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# An isotopic and sedimentological study of deepwater carbonates Lobburi, Central Thailand

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**Abstract**

The present study is concerned with the application of sedimentological and geochemical isotope analysis approaches in order to predict the depositional environment, fluid evolution history and reservoir rock property alteration, tied to burial and uplift of Permian basinal and platform margin sediments in outcrops in central Thailand (UTM: X:705100;707000 and Y:168600;1627400).Three representative measured section were constructed, two in a mixed carbonate-siliciclastic interval and one in a sequence of intercalated hemipelagic mud-volcaniclastics. A combination of field observation and laboratory analysis established three distinct lithofacies, namely: a) mud-wackestone, b) wacke-packstone and C) grainstone (rudstone). Multiple diagenetic features were observed microscopically and most are related to a progressive burial (mesogenetic) evolution. Stylolite dissolution seams and penetrative grain-to-grain contact features account for significant losses in reservoir rock porosity with complete matrix permeability once the succession under study attained deeper burial domains. Related to this evolution the stable isotopic signatures shows two distinct field behaviors in a C-O covariant crossplot that defines two separate plot fields for the sampled matrix and calcite veins. Two different timings/stages of calcite veins were also identified based related to calcite stabilization in earlier versus later burial and likely indicate mesogenetic calcite formed from earlier somewhat (cooler) and somewhat later (warmer) burial fluids.

**Keywords**: Diagenetic fluid evolution, Deepwater Carbonates, Central Thaïland,

## 1. INTRODUCTION

Several studies had been conducted concerned with hydrothermal fluid evolution history and depositional environment centered on the platform Permian carbonate in Saraburi region by several authors (Warren et al., 2014, Susanto, 2010), in order to predict and understand their implications with respect to reservoir property destruction.

Reservoir rock characterization is considered as one of the most important task during the hydrocarbon exploration phase. Understanding the depositional setting, geometrical distribution and diagenetic evolution of the fluid crossflows and their results in the reservoir rock is helpful. Thus, this study discusses the implications of the depositional and diagenetic fluid evolution on reservoir quality of the deepwater mixed Permian limestone and mudstone of Saraburi group, Central Thailand, particularly in the Lopburi region.

### 1.1. Study area

The study area is located in the western part of Central Thailand, Lopburi district, Wat naphralan Municipality, and lies between the Khao Khad and Pang Asok formations as shown in the map below. **Fig1.**

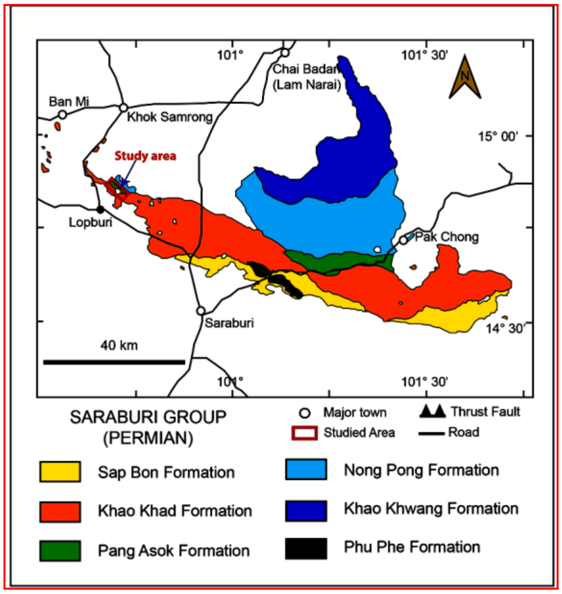


**Figure 1**. Map of the study area depicted by red rectangle on the Map.

The main purpose of the study is to compare and contrast in terms of deposition and diagenetic fluid evolution history behavior in the Deepwater mixed carbonate and mudstone when compared to the previous signatures registered on the Permian carbonate platform.

## 2. METHODOLOGY

All data utilized in this research is derived from the outcrop observation and laboratory study.

Representative samples were collected and carefully selected for thin section, stable isotopic and XRD analysis.Three sedimentary sections were measured and interpreted in order to understand the stratigraphic architecture, depositional environment and geometrical distribution of the limestone in the study area, using standard procedures outlined by (Tucker, 2003 and Coe, 2010).

