Fluid History of Hydrothermal Textures in an Exposed Quarry in Chumphae District, Khon Kaen Province, Northeast Thailand

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Abstract

Fractured reservoirs produce gas in the Phu Horm & Nam Phong region of NE Thailand, but the reasons for this production, as well as timing of the fracturing and porosity enhancement in the Permian limestone host are poorly documented and not well understood. Fractured and brecciated analogues to Phu Horn reservoir outcrop were studied within a nearby quarry on the western margin of the Khorat Plateau, near Chum Phae, KhonKaen. There we have exposures of different types of local fault-controlled breccias and more widespread less disturbed non-breccia areas, with distribution patterns controlled by the interactions of tectonic fracturing and fluid flow. Detailed measurements of fracture orientation and density in the quarry show that the scale of fracturing, the fracture trends, and distances between fracture corridors are not unlike similar scale features in Phu Horn field, but the maximum horizontal stress directions are not the same.

In the quarry, the integration of outcrop observations (fracture orientations and mesoscale textures) with microscale laboratory analyses (thin section, XRD and stable isotope determinations) define the timing of fracturing in relation to episodes of tectonically-driven fluid flow. Stable isotopes were collected from a series of matrix blocks and calcite veins in both the brecciated and non-brecciated zones. The integration of the stable isotope measurements in these two zones, with the thin sections collected from the same sample sites, shows that matrix blocks in non-brecciated zones are less altered than matrix in the brecciated zones. Matrix blocks in brecciated zones show evidence of pervasive hydrofracturing, indicated by dense networks of criss-crossing microveins and a re-equilibration in the isotope data.

The matrix in the nonbrecciated zone preserves the regional burial signal typical of the Permian carbonates of northern and central Thailand. In contrast the micro-veined hydrofractured matrix in the breccias and all the calcite from fractures in both zones show the influence of a carbon-depleted organically-influenced fluid source, tied to a tectonically-driven fluid flow event. This event is later than burial during the Indosinian Orogeny and may be as young as mid Cenozoic. It is not related to modern meteoric karstification.

Based on this new isotopic insight, we now know that there was pervasive hydrofracturing during overpressure-driven deformation in northern Thailand. It occurred in a tectonically-drivenmethanogenically-influenced fluid escape event. It is likely that this fluid event played an important role in the development of fractured reservoirs in the subsurface of northern Thailand.

Keywords: Permian limestone, fractured carbonate reservoirs, calcite veins, breccia zone vs non breccia zones, isotope stable.

1. Introduction

The Khorat Plateau in Northeast Thailand is a structurally complex and an interesting region for petroleum exploration. From 2006 until now, most of the drilled wells in the region aimed to test fractured Permian carbonates plays. Twenty one exploration wells have been drilled to date resulting in two producing fields (Nam Phong and Sin PhuHorm). These wells penetrated the Permian reservoir on valid structures (confirmed in 6 of the 21 wells drilled) and they have been significantly successful in encountering hydrocarbons.

All of the known gas fields are located along a narrow trend in the central northern part of the Khorat Plateau where the maximum stress is mostly controlled by N-S and NW-SE trends in dolomites and fractured-carbonate reservoirs. But the quality and the distribution of the limestone reservoir analog outcrops, with associated fractures and breccia zones along the western margin of Khorat Plateau, are poorly documented. Beside the basic structural trends that are exposed in a series of small cement quarries, there is an evidence of a complex fluid evolution possibly related to different tectonic overprint. (Utomo, 2010 &Susanto, 2010).

My study area is located at 16^{O}40.714' latitude and 101^{o}50.504' longitude, just off highway 12 in the Chumphaedistrict, KhonKaen province. It is centred in an active cement quarry at the western margin of the Khorat Plateau and in the Permian limestones of the PhaNokKhao platform (Fig. 1).

Numerous small breccia zones occur in my study area adjacent to non-breccia zones crosscut by numerous fracture sets. The aim of this study is to determine the timing of fluid flow events associated with the breccia zones, explain the origin of the associated fracture sets as well as calcite veins, and if possible determine the nature and timing of the fluid flows that precipitated calcite veins in the non breccia and breccia zones. My ultimate aim is to define a fluid-fracture evolution model that can be used to better understand the origin of the fractured Permain reservoirs in this part of the Khorat Plateau.

