casts, however, suggests that the environment was within supersaturated warm water. Energy levels were low with gentle wave agitation able to promote ooid formation. Lloyd et al. (1987) show that ooid generation can occur in protected environments such as intertidal shore faces and beaches where wave and current agitation could be generated by prevailing winds. The ooids in sample PC7-8D may have accumulated on a beach or in very shallow water on the back-reef side of a barrier island.

3.3 PC8 Section

The base of the PC8 section is located 920 feet north northeast of the base of PC7 (31˚ 10' 40.0152" N, 104˚ 17' 59.7249" W) about a third of the way up the northern hill at the eastern wall of Panther Canyon (figure3.23). The strata of the section are younger than those in the PC7 section with no apparent time overlap based on the fusulinacean biostratigraphy. As with the PC7 section the focus of the present study concerned the bedded strata superposed upon the massive Capitan Reef Formation forming the bottom of the hill in Panther Canyon. Identifying the initiation of bedding in this section was an easier task compared to PC7 due to the steepness of the hill inhibiting floral cover (figure 3.24). Towards the top of the hill the slope angle decreases and cover becomes a limiting factor for data collection making accurate thickness measurement problematic (figure 2.25). In total, PC8 section has a thickness of 86 meters comprising 15 different packages.

Figure 3.23 Photograph looking up at section PC8. Section measured approximately in the middle of the picture over the top of the ridge to the right.

Figure 3.24 Photograph of the base of section PC8. Exposure quality is high where the hill angle is steep preventing floral cover and surface weathering and erosion.

Figure 3.25 Photograph from near the top of section PC8. Exposure quality significantly decreases inducing bed thickness uncertainty.

3.3.1 *Package (I) – Reefal Dolostone*

Description

Sample PC8-1 (figure 3.26) is dolostone. All the original calcite was diagenetically replaced by dolomite destroying the original texture of the rock in the process except for the presence of a few bioclastic ghosts. Bryozoans, brachiopods, sponges, and even a few odd corals are present amongst these ghosts. Small fecal pellets are also present.

Interpretation

Little remains to interpret due to dolomitization of the original fabric of the rock except for the presence of common reef-building faunal ghosts and fecal pellets. Therefore, the depositional environment is believed to have been of reef origin.

3.3.2 *Package (II) – Reefal Dolostone*

Description

Package (II) is 7.4 meters thick and three samples (PC8-2A, PC8-2B, and PC8-2C) were taken with an interval of 2.4 meters. Each sample is entirely dolostone showing variable textures. The base of the package, represented by sample PC8-2A (figure 3.27), displays a mottled texture containing medium sand-sized, indistinguishable allochem ghosts amidst many sparry filled, rounded voids. Several of these voids contain a small thickening of material at the bottom providing a convenient indicator of the original orientation of the rock, and are interpreted as geopetal structures that likely formed before dolomitization. The second sample, PC8-2B (figure 3.28), has a much finer texture than sample PC7-2A. Dolomitization is also

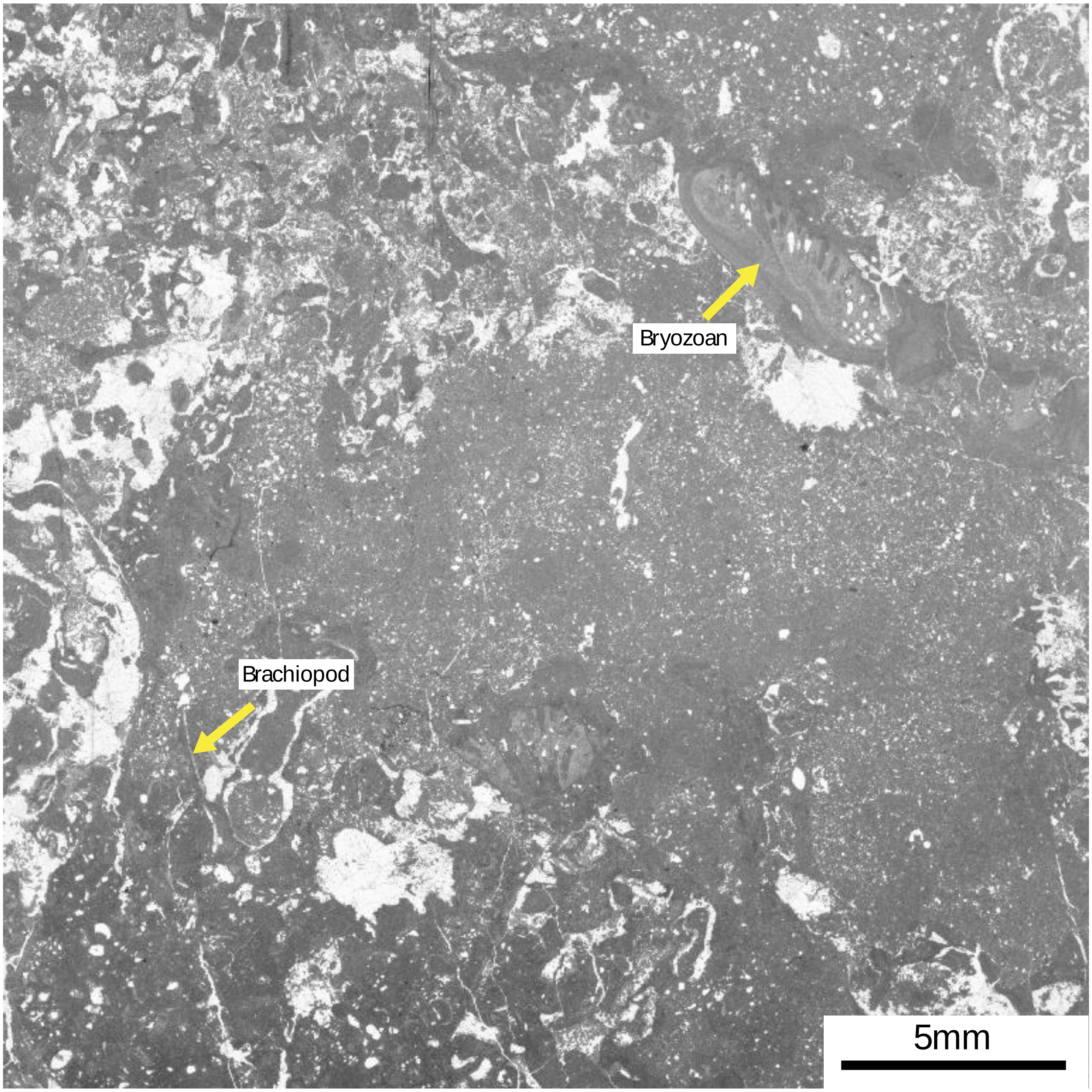

Figure 3.26 Photomicrograph depicting the microfacies of package (I) of section PC8 (sample PC8-1): reefal dolostone containing bryozoan and brachiopod fossil ghosts.

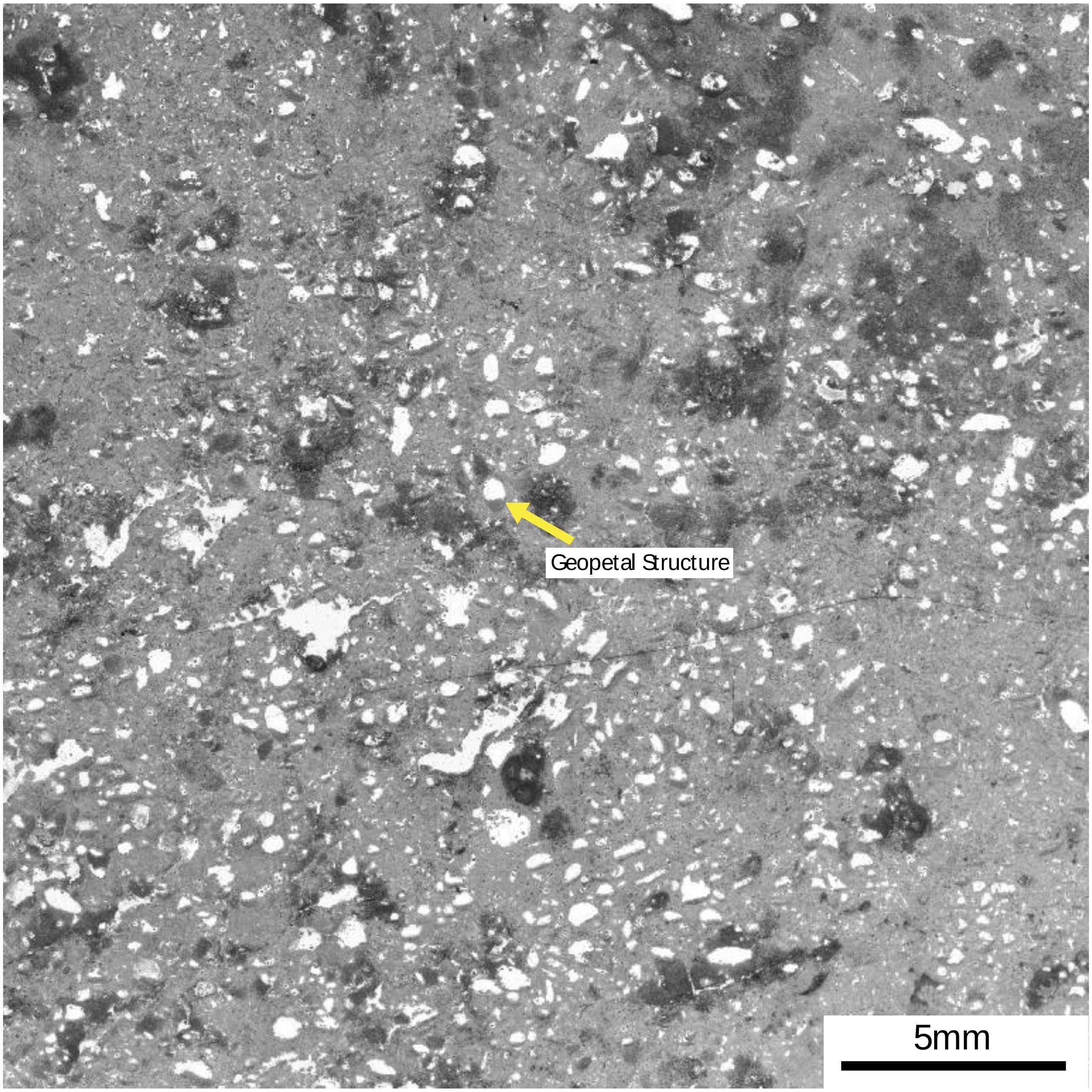

Figure 3.27 Photomicrograph depicting the microfacies in the base of package (II) of section PC8 (sample PC8-2A): reefal dolostone containing cryptic fossil ghosts sometimes represented as partially filled casts showing geopetal structure.

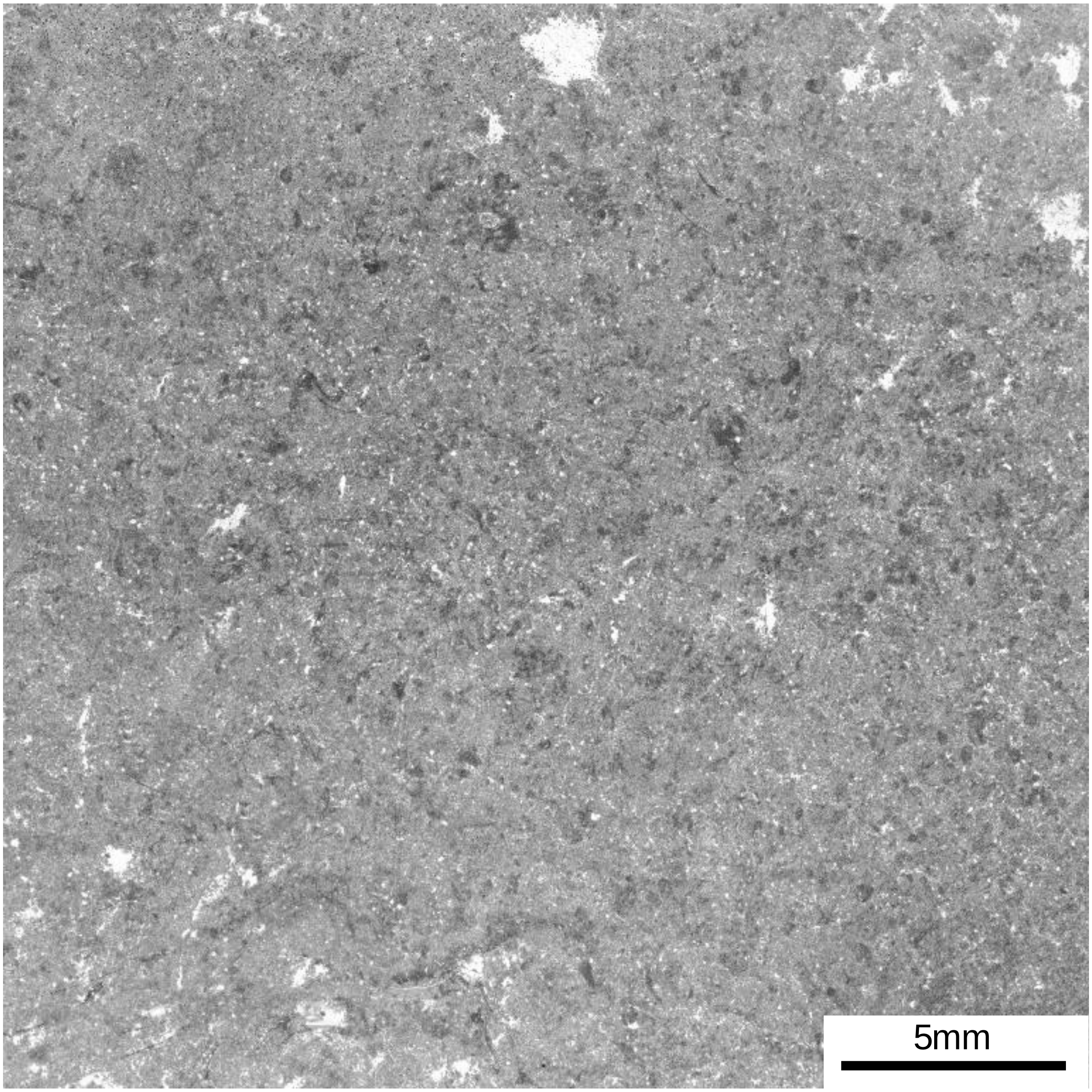

Figure 3.28 Photomicrograph depicting the microfacies in the middle part of package (II) of section PC8 (sample PC8-2B): reefal dolostone.

stronger as no allochems can be easily recognized. Based on their outline, a few relict allochems may have been intraclasts. Voids are fewer, have a more angular outline and weaker boundaries.

The rock at the top of package (II), sample PC8-2C (figure 3.29), is thoroughly dolomitized. It contains voids which are much larger than those found in either samples PC8-2A or PC8-2B. These voids are filled by euhedral sparry cement. A single calcareous sponge relict fossil was seen, and all others are presumed to have been destroyed during dolomitization.

Interpretation

Few clues were available to aid in the interpretation of the depositional environment responsible for generating package (II). Based on the geographic position of the package being 920 feet north of the back-reef lagoonal washover deposits from section PC7 and the few bioclast ghosts made by reef-dwelling organisms present low in the package, the depositional environment may have been reefal.

3.3.3 *Package (III) – Supratidal Dolostone*

Description

Package (III) is one meter thick and the rock is dolostone. Only one sample was collected: PC8-3 (figure 3.30). Small voids are present and the texture is very fine containing few recognizable allochems apart from sparse foraminiferal test casts.

Interpretation

Strong dolomitization makes interpretation problematic. Foraminiferal casts are the only recognizable clue. The environment was possibly supratidal with very shallow water where few organisms lived other that very shallow-water dwelling foraminifers.

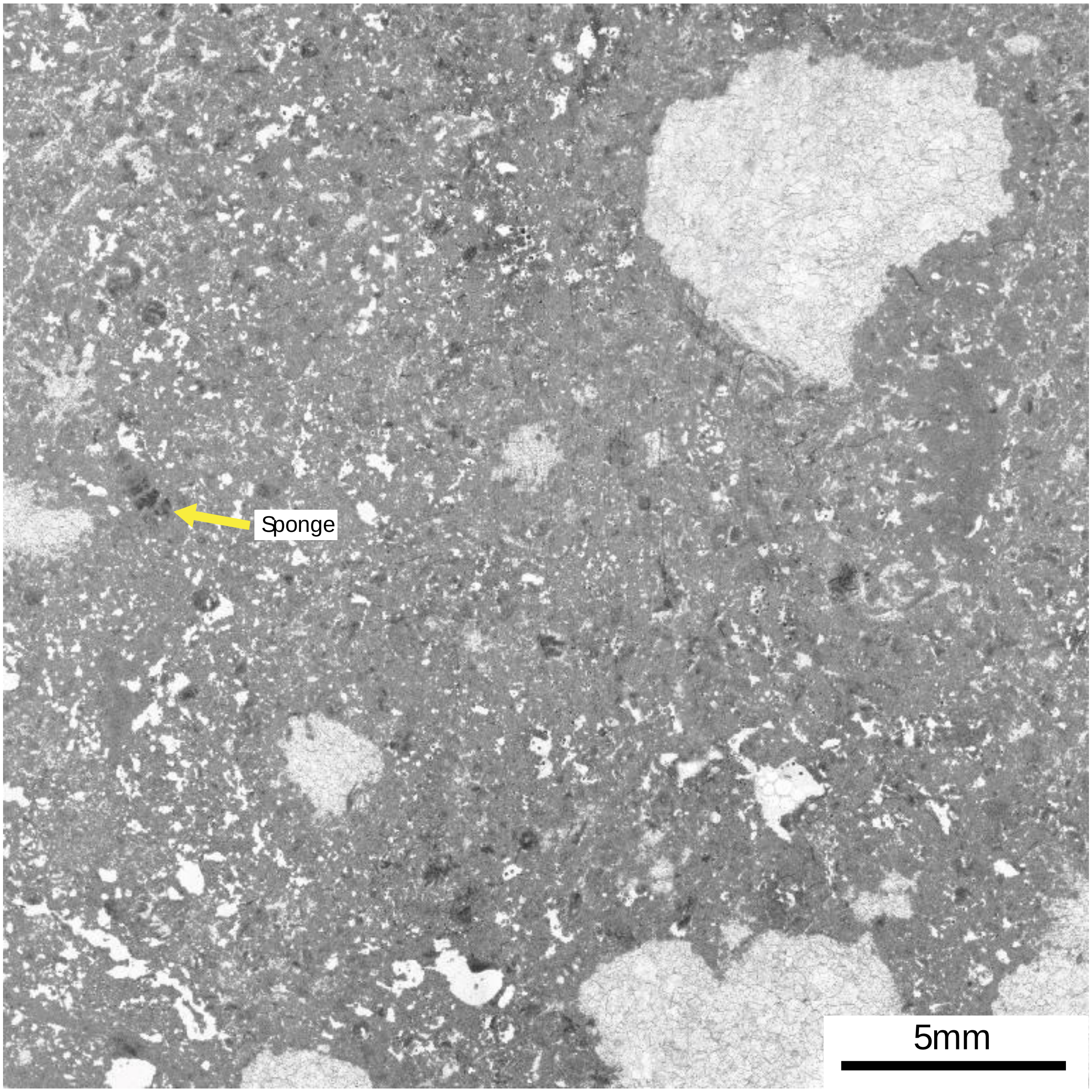

Figure 3.29 Photomicrograph depicting the microfacies in the top of package (II) of section PC8 (sample PC8-2C): reefal dolostone containing fossil ghosts including a singleton sponge.

