

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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18	Table of Contents
19	Abstract3
20	Journal articles7
21	Statement of Authorship8
22	Declaration18
23	Chapter I19
24	Project Overview
25	Chapter II
26	Thesis Outline23
27	References
28	Chapter III
29 30	Structural of the Sibumasu-Indochina Collision, Central Thailand: A section through the Khao Khwang Fold and Thrust Belt
31	Chapter IV
32 33	Determination of the tectonic evolution from fractures, faults and calcite twins on the south- western margin of the Indochina Block50
34	Chapter V
35	Detrital zircon analysis of the southwest Indochina terrane, central Thailand: Unravelling the
36	Indosinian orogeny
37	Chapter VI
38 39	Geochronological and geochemical study of mafic and intermediate dykes from the Khao Khwang Fold-Thrust Belt: Implications for petrogenesis and tectonic evolution112
40	Chapter VII
41 42	The effect of active margin tectonic on palaeostress magnitudes: Results after calcite twin analysis in central Thailand
43	Conclusions and Perspective
44	Supplementary Data
45	Appendix A
46	Appendix B
47	Appendix C
48	Appendix D217
49	Appendix E
50	

Abstract

52 The south-western margin of the Indochina Block and more specifically the Khao Khwang Fold-Thrust 53 Belt (KKFTB) within the Saraburi region in the southern portion of the Loei volcanic belt, holds a 54 pivotal role in the reconstruction of the Permo-Triassic evolution of the Indosinian orogeny in SE 55 Asia. Bound to the east by the Khorat Plateau and to the west by the Nan-Uttardit-Sa Kaeo Suture 56 Zone; the KKFTB offers a breath of information regarding inter-terrane correlations and the Late 57 Palaeozoic –Early Mesozoic tectonic setting on the northern margin of the Palaeo and Meso Tethys. 58 The KKFTB offers a natural and ideal laboratory to work out critical components of the tectonic 59 evolution of SE Asia. However it has not often been deeply considered in the models describing the 60 Palaeozoic and Mesozoic phases of the Indosinian tectonic events. The trend of the regional suture 61 zones between the terranes involved in the Indosinian orogeny, such as the sutures between the 62 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 63 64 oriented. Hence, in the last decades it has been widely accepted the interpretation where the 65 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 66 67 detailed tectonic evolution of the portion of the Indochina terrane's margin formed by Khao Khwang 68 Carbonate Platform area of the Saraburi Group, in central Thailand. This area is unusual because: 1) 69 an extensive area representing a thin-skinned fold and thrust belt is well-exposed due to quarrying; 70 and, 2) the fold and thrust belt displays a series of E-W and WNW-ESE striking thrusts and associated 71 folds that are not easily explained in the context of the traditional interpretation where the terranes 72 have been accreted broadly along N-S striking collisional zones. Detailed structural observations in 73 numerous quarries around Highway 21, in a 13 km long dip-direction traverse, revealed that overall 74 the thrust belt is composed of several large thrusts with an approximately northwards transport 75 direction. In the southern part of the area, south-verging structures are present. Although the 76 dominant structural trend is northwards-verging, interference structures, and late strike-slip faults 77 indicate there is more than one phase of structural development present.

78 Considering the polyphase tectonic history of this zone, we considered that integrating a study of 79 fault and fracture with calcite twin analysis might be useful in order to determine the evolving paleo-80 stress magnitudes and principle stress directions that developed during the tectonic evolution of this 81 highly deformed, polyphase orogen. The tectonic data from the Permian and Triassic carbonates of 82 the Khao Khad Formation of the Saraburi Group, