Bulletin of Earth Sciences of Thailand

DEPOSITION AND DIAGENESIS IN A PERMIAN PLATFORM FRINGE ENVIRONMENT, MUAK LEK, THAILAND

Casey Rudick

Petroleum Geoscience Program, Department of Geology, Faculty of Science,

Chulalongkorn University, Bangkok 10330, Thailand

*Corresponding author email: caseyrudick@gmail.com

ABSTRACT

Thailand hosts an abundance of Permian platform and basin carbonate sequences and outcrops. However locating a site that preserves a continuous sequence, from toe slope to reefal crest, has proved elusive. An area situated on the fringe of a Permian carbonate platform that captures such a continuous sequence was identified and is the focus of this study.

Found in the Muak Lek, Central Thailand, the locale is situated 280m downdip from a previously documented outcrop that proved to be a reefal crest. Downdip from this area of interest were deep water shales. This transitional zone was analyzed with regards to depositional history, structural framework, and diagenetic processes.

Fieldwork and laboratory analyses revealed three distinct units. The first, the lowermost foundation of the platform, was revealed to be an accumulation of primarily crinoidal rudstones. This omnipresent facies is a talus unit that had been transported from another reef. These events are attributable to collapse of the outer rim of the adjacent platform and/or faulting.

The second unit was a biologically-mundane layered stacking of progradational rudstones, with upsection hints of increasing chert content. Stacking was demarcated by its chert abundance. The unit indicates a transitional zone for the basin talus accumulations and passes into the overlying third unit. The second facies reflects a slope, possible upper slope, environment.

The final and overlying third facies unit is comprised of boundstones with encrusters and bryozoa. In-situ corals and cementstones were evident. Relicts of sponge colonies were clustered above, below, and throughout. These varying pulses of biota collectively formed a mosaic texture. This unit was the topographic high of the entire formation studied, and more importantly, the local reefal crest.

Each facies unit experienced some degree of diagenetic alteration. Evidence comes in the form of calcite cements with sparry, fibrous, radial, and syntaxial texture. Ferroan calcite cement was found in the first facies unit. Isotope analyses revealed: early burial, late burial, and telogenetic trends on a covariant O-C chart. However further inspection showed the reefal crest has oxygen values that did not exceed -10.47 O % VPDB. Units 2 and 3 cements experienced fluids evolved well beyond this, with upwards of -13.7 % O VPDB . This indicates both:

1) a relatively early porosity-shutdown in the crestal sediments

2) that they did not experience significant crossflows of late burial fluids.

Contextual sources corroborating these oxygen isotope values to be largely consistent with precipitation from relatively low temperature fluids, when compared to more thermally evolved oxygen isotope signatures in Saraburi carbonates sampled in more structurally complex settings, (Ampaiwan, P., 2011, Kuenphan, N. 2011, Thanudamrong, S., 2011).

INTRODUCTION

Permian limestones are bountiful in Thailand. Their frequency gives way to many different depositional settings, diagenetic styles, and structural formations. The objective of this study is to classify a continuous carbonate outcrop with regard to its diagenetic and depositional history, with the succession broken down into sediment associations related to:

1) Platform
2) Outer platform/upper slope
3) Basin

That is, this study aims to provide evidence of depositional and diagenetic evolution in a region preserving a continuous succession passing from outer platform to upper slope settings and to define the style of textural, bed contact and bedform evolution as sedimentation passes from a deeper to shallower water setting.

Significance

Outcrops of the "Saraburi Limestones" showing continuous platform to basin continuity are uncommon. Knowledge of this outcrop's location owes itself to the momentum generated by previous studies. Up until now continuous platform-basin outcrops of Saraburi Limestones have evaded documentation. The current study location is pivotal in elucidating a Saraburi Limestone platform-to-basin transition. The consequences of this research will provide a structural/sedimentological model, along with the depositional history and diagenetic evolution, as held in the various replacements and cements.

Meso-scale Depositional Features

Unit 1: Talus Lithofacies

Basinal environments are dominated by the low-energy fine-grained siliciclastic sediments and often contain sporadic mechanical and gravitationally reworked sediments, e.g. talus accumulations. This paper shall employ the following definition for talus accumulation: talus is defined as retransported material originating from the platform (Grotzinger, 1995). Unit 1, the Talus Lithofacies, is typified by both fine-grained siliciclastic sediments and mechanically transported non-basinal carbonate packstones.