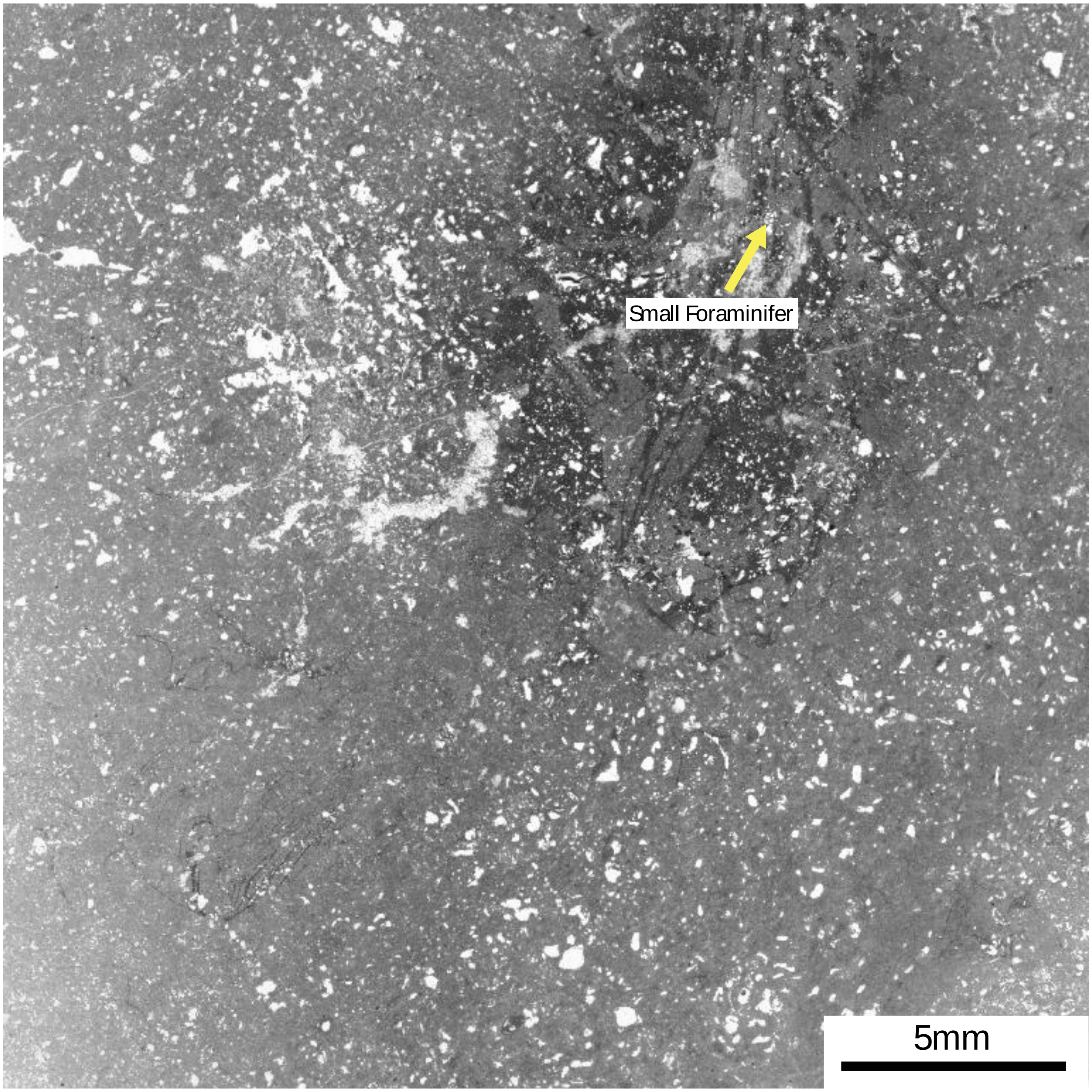

Figure 3.30 Photomicrograph depicting the microfacies of package (III) of section PC8 (sample PC8-3):supratidal dolostone containing sparse, poorly preserved small foraminifers.

3.3.4 *Package (IV) – Lagoonal Dolomitic Intrasparite*

Description

Package (IV) is 3.1 meters thick and was sampled at the base, sample PC8-4A (figure 3.31), and at the top, sample PC8-4B (figure 3.32). Both samples are composed of dolostone, however, the original texture of the rock has largely been preserved. Degradation has been restricted to internal allochem structures and void boundary dolomite crystallization. Sample PC8-4A has an allochemical composition of intraclasts with a bimodal distribution of grain-sizes with drastically differing internal structure. Approximately 65% of the grain population is less than one millimeter in diameter. These grains are dark colored with no recognizable internal structure, likely due to dolomitization. Remaining constituents range in diameter from one to three millimeters. These larger intraclasts have a fine internal texture and often contain large voids usually filled with subhedral calcite spar. The matrix is devoid of micrite and is composed of calcite spar and dolomite.

The matrix observed in sample PC8-4B is largely composed of dolomite containing less calcite than the previous sample and is devoid of micrite. The allochems are composed of intraclasts supplemented by sparse bioclasts including brachiopod fragments and algae. Dolomitization renders confident identification problematic. The allochems are faintly preserved and show relict carbonate coating on their exterior. Sorting is poor and grain sizes range from fine sand to coarse sand sized particles.

Interpretation

Before dolomitization both samples were probably intrasparite. They were likely deposited within a back-reef lagoonal environment by storm generated barrier washover

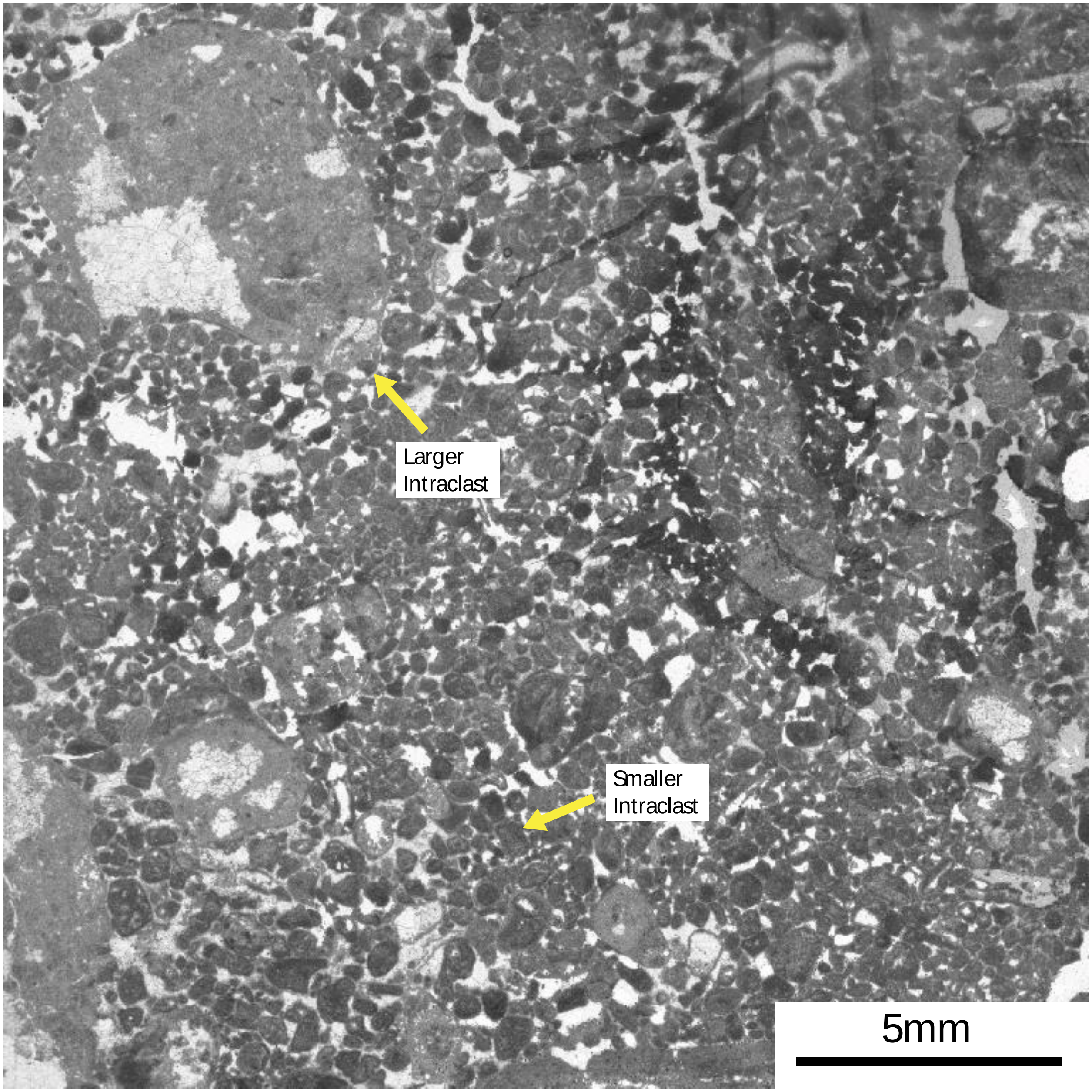

Figure 3.31 Photomicrograph depicting the microfacies in the base of package (IV) of section PC8 (sample PC8-4A):lagoonal dolomitic intrasparite containing a bimodal distribution of larger and smaller intraclasts.

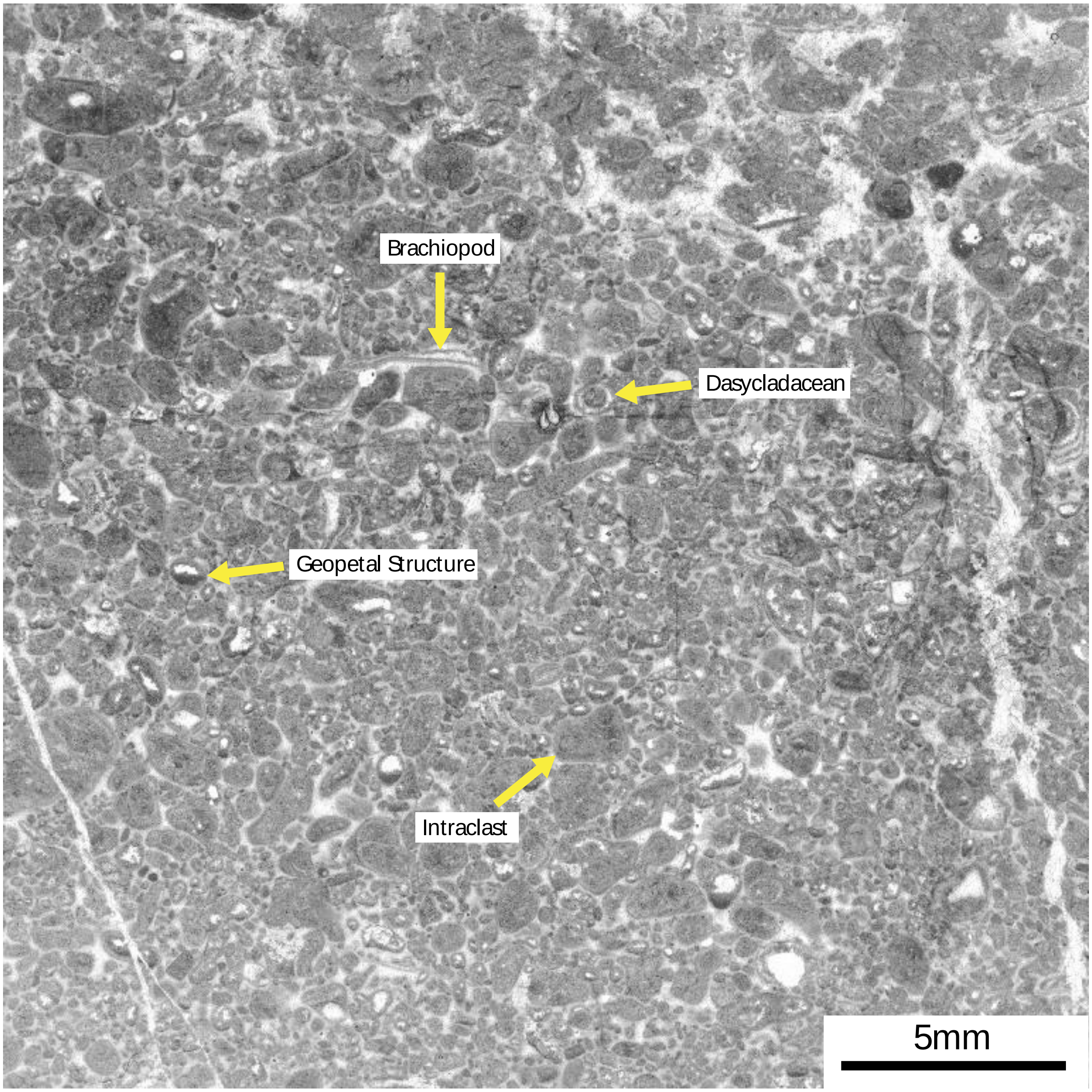

Figure 3.32 Photomicrograph depicting the microfacies in the upper part of package (IV) of section PC8 (sample PC8-4B): lagoonal dolomitic intrasparite containing a few fossil ghosts of dasycladacean algae and brachiopods. Intraclasts are the predominant allochems present. Geopetal structures within voids in the sample are illustrated.

deposition like several of the packages illustrated in section PC7. The bimodal distribution of grain sizes from sample PC8-4A was likely caused by two different sediment sources being bombarded by waves which eroded and transported the grains towards the depositional basin.

3.3.5 *Package (V) – Brachiopod Dolostone, Lagoonal Dolomitic Intrasparite, Back-reefal Intraclastic Biosparite*

Description

Package (V) is 5.0 meters thick and three samples (PC8-5A, PC8-5B, and PC8-5C) were taken at an interval of one sample every meter and a half. The rocks at the base of the package are thoroughly dolomitized and becomes less so towards the top. The original texture of sample PC8-5A (figure 3.33) is destroyed apart from bioclast ghosts recognized to be brachiopod fragments and are commonly distributed throughout the fabric. The carbonate composition of the fragments seems to be more resistant to the dolomitization process than the rest of the sample. Recognizing matrix from non-matrix allochems is impossible due to the high degree of dolomitization.

Sample PC8-5B (figure 3.34) is also composed of dolomite, however there remains a clear delineation between matrix and allochem. Based solely on the external shape of most grains, they appear to have been intraclasts ranging in size from very-fine to medium sand. Sporadic fossil ghosts can be made out including very small crinoids, dasycladacean algae, and gastropods. All internal allochem structure is indistinguishable.

The top of package (V), sample PC8-5C (figure 3.35), shows little evidence of dolomitization, and thus preservation is much better compared to samples taken from lower in the package. Allochems are primarily bioclasts supplemented by intraclasts. Fossil bioclasts include numerous dasycladacean algae and fusulinaceans of the genus *Reichelina.* Other small

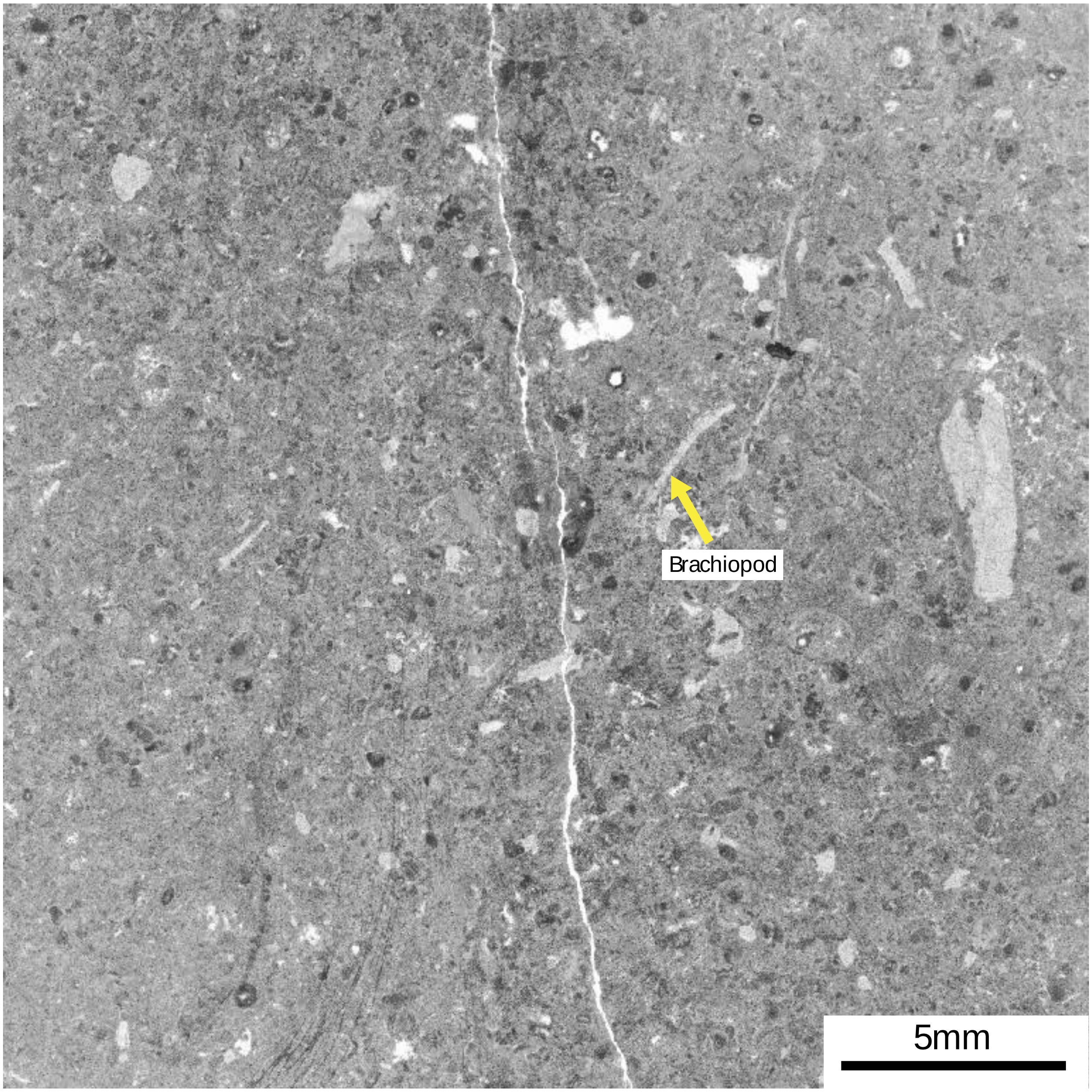

Figure 3.33 Photomicrograph depicting the microfacies in the base of package (V) of section PC8 (sample PC8-5A):brachiopod dolostone containing brachiopod fragments.