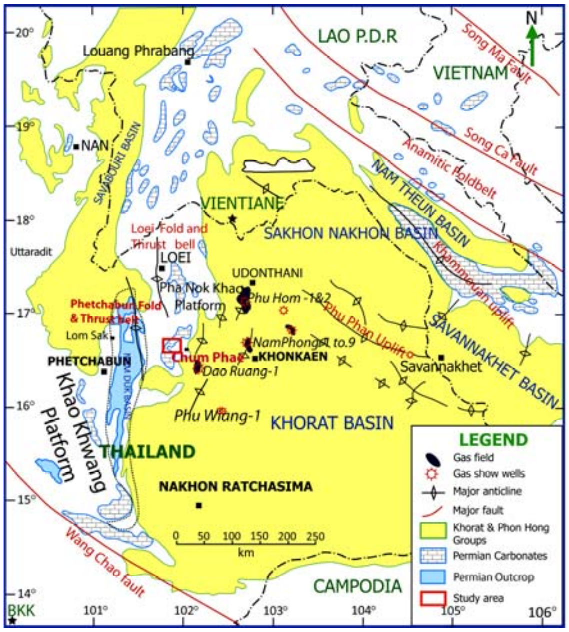

Figure 1. Surface geological elements of the Khorat Plateau Basin, hydrocarbon discoveries and the study area indicated by red rectangle (after Lovatt, Smith & Stokes, 1997; Metcalfe and Sone, 2008).

2. Method

All of data in this report come from the outcrop in the quarry shown in figure 5 and located at 16^{o}40.714' latitude and 101^{o}50.504' longitude. To set up the structural and geological framework of the study, I measured dip direction and dip angle in all types of fractures exposed in the quarry, along with the bedding orientation. I also measured two spectral GR transects sampling a brecciated and a non brecciated interval and collected relevant samples for isotope, thin section and XRD analyis. All of this information is summarised in figure 2.

3. Results (breccia zones vs non breccia zones)

3.1. Mesoscale

Breccia zone are separated from non-breccia zones based on the disaggregated shapes of the clasts and by pervasive sparry calcite inthe surrounds of the clasts in a breccia zone, versus the dominance of calcite as veins in the non breccia zones. The level of calcite veining varies in a non brecciated zone from abundant to minor (Fig. 3a&3b).

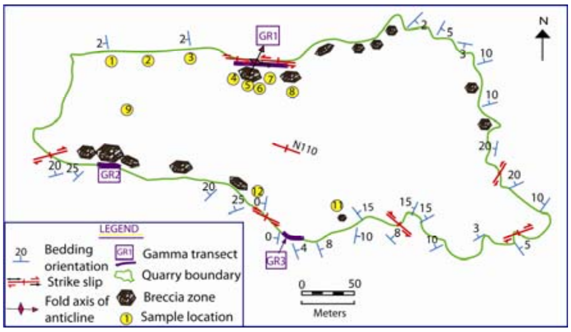

Figure 2. Mapping surface of the Permian limestone quarry in Chum Phae, KhonKaen, Thailand.

In a breccia zone, clasts of chert and limestone are fragmented, mixed and encased in calcite, while in the non breccia zones we can see stratiform chert lenses still in the position where they first formed in early diagenesis, namely flattened, elongate and sub-parallel to bedding. The most intense brecciation typically occurs in finer grained (crystalline), rather than in coarser grained, hosts. But the level of brecciation is pervasive across both types in the more highly tectonised areas.

3.2. Microscale scholle

Based on the carbonate classification of Dunham, 1962, with modification by Embry and Klovan, 1971, the suite of Permian limestone in my outcrop includes: wackstone to packstone, packstone and rudstone. Numerous fossils (fusulinids, crinoids, forams) found in most thin sections suggest depositional and climatic conditions during Permian were shallow marine with warm, clear waters and a tropical climate.