Talus accumulation was found at the base of every face. This group, Unit 1, is an accumulation of talus, 15m tall. At the base of each Section lies large boulders, with internal compositions dominated by packstones with grain components a combination of bioclast fragments and crinoidal debris. The boulders range from .5m – 4m in diameter. They are subrounded and embedded within the face of their section. Their grain size maintains consistency, with only minor fluctuations of large crinoidal stems. These large grains are subrounded and contain micritic rimming with occasional spar cavities (see *Microfacies*). Talus boulders were classified by their relative location within their stratigraphic column and size.

Volcanic Intrusions

Andesitic sills outcrop in each of the carbonate sections. It is typically found cross cutting the underlying carbonate beds. Isotope samples taken from carbonate beds immediately bordering the sill, have anomalously negative Oxygen values, see isotopes. This indicates local post-depositional heating related to the intrusion.

Siliciclastics

Shales underlie and intercalate with carbonates across the grounds of the entire outcrop. Their color ranges from black to pink-grey, each of which is unique to their respective section, save for Section 5 where shale colors are varigated.

The shale section is down dip from the other sections, and is dominated by shale and siltstones. A road was cleared between the carbonate and the shales of section 5. The road exposed the andesitic sill that occurs at this position across much of the quarry. The road's orientation gave a parallel crosscut to the platform edge and the deep-water shales. The exposure corroborates Morley's earlier research. The face of Section 5 faces directly towards the carbonate reef documented by Maryam Mirzaloo (2013).

The boulders occurs within orange and light grey shale beds. The shale beds at the boulders' base have not been disturbed. The flanking shale beds encase them in a wrapping fashion, and overlying shale beds are continuously flat , once again.

Unit 2: Slump Lithofacies:

The outer platform to upper slope environment is situated between the shallow water photic zone of the carbonate producing platform and the fine-grained siliciclastic and talus-accumulated basin. This range inherently contains a spectrum of depositional energies. Similar to Unit 1, the Unit 2 rocks are crinoid-dominated. It is distinct from Unit 1 by its geometry, chert abundance, color, and biodiversity. Unit 2 overlies Unit 1, but is separated by a shale interval. Found only in Section 2, Unit 2 spans a vertical distance of 40 meters and tapers from an exposure 50 meters wide at the base to 30 meters at the top. Packestones occur at the base and are stacked into large massive rock units, 4 meters thick with a total of 10 vertical meters. With ascension, there is an increase of chert nodules in the section and a transition to rudstone dominance. Cherts reach peak abundance at the apex of the unit where sponge colonies, encrusters, gastropods, and mud catchers are obvious. Unit 2 is uniformly steel grey and lacks the orange overprint from sediment and telogenesis found in the lower Talus unit.

Unit 3: Reef Lithofacies

The capstone lithofacies unit is a reef with clear evidence of local biogenic binding and early marine cementation. Stratigraphically, it lies above the slump deposits of Unit 2. The lateral extent is a mere 30 meters suggesting an isolated patch reef formation, rather than more substantial barrier reef. It is comprised of bryozoa, sponges (calcareous and siliceous), corals, and cementstones. This lithological association is analogous to that in the Guadalupian Capitan Limestone of West Texas and New Mexico, see *Discussion*.
There are pockets of boundstones (discussed further in the microfacies section) which are interspersed by grainstone-dominant matrix rocks containing crinoid debris, calcareous algae, gastropods, and shell fragments. Mud clasts in pockets -protected cavities- are scattered throughout, lending to a wackestone classification. This variation in rocktype defines a mosaic framework throughout the reef. The boundstones along with the grainstones suggest a high-energy environment. These boundstones combined with the hints of wackestones are typical of reefal mud mound buildups in Permian boundstones (Ahr, 2008).

The most notable features of this reef are its cementstones and the large mounds of coral frames. Both of these features are boundstones, however the cementstones (confirmed in Thin Section) were laterally extensive whereas the corals were local mounds, no more than a few meters across

MICROFACIES

Cementation types were scrutinized from each of the lithofacies define during section measurement. This aids in understanding the post-depositional history, aka diagenesis. Subsurface diagenesis is divided into three categories: Eogenetic, Mesogenetic, Telogenesis.