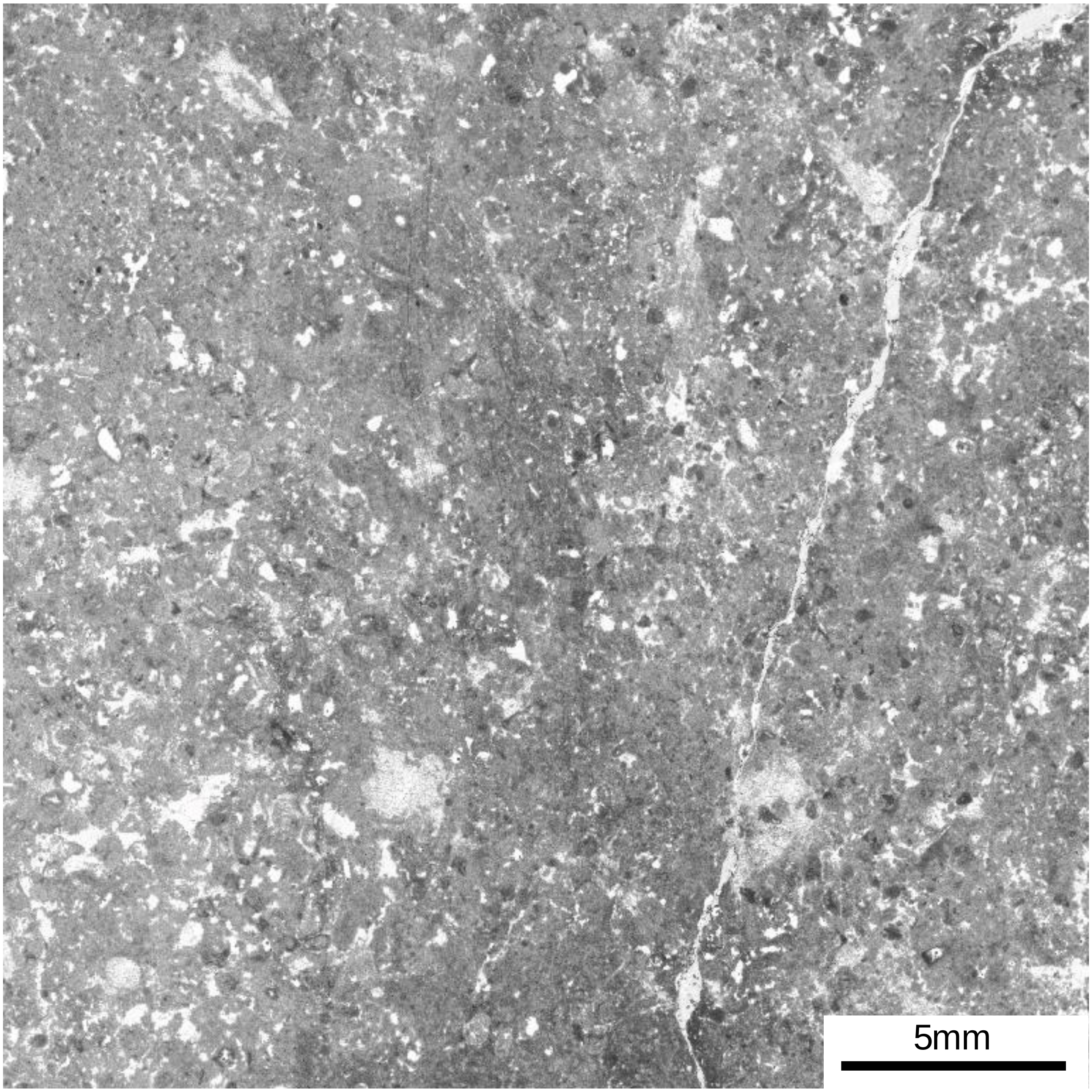

Figure 3.34 Photomicrograph depicting the microfacies in the middle part of package (V) of section PC8 (sample PC8-5B): lagoonal dolomitic intrasparite.

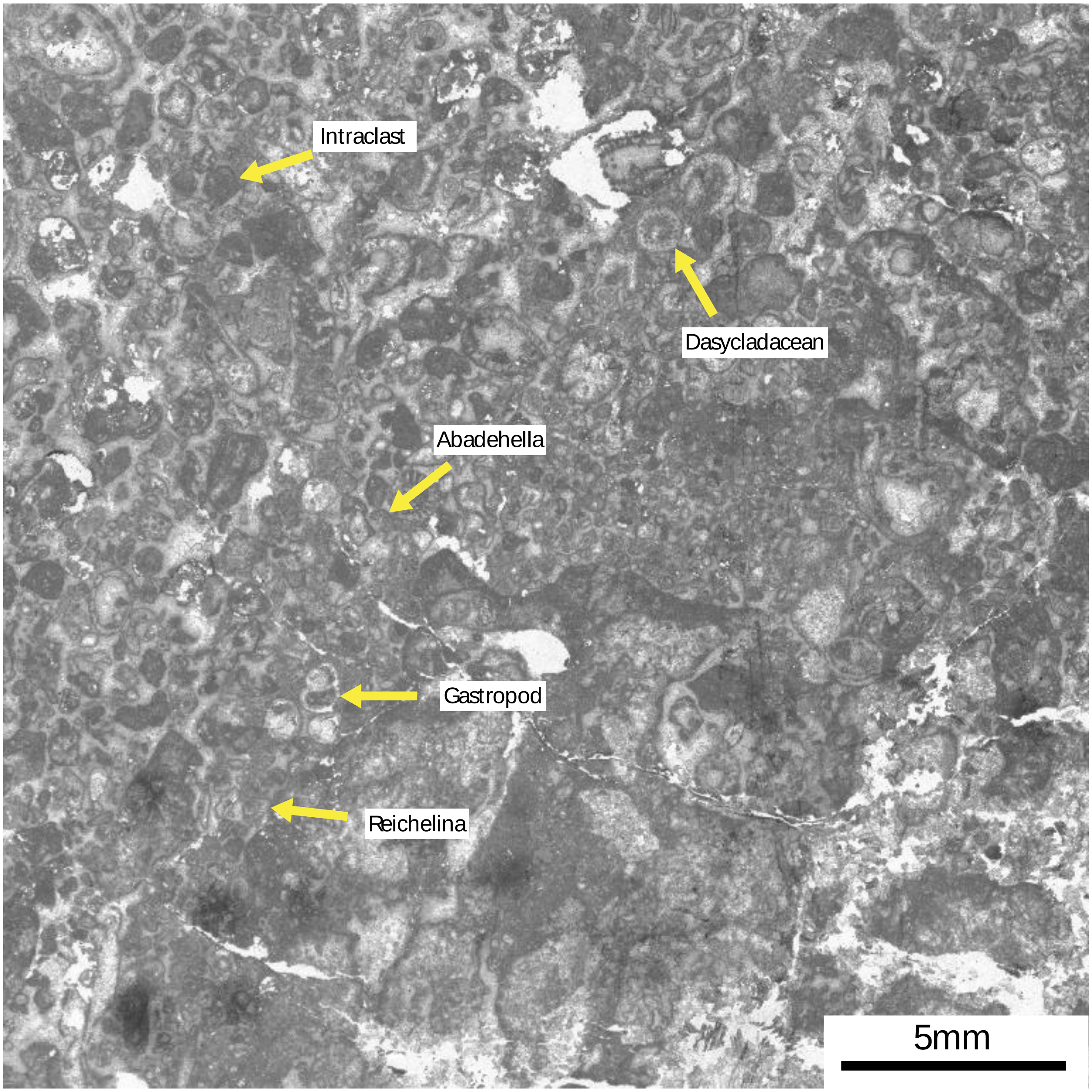

Figure 3.35 Photomicrograph depicting the microfacies in the upper part of package (V) of section PC8 (sample PC8-5C): back-reefal bioclastic intrasparite containing dasycladacean algae, gastropods, Reichelina, small foraminifers, and intraclasts.

foraminifers are sparse and include *Abadehella*. Small gastropods are also rare. The matrix is calcite spar devoid of micrite.

Interpretation

Little can be said about the thoroughly dolomitized sample at the base of the package (PC8-5A). With no original texture present there is little data remaining to interpret.

The microfacies of sample PC8-5B was likely the product of storm generated washover deposition within a back-reef lagoonal environment. The intraclasts and sparse bioclasts were mechanically weathered and eroded from a barrier island/reef structure and were entrained in the waves and transported by overtopping waves into the lagoon. Dasycladacean algae observed amongst the bioclast population are a clear indication of a tropical lagoonal setting. Mud deposited within the low energy lagoonal environment was perturbed by powerful waves and transported out of the lagoon when the storm abated along with the receding storm surge. Micrite free grainstone was deposited within the normally calm lagoon.

The large bioclast population within sample PC8-5C indicates that sediments found at the top of package (V) were deposited and buried during a period of prolonged meteorological quiescence. The evidence of such conditions is seen in the sample by large populations with low species diversity preserved intact within the depositional environment. In sample PC8-5C, the fusulinacean *Reichelina* and dasycladacean algal bioclasts are common indicating the environment was viable for communal populations to thrive. Energy levels were adequate to winnow any mud from the matrix indicating the depositional setting was situated above the fair-weather wave base in shallow water. The upper portion of package (V) is a grainstone.

3.3.6 *Package (VI) – Lagoonal Dolostone*

Description

Package (VI) is 1.5 meters thick and one sample was taken, PC8-6 (figure 3.36). Most allochems within the microfacies are unrecognizable because of dolomitization. Fossil ghosts are common, however, and include brachiopod shell fragments, dasycladacean algae, and sparse foraminifers. The most prevalent allochems are probably intraclasts, and their sorting is poor and the matrix composition is not preserved.

Interpretation

Based solely upon the presence of dasycladacean algae amongst the total bioclast population the depositional environment was a back-reef lagoon. Little else can be inferred about the setting responsible for creating the original texture of the rock because it has been heavily altered by dolomitization.

4.3.7 *Package (VII) – Not sampled due to lack of exposure*

Package VII is represented by 6.5 meters of ground cover consisting of modern alluvium and desert flora. No outcrops were found within the interval to sample.

3.3.8 *Package (VIII) – Lagoonal Bioclastic Intramicrite, Lagoonal Intraclastic Biomicrite*

Description

The microfacies of package (VIII) changes bottom to top from a fossiliferous packstone to a fossiliferous wackestone. Two samples were collected from the package, PC8-8A (figure 3.37) from the base and PC8-8B (figure 3.38) from the top. Both show microfacies containing a micrite matrix and generally similar bioclast allochem compositions. Sample PC8-8A contains a

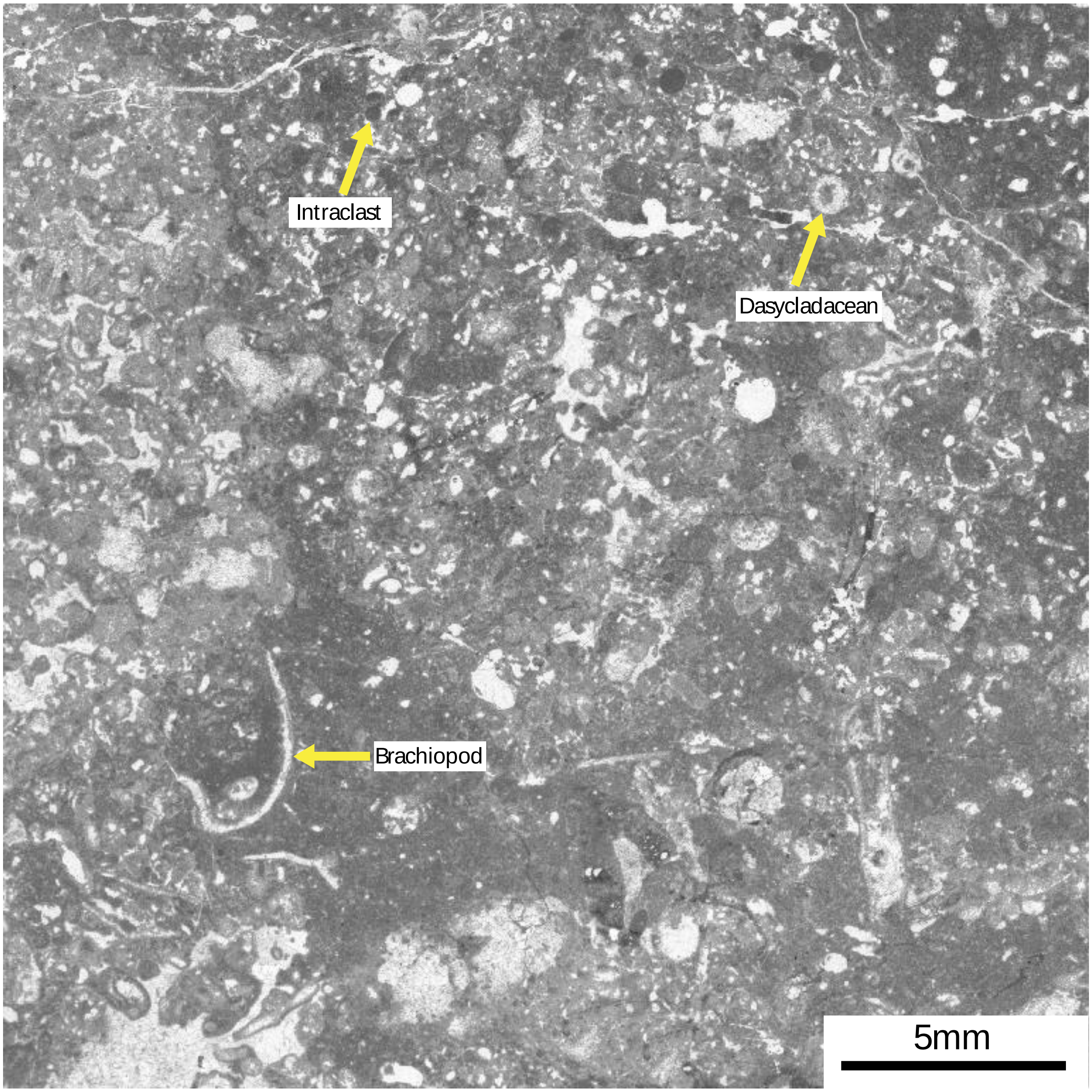

Figure 3.36 Photomicrograph depicting the microfacies of package (VI) of section PC8 (sample PC8-6): lagoonal dolostone containing dasycladacean algae, brachiopods, and intraclasts.

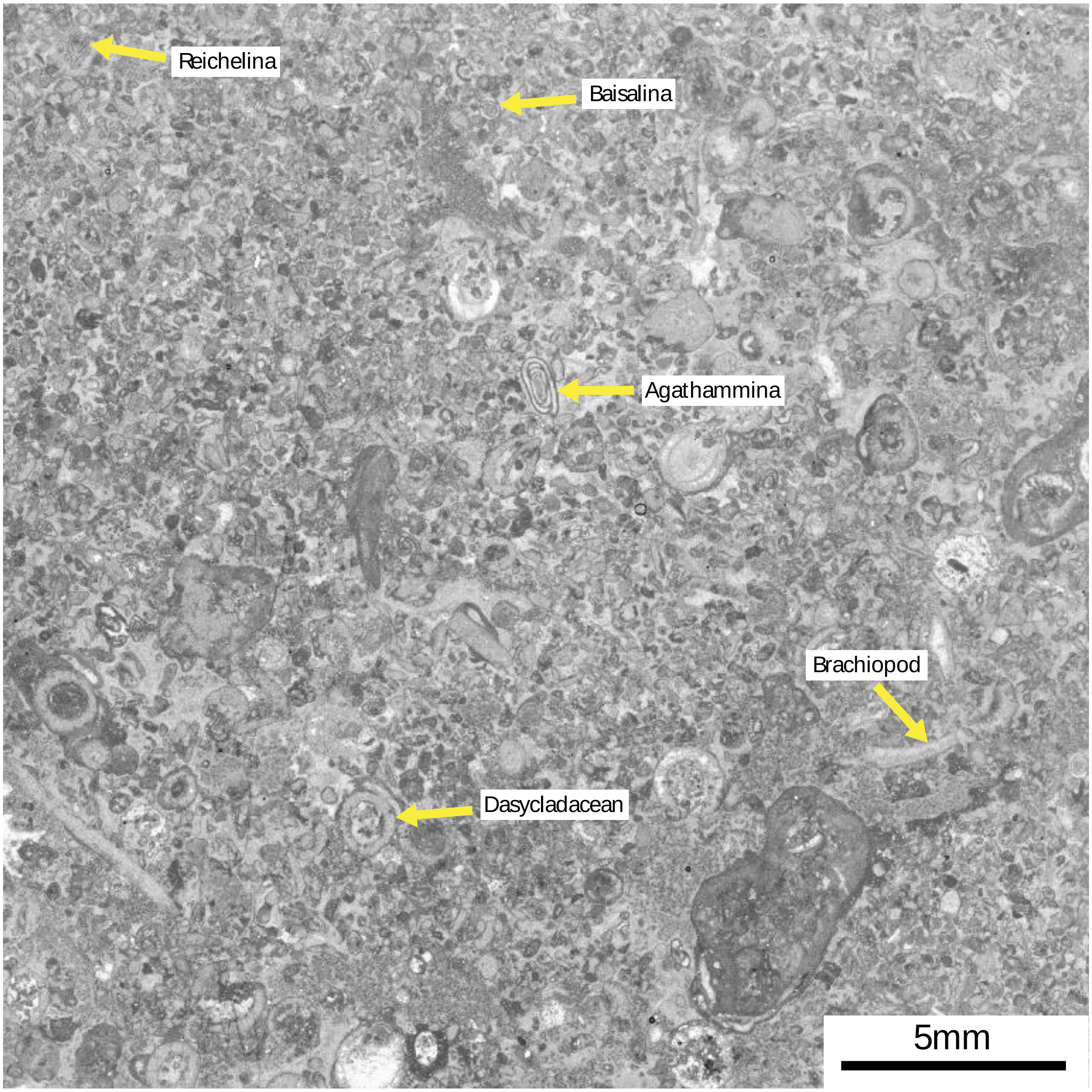

Figure 3.37 Photomicrograph depicting the microfacies in the lower part of package (VII) of section PC8 (sample PC8-8A): lagoonal bioclastic intramicrite containing dasycladacean algae, Reichelina, small foraminifers, brachiopods and intraclasts.

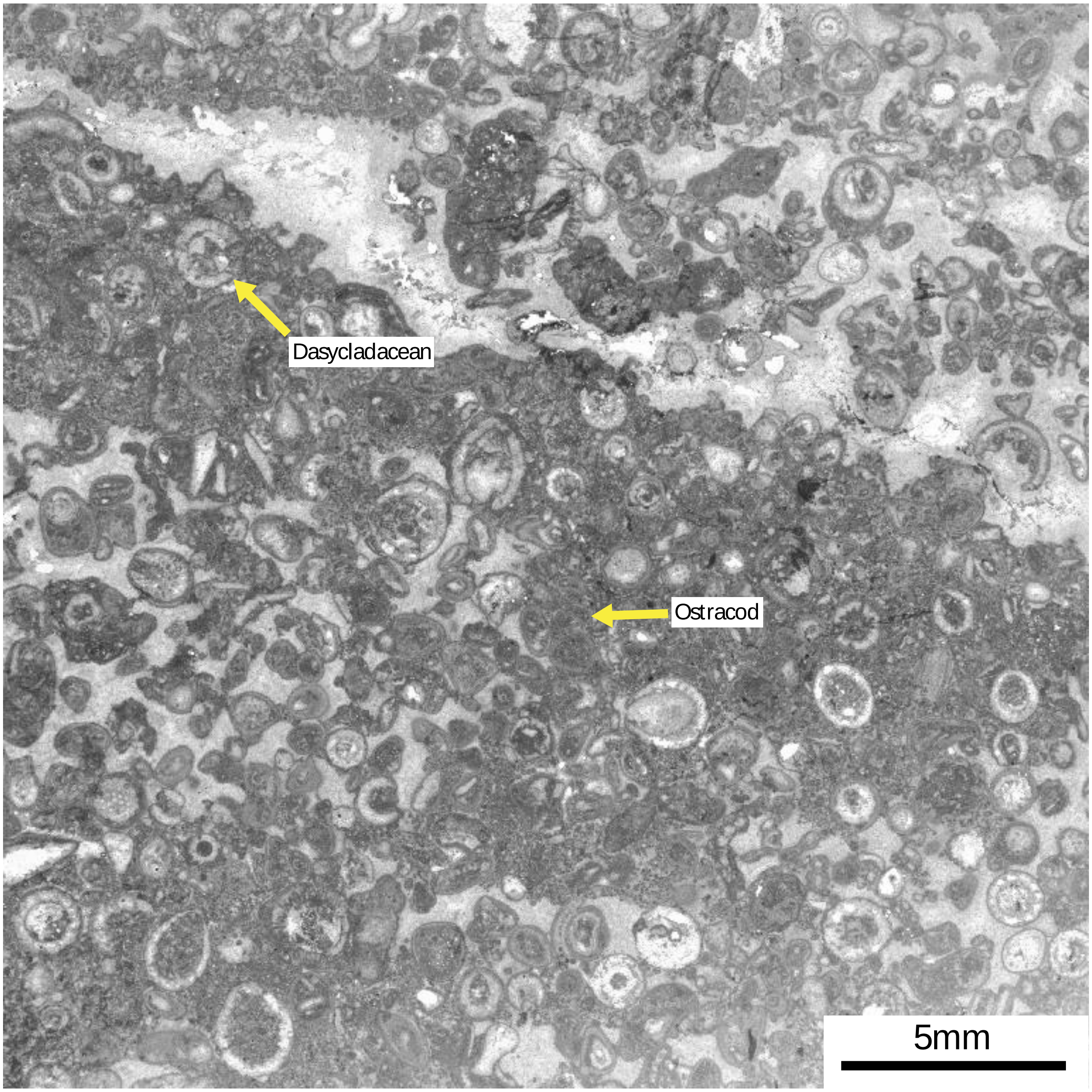

Figure 3.38 Photomicrograph depicting the microfacies in the upper part of package (VIII) of section PC8 (sample PC8-8B): lagoonal intraclastic biomicrite containing dasycladacean algae and a few ostracods. Intraclasts are also present.

high proportion of very-fine sand-sized intraclasts. Sample PC8-8B also contains similar intraclasts but in fewer numbers. Notably, dasycladacean algae are prevalent amongst the bioclast populations of both samples. Gastropods, ostracods, and small foraminifers, including *Agathammina* and *Baisalina americana* Nestell and Nestell are also present. Abundant within package (VIII) are specimens belonging to the fusulinacean species *Reichelina lamarensis* Skinner and Wilde. *R. lamarensis* defines a fusulinid zone within the middle part of the Tansill Formation above the *Paradoxiella* zone and below the *Paraboultonia* zone (Wilde and Rudine, 2000). The known range of *B. americana* is restricted to the middle part of the Tansill Formation within the *R. lamarensis* zone at Dark Canyon in the Guadalupe Mountains, New Mexico (Nestell and Nestell, 2006). *Rauserella bengeensis* Wilde and Rudine is also present and known to extend to within the *R. lamarensis* zone (Nestell and Nestell, 2006). These index species provide confidence to assign package (VIII) to the middle part of the Tansill Formation below the Ocotillo Member.