Microfacies analysis was carried out on 14 thin sections and rock texture description follows theclassification of Embry and Klovan, 1971, Flugel, 2010 and Scholle, 2003. Stable isotopic analysis of $\delta^{13}C$ and $\delta^{18}O$ was performed in Monash University Laboratory, Melbourne, to better define the diagenetic fluid evolution history of the studied limestone.

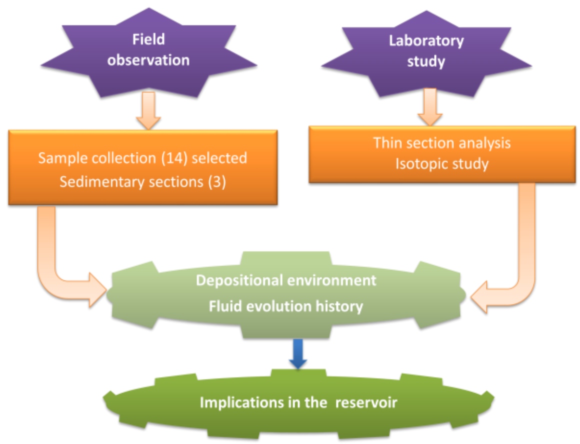


**Fig.2.** Simplified workflow to approach the problem.

## 3. Results

3.1. Geological and sedimentological documentation.

The studie doutcrop consists of two main lithologies;1) limestone and 2) interbedded, silt-shale-volcaniclastics. The limestone varies from gray to dark-gray in color ranging from mudstone-wackestone, packstone, grainstone (rudstone), thin to thick bedded units, dipping preferentially N060/50SE and rich in foraminifera (fusulinids), crinoids and gastropods. Chert beds and nodules occur associated with the limestone.Three sedimentary sections were measured along the study area in order to understand the distribution, geometry and large scale architecture of the potential limestone reservoir. Fig. 3

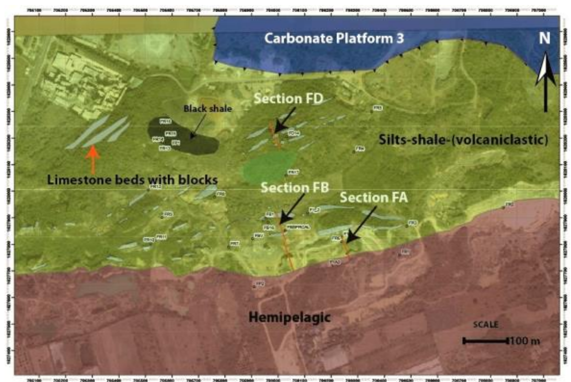


**Fig.3.** Map showing the locations of the 3 measured sections and lithology distribution along the study area

Three sedimentary sections were measured during the field investigation.

Section FA was measured across the interbedded and heavily deformed and folded silt-shale-volcaniclastics.
unit. Sections FB and FD were measured across the limestone unit interbedded with shales and volcaniclastics. See Fig 3 and table 1 for detailed description

**Table.1.** Detailed descriptions of the measured sections.

| Sections | n° Units | Thickness | Description |
|---|---|---|---|
| **FA** | 9 | 44.55 m | Consists of an interbedded sequence of silt-shale, some volcaniclastics (tuff and breccia), section is heavily weathered, deformed and folded. It overlies the limestone unit. Slump unit is clearly preserved in this formation. |
| **FB** | 6 | 29.10 m | Composed of 3 different limestone facies, namely;1) mudstone-wackestone, 2) wack-pakestone and 3) grainstone (rudstone). Scours, parallel laminations, loading structures were all obvious in this formation. Turbiditic sequences were also identified, mostly showing ta, tb and tc facies of the Bouma turbiditic model. |
| **FD** | 6 | 31 m | Consist of turbiditic and talus debris limestone interbedded with silt-shale volcaniclastics. Very rich in foraminifera (mainly fusulinids) and crinoids. At the contact (volcaniclastic-talus debris), shale injection is observed, perhaps due to differential compaction. |

## SECTION FA

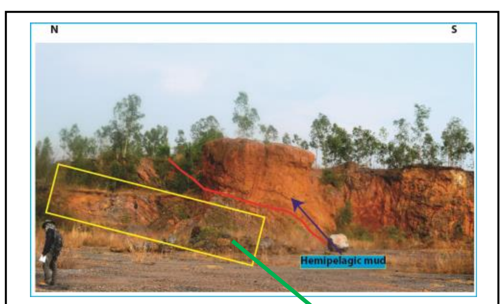


**Fig.4.** Showing interlayered silt-shale volcaniclastic unit and the contact between silt-shale and volcaniclastics with hemipelagic mud (red line)