Several features are common to both the breccia and non breccia zones and a similar set of microstructures are present in cross cutting calcite veins in most thin sections. Microscale crosscutting vein calcite textures indicate the rock in both zones experienced several stages of vein development (Fig.4a). Matrix in rudstoneand packstone contains more than 10% skeletal grains. Matrix in the more intensely developed breccia zone still retains evidence of an earlier burial (pre-veining) formation of syntaxial overgrowth on crinoid grains (Fig.4c). Stylolites show that overpressure was ongoing with different timings and displacements with respect to calcite veining, some stylolites were earlier than veining, some later (Fig.4f). Chert in the clasts in breccia and in non breccia zones is the same, early diagenetic, and is composed of fine crystalline silica.

Figure 3. Matrix and calcite veins in (a) breccia zone, (b): in non breccia zones.

Figure 4. a) Three stages of development in a breccia zone (S7); (c) & (d): Crinoidalpackstone with calcareous algae, syntaxial overgrowth of echinoderm in breccia zone (S11); (f): Calcite crystals are truncated by stylolites + the displacement of calcite veins in the earlier calcite veins shows the different stages in non breccia zones (S2).

Beside these features, which are common to the breccia and non-breccia zones, other microscale features are not:

- In the breccia zones, numerous calcite veins can criss-cross and intermix in the matrix at the microscale. When this texture is present, any isotope sampling done in the matrix using a dental drill will be a measure of both the vein's and the matrix character (Fig. 5a). Clasts of differing lithologies often mix together in a breccia zone and include chert, packstone, or some wackstone-packstone with or without sufficient size to identify it as a rudstone. In such zone, it is also hard to drill only calcite.

- In the non breccia zones, calcite veins are more clearly separated from adjacent matrix and we do not see many examples of the much higher levels of fine vein criss-crossing, which we saw in the matrix in breccia zones (Fig. 5c). Dark grey chert in the matrix can have rare dolomite rhombs and like the enclosing packstone is cut by calcite veins.

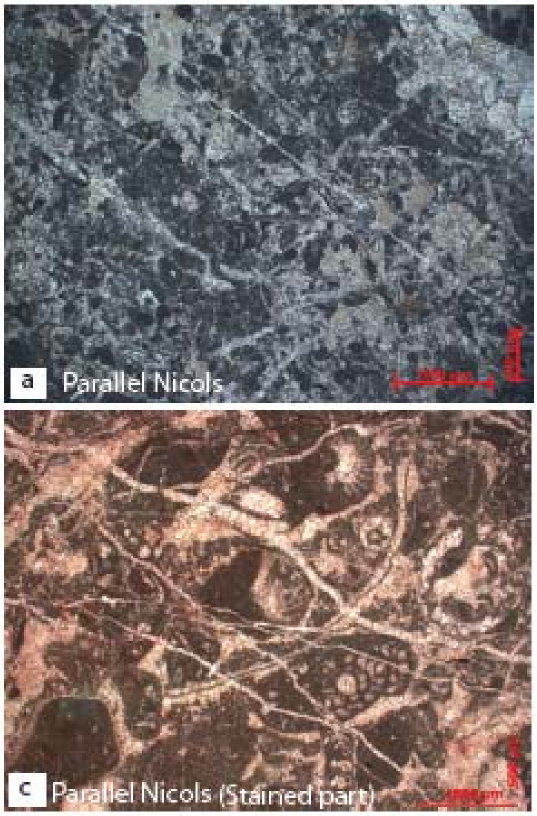

Figure 5. (a) Fine calcite veins criss-crossing and mixing/dispersing into matrix in the more intensely altered breccia zone (S5); (c): calcite veins that are more clearly separated from matrix.

3.3. XRD

XRD was run on selected samples to confirm the mineralogy determined from stained thin sections. In addition, XRD can help to identity the presence of additional minerals not recognised in the thin sections. However, in this case the XRD result is consistent with what was observed on thin section and no additional phases were present.

