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Structural and fluid evolution of Saraburi Group sedimentary carbonates, central Thailand: A tectonically driven fluid system

John Warren[a,*], Christopher K. Morley[b,d], Thasinee Charoentitirat[a], Ian Cartwright[c], Prueksarat Ampaiwan[b], Patcharin Khositchaisri[b], Maryam Mirzaloo[a], Jakkrich Yingyuen[b]

[a] Dept of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand
[b] PTTEP, EnCo, Soi 11, GGS, Vibhavadi Rangsit Road, Chatuchak, Bangkok 10900, Thailand
[c] School of Geosciences, Monash University, Victoria, Australia
[d] Department of Geological Sciences, Chiang Mai University, 239 Huay Kaew Road, Chiang Mai 50200, Thailand

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ABSTRACT

A stable isotopic study, focused on calcite cements, vein-fill calcite and various bioclasts was conducted on variably deformed and thrusted Lower and Middle Permian carbonates of the Saraburi Group. Samples were collected in quarry faces across 3 areas in the Saraburi–Lopburi region of central Thailand. Stable isotope crossplots (carbon and oxygen), using texture-aware isotope samples, defined variable, but related, fluid-cement histories, which are tied to regional burial and then orogenic overprints driven by the Indosinian (Triassic) orogeny. This was followed by telogenetic overprints, driven by late Cenozoic uplift. The studied carbonates were deposited along the western margin of the Indochina Block, where they were deposited as isolated calcareous algal, sponge and fusilinid-rimmed platforms on highs bound by extensional faults. The platform areas passed laterally and vertically into more siliciclastic dominated sequences, deposited in somewhat deeper waters within probable fault-bound lows. Regional post-depositional mesogenetic fluid-rock re-equilibration of the isotope values in ongoing calcite precipitates occurred until the matrix permeability was occluded via compaction and pressure solution. This regional burial regime was followed by collision of the Indochina and Sibumasu blocks during the Indosinian (Triassic) blocks, which drove a set of structurally focused (thrust-plane related) increasingly warmer set of fluids through the studied sequences. The final diagenetic overprint seen in the isotopic values of the latest calcite cements occurs in a telogenetic (uplift) setting driven by Cenozoic tectonics and isostatic uplift. Integration of isotope data with its structural setting establishes a clear separation in fluid events related to two time-separate tectonic episodes; its fluid chemistry defines the Permo-Triassic closure of the Paleotethys and its subsequent reactivation during the Tertiary collision of India and Asia. The C–O covariant plot fields in the Permian carbonates of central Thailand are so distinct that it is possible to use their signatures to separate burial from meteoric cements in drill cuttings and hence recognise equivalent subsurface unconformities and likely zone of porosity development in possible "buried hill plays in Thailand.

1. Introduction

Fluid flow and fluid–rock interactions in fold and thrust belts are of considerable interest for determining a better understanding of their structural and tectonic development, as well as fluid distribution in relation to mineral exploitation, and the trapping of hydrocarbons. Syntectonic veins record evidence for fluid flow during deformation, and provide important data about the stress and strain state during episodes of deformation (e.g. Lacombe, 2010; Beaudoin et al., 2012) as well as information about the origin and temperature of the fluids (e.g. Hudson, 1977; Dietrich et al., 1983; Kirschner et al., 1995; Beaudoin et al., 2011; Lacroix et al., 2014). Syntectonic veins commonly represent responses to accommodation of minor deformation during folding (e.g. Evans and Fischer, 2012; Beaudoin et al., 2011, 2012), and shortening by pressure solution (Dietrich et al., 1983), while others record significant fluid migration, particularly along major thrusts (e.g. Travé et al., 1998; Badertscher et al., 2002; Wiltschko et al., 2009). Fluids precipitating minerals in these veins may originate as single or mixed sources from depth, the formation, or meteorically. The analysis of stable oxygen and carbon isotopes is one key element in

* Corresponding author. Tel.: +66 (0)22352464.
E-mail addresses: jkwarren@ozemail.com.au (J. Warren), chrissmorley@gmail.com (C.K. Morley).

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determining how fluids of different temperatures and origins have contributed to structural development spatially and through time (e.g. Dietrich et al., 1983; Kirschner et al., 1995; Meneghini et al., 2012; Ronchi et al., 2010; Vadeginste et al., 2012; Lacroix et al., 2014). The 'squeegee model' is the most widely adopted general model for fluid migration in fold and thrust belts (e.g. Oliver, 1986; Machel, 2004). In this model fluid migration from depth and dolomite formation are related to progressive foreland folding and thrusting, where hot fluids are driven towards the foreland and ultimately mix with, and are diluted by meteoric waters, e.g. Southern Canadian Rocky Mountains (e.g. Kirschner and Kennedy, 2001; Cooley et al., 2011), Apennines (Ronchi et al., 2010). Meteoric water infiltration does not, however, always dominate in the later stages of deformation. For example a stable carbon and oxygen isotope study from veins at about 3 km depth in the Monte Rentella shear zone, Apennines Italy show evidence for cyclic fluid pulses where hot fluids (150°–200 °C) were pumped from depth to flood the fault zone at shallower levels (Meneghini et al., 2012). The few regional studies so far conducted on larger-scale fluid flows within fold and thrust belts indicate there are considerable lateral variations in fluid flow characteristics both in the transport direction between major thrusts (e.g. Lacroix et al., 2014) and along strike (e.g. Fitz-Diaz et al., 2011).

Commonly studies of fluid flow evolution in fold and thrust belts are driven by the need to better predict the subsurface distribution of hydrocarbons in reservoirs whose porosity and permeability are affected by burial, uplift and deformation. Similarly in Thailand the Saraburi Group carbonates, which are the focus of this study, are the main gas reservoirs in the NE of the country. The carbonates have very limited remaining porosity, that locally is enhanced by dolomitization and hydrothermal chertification, fractures are also important to reservoir performance (Booth and Sattayarak, 2011). Hence understanding the fracture, diagenetic and fluid migration history of the reservoirs is necessary for prediction of reservoir properties. The Saraburi–Pak Chong fold and thrust belt area of Central Thailand discussed in this paper can be used as an analogue for understanding the subsurface reservoirs in NE Thailand.

The studies discussed above come from well described, extensively studied fold and thrust belts. The Saraburi–Pak Chong fold and thrust belt is the opposite, no previous detailed structural studies have been conducted on the region. Hence there are many fundamental aspects of the geology that need to be addressed in our studies. The Permian carbonate and siliciclastic deposits of the Saraburi Group are deformed in an E–W trending, predominantly north-verging, fold and thrust belt (Khao Khwang Fold and Thrust belt; Morley et al., 2013). The belt is located some 100 km north of Bangkok city, at the northern edge of the Central Plain of Thailand (Fig. 1A,B). Excellent exposures are present in the area due to quarrying, and building, together with some natural outcrops. Exposed carbonates have undergone a complex burial and uplift history since their deposition in the Permian.

The fold and thrust belt developed mostly during the Triassic–Early Jurassic Indosinian Orogeny (Sone and Metcalfe, 2008; Morley et al., 2013). The complete diagenetic history is affected by events that include burial on a rifted Permian passive margin, folding, thrusting, uplift and erosion during the Triassic, additional burial under 2–3 km of sediment during the Late Triassic–Cretaceous, and subsequent exhumation during Paleogene transpressional deformation and Neogene–Quaternary regional uplift, driven by the distal effects of the Himalayan Orogeny and tectonic events within SE Asia (Figs. 2, 3; Racey, 2009; Morley, 2012; Morley et al., 2013).