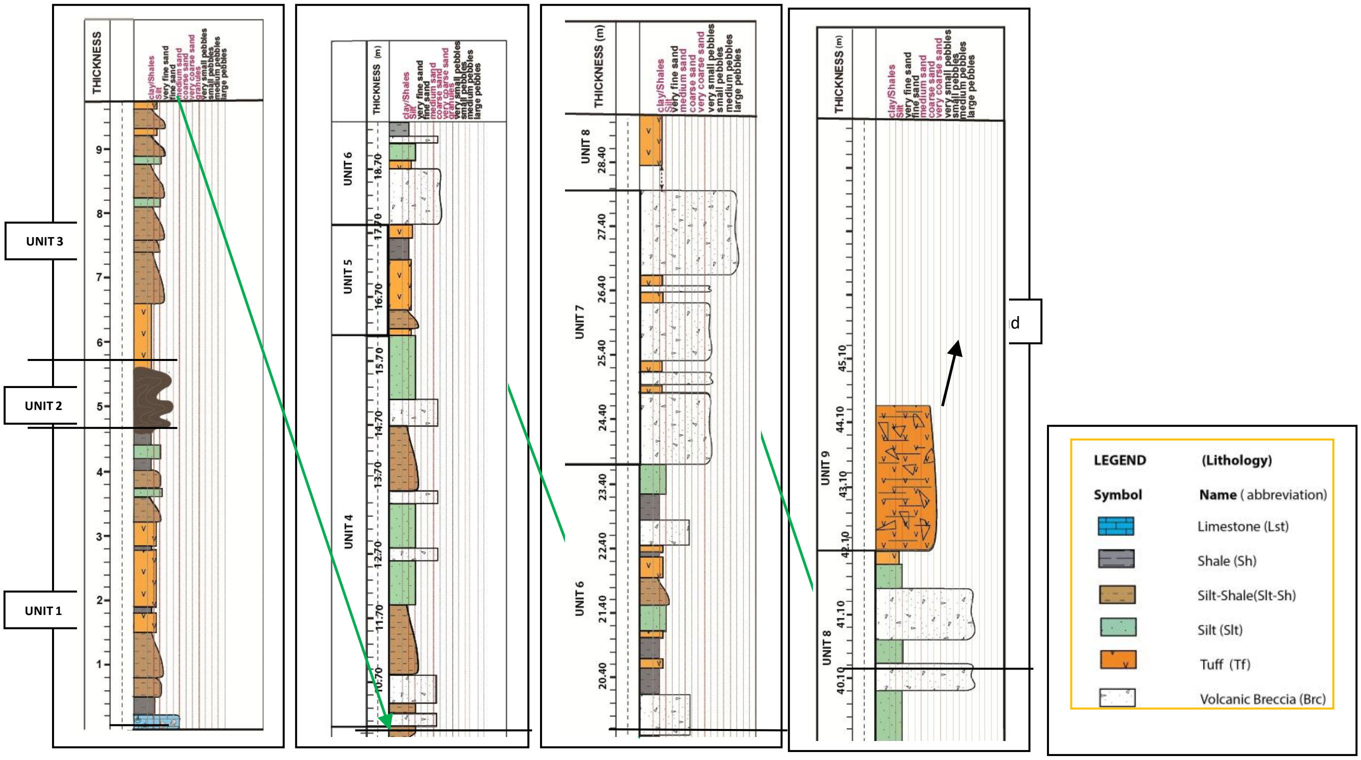


**Figure 5**. Graphic log of section FA showing intercalated silt-shale-volcaniclastics (tuff and breccia) note the increasing in granulometry towards the top of the unit.