Interpretation

Both samples were deposited within an environment of insufficient energy to winnow micrite from the matrix of the microfacies. The water must have been calm under normal conditions. The abundant dasycladacean algae are a strong indicator of a calm, back-reef lagoonal depositional setting which is consistent with the preservation of a micrite matrix. The difference between the two samples is the grain to matrix proportions. Sample PC8-8A is a packstone, whereas sample PC8-8B is a wackestone. One possible explanation could be that water levels may have deepened due to small scale eustatic fluctuation during the deposition of package (VIII) sediments. Energy levels would have decreases as a result allowing for finer mud-sized particles to fall out of suspension and deposit onto the lagoonal floor.

3.3.9 *Package (IX) – Reef/back-reef Marginal Biomicrite*

Description

Two samples were collected, one from the base (PC8-9A) (figure 3.39) and one from the top (PC8-9B; figure 3.40) of package (IX). The microfacies at the base of the package contains a poorly washed matrix containing approximately 80% micrite and 20% spar. The fabric is allochemically composed of fossil bioclasts including *R. lamarensis*, brachiopod fragments, dasycladacean algae, gastropods, and sponges. Intraclasts are present, but less than 10% of the allochem population.

The matrix composition of the top of package (IX) (sample PC8-9B) contains a much higher proportion of spar compared to the sample taken near the base of the package. Based on Dunham's (1962) classification of carbonate rocks, strata at the base of the package is packstone, whereas the top of the section is composed of grainstone. Allochems of sample PC8-9B are composed of bioclasts including *R. lamarensis, B. americana* and other small foraminifers, gastropods, ostracods, bryozoans, and a encrusting organism, possibly *Archaeolithoporella*.

Interpretation

The bioclast allochem population contains reef-building fauna including sponges and *Archaeolithoporella* amongst many typical lagoonal dwelling fauna such as *Reichelina,* dasycladacean algae, and small foraminifers. The depositional environment of the rocks forming package (IX) was situated within a transitional margin of a reef and back-reef based on the diverse allochem assemblage. Energy levels were variable depending on the structural protection provided by the reef. Protected areas would be affected by less energy and would

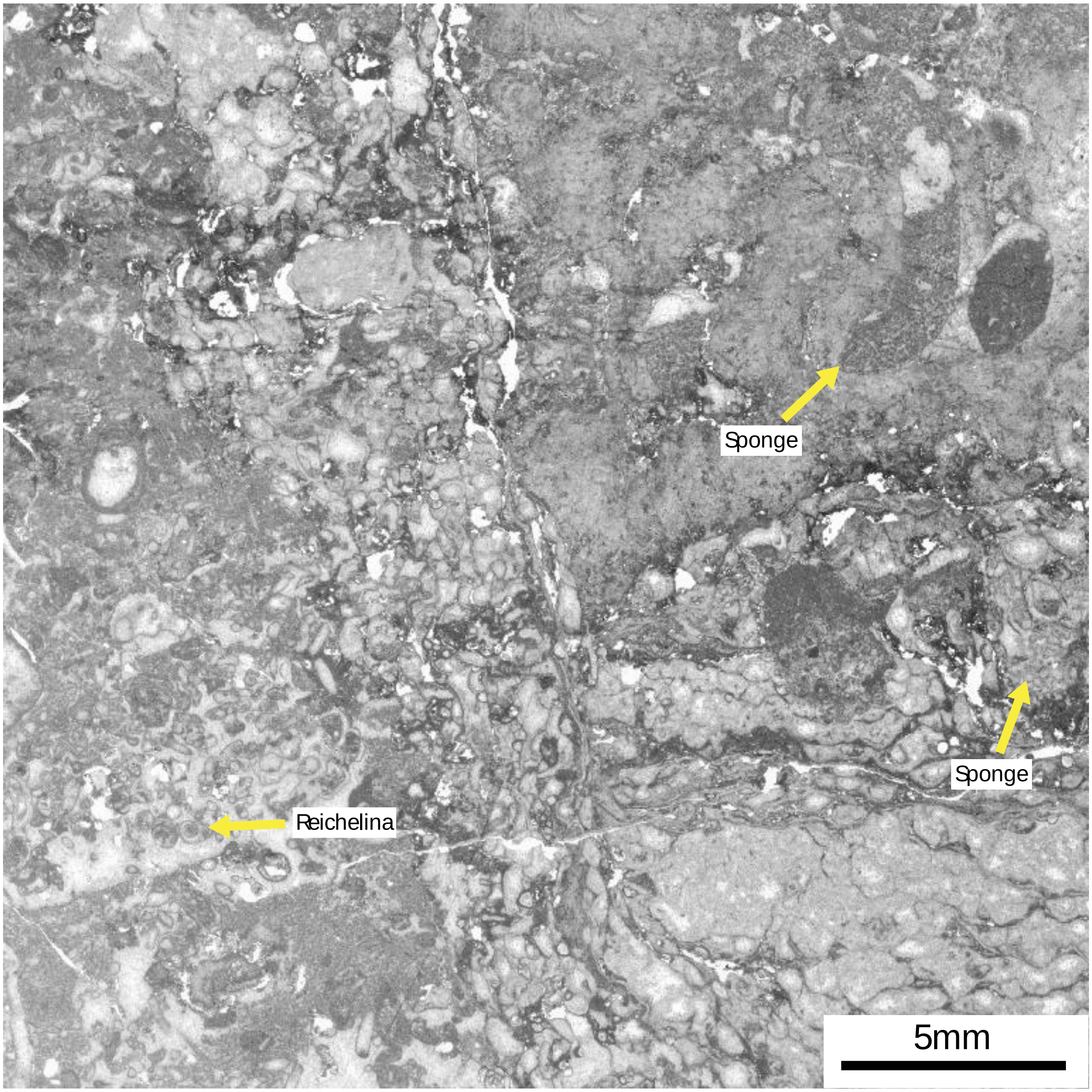

Figure 3.39 Photomicrograph depicting the microfacies in the lower part of package (IX) of section PC8 (sample PC8-9A): reef/back-reed marginal biomicrite containing sponges and Reichelina.

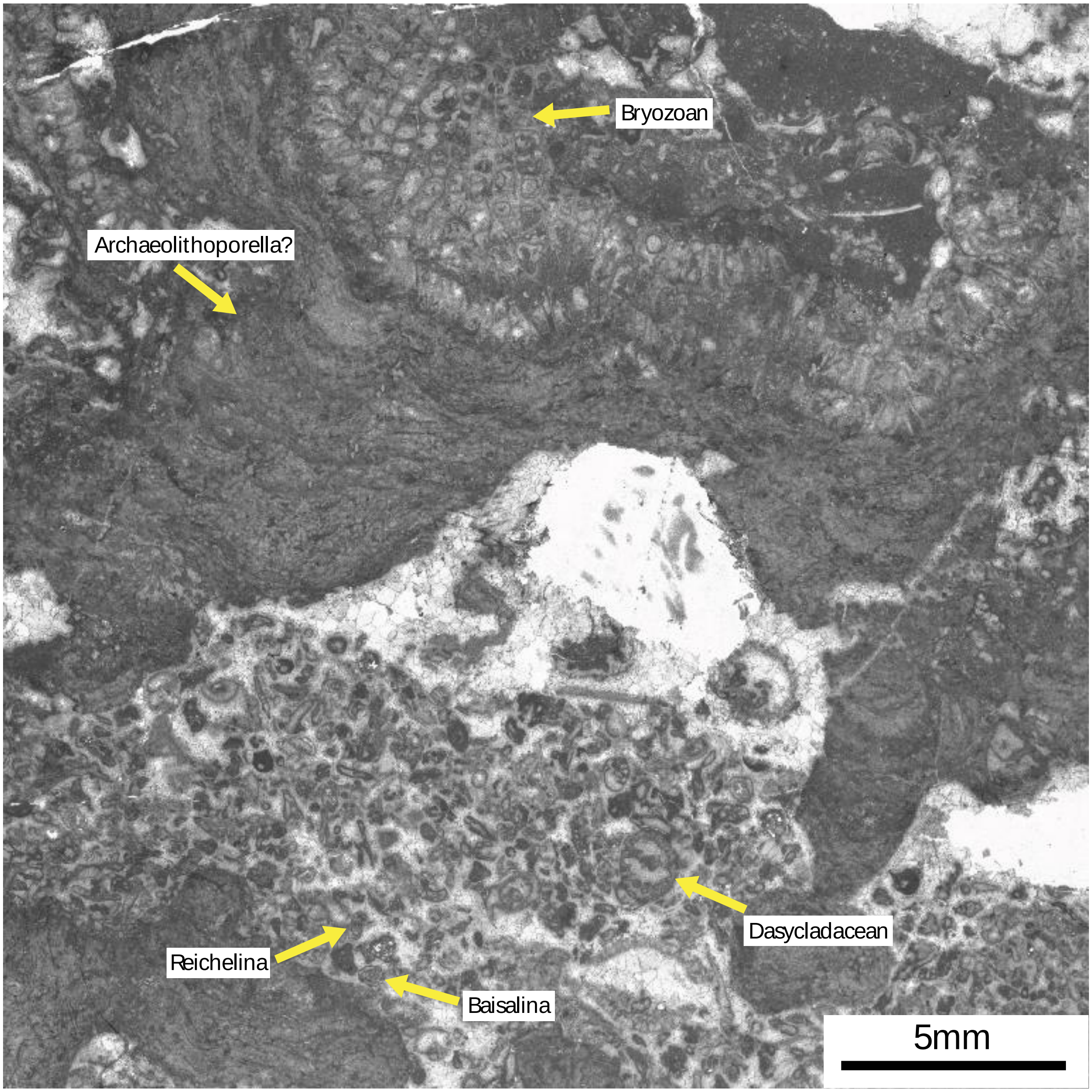

Figure 3.40 Photomicrograph depicting the microfacies in the upper part of package (IX) of section PC8 (sample PC8-9B): reef/back-reef marginal biomicrite containing dasycladacean algae, bryozoans, Reichelina, small foraminifers, and a stromatolitic encrusting fauna, possibly Archaeolithoporella.

contain a micritic matrix as a result. Unprotected areas would be winnowed and sparry calcite would subsequently precipitate within the intergranular space.

3.3.10 *Package X – Lagoonal Micrite*

Description

Package (X) is meters 4.5 meters thick and only one sample was taken, PC8-10 (figure 3.41). No allochems were observed within the microfacies and the fabric is a gray micrite. Several vugs are distributed throughout the rocks, often partially filled by sparry calcite, but sometimes remaining unfilled and open. In hand sample faint alternations of light and dark stripes were observed. In thin section, however, these stripes seem to disappear and display no internal structure. It is possible they are of bacterial origin, or they could be seasonal calcareous mud composition changes due to climactic effects, called varves.

Interpretation

Only extremely calm water can produce a clean micrite, such as an unperturbed, deep lagoon. The lack of fossils within the package indicates conditions prohibiting biologic production. The vugs may represent dissolved bioclasts left behind by benthic organisms.

3.3.11 *Package (XI) – Lagoonal Bioclastic Intrasparite, Lagoonal Bioclastic Intramicrite*

Description

Package (XI) is 3.7 meters thick and was sampled at two places. The package is composed of limestone displays a grain dominated microfacies. Grains are predominantly composed of dark, irregularly shaped intraclasts supplemented by bioclasts and include *Reichelina*, dasycladacean algae, *Baisalina, Abadehella*, other small foraminifers, and

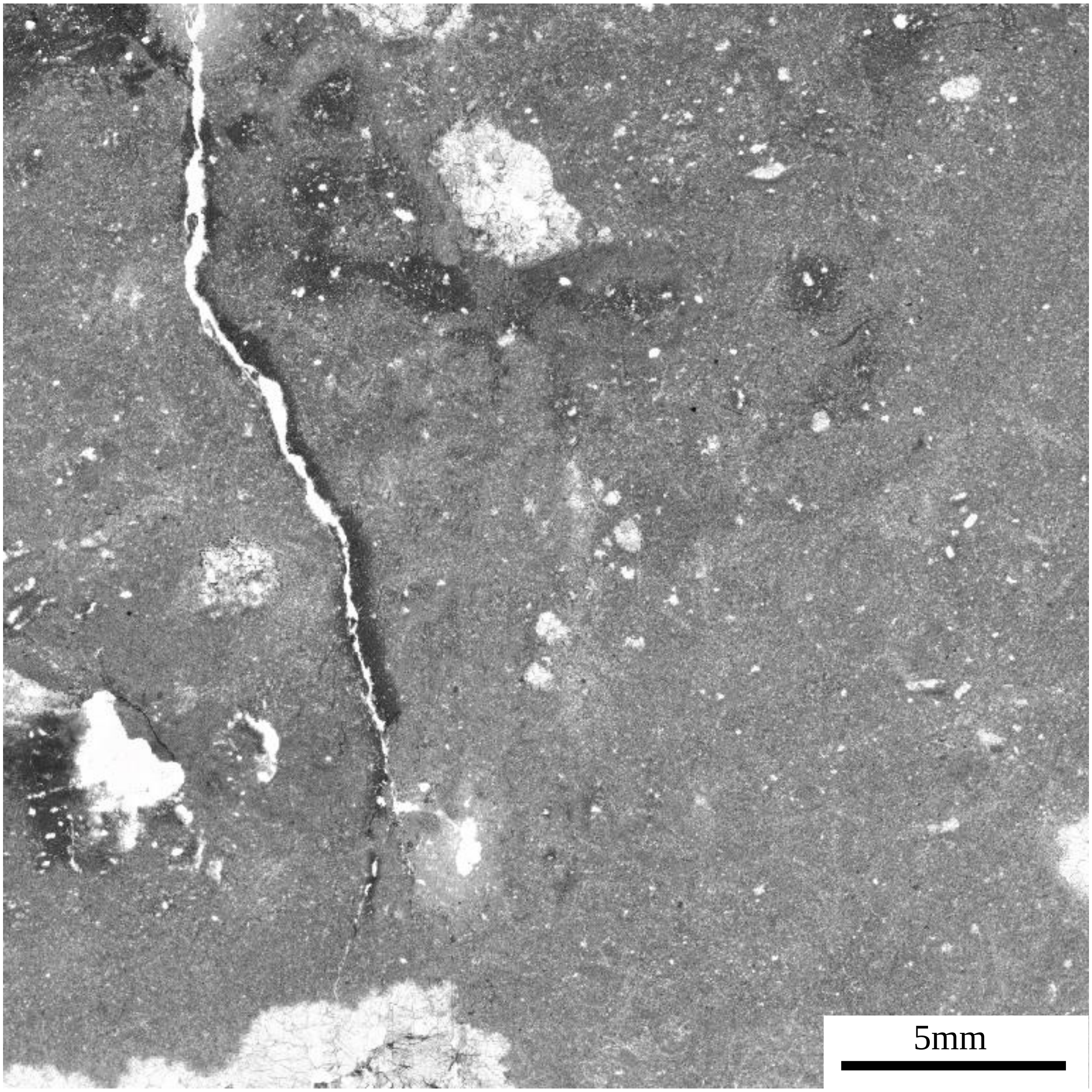

Figure 3.41 Photomicrograph depicting the microfacies of package (X) of section PC8 (sample PC8-10): lagoonal micrite.

ostracods. The base of package (XI) (sample PC8-11A) (figure 3.42) has a spar dominated matrix which becomes more micritic towards the top of the package (sample PC8-11B) (figure 3.43). Sorting is moderate.

Interpretation

Indicative of a typical back-reef lagoonal depositional setting, disarticulated dasycladacean algae are pervasive throughout package (XI). Other bioclasts, *Reichelina* and *Baisalina* in particular, appear to support the same conclusion: the depositional environment was lagoonal. Intraclast provenance is likely storm related. The package likely represents a barrier washover deposit.

3.3.12 *Package (XII) – Lagoonal Bioclastic Pelsparite*

Description

Package (XII) is half a meter thick and one sample was collected, PC8-12 (figure 3.44). Small, thin walled, subspherical to oblong, spar filled carbonate peloids are the predominant allochems found within the microfacies of package (XII). Their origin is enigmatic, but these peloids possibly represent the fossil remains of some type of small marine biota. Any soft parts held within or outside their thin carbonate shell are not preserved. *Reichelina* and *Rauserella* are present along with small foraminifers, sparse dasycladacean algae, sponges, brachiopod fragments, and ostracods. The matrix is composed of sparry calcite showing at least two stages of crystal growth.