The carbonates exposures in quarries show extensive, and highly varied sets of calcite veins, developed in different structures (i.e. folds, thrusts, strike-slip faults), and during various tectonic events. In some quarries the limestones are strongly recrystallized, but in others the earlier stages of carbonate diagenesis (marine cements) appear to be preserved. There is sufficient exposure available to understand both the general trends of the fluid history through time, and the detailed rock-fluid interactions during the Indosinian deformation. The overall focus of this study is to define the fluid/texture-based diagenetic evolution of burial and basinal fluid cements and to place these isotope-based outcomes in a regional framework. Three areas are described, which illustrate different stages in the modification of the initial carbonate

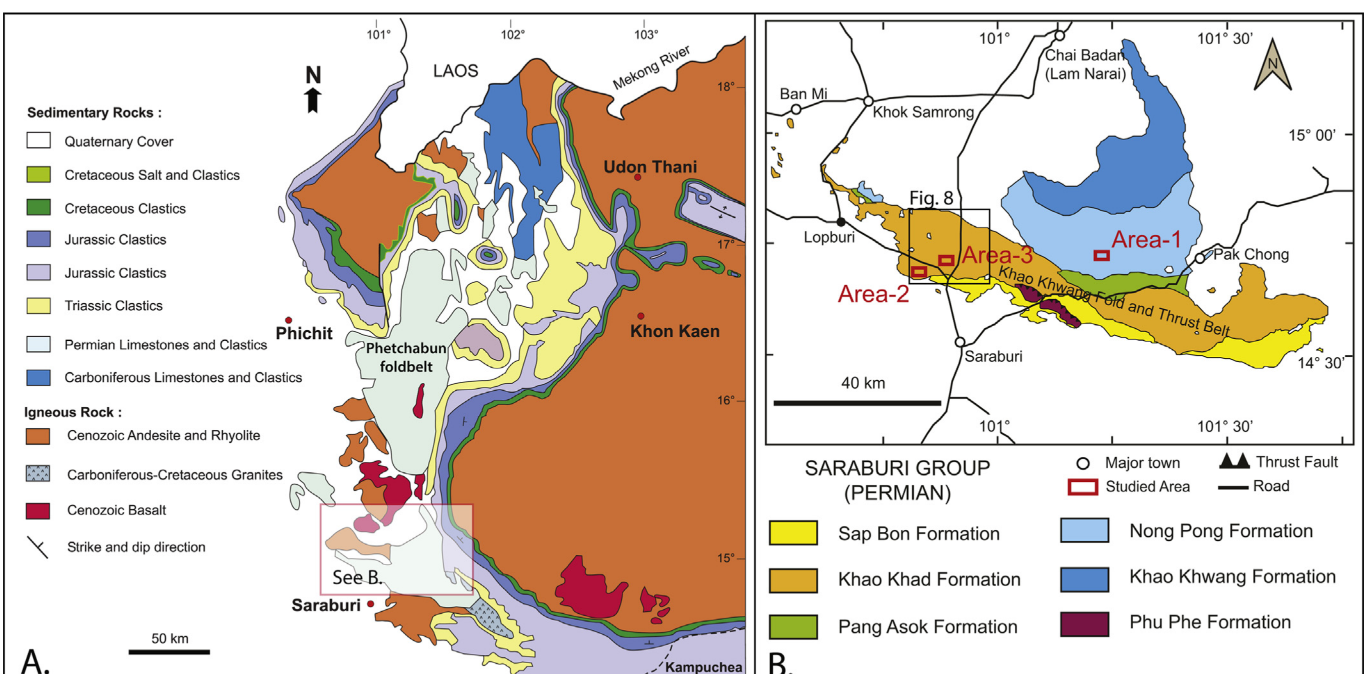

Figure 1. Regional Geology of Thailand. A) General geology of the Saraburi, Kohn Kaen, Udon Thani, Phichit region showing position of Petchabun foldbelt. B) Generalised Permian geology of the Pak Chong – Lopburi – Saraburi region location given by rectangle in Figure 1A. Refer to Figure 3 for study location with respect to Bangkok.