## Section FD

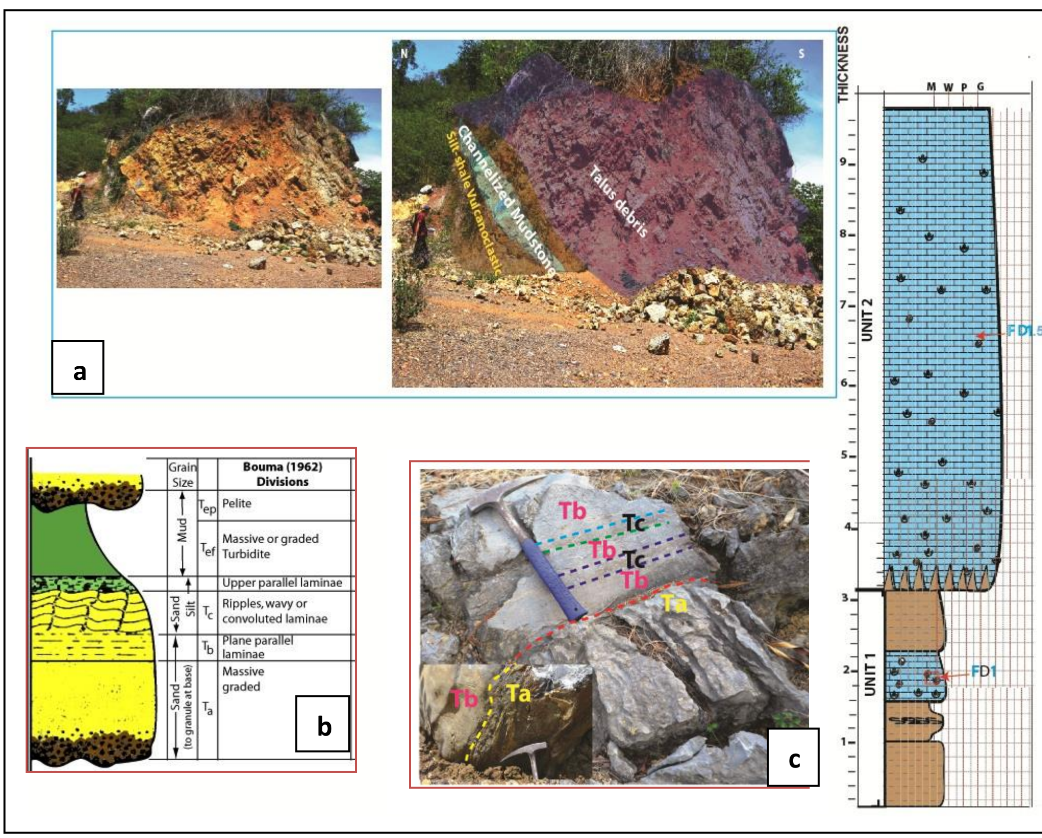


**Fig.6.** Showing A) Channelized turbiditic mudstone deposited in low energy environment, immediately on top of mudstone seats a talus debris unit, poorly sorted muddy pebbles within fine muddier matrix probably transported during the slope failure. B) . And C) The first showing the classic bouma sequence and the second showing field photo with Ta,Tb and Tc facies type

Same level of detail was also done for the section FB and it can be found in the appendix 2 of the original report.

3.2. Microfacie analysis and diagenesis

Detailed microscopic description of the selected carbonate thin sections samples from the two measured carbonate sections (FB and FD) define 3 major lithotypes,namely;

**Mudstone/Wackestone**, **Wackestone/packstone**, and grainstone (**rudstone**)

**1) Mud-wackestone.**

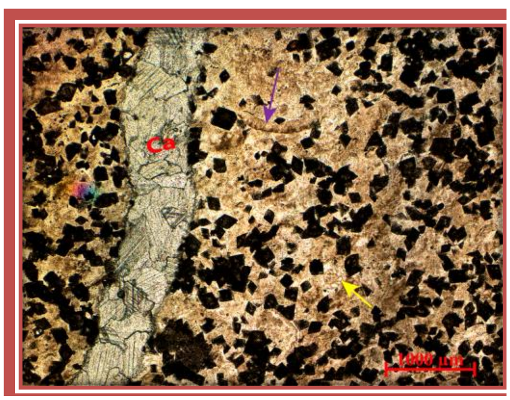

**Fig.7.** Photomicrograph sample FB1 NL, showing mudstone composed mainly of algal spicules and some gastropods and forams. Black rhombic shaped crystals are probably calcite being replaced.