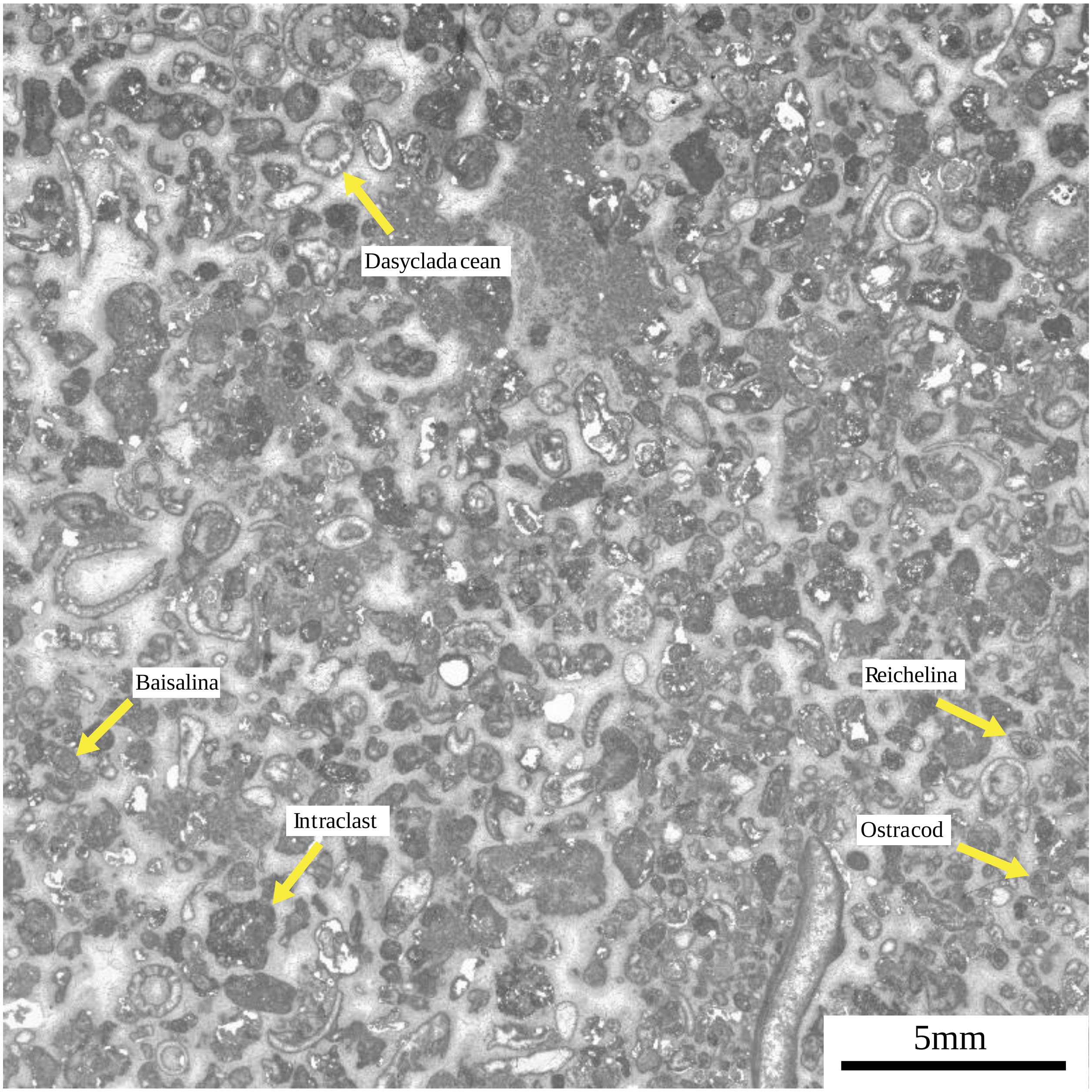

Figure 3.42 Photomicrograph depicting the microfacies in the lower part of package (XI) of section PC8 (sample PC8-11A): lagoonal bioclastic intrasparite containing dasycladacean algae, Reichelina, ostracods, and intraclasts.

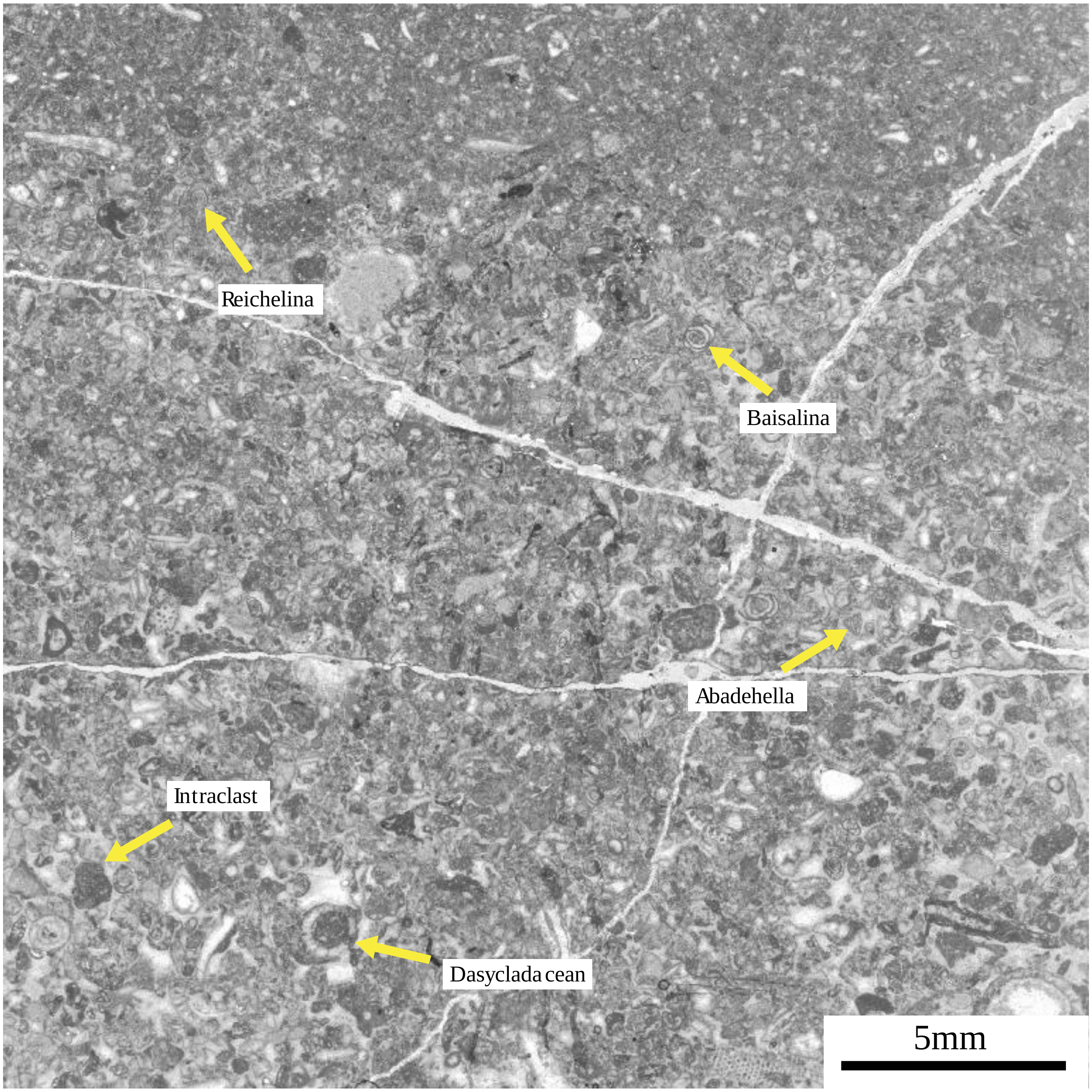

Figure 3.43 Photomicrograph depicting the microfacies in the upper part of package (XI) of section PC8 (sample PC8-11B): lagoonal bioclastic intramicrite containing dasycladacean algae, Reichelina, small foraminifers, and intraclasts.

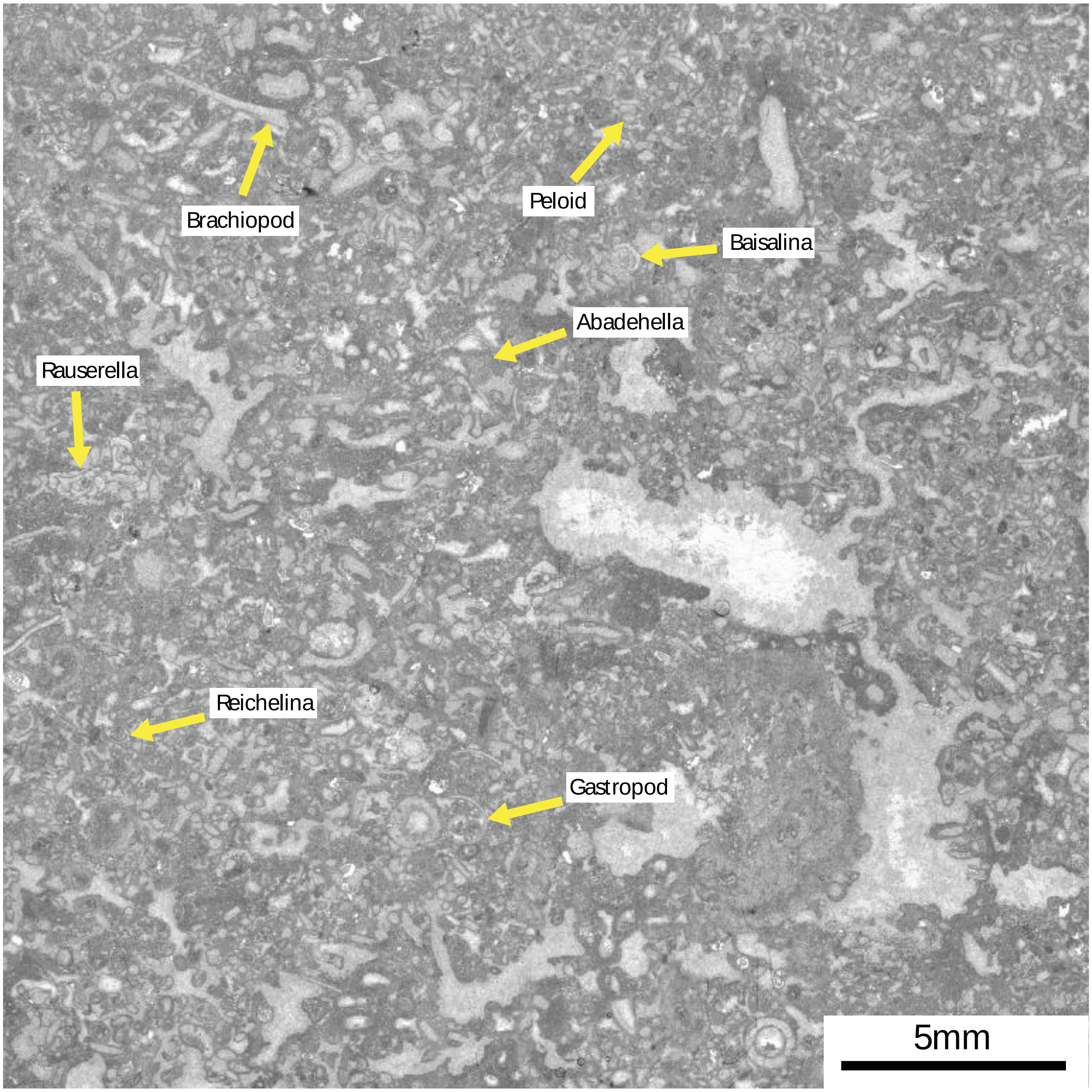

Figure 3.44 Photomicrograph depicting the microfacies of package (XII) of section PC8 (sample PC8-12): lagoonal bioclastic pelsparite containing dasycladacean algae, Reichelina, Rauserella, small foraminifers, brachiopods, gastropods, and thin walled, subspherical, spar-filled peloids.

Interpretation

Package (XII) represents back-reef lagoonal deposition above the fair weather wave base with adequate energy to winnow any micrite from the sediments. The absence of lithic intraclasts suggests the rocks were not deposited as a result of any meteorological event as was the case for much of the other lagoonal grainstone from the study area. Calcite spar was able to infiltrate the pore space between grains after deposition. Bioclasts such as dasycladacean algae and fusulinacean *Reichelina* are typical flora and fauna from a lagoonal setting.

3.3.13 *Package (XIII) – Proximal Back-reef Sponge Calcirudite with Micrite Matrix*

Description

Package (XIII) is 1.2 meters thick and one sample was harvested, PC8-13 (figure 3.45) The microfacies of package (XIII) is poorly sorted with small, sand-sized allochems amongst numerous diverse calcareous sponge fossils greater than two millimeters in size. A few sponge skeletal allochems show an originally hollow spongocoel that has been filled with calcite spar. The smaller grains of diverse bioclasts include dasycladacean algae, *Reichelina*, ostracod valves, gastropods, *Tubiphytes*, and small foraminifers including *Agathammina* and *Globivalvulina*. Fine sand sized intraclasts, resembling peloids, are numerous amongst the bioclast allochems. The matrix is composed of micrite.

Interpretation

Sponges were a major reef-building fauna of the Capitan Reef complex and the dasycladacean algae have been interpreted to appear in back-reef lagoonal settings. Both faunal groups juxtaposed within the same sample is an indication that the depositional environment

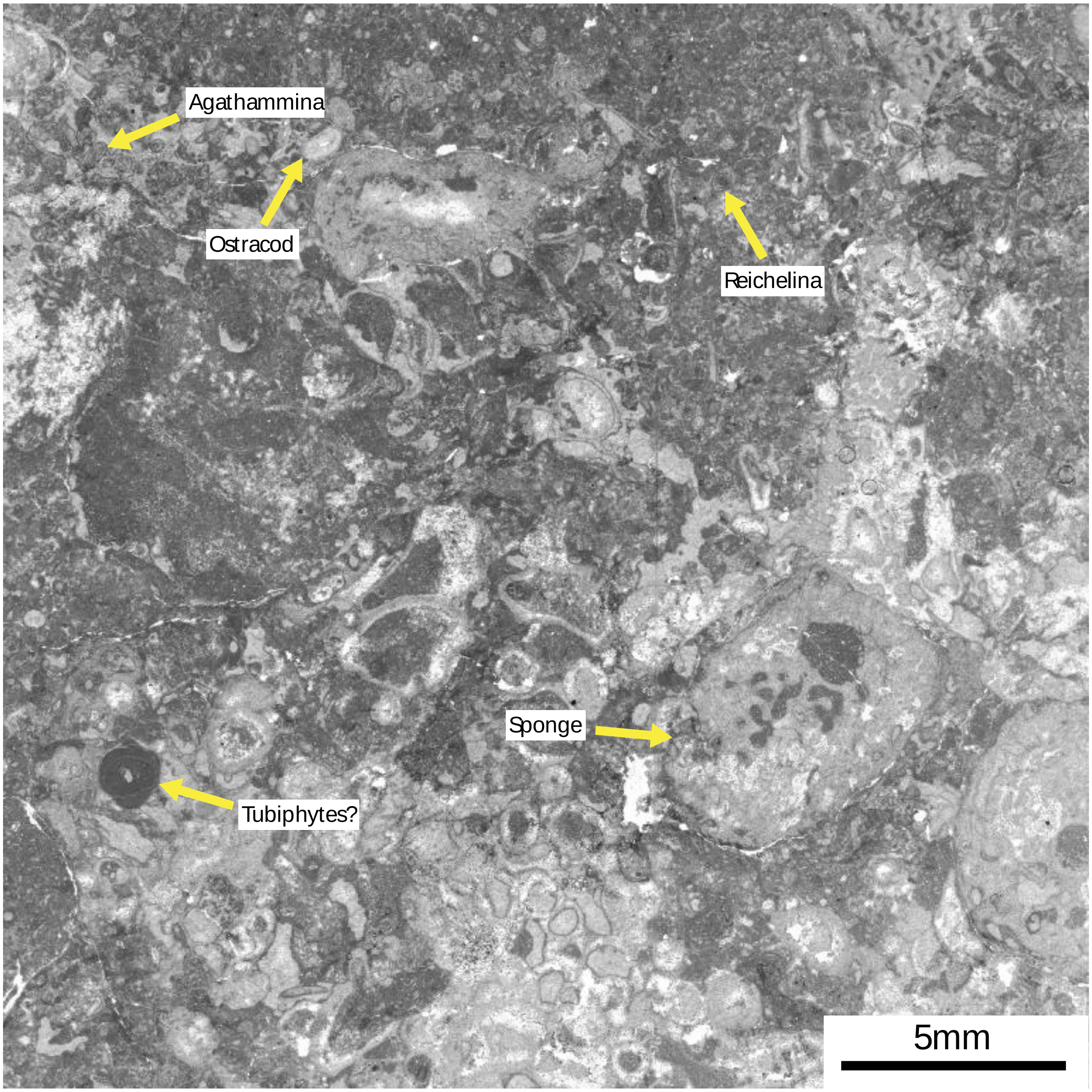

Figure 3.45 Photomicrograph depicting the microfacies of package (XIII) of section PC8 (sample PC8-13): proximal back-reefal sponge calcirudite in a micrite matrix containing sponges, Reichelina, small foraminifers, ostracods and possibly Tubiphytes.

responsible for generating microfacies of package (XIII) was positioned at the margin of a reef and back-reef setting.

3.3.14 *Package (XIV) – Lagoonal Reichelina Biomicrite*

Description

Package (XIV) is 0.9 meters thick and was sampled one place, PC8-14 (figure 3.46). The microfacies texture of package (XIV) has a matrix composed of micrite and varies between wackestone and packstone, but the allochem composition remains consistent. *Reichelina* is abundant in the sample along with *Rauserella* and other small foraminifers including *Agathammina* and *Palaeonubecularia*. Skeletal grains include brachiopod fragments, dasycladacean algae, and gastropods. In places a sharp contrast in texture separates wackestone areas from packstone areas indicating the possible presence of some variety of burial pressure diagenetic feature such as a dissolution seam of a faint stylolite.

Interpretation

The depositional environment responsible for generating microfacies of package (XIV) was a biologically productive back-reef lagoon. The evidence of such an environment is the floral and faunal assemblage of dasycladacean algae and fusulinacean *Reichelina* within a micrite matrix. The presence of micrite suggests low energy, calm water protected from wave agitation by a barrier reef.

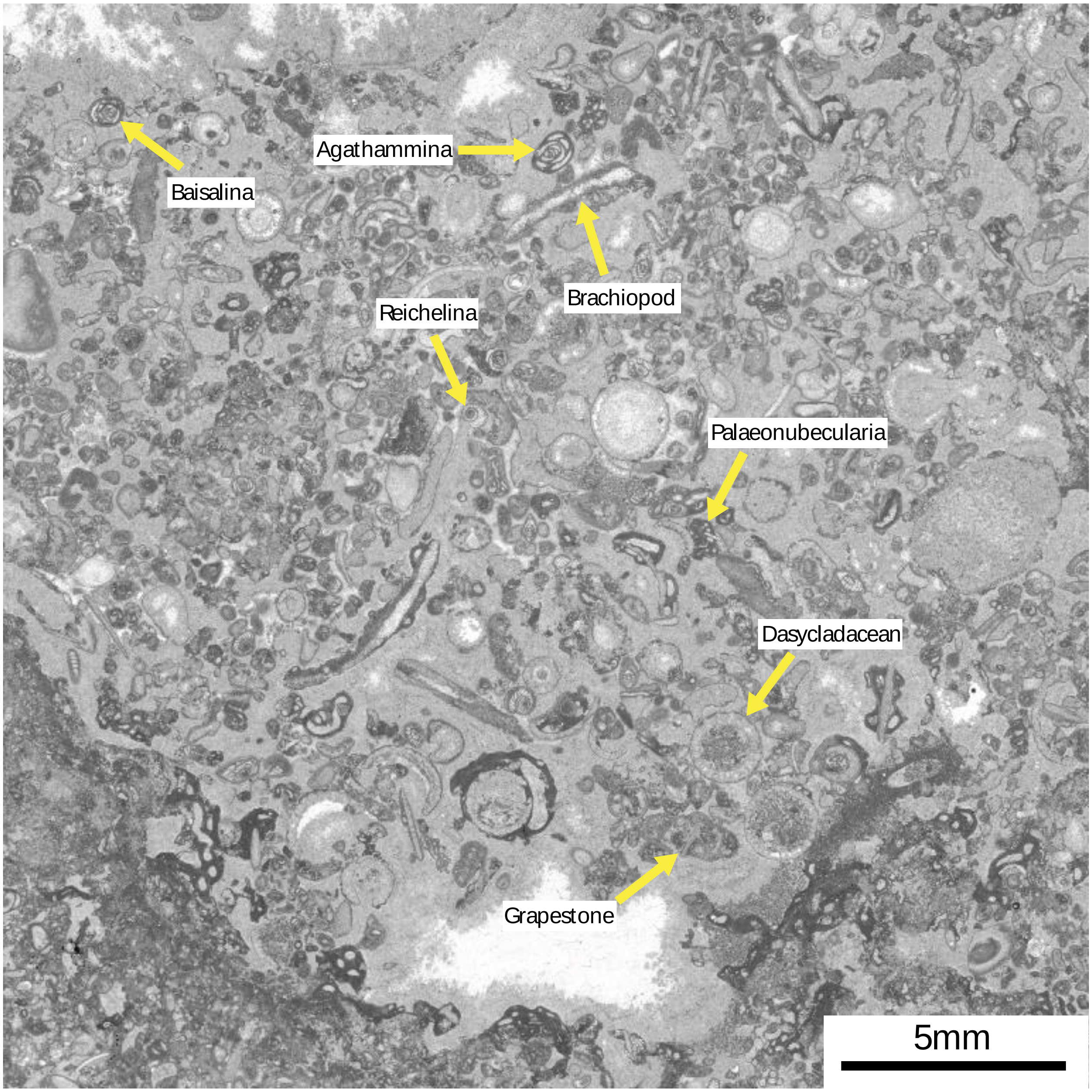

Figure 3.46 Photomicrograph depicting the microfacies of package (XIV) of section PC8 (sample (PC8-14): lagoonal Reichelina biomicrite containing dasycladacean algae, Reichelina, small foraminifers, brachiopods, grapestones.