3.4. Spectral GR

Three gamma ray transects were run (Fig. 2). They sampled: 1) a breccia zone in a fault and fold zone, 2) a pure breccia zone, 3) a non breccia zone within host lithologies of differnt grain sizes. The K value in 3 sections almost zero shows that not much clay component in the rock that I measured.

Breccia zone with more clasts and less calcite show higher values in transects 1 &2. Total GR and K, Th, U were all near zero, indicating a clean limestone. In the lower part of the transect 3, Th is elevated and tracking total GR and U unlike the other two measured sections. This lower portion is made up wackstones and packstone with numerous dark grey chert nodules developed along the bedding. The elevated thorium content may indicatean elevated terrigenous clay content in this section.

3.5. Fracture analysis

More than 600 fracture sets were measured, including mineralised fractures where calcite veins fill in the fracture and non-mineralized fractures. Non-mineralized fractures are subdivided into two types: 1) diffuse fracture (usually perpendicular to bedding; the aperture and density of this fracture type depends on the mechanical strength of the lithology hosting the fracture) and corridor fractures (that do not depend on lithology of rock, they can cut through major bed contacts, their length can be very long). In addition I also measured the trend of all slickensides. The majority of the slickensides indicate sinistral movements with a WNW-ESE strike, but some indicate dextral motion with a NE- SW strike (Fig.2).

+ Calcite veins filled in fracture

Based on the fracture orientation data, calcite veins can be broken out into 3 major groups: the first one trends N-S with the strike N0-10; the second orientation has average orientation that is NE-SW (N45): the third with the strike of approximately N115 (or W-E).

+ Non mineralized fracture

- Diffuse fracture

The orientation of diffuse fractures is quite scattered and it is difficult to group this type of fracture, all five sections have different orientations and S_{hmax}, so I didn't group them.

- Corridor fractures

Corridor fractures are grouped into 2 major groups: the first group with S_{hmax}as NE-SW, while $S_{hmax}$of the second group is WNW-ESE).

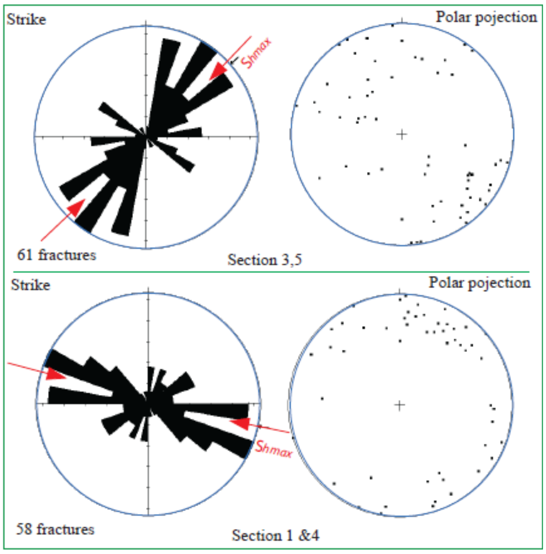

Figure 5. Two major fracture sets in the outcrop.

3.6. Stable isotope

For the samples that I chose for thin section analysis, I drilled out samples of both calcite veins and matrix. My stable isotope results are broken down according to whether the vein calcite and matrix samples were taken in a breccia zone or a non breccia zone in an attempt to define any differnces in the calcite and matrix recystallisation styles in either area (Fig.6).

Figure 6 shows that isotope determination from matrix in a nonbreccia (solid green diamonds) zone plot in a relatively narrow band of δ ^{13}C and δ ^{18}O values, compared to the other three groups of samples. This plot field does not extend into the much more negative (depleted) carbon values seen in the analyses taken from adjacent calcite veins in the non-breccia zones (open green circles). In contrast stable isotopes from both matrix and calcite vein in the brecciated zones (solid pink diamonds and solid pink circles, respectively) show much broader and overlapping plot fields.

