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The Tectonic Evolution of Khao Khwang Fold-Thrust Belt, Central Thailand: new Insights in the Permian and Triassic Evolution of the Indosinian Orogeny in SE Asia

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Abstract

The south-western margin of the Indochina Block and more specifically the Khao Khwang Fold-Thrust Belt (KKFTB) within the Saraburi region in the southern portion of the Loei volcanic belt, holds a pivotal role in the reconstruction of the Permo-Triassic evolution of the Indosinian orogeny in SE Asia. Bound to the east by the Khorat Plateau and to the west by the Nan-Uttardit-Sa Kaeo Suture Zone; the KKFTB offers a breath of information regarding inter-terrane correlations and the Late Palaeozoic –Early Mesozoic tectonic setting on the northern margin of the Palaeo and Meso Tethys. The KKFTB offers a natural and ideal laboratory to work out critical components of the tectonic evolution of SE Asia. However it has not often been deeply considered in the models describing the Palaeozoic and Mesozoic phases of the Indosinian tectonic events. The trend of the regional suture zones between the terranes involved in the Indosinian orogeny, such as the sutures between the Sukhothai and Indochina terranes (*Chiang Rai Tect. Line*, *Nan Suture Zone*), and between the Sukhothai and Sibumasu terranes (*Sa Kaeo Chanthaburi Accretionary complex*), are roughly N-S oriented. Hence, in the last decades it has been widely accepted the interpretation where the Indosinian orogeny developed between strongly linear terranes. However, the effects of the Permian and Triassic tectonic events in Thailand have often been interpreted without considering the detailed tectonic evolution of the portion of the Indochina terrane's margin formed by Khao Khwang Carbonate Platform area of the Saraburi Group, in central Thailand. This area is unusual because: 1) an extensive area representing a thin-skinned fold and thrust belt is well-exposed due to quarrying; and, 2) the fold and thrust belt displays a series of E-W and WNW-ESE striking thrusts and associated folds that are not easily explained in the context of the traditional interpretation where the terranes have been accreted broadly along N-S striking collisional zones. Detailed structural observations in numerous quarries around Highway 21, in a 13 km long dip-direction traverse, revealed that overall the thrust belt is composed of several large thrusts with an approximately northwards transport direction. In the southern part of the area, south-verging structures are present. Although the dominant structural trend is northwards-verging, interference structures, and late strike-slip faults indicate there is more than one phase of structural development present.

Considering the polyphase tectonic history of this zone, we considered that integrating a study of fault and fracture with calcite twin analysis might be useful in order to determine the evolving paleo-stress magnitudes and principle stress directions that developed during the tectonic evolution of this highly deformed, polyphase orogen. The tectonic data from the Permian and Triassic carbonates of the Khao Khad Formation of the Saraburi Group, revealed that five tectonic stages might have developed before, during, and after, the Triassic Indosinian Orogeny. Only the first three stages pre-date the main layer-parallel shortening event. Sone and Metcalfe (2008) modelled a back-arc opening between the Sukhothai volcanic-arc and the Indochina terrane. Hence, we interpreted the first phase of extension as a pre-Indosinian N-S deformation reflecting either pre-Indosinian extension, possibly related to, extension foreland-ward of an evolving contractional orogeny, created due to flexure in the peripheral bulge (Doglioni, 1995; Langhi et al., 2011; Tavani et al., 2015), or Permian supra-subduction zone extension. The second stage yields paleostress tensors of both strike-slip and pure compression, which are consistent with a pre-folding compression. This phase described an event that was largely perpendicular to the fold axes of the main structures, while the third stage is associated with an E-W compressional strike-slip phase. A further two stages took place after, or during, the main folding event and correspond to N-S compression and to an E-W

composite strike-slip/contractional stage, the latter which is interpreted to represent Cenozoic deformation related to the India-Asia collision.