3.3.15 *Package (XV) – Reefal Sponge Calcirudite with Micrite Matrix*

Description

Chambered, calcareous sponges are pervasive within the microfacies of package (XV), which is a meter thick. One sample was collected, PC8-15 (figure 3.47). The spongocoel of many of these sponges are filled by micrite and very small carbonate peloids showing well developed geopetal structure. Sparse foraminiferal bioclasts are present amidst the sponges including specimens belonging to the genera *Reichelina* and *Agathammina*. Brachiopod fragments and ostracod valves are also seen among the bioclast assemblage. A few allochems are observed to be composed of a single calcite crystal, identified by having a uniform extinction angle under crossed nicols, indicating a possible echinoderm origin. Notably, dasycladacean algae are absent. Very fine-grained peloids are present which may be organic or inorganic in nature, possibly bacterially originated (Scholle and Ulmer-Scholle, 2003). The matrix of the package is composed of micrite. The rock is classified as a packstone.

Interpretation

Based on the population of sponges and the notable absence of dasycladacean algae within the microfacies, package (XV) is interpreted to have been deposited within a reef environment. Sponges were an important reef-building fauna during the Guadalupian epoch (Newell et al., 1953). No dasycladacean algae in an indication the environment was unlikely to have been a lagoon as these algal flora was very common in the lagoons at the time of deposition. Energy levels were low as evidenced by the presence of micrite matrix of the sample indicating the reef was protected from wave action. The environment was likely positioned in the back-reef zone.

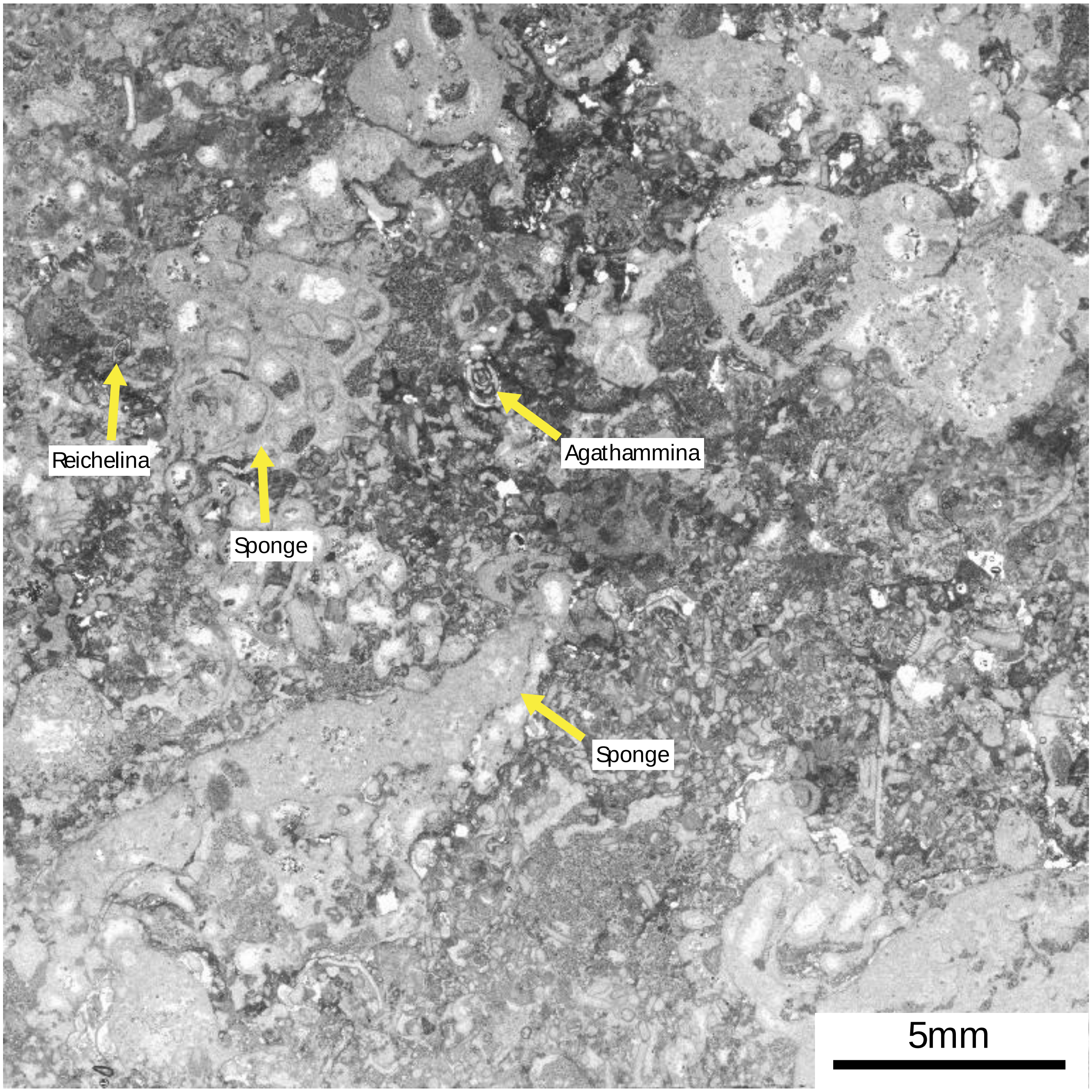

Figure 3.47 Photomicrograph depicting the microfacies of package (XV) pf section PC8 (sample PC8-15): reefal sponge calcirudite with a micrite matrix containing sponges, Reichelina, and small foraminifers.

3.3.16 *Package (XVI) – Lagoonal Bioclastic Intramicrite*

Description

Package (XVI) is a meter thick and was sampled in one place, PC8-16 (figure 3.48). The allochem population present within the microfacies is predominantly composed of fine- to medium-grained intraclasts. Internal structure of the intraclasts is often partially or completely micritized. Micritization in marine settings is a result of micrite precipitation within borings created by endolithic algae on grain surfaces (Kobluk and Risk, 1977). Some intraclasts remain intact showing they are composed of carbonate grapestone aggregates of smaller, unidentifiable allochems. Bioclasts are also present within the allochem population including dasycladacean algae, foraminifers such as *Reichelina* and *Agathammina*, ostracods, and sparse brachiopod fragments. Many of the exterior surfaces of the grains show a thin rind of calcite coating, possibly cyanobacterially precipitated. The matrix is composed of micrite.

Interpretation

The rocks of the package (XVI) were deposited within a reasonably calm lagoon where reef detritus could accumulate and remain. Dasycladacean algae amongst the bioclast population is an indicator of a back-reef lagoonal setting. Energy levels must have been low as evidenced by the micrite matrix preserved between the grains. Reef weathering and erosion is a likely source of the intraclasts. Determining a transport mechanism is problematic as any prolonged water current would be sufficient to winnow any mud from the sediments, yet it remains. It is possible that an aeolian transport mechanism is responsible for depositing of the intraclasts within the lagoon.

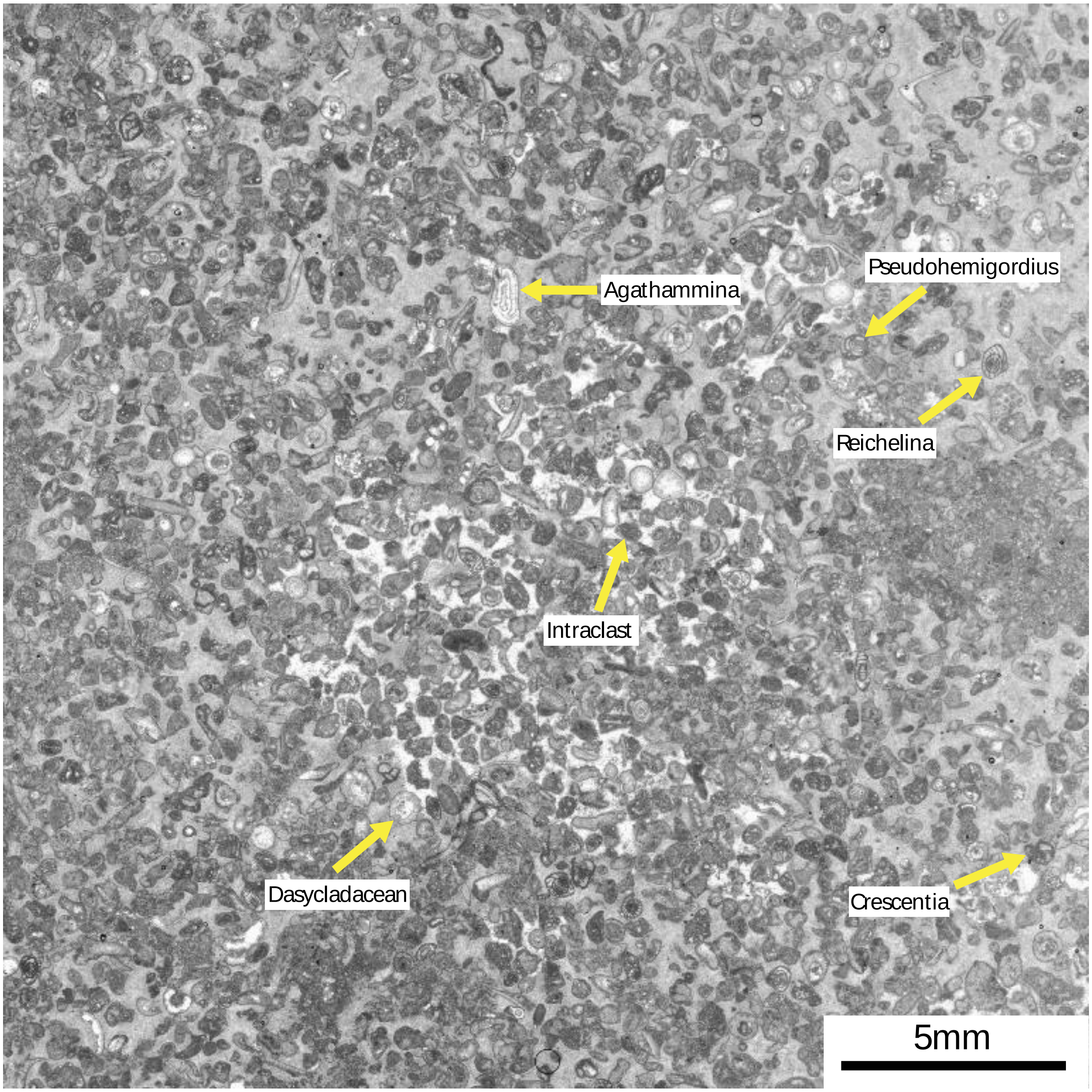

Figure 3.48 Photomicrograph depicting the microfacies of package (XVI) of section PC8 (sample PC8-16); lagoonal bioclastic intramicrite containing dasycladacean algae, Reichelina, small foraminifers, and intraclasts.

3.3.17 *Package (XVII) – Lagoonal Dasycladacean Biomicrite*

Description

Package (XVII), 3.5 meters thick and sampled in one place (PC8-17, figure 3.49), contains a microfacies consisting of fully articulated dasycladacean algal colonies within a poorly preserved biomicrite. Micritization of allochems is extensive throughout the sample making carbonate lithological classification problematic. The thallus segments of the algae are cut in various ways showing transverse sections of a dasycladacean algal colony, possibly the genus *Mizzia* or a close relative. Foraminifers such as *Reichelina* and *Agathammina* occur between the algal remains along with a few gastropod and brachiopod fragments. Fenestral cavities are present and filled by small carbonate particles or micrite.

Interpretation

The presence of dasycladacean algae is an indication of a calm lagoonal depositional environment. The fact that the algal colonies remain intact is anomalous as dasycladacean algae are usually found as disarticulated fragments with other bioclasts. Energy levels were low and inadequate to winnow micrite from the sediments. The rock is a wackestone.

3.3.18 *Package (XVIII) – Lagoonal Dasycladacean Intradismicrite*

Description

The top of the PC8 section is represented by package (XVIII), one meter thick and sampled once, PC8-18 (figure 3.50). The microfacies of the unit is allochemically composed of angular to sub-angular, dark colored intraclasts and bioclasts. The intraclasts are typically carbonate grapestone composed of indiscriminant grain aggregates. Bioclast composition of the microfacies includes

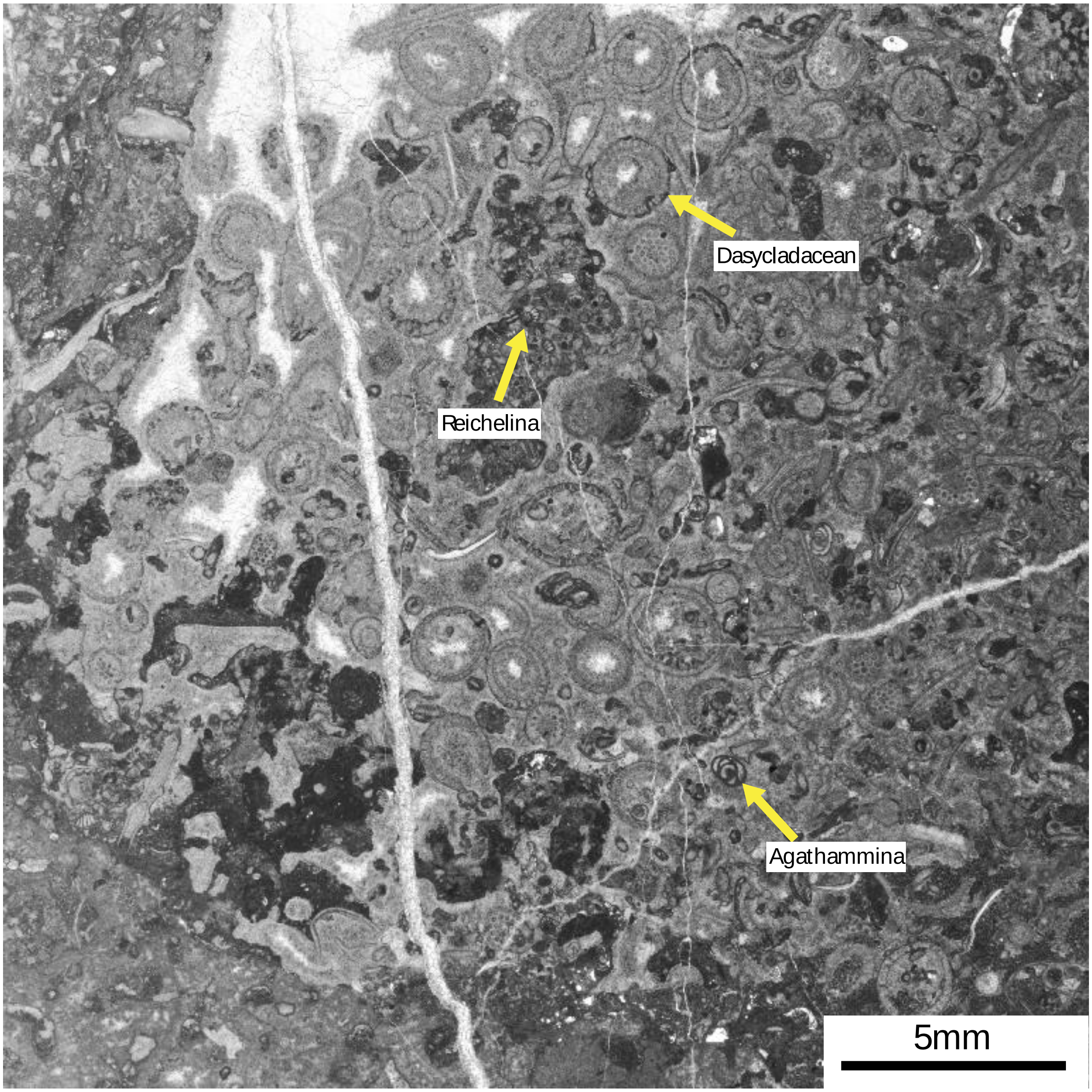

Figure 3.49 Photomicrograph depicting the microfacies of package (XVII) of section PC8 (sample PC8-17): lagoonal dasycladacean biomicrite containing fully articulated colonies of dasycladacean algae, Reichelina, and small foraminifers.

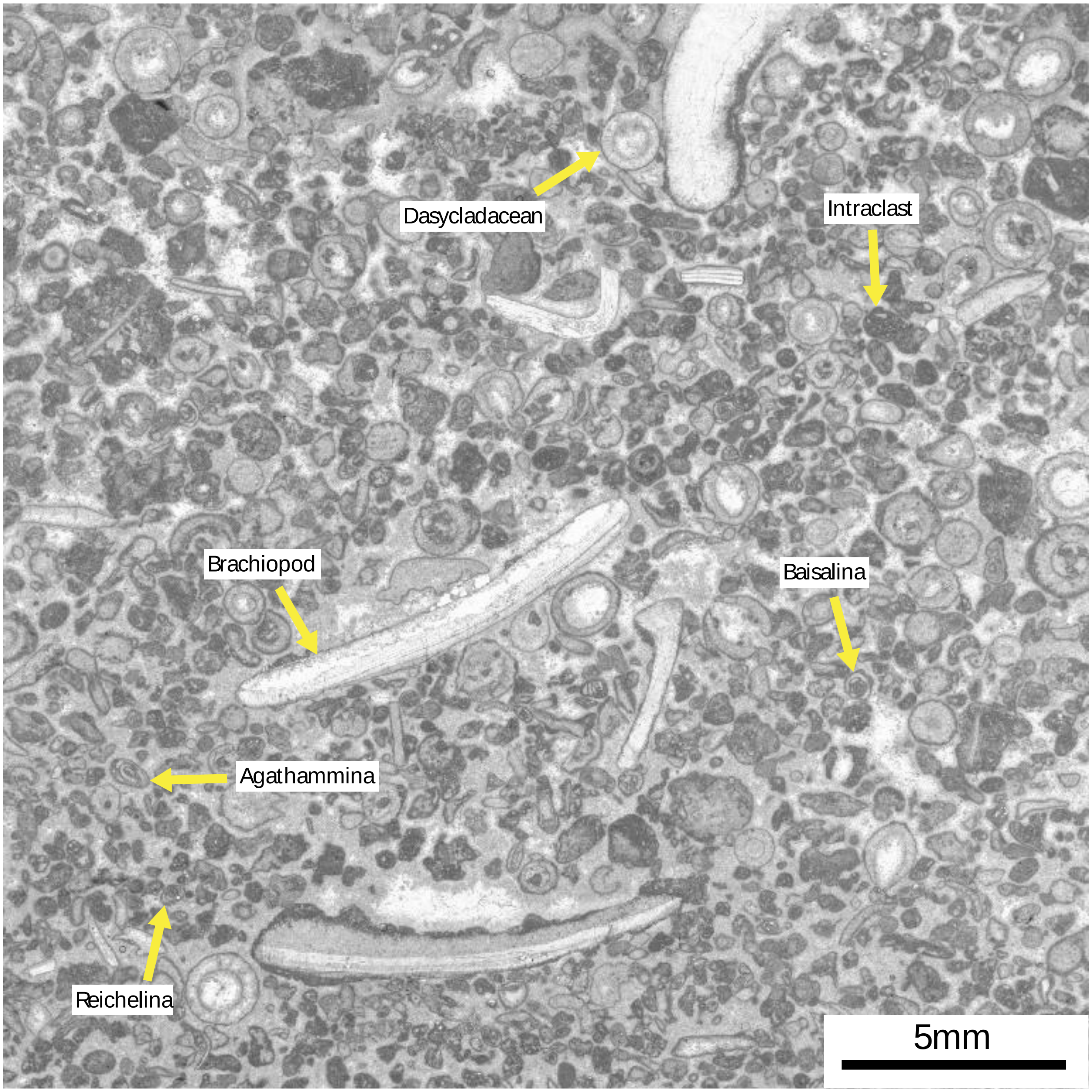

Figure 3.50 Photomicrograph depicting the microfacies of package (XVIII) of section PC8 (sample PC8-18): lagoonal dasycladacean intradismicrite containing dasycladacean algae, Reichelina, small foraminifers, brachiopods, and intraclasts.

dasycladacean algae, brachiopod fragments, foraminifers *Reichelina*, and *Baisalina*. The algae comprises the highest percentage of the bioclastic component of allochems. The cement matrix appears to be composed of micrite with drusy or blocky spar within areas devoid of grains. In some places, however, the micrite appears to grow radially from grain surfaces and meet at a seam in the center of the intergranular space. Originally, the radially growing cement was probably isopachous spar that has been diagenetically altered to micrite either by endolithic algal boring and refilling or by some chemical process.