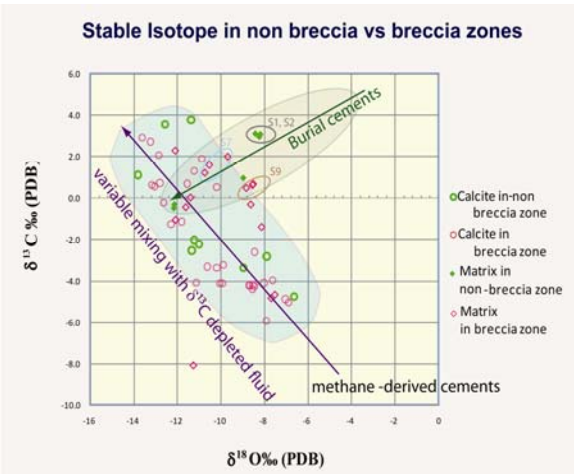

Figure 6. Stable isotopes show two different trends Burial trend is based on Baird (1993), Ampaiwan (2011) and Thanudamrong (2011).

4. Discussions

4.1. Fluid history in the outcrop

When comparing the stable isotope signatures in my area with the other areas at the south of Khorat Plateau or in the Gulf of Thailand, the different trend associated with δ^{13}C-depleted fluids traveling through the rocks exposed in my quarry is obvious. In my area, I started out my sampling using a two-zone based classification from non brecciazones versus breccia zone and expected to see more alteration developing in the calcites of the breccia zone compared to the non breccia zones. But in the end I didn't really see that simple subdivision in my isotope data. The thin sections were key in recognising two things that also became fundamental to my interpretation of the nature and timing of that δ^{13}C-depleted fluid event. I know now (based on recogntion of micro-veining) that it came from a catagenic not a meteoric karst source and that its emplacement postdated Indosinian burial. It is probably a fluid flow created by the effects of the Cenozoic Himalayan orogeny.

The values in the matrix in the non breccia zones have a much more restricted distribution. The criss-cross texture dominates those matrix samples in the brecciated zone that have more ^{δ13C} depleted values. Such samples show numerous pervasive micro-veins, which are now interpreted as the result of pervasive hydrofracturing in zones of tectonic brecciation driven by overpressuring.

4.2. Tectonic activity controls the outcrop

Two major sets of fracture orientations, present in my study area, suggest a complex tectonic history and a combination of Indosinian and Himalayan stresses. The fracture response to the orientation of maximum horizontal stress can be interpreted in my area to be focused in shear zones within conjugate fault sets.

The WNW-ESE horizontal stress component is consistent with a set of left lateral and horizontal movements. The NE-SW horizontal stress, also seen in my outcrop, is parallel to right lateral movements. One of the dextral motions is not horizontal it may be a partially rotated remain from when Sibumasu and Indochina Blocks collided during the Indosinian I Orogeny.

The WNW-ESE horizontal stress system can be very late because almost all of the sinistral motions measured in the quarry are horizontal (except one where the plunge is 30°). This trend may much later than the Indosinian and perhaps be due to the collision of India with Asia during the Cenozoic.

5. Conclusions

This paper outlines the timing of fracturing in relation to episodes of tectonically driven fluid flow and brecciation. It can be summarized as follows:

- A series of horizontal sinistral motions (strike WNW-ESE), compared to lesser dextral motions (NE-SW), suggest that the western margin of Khorat Plateau is controlled by post-Indonesian events, much more than a response to the Indosinian I Orogeny. This area also doesn't seem to have the same maximum horizontal stress direction compared with the PhuHorm& Nam Phong fields to the northest and the Dao Ruang fields to the southest.

- Brecciavs non-breccia zones can be differentiated using a combination of the stable isotope and thin sections. Matrix blocks in non-brecciated zones are less altered than matrix in the brecciated zone. Matrix blocks in brecciated zones show evidence of pervasive hydrofracturing, indicated by dense networks of criss-crossing micro veins and a re-equilibration in the isotope data.