**2) Wacke/Packestone**

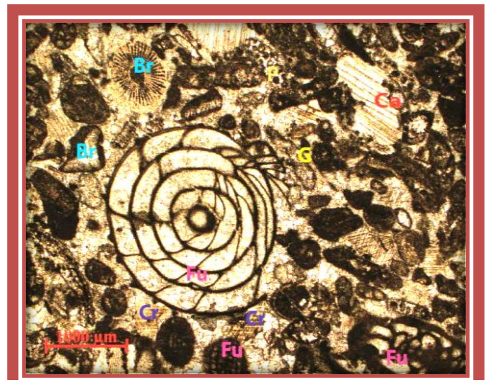

**Fig.8.** Photomicrograph FB1.7A NL, showing wacke/packestone composed mainly of micritized bioclasts, fusulinids, crinoids and briozoans. Calcite precipitaiting and closing primary porosity.

**3) Gainstone (Rudstone)**

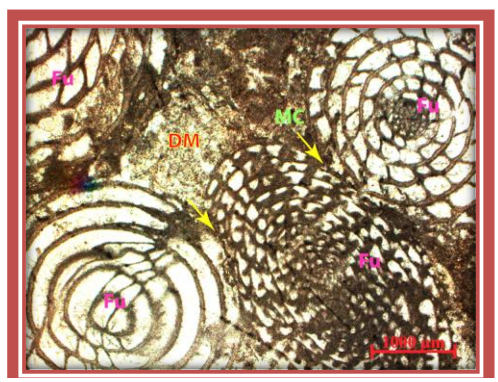

**Fig.9**. Photomicrography showing a micritized grainstone composed of huge circular and deformed fusulinids and late stage calcite precipitating and closing the primary porosity.

## 4. DISCUSSION

### 4.1. Depositional environment

The detailed stratigraphic, geological and microfacies analysis of the studied limestone succession allows one to infer that the carbonate sequence was deposited in an upper-slope to deep basin environment, with little or no evidence of sea level change or subaerial exposure (due to its deep water setting). The limestone was deposited by turbidity currents, with material in suspension, transported to the deep basin region.

Channelized mudstone, slump structures and turbiditic sequences identified in the field, as well as the talus debris succession are the primary evidence of a relatively deep water depositional environment, with relatively steep up-dip slope that allows the generation of prograding turbididic currents. See fig.6.

The hemipelagic (siliciclastic) sequence that encases the talus blocks and turbidites was formed as a result of rain of shelf and volcanogenic-derived fines settling through the deeperwater column.see figure 10 for the proposed depositional model.

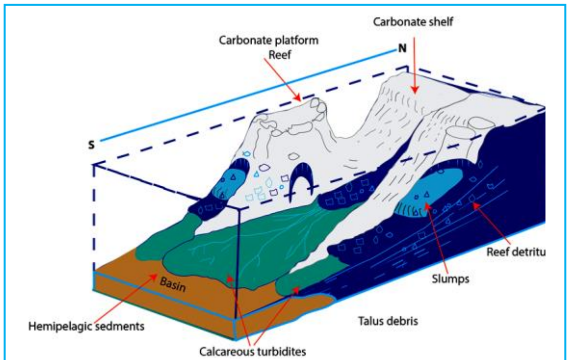


**Fig. 10.** Showing proposed depositional model

### 4.2 Diagenitic fluid evolution history

Isotopic and microscopic data provides a good match with respect to the diagenetic fluid evolution history of the studied limestone. The main diagenetic processes, as preserved in the limestones of the study area, is mesogenetic re-equilibration (Burial compaction).

Diagenetic features developed during the progressive increasing of burial compactions enables to establish two main stages of burial compaction namely:

a) Shallow burial

This stage of burial diagenesis is characterized by intense micritization and cementation due to precipitation of calcite cement. Sea water is under saturated with respect to the $CaCo_3$ consequently starts the precipitation of $CaCo_3$ reducing all the primary porosity. Three main cements are found the studied limenstone namely, micritic(coating the grais), drusy mozaic, and sparry calcite.

b) Deep burial

This stage of burial compaction is characterized by two main processes namely; mechanical and chemical compaction.

During the mechanical compaction the grain-to-grain contact are much more interpenetrative showing the concave convex contact style and the porosity is extremely reduced. Precipitation of large and imperfection free calcite crystals also occur during this phase. Fractures are also generated during this phase and most of them are immediately cemented by sparry calcite cement.

Chemical compaction, is the later stage of diagenesis and indicates increasing chemical of pressure solution due to over burden and tectonic stresses.

First the grain to grain contacts and then simple grain contacts develop into planar and sutured grain contacts (Ahr, 2008). Later pervasive chemical dissolution spreads out from these dissolution contacts to become stylotites.