Interpretation

If the micrite is a secondary effect, as suspected above, the original cement was sparry calcite indicating the depositional energy levels was adequately high to winnow any primary micrite from the environment. Dasycladacean algae bioclasts indicate the environment was situated within a back-reef lagoon and the lithic carbonate grains are indeed allochthonous intraclasts likely eroded and transported from the reef. The energy required to generate reef-derived intraclasts was the same source which winnowed the micrite from the lagoonal sediments: a powerful wave generating storm.

3.4 Sequence Stratigraphy

Much of the sequence stratigraphy framework of the Permian of West Texas has been established by Kerans and his colleagues (Kerans, 1995; Tinker, 1998; Kerans and Tinker, 1999; Kerans and Kempter, 2002; Rush and Kerans, 2010). They utilized field analysis techniques for identifying cycle stacking patterns, vertical facies proportions, stratal preservation, facies-tract offset, and stratal geometry and established a high resolution framework for a nested hierarchical system of cycles, cycle sets, high-frequency sequences (HFS), and composite sequences (Rush and Kerans, 2010) (figure 3.51). The Guadalupian age strata have been shown to comprise 30 high-frequency sequences (G01-G30) vertically stacked to form six composite sequences, CS9 through CS14 in the Guadalupe Mountains (Kerans and Tinker, 1999).

The smallest divisions, meter-scale cycles, represent a series of strata deposited during a single sea-level rise and is equivalent to a 6th-order cycle. A cycle set is equivalent to a 5th-order eustatic cycle and is diagnosed to be a group of cycles representing a single retrogradational, progradational, or aggradational trends. The nature of these trends is interpreted based on any vertical facies proportions. High-frequency sequences represent a complete retrogradation to progradation sequence with a maximum flooding surface between them. They include a lowstand systems tract (LST), a transgressive systems tract (TST), and a highstand systems tract (HST) (Mitchum and Van Wagoner, 1991). HFS’s are equivalent to a 4th-order cycle and are specific to a single depositional setting. Composite sequences are equivalent to 3rd-order cycles and span across depositional settings. They represent a transgressive systems tract to a highstand systems tract sequence.

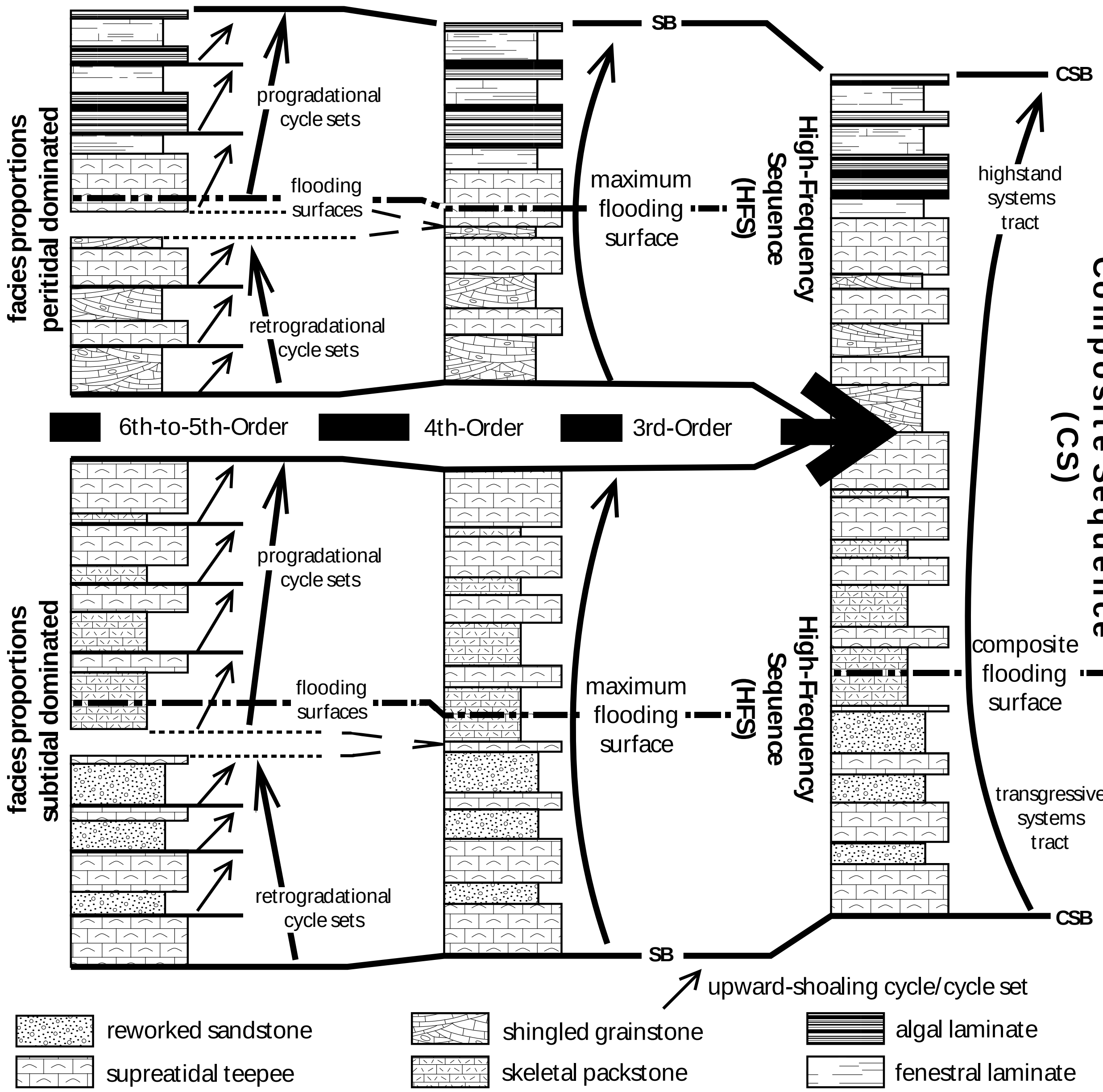

Figure 3.51 Nested hierarchy of depositional sequences A Third-order composite sequence (CS) is subdivide into fourth-order high-frequency sequences (HFS) containing fifth-order cycle sets. Cycle sets can be further subdivided into sixth-order cycles. (After Rush and Kerans, 2010)

Sequence stratigraphic analysis of time equivalent strata to the current study was described in great detail from Walnut Canyon in the Guadalupe Mountains of West Texas (Rush and Kerans, 2010). Walnut Canyon strata was situated further inland of the current study location in a shelf crest/middle shelf depositional setting. Panther Canyon deposits rest further seaward in the lithologically dissimilar outer shelf lagoon/back-reef/reef regime. Fortunately, the two areas are easily correlated based upon the presence of a short lasting interval of *Yabeina texana* Skinner and Wilde which occurs at the base of Tansill strata at Walnut Canyon and at the base of package (VII) in the PC7 section at Panther Canyon.

The serendipitous occurrence of *Y. texana* at both localities allows for the stratified layers above the Capitan Formation at the mouth of Panther Canyon to neatly fit into the already established framework established by Kerans and his colleagues (Wilde, 1999; Nestell and Nestell, 2006; Rush and Kerans, 2010) despite the lithologic dissimilarities (figure 3.52). Fossil occurrences and stratigraphic sequence divisions are both timing events, therefore their comparison is valid. Panther Canyon strata are situated within the uppermost composite sequence of the Guadalupian: Permian CS14, and the *Y. texana* bed, PC7 package (VII) – sample PC7-7A, marks the base of the G27 HFS. The base of the next HFS of the Guadalupian sequence framework, G28, is coincident with the first occurrence of *Reichelina lamarensis* Skinner and Wilde which is observed in package (V) –sample PC8-5C of the PC8 section.

The next HFS, GS29, is coincident with the base of the Ocotillo Member within the upper portion of the Tansill Formation and last occurrence of *R. lamarensis* at the Walnut Canyon locality (Rush and Kerans, 2010). At Panther Canyon, *R. lamarensis* persists to the top of the PC8 section, therefore the section stops somewhere towards the top of G28. The Ocotillo

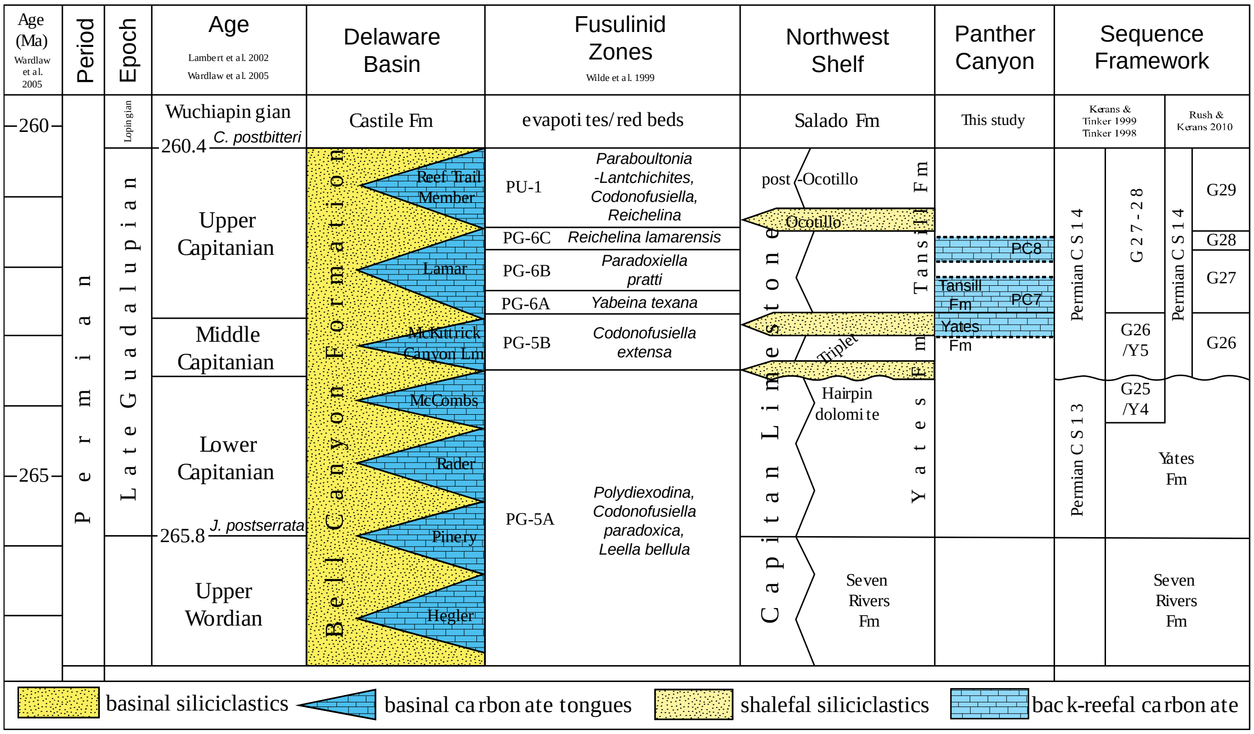

Figure 3.52 Chronostratigraphic and biostratigraphic chart for the Upper Permian (modified from Rush and Kerans, 2010). The Fusulinid zones established by Wilde (1999). Absolute age determined by Wardlaw et al. (2005) and Lambert et al. (2002) using conodonts. Current absolute age data is slightly different than presented herein. For example, the first occurrence of C. postbitteri is considered to be approximately at 259.1 m. a. and J. postserrata at 265.1 m. a. (Henderson, 2016). Sequence framework established by Tinker (1998) and Kerans and Tinker (1999). Sequence framework resolution improved by Rush and Kerans (2010).

Silt Member has not been reported in the Apache Mountains area.

Low exposure quality and discontinuous sections at the mouth of Panther Canyon make high resolution sequence stratigraphic analysis problematic. Cycle sets are incomplete making cycle level analysis the highest resolution possible to be interpreted. The current study identifies an idealized, upward shoaling cycle to include: (1) a structural sponge and/or bryozoan bearing calcirudite strengthened by encrusting fauna reef facies tract; (2) middle beds composed of reef/back-reef marginal biosparite often containing both lagoonal flora and fauna as wll as reefal sponges; and (3) dasycladacean algae bearing fossiliferous intramicrite or intrasparite typical of the lagoonal facies tract. The PC7 section shows three cycles (figure 3.53) and the PC8 section shows at least five (figure 3.54, 3.55).

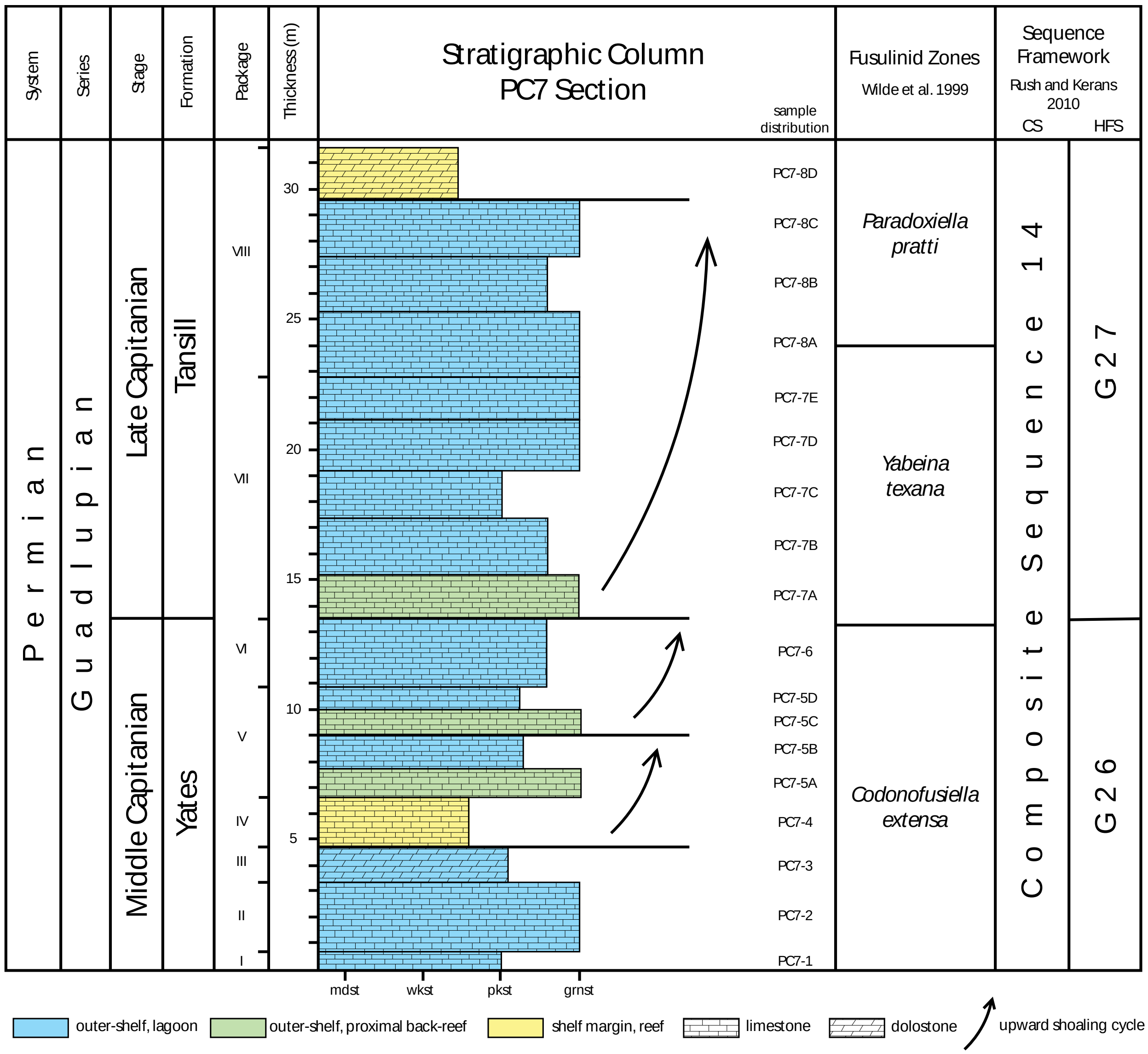

Figure 3.53 Stratigraphic column of the PC7 section at the mouth of Panther Canyon. Three lithofacies are recognized: outer-shelf lagoon, outer-shelf proximal back-reef, and shelf-margin reef. Upward shoaling cycles can be seen based on the lithologic stacking pattern of shelf-margin, reef—outer-shelf, proximal back-reef—outer-shelf, lagoonal deposits. Fusulinid zonation established by Wilde et al. (1999). Sequence framework based on Rush and Kerans (2010).