- The Permian strata at the subsurface of the Khorat Plateau can preserve the regional burial signal typical of the Permian carbonates of northern and central Thailand in both of matrix and calcite veins in the rock. Beside the micro-veined hydrofractured matrix in the breccia, all the calcite from fractures in both zones also show the influence of a carbon-depleted organically-influenced fluid source, tied to a tectonically-driven fluid flow event. The integration of all data suggests the fluid flow may be coming from catagenic CO_2, it not related to modern meteoric karstification but to the variable mixing with $\delta^{13}C$-depleted fluids during a later stage (mid Cenozoic). This fluid event has not been recognised previously, and similar late fluids may have played a role in the permeability development of Phu Horm fields.

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7. References

Ampaiwan, P., 2011, Structural development of thrusts, folds and fractures in quarry exposures or Permian limestones, Saraburi province, central Thailand: Implication for fracture reservoir development in NE Thailand: Master thesis of Chulalongkorn University, Bangkok, Thailand, 44 pp.31

Baird, A., and D. Bosence, 1993, The sedimentological and diagenetic evolution of the Ratburi Limestone, PeninsularThailand: Journal of Southeast Asian Earth Sciences, v. 8, p. 173-180.

Dawson, O., 1993, Fusiline foraminiferal biostratigraphy and carbonate facies of the Permian Ratburi Limestone, Saraburi, central Thailand: Journal of Micropalaeontology, v. 12, p. 9-33.

El Tabakh, M., and C. Utha-Aroon, 1998, Evolution of a Permian carbonate platform to siliciclastic basin: Indochina Plate, Thailand: Sedimentary Geology, v. 121, p. 97-119.

Flügel, E., 2010, Microfacies of carbonate rocks : analysis, interpretation and application: Heidelberg, Springer, 984 pp.

Fontaine, H., 2002, Permian of Southeast Asia: an overview: Journal of Asian Earth Sciences, v. 20, p. 567-588.

Hendry, J. P., 2002, Geochemical trends and palaeohydrological significance of shallow burial calcite and ankerite cements in Middle Jurassic strata on the East Midlands Shelf (onshore UK): Sedimentary Geology, v. 151, p. 149-176.

Malila, K., 2011, Khorat Gas Sand: The 4th Petroleum Forum, Department of Mineral Fuels, Bangkok, Thailand, p. 48.

Metcalfe, I., 2006, Palaeozoic and Mesozoic tectonic evolution and palaeogeography of East Asian crustal fragments: The Korean Peninsula in context: International Association for Gondwana Research, v.9, p. 24-46.

Morley, C. K., 2004, Nested strike-slip duplexes and other evidence for Late Cretaceous-Paleogenetranspressional tectonics before and during India-Eurasia collision, in Thailand, Myanmar and Malaysia: Journal Geol. Soc. London, v. 161, p. 799-812.

Nelson, C. S., and A. M. Smith, 1996, Stable oxygen and carbon isotope compositional fields for skeletal and diagenetic components in New Zealand Cenozoic nontropical carbonate sediments and limestones: a synthesis and review: New Zealand Journal of Geology and Geophysics, v. 39, p. 93-107.

Racey, A., 2009, Mesozoic red bed sequences from SE Asia and the significance of the Khorat Group of NE Thailand: Geological Society, London, Special Publications, v. 315, p. 41-67.

Scholle, P. A., and D. S. Ulmer-Scholle, 2003, A Color Guide to the Petrography of Carbonate Rocks: Grains, textures, porosity, diagenesis, v. 77: Tulsa, Okla, American Association of Petroleum Geologists Memoir, 459 pp.

Susanto, W., 2010, Diagenetic and isotope evolution recorded in calcite cements in a large Indonisian fault zone in Permian platform- interior carbonates of Northeast Thailand: Master thesis of Chulalongkorn University, Bangkok, Thailand, 83 pp.

Thanudamrong, S., 2011, Structure style and fracture characteristics of thrusted and folded Permian Carbonates in the Siam City Cement Company quarry, Tab Kwang, Saraburi; Analogs for fracture carbonates: Master thesis of Chulalongkorn University, Bangkok, Thailand, 54 pp.

Utomo, R., 2010, Fracture characterization in contrasting platform carbonate facies, MuakLek and Chum Phae areas, central - northeast Thailand: Master thesis of Chulalongkorn University, Bangkok, Thailand, 72 pp.