Central Thailand and more specifically the KKFTB has a remarkable record of Palaeozoic and Mesozoic sedimentation preserved in a sequence of well-exposed quarries. These rocks have been traditionally lumped together in several formations forming the Saraburi Group. However, until recently, there has been very little sedimentological data with almost no geochronological study available to investigate the depositional environment and tectonic setting where the sedimentation took place. Until now, very little has been known about the ages of the siliciclastic rocks within the basin on the edge of the Indochina terrane, the provenance of the original sediments and, particularly, the change of provenance through time. Because of this, the existing basin evolution models lack essential constraints and, therefore, the significance of this basin for the tectonic evolution of central Thailand is poorly known. Hence, we performed a coupled U-Pb and Lu-Hf isotopic study on 837 detrital zircons from in-situ sedimentary rocks packages within the KKFTB. These analyses revealed that the detrital age spectra spanning from Upper Triassic to Palaeoarchean. The entire dataset have a common age peak at ca. 450 Ma, and all samples contain zircons with ages between 0.2-0.3, 0.4-0.6, 1.0-1.3, 1.7-1.8, 2.2-2.7 Ga. A few zircons predate 3.0 Ga. Multidimensional-scaling analysis of detrital zircons from throughout SE Asia demonstrate that the detrital zircon age spectra of the siliciclastic units of the Saraburi Group resemble that of Permian-Triassic detritus found elsewhere in the Khorat Plateau and throughout Vietnam and southeast China, implying that these areas share similar sources. These sources may be the, now largely covered, Indochina basement, and/or contiguous continental crust in terranes already amalgamated to Indochina at that time. Detrital zircons as young as 205 ± 6 Ma show that some formations of the Saraburi Group, previously considered being of Middle-Late Permian age, are no older than Late Triassic. Therefore, we propose a depositional model, for the region, of a Permian rift or passive margin setting that evolved into piggy back and foredeep basins during an extended period of folding and thrusting in the Triassic.

The collision between Sukhothai and Indochina is marked by the emplacement of a moderately large igneous and volcanic province on the margin of the Indochina terrane named the Loei volcanic belt. However, the southern portion of the volcanic belt has never been investigated and, here we attempt to bridge this gap of information presenting new geochronological, geochemical and isotopic data. The KKFTB records two different stages of from ca. 250 Ma (Pak Chong granodiorite – east to the KKFTB) to ca. 200 Ma (Khao Yai rhyolite – south of the KKFTB) associated with the collision of the Sukhothai volcanic arc. The mafic dyke swarming in the folded layers of the KKFTB are calc-alkalic in major element compositions, highlighting the possible continental setting. The entire set of mafic dykes can be subdivided in three different volcanic groups; however, all the groups present similar chemical footprints with high LILE and LREE, and low HFSE. This exposes the volcanic arc nature of the Loei volcanic system. Isotopically, the three groups are characterized by subtle differences in εNd(t) values (from 2.94 to 5.16) and initial $^{87}Sr/^{86}Sr$ ratios (from 0.705 ~ 0.706). The high levels of NI, Cr and Mg# along with low levels of SiO_2 suggests high inputs from the mantle during their genesis. However, the volcanism is likely to not represent primary melts, as judged from their MgO (average <6.1%), Mg# (0.29–0.99) and Ni contents (1.5–320 ppm). These characteristics suggest that they most likely underwent a degree of fractional crystallization prior to emplacement. All the rocks from the KKFTB show a distinct trend that straddle from MORB to IAT Ti/V fields. These geochemical features might be representative of a tectonic setting where the arc-affine rocks of the

KKFTB represent the stage of the subduction of the slab (proximal BAB) between Sukhothai and Indochina. During the Late Triassic the volcanic system evolved, possibly after the Indochina-Sukhothai slab break-up, in a more MORB-like magma with higher levels of Ti depletion, represented by the samples within the MORB field.

The complex structural characters, the spread depositional ages of the sedimentary units, the different ages of the deformation and the complex geochemistry of the volcanic rocks within the KKFTB strongly support that this small tectonic domain underwent to a complex and polyphasic tectonic history during the Permian and Triassic stages of the Indosinian orogeny associated with the amalgamation of the actual SE Asia.

“Science, my lad, is made up of mistakes,
but they are mistakes which it is useful to make,
because they lead little by little to the truth.”

-Jules Verne – ***A Journey to the Centre of the Earth***

Journal articles

Arboit, F., Collins, A. S., King, R., Morley, C. K., & Hansberry, R. (2014). Structure of the Sibumasu–Indochina collision, central Thailand: A section through the Khao Khwang Fold and thrust belt. *Journal of Asian Earth Sciences*, *95*, 182-191.

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Arboit, F., Collins, A. S., Morley, C., King, R., Amrouch, K. (2016). Detrital zircon analysis of the southwest Indochina terrane, central Thailand: Unravelling the Indosinian orogeny, *GSA Bulletin*. *In press*.

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