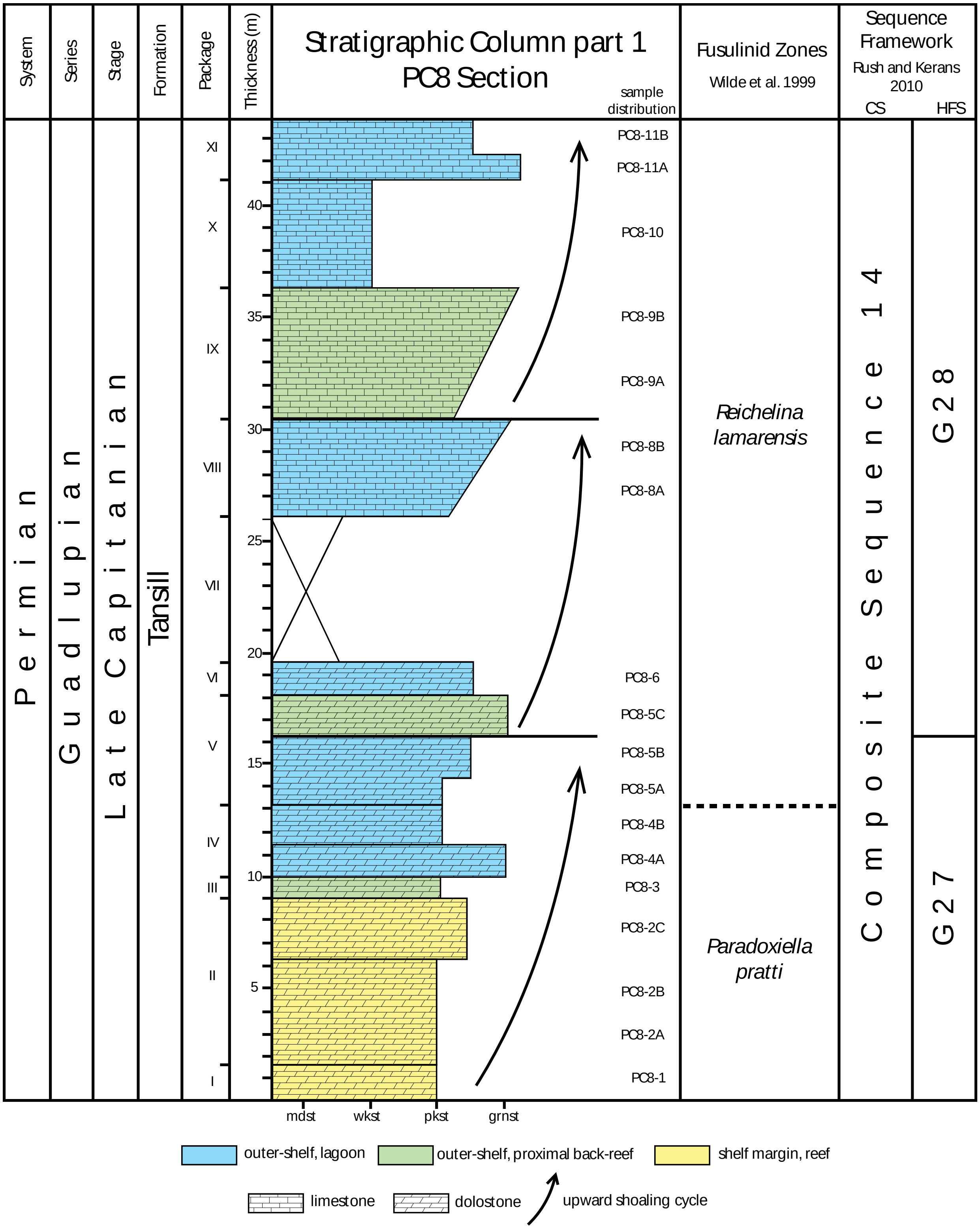

Figure 3.54 Stratigraphic column part 1 (continued on the next page) of the PC8 section at the mouth of Panther Canyon. Three lithofacies are recognized: outer-shelf lagoon, outer-shelf proximal back-reef, and shelf-margin reef. Upward shoaling cycles can be seen based on the lithologic stacking pattern of shelf-margin, reef—outer-shelf, proximal back-reef—outer-shelf, lagoonal deposits. Fusulinid zonation established by Wilde et al. (1999). Sequence framework based on Rush and Kerans (2010).

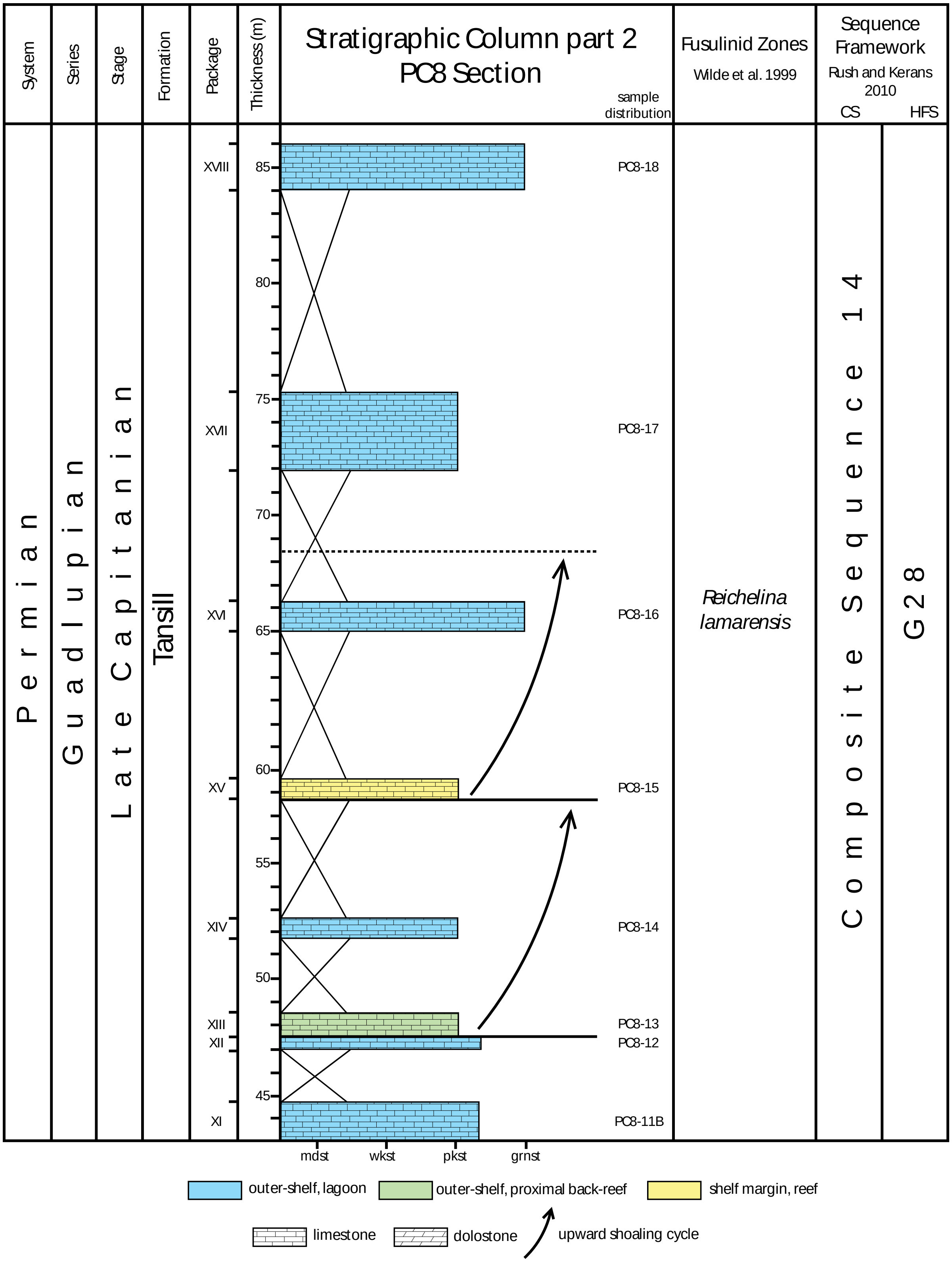

Figure 3.55 Stratigraphic column part 2 of the PC8 section at the mouth of Panther Canyon. Three lithofacies are recognized: outer-shelf lagoon, outer-shelf proximal back-reef, and shelf-margin reef. Upward shoaling cycles can be seen based on the lithologic stacking pattern of shelf-margin, reef—outer-shelf, proximal back-reef—outer-shelf, lagoonal deposits. Fusulinid zonation established by Wilde et al. (1999). Sequence framework based on Rush and Kerans (2010).

3.5 Possible Depositional Model

The lithofacies of the carbonate rocks above Capitan Reef lithofacies in the Panther Canyon area appear to be controlled by two distinct factors: eustacy and storm events (figure 3.56). Other factors, climate, water chemistry, and biogenetic factors facilitated the deposition of carbonate rock, but the distinct microfacies seen in the samples were generated by global sea level variation and storm influence. Three distinct facies tracts are recognized in the study area: (1) shelf margin, reef, (2) outer shelf, reef/back-reef margin, and (3) outer shelf, lagoon. These facies tracts were located within the outer shelf of a reef rimmed carbonate platform. Within the stratified sections above the massive Capitan reefal rocks (greater than 50 meters thick), these facies tracts are stacked indicating a eustatic sea-level condition. Thus, depositional environment positions would fluctuate shelf- and basinward in time. Storms affected sediment deposition by generating waves and surges which could mechanically weather and erode the barrier reef as well as entrain previously deposited sediments and transport them around the platform.

3.5.1 *Shelf Margin, Reef Facies Tract*

The thick Capitan Formation is a quintessential example of a Permian barrier reef (Newell et al., 1953). It was constructed by *in situ*, sessile, baffling and frame building organisms including sponges, bryozoans, and sparse corals. The hard, calcareous structural elements of these organisms were stabilized by encrusting fauna including *Archaeolithoporella*. *Solenopora*, *Tubiphytes*, and *Collenella* (Toomey and Babcock, 1983). Lithologically, the reef facies is composed of boundstone containing diverse reef-dwelling floral and faunal elements. The shelf margin reef is the most seaward facies tract found within the study area, which is important to note for the sequence stratigraphy analysis discussed in the next section (section 3.5).

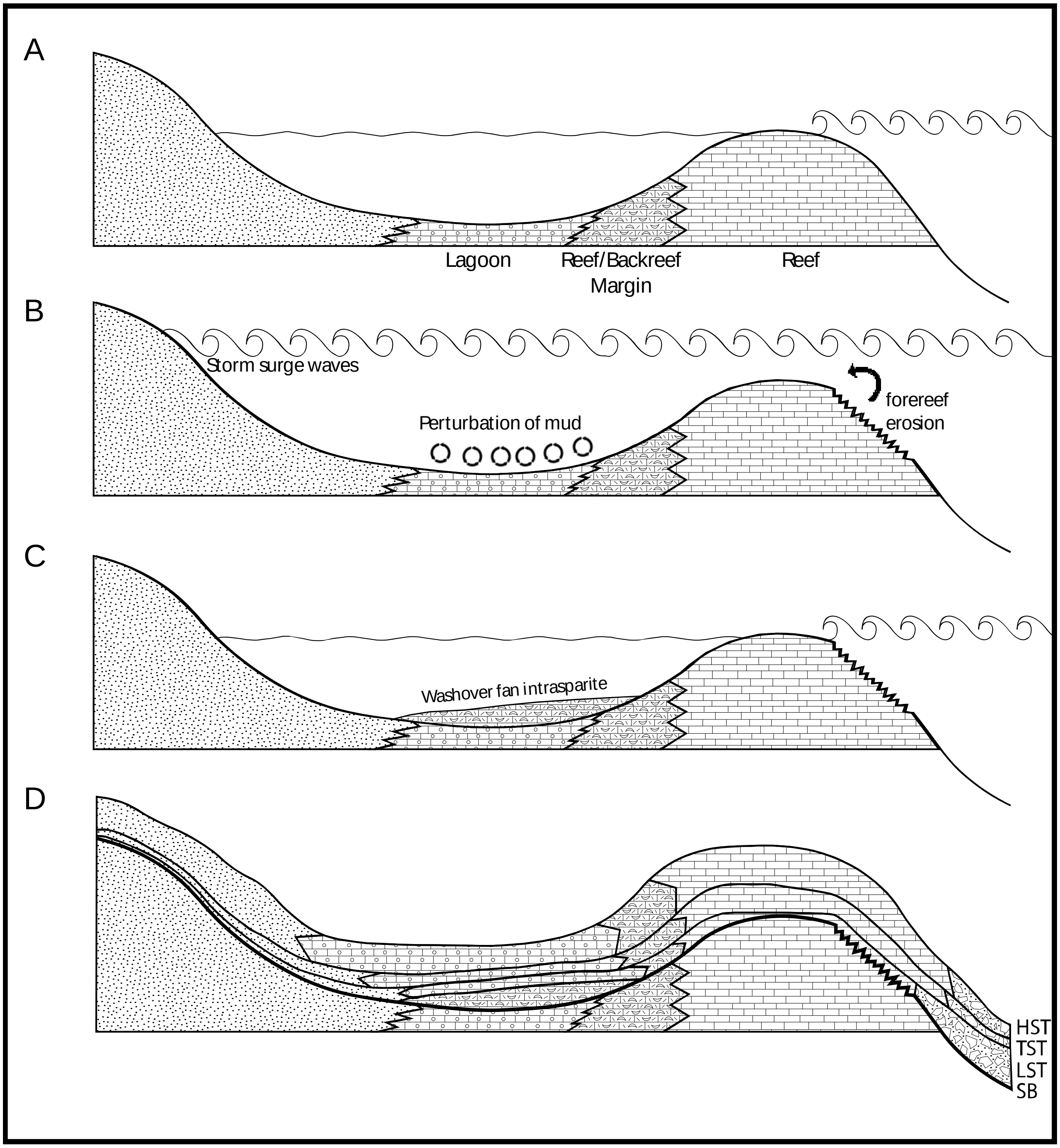

Figure 3.56 Depositional model for the outer shelf and shelf margin facies tracts. (A) Shallow barrier reef protects the outer shelf lagoon and reef/back-reef margin from wave action. (B) Storm induced waves erode the fore-reef creating intraclasts and transports them towards the lagoon. Mud is winnowed from lagoon sediments and suspended. (C) Storm abates and energy levels return to normal. Intraclasts deposit in the lagoon and suspended mud is transported out of the lagoon along with the receding storm surge. (D) Eustatic effects on facies tract migration.

3.5.2 *Outer Shelf, Proximal Back-reef Facies Tract*

Description

The proximal back-reef is a shallow subtidal belt, above the fair weather wave base, directly shelfward of the reef. The environment was protected by the reef barrier and energy levels was low, yet adequate to winnow any carbonate mud from the intergranular matrix. Ion rich fluids infiltrated this space after burial and calcite spar was precipitated. Grainstone is not exclusive to the reef/back-reef margin, however, it is also common within the reef/back-reef margin as well as within the lagoonal setting. Distinguishing among these distinct facies tracts can be problematic. Important diagnosing characteristics of the marginal facies is the presence of large population groups of one fossil species preserved intact within the same unit. Fusulinaceans and other smaller foraminifers were a common group to be productive and flourish within the reef/back-reef margin. Reef-building fauna such as sponges and bryozoans are commonly found within the reef/back-reef marginal facies (Toomey and Cys, 1977).

3.5.3 *Outer Shelf, Lagoon Facies Tract*

Lagoonal facies are deposited in calm, hypersaline water below the fair weather wave base, protected from wave action or currents by the basinward barrier reef. Typical lagoonal facies contain a micritic matrix and range in allochem proportions from packstone, wackestone, to mudstone. Lagoonal allochems are primarily bioclasts including dasycladacean algae, foraminifers, *Bellerophontid* gastropods, brachiopod fragments, ostracods, and the problematic taxon *Archaeolithoporella* (Toomey and Cys, 1977).

However, grainstone facies have been discovered within the lagoonal province at Panther Canyon, which is unexpected. These grainstone facies contain large populations of intraclast allochems amongst sparse dasycladacean algal bioclasts known to be indicative of back-reef lagoons (Kirkland and Chapman, 1991). The mechanism responsible for intraclastic grainstone deposition within a lagoonal depositional setting is interpreted to storm induced wave barrier washover deposition (Li et al., 1997; Leatherman and Williams, 1983).

CHAPTER 4

CONCLUSIONS

The Capitan Reef is a well-known and easily recognizable 400-1200 foot thick, 2.5-3.5 mile wide, massive, shelf marginal carbonate lithofacies which fringes the Delaware Basin of present day West Texas and southeastern New Mexico. In the Guadalupe Mountains strata positioned shelf-ward of the Capitan Reef have been thoroughly studied and interpreted to represent back-reef shelf carbonate facies which laterally grade into clastics and evaporites away from the basin. In the Glass Mountains situated along the southeastern rim of the Delaware Basin, however, equivalent back-reef strata are not nearly as widespread compared to those in the Guadalupe Mountains. Often, they are entirely missing due to flexural subsidence effects on deposition caused by the Marathon Orogeny (Wardlaw and Rudine, 2000). These stratigraphic differences indicate that the back-reef strata stretched across the full extent of the Capitan Reef trend are not laterally homogeneous and justify the use of entirely different formational names between the two areas.

In the Apache Mountains, located between the two areas, little study has been conducted to investigate the continuity of equivalent back-reef strata compared to the Guadalupe and Glass Mountains. Wood (1965, 1968) proposed the Apache Mountains sequence of late Guadalupian age back-reef strata is genetically similar to back-reef strata in the Guadalupe Mountains area in terms of its lithostratigraphic characteristics. The formations names, Capitan, Seven Rivers, Yates, and Tansill, used for the Guadalupe Mountain strata were thus applied to those of the Apache Mountains. The current study examines this decision in light of new biostratigraphic and lithostratigraphic evidence and finds Wood's logic to be sound, at least for strata in the Panther Canyon area, where the Capitan Formation, uppermost portion of the Yates Formation, and the lower and middle portions of the Tansill Formation can be confidently identified.

Panther Canyon cuts through the northern escarpment in the eastern sector of the Apache Mountains and contains layered back-reef carbonate superposed on thick, massive carbonate of the Capitan Formation. Two sections were measured and sampled for microfacies analysis to determine their depositional history. Section PC7 is 31.8 meters thick and contains eight distinctly identifiable packages of strata. Section PC8 is 86 meters thick and contains eighteen such packages. Three distinct microfacies tracts were identified within the two sections: (1) sponge and bryozoan calcirudites representative of a shelf margin reef system; (2) shallow proximal back-reef biosparites containing productive reef and lagoonal-dwelling faunal populations; and (3) disarticulated dasycladacean algae bearing lagoonal intrasparites and intramicrites.

The lagoonal environment lithofacies contain high energy regime carbonate rocks containing intraclast allochems within a sparry calcite matrix, which are uncommon and unexpected within typical lagoonal settings (Li et al., 1997). Storm induced barrier washover was determined to be the mechanism responsible for their deposition (Leatherman and Williams, 1983; Li et al., 1997). A rapid rise in sea level induced by high speed, unidirectional wind currents in tandem with high energy wave action could cause erosion in the fore-reef and allow sediments to be transported past the barrier reef towards the lagoon where wave action would winnow fine carbonate mud from the lagoonal sediments. The mud particles would be suspended in the water column and transported out of the lagoon through tidal inlets in the barrier complex when the storm surge receded. Fore-reef debris also could be deposited within the lagoon.

Occurrences of fusulinaceans in Panther Canyon area strata allow the biostratigraphic correlation of Apache Mountain back-reef strata across the Delaware Basin to sections of similar aged back-reef strata in the Guadalupe Mountains area as well as those present in the Glass Mountains. *Codonofusiella extensa* Skinner and Wilde occurs in an interval from package (V) to package (VIII) in the PC7 section. *C. extensa* is also present in the upper part of the Yates Formation in Dark Canyon and Walnut Canyon in the Guadalupe Mountains (Tyrrell, 1969; Nestell and Nestell, 2006; Rush and Kerans, 2010). *Yabeina texana* Skinner and Wilde is present in sample PC7-7A. *Paradoxiella pratti*? Skinner and Wilde occurs in samples PC7-8B and PC7-8C. *Reichelina lamarensis* Skinner and Wilde occurs in sample PC8-5C and persists through the top of the section. The presence of these various late Guadalupian age species conform to the fusulinacean zonal scheme established by Wilde (1990) from the Guadalupe Mountains and Glass Mountains (Wilde et al., 1999; Wilde and Rudine, 2000).

Also, the occurrences of these fusulinaceans allow for the Panther Canyon area strata to fit into the sequence stratigraphic framework of the Guadalupian back-reef strata in the Guadalupe Mountains area established by Kerans and his colleagues (Kerans, 1995; Tinker, 1998; Kerans and Tinker, 1999; Kerans and Kempter, 2002; Rush and Kerans, 2010). *Y. texana* is coincident with the beginning of high frequency sequence (HFS) G27 which occurs in the middle part of the PC7 section. *R. lamarensis* is coincident with the beginning of HFS G28 which occurs towards the base of the PC8 section. Both of these HFSs occur within the final composite sequence, CS14, of the Guadalupian epoch (Rush and Kerans, 2010). A possible depositional model was presented incorporating the effects of eustacy coupled with the influence of storm events to explain the depositional style of the back-reef carbonate strata located at Panther Canyon. Stacked carbonate lithofacies indicates the depositional environment alternated between a reef, proximal back-reef, and a lagoon as a result of sea level change through time.

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Joshua C. Moore earned an Associate of Science from Collin College in Plano, Texas in 2008 where he first discovered his passion for the Geosciences. He took three years off from school to work as an ophthalmic assistant while his fiancé completed her education. He then went back to school at The University of Texas at Arlington and completed his B.S. degree in Geology with a minor in biology in 2014 and began persuing an M.S. degree in Environmental and Earth Science later the same year. Future endeavors include pursuing a career in the environmental sector.