The stylolites develop as late diagenetic events and compaction-induced bedding parallel stylolites typically become common when burial depths are greater than 1 km (Ahr, 2008).

These are actually manifestation of a diagenetic phenomenon, called pressure-dissolution or chemical compaction. See figure 12 below, showing diagenetic features produced during progressive burial compaction process.

Development of fractures and microfratures are considered to be a result of increasing of burial compaction that in its later stages are also influenced by the Indosinian orogeny. The major fractures that cut across the smaller earlier fracture figure.13, are like a result of intense tectonic activity that also lead to doleritic sill intrusion during the Later-Permian/Early Triassic Indosinian orogeny.

4.2 Isotopic signatures

Examination of isotopic signatures shows a clear and notable digenetic burial trend and a secondary catagenic mixing trend. That is, distribution of $\delta^{18}O$ and $\delta^{13}C$ values on the C-O covariant crossplot defines 2 distinct plot fields separated by distinctive carbon values.

One trend, the burial trend, is characterized by positive values of carbon (above zero) and the other shows negative values of Carbon (below zero). Along the burial trajectory it is possible to divide it into 3 different subfields, based on relative increasing negative isotope value of $\delta_{18}O$.This burial trend overlaps the Saraburi burial trend established by Warren et al. (2014). Increasing $\delta_{18}O$ isotopic value in C-O covariant crossplots is related to gradual increasing temperatures and ongoing rock-matrix re-equilibration during the burial compaction process, and is indicative influence of increasing temperatures in the deeper burial environment (Moore, 2001, Ahr, 2008, Warren et al., 2014).

The 3 subfields represent three different stages of burial diagenesis namely early mesogenesis, mesogenesis and later mesogenesis respectively.

Early mesogenesis and mesogenesis can be associated with a shallower burial setting. The $\delta_{18}O$ and $\delta_{13}C$ isotope values of these cements and matrix range from (-6.1 to-10.2 and -0.1 to +4 respectively) indicating relatively cooler burial temperatures.

The later mesogenesis (later burial) phase is indicated in the C-O covariant crossplot as more negative $\delta^{18}O$ values and relatively high $\delta^{13}$ C value (-13.1 to13.4 and 1.9 to 2.2 respectively). These are interpreted as an indication of the hottest temperatures preserved isotopically and are possibly related to the late stage calcite fracture infilling before all permeability was lost until the rock was uplifted (Susanto, 2010). Fig.13.