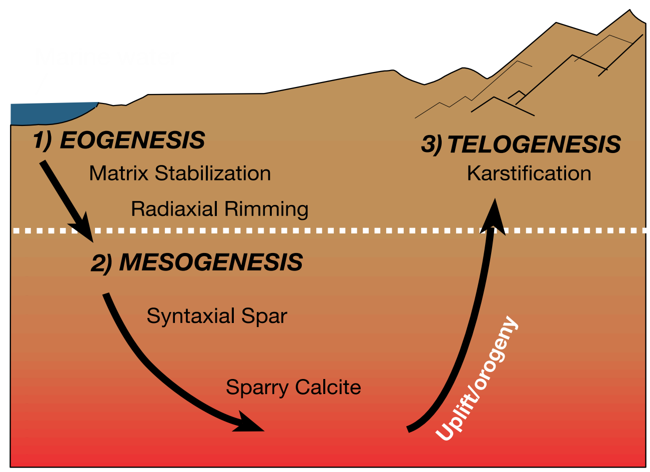

Figure 1. Paragenetic sequence displaying order of texture creation found in the petrographic study of the thin sections.

Eogenesis refers to near-surface burial processes that occur shortly after deposition and before burial. The driving mechanism for this cementation is either marine water lens or meteoric fluid flushing. Thin section analysis found eogenesis prevalent in each of the lithofacies. This presented itself mostly as radial calcite rimming biotal fragments and indicating a replacement of an early marine cement (Figure 1).

Mesogenesis follows eogenesis, and originates with burial. This was found as syntaxial calcite overgrowths typically focused on crinoids in each of the facies units (Figure 7b). The later, burial sparry calcite is typically found in cavities and veins (Figure 1).

Telogenesis is the tertiary step in diagenesis and refers to features created during the uplift and subsequent exposure of subsurface carbonates. This often results in exposure to meteoric water crossflows and associated porosity and permeability changes.

Thin section petrology identified 4 carbonate microfacies within the mesoscale lithofacies:

A) Boundstone B) Rudstone

C) Packstone D) Wackestone

Boundstones were found only in the Reef Lithofacies. These were in-situ cementstones and coral textures with minimal amounts of burial cementation, due to earlier pervasive eogenetic cements shutting down the rocks permeability

Rudstones were found in the Reef Lithofacies and Slump Lithofacies. In the Reef, they contained bryozoa, sponges, gastropods, and calcareous algae within a crinoidal and or fusulinid mud matrix. The Slump rudstones show lower biodiversity; mostly crinoids, with occasional fusulinids.

Packstone facies were found in the underlying Talus and Slump Lithofacies. They are made up almost entirely of crinoidal debris, with patches of algae and other bioclastic remnants. The debris suggests high-energy transport. Naturally, they are most abundant in the Talus lithofacies.

Wackestone facies are present in the Reef Lithofacies. They are composed of crinoidal debris with variable amounts of foraminifera, bivalves, and gastropods. The micritic supported matrix and bioclastic preservation suggests low energy conditions. Within the Reef Lithofacies, it is only found in the mud patches between boundstones is likely a sediment fill that accumulated in more sheltered positions such as near the base of overlapping framework constructors or in cavities. The combination of wackestone and boundstones (and rudstone) confirms the mosaic framework of the Reef Lithofacies.

STABLE ISOTOPE ANALYSIS

Calcite samples were selected, with regards to their texture, in order to determine their O and C values. With burial, oxygen isotope values become increasingly negative. This reflects the changes in rock-fluid re-equilibration as fluid temperatures increase (Hoef, 2009). During burial, subsurface fluids percolate into rock pores and leave diagenetic overprints, i.e. crystallization. This causes a decrease in porosity, ultimately leading to complete matrix permeability shut down. Carbon isotopes values are dependent on CO_2 and become more negative with increased CO_2 concentrations. CO_2 can be sourced from meteoric percolation, biological activity, and/or hydrocarbon maturation.

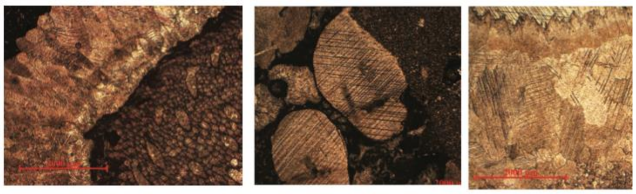

Figure 2. Left: Radial axial calcite rimming on a broyozoa. Center: Syntaxial spar found overlying crinoid debris. Right: Sparry calcite found adjacent to a vein, and juxtaposed with micrite.

95 samples were taken from the 6 Sections and analyzed using standard techniques at Monash University. The results are on displayed in C-O crossplot in Figure 12. The plotfields show two trends: a burial trend that overlies the burial tend defined by the previous studies of Saraburi Limestone, Warren et al. (2014), and a meteoric mixing trend related to telogenetic overprints tied to uplift.