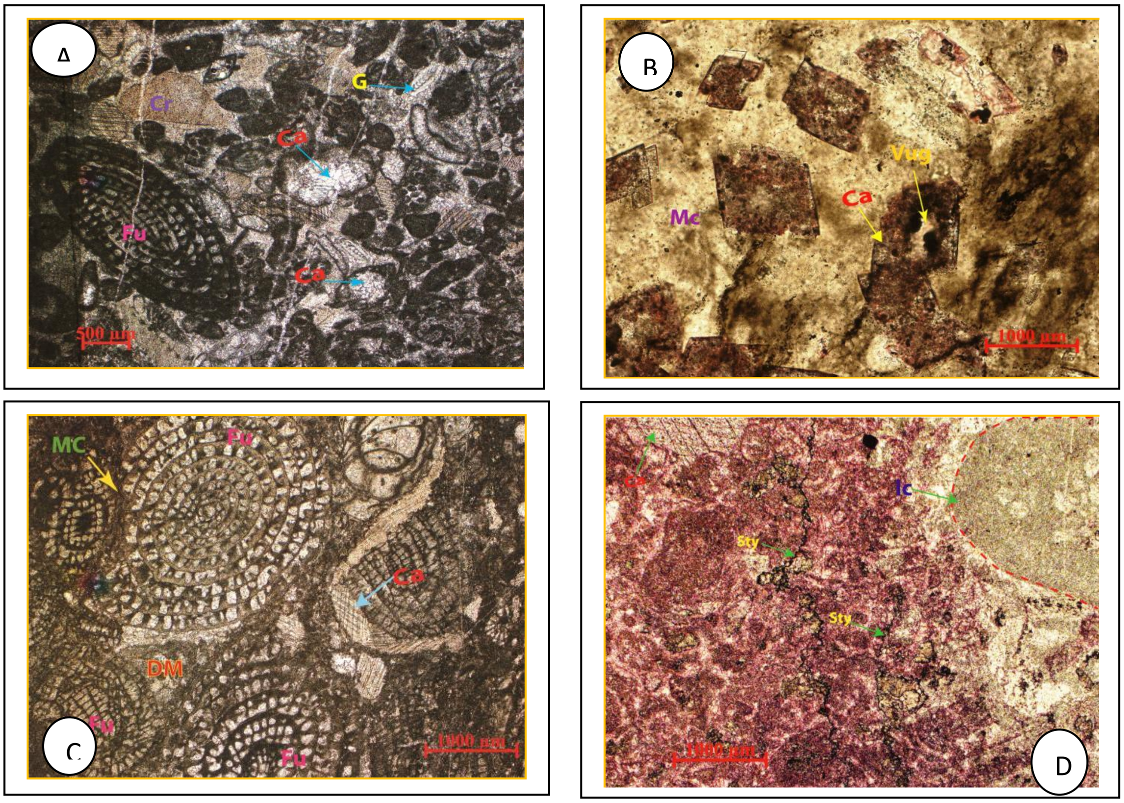


**Fig.11.** Photomicrographs showing diagetic features developed during progressive burial compaction A) precipitation of calcite cement replacement of grains and micritization, B) precipitation of rhombic shape calcite, C) mechanical compaction, intense grain packing and reduction of porosity, D) chemical compaction and dissolution of mineral grains forming stylolite seams.

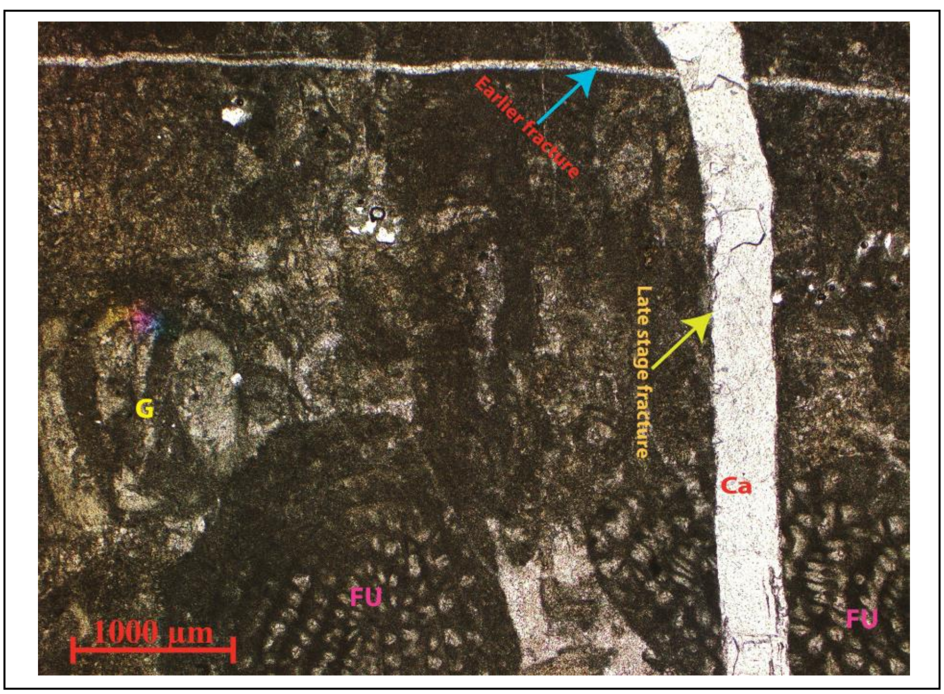


**Fig. 12**.Two calcite veins suggesting two different fluid evolution history se the cross cutting relationship

The isotopic value shows two distinct distributions in terms of samples from calcite veins. They likely differ in terms of process or composition of involved thermal fluids that generated thicker more prominent calcite veins, which are mostly perpendicular to the bedding and cut across bioclastic constituents (fusulinids) and the smaller/thinner veins.

The thicker-later calcite veins and their more negative oxygen values (blue lozenges in Figure 13 were likely generated during the Triassic Indosinian orogeny that brings hotter fluids and doleritic sill intrusions. The thinner-earlier calcite veins have less negative oxgen values and so likely relatively cooler and probably were generated during the later stage of the burial compaction process prior to orogeneis, they can be considered as merely a "sweating" product of the limestone during burial diagenesis.

The second plot field seen in Figure 13 (mixing catagenic) is characterized by negative values of carbon (below zero) and oxygen, it is probably related to a catagenic process related to the compaction fluids produced by the intercalated organic-entraing shales and is a result of an increasing in burial diagenesis and consequently (pressure temperature) driving fluids and associated CO2 and bicarbonate from the intercalated shales (see also Ludwig, 2014)..

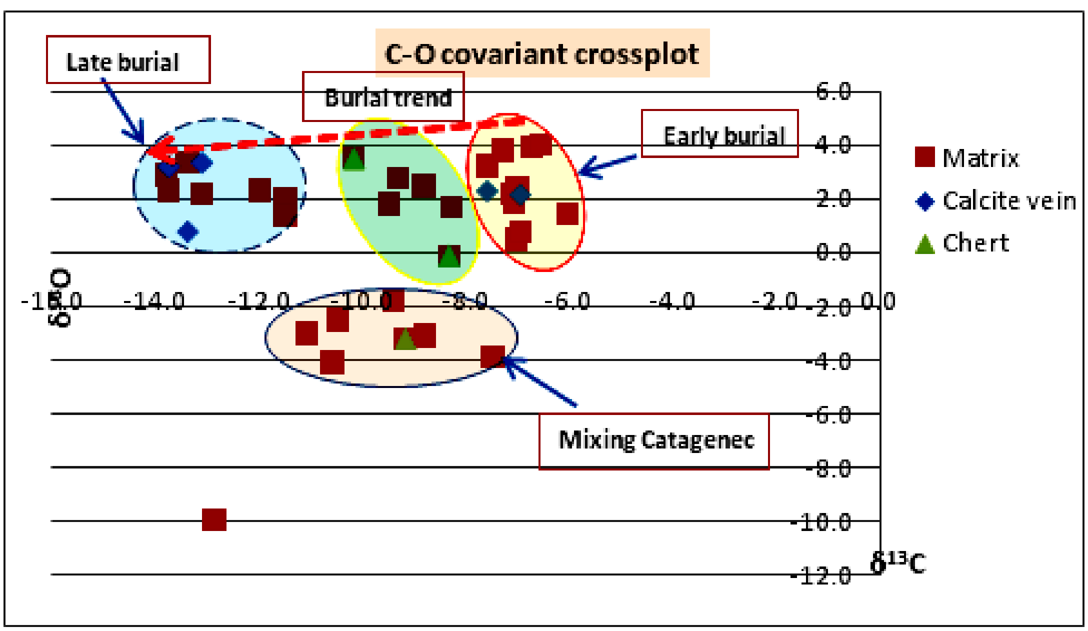


**Fig.13.** Showing two distinct diagenetic process fields, compaction burial trend and mixing catagenic respectively

## 5. CONCLUSIONS

The study of deep water carbonates and mudstone in Lopburi-Pak Chong, Central Thailand establishes:

1) The studied sequence consists of a mixed carbonates and siliciclastic, where the carbonates are divided into three main lithofacies namely; mud-wackestone, wacke-packstone and grainstone (rudstone), respectively.

2) Siliciclastics are deepwater assemblages (hemipelagic and volcaniclastic/terigenous mud), which in the study are a result of settling of marine pelagic and windblown material through the water column. Due to inherent high ductility these units are heavily deformed and folded.

3) Carbonates were deposited as isolated turbiditic sequences due to the slope failure, perhaps during the relative lowering in sea level.

4) Isotope values shows that the matrix was permeable enough to allow fluid flow throughout the rock until it has been locked-off in the late burial diagenesis.

5) A combination of depositional, diagenetic and isotopic evidence shows these deepwater limestones are depositionally distinct from the relatively shallower nearby platform carbonates in terms of lithology and facies association but are similar isotopically (in terms of their diagenetic fluid evolution history).

6) Mudstone/wakestone and Wackestone/packstone lithofacies exhibit higher porosity and permeability signatures when compared to lower poro-perm of the graistone lithofacies due to pervasive cementation.

7) Porosity was enhanced in the grainstone litofacies due to generation of brittle fractures caused during the Triassic Indosinian orogeny, but these fractures were quickly occluded by precipitation of calcite cements (with characteristic warmer, more negative oxygen isotope signatures.

8) Fluids and associated calcite cements derived from shale have distinct catagenic signatures.

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