The isotope values along the burial trend of this outcrop are divisible three groupings based on Oxygen values. These groupings reflect increasing fluid temperatures. These groups were interpreted as:

Group 1: Eogenesis

Group 2: Early Mesogenesis - Late Mesogenesis

Group 3: Late Mesogenesis

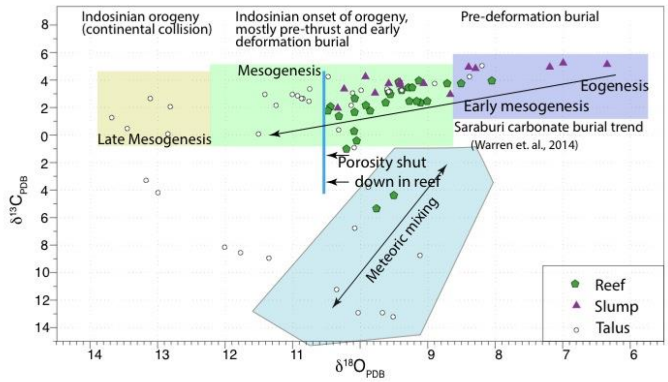

Figure 3. Isotope values placed in their larger facies context. The Slump facies appears first with the least negative oygen and carbon values. This indicates earliest stabilization of the mud by pore fluids. Reef components appear in a tight oxygen window, suggesting smallest range of varying diagenesis. The reef begins to display meteoric mixing and or biogenic influence with the increasingly negative carbon values. The reef and slump share the same negative oxyge extent. The Talus facies is scattered, suggesting diverse range of post-depositional exposure. It contains the most negative oxygen and carbon values.

Isotopic Results

Group 1 is the least thermally evolved; explaining the matrix-only consistency. Group 2 is a transitional zone of thermal evolution, as corroborated by the diversity of sample textures. Group 3 has experienced the hottest burial temperatures, and consists only of sparry calcite. The first to stabilize are the tighter zones, e.g. matrices. Following matrix stabilization found was eogeneic radial rimming around bioclasts, then syntaxial calcite overprint in crinoids, then sparry calcite alteration of original formation, then sparry calcite in veins and cavities. This timeline is deduced by the textures' corresponding temperatures.

The Talus lithofacies was relatively chaotic. The oxygen values indicates the Talus unit experienced the most diagenetic thermal evolution possibly because, unlike the platform carbonates the shales continued to fracture and allow mesogenetic fluid ingress long after the carbonate permeability had shut down. The carbon values in the talus unit also indicate that a signifiant degree of meteoric entry and mixing was focused in the Talus unit; the most negative values likely indicate cements due to soil gas, related to a recent telogenetic overprint, unrelated to deposition and subsequent burial diagenesis.

The Slump lithofacies unit is characterized by its: 1) relatively thermally cool values; 2) a flat burial trend towards increasingly negative oxygen values. The thermally cool values come from the muddy matrix samples found in packstones and rudstones. This suggests earlier stabilization of the mud with re-equilibrating burial fluid interactionss.

The Reef lithofaces unit has a relatively tight and somewhat more postive oxygen distribution. This suggests early porosity shut-down from interacting burial fluids Comparison with the data from Warren et. al, 2014 demonstrates a striking similarity. The data from this thesis study's Muak Lek outcrop follows the same general burial trend. This infers a pervasive regional tectonic overprint on the isotope signatures.

RESULTS AND CONCLUSIONS

Field survey, isotope analysis, and petrology, gave a detailed dataset for interpreting the depositional and diagenetic evolution in a Permian platform outcrop, see . This work revealed three distinct lithofacies units within the abandoned quarry. The nature of each lithofacies' structure, microfacies composition, and isotope values indicate a continuous, depositional stacking of Reef atop Slump atop Talus.

The Talus lithofacies unit is interpreted as the foundation of deposition (the rest of the outcrop) in a basin-margin to basin environment. The talus unit was capped with a highly weathered section of shales. This shale further suggests high-energy relocation of coarse debris to a low energy basinal environment. The next lithofacies, the amorphous Slump, demonstrated a notably lower energy deposition. The uppermost lithofacies unit, the Reef Unit, is interpreted to be the crest of this formation. The in-situ boundstones documented, (i.e. cementstones and corals) along with bryozoa, sponges, and encrusters, typify a reef formed in relatively anoxic waters, as existed worldwide at times in the Permian (Grotzinger, 1995).. Modern analogues are not available for this style of reefal assemblage, as platform waters associated with reefs today are fully oxidized. However, Precambrian reefs grew cementstones in anoxic waters, whose only possible component were microorganisms.. This confirms cementstones as in-situ microbial products, rather than chemical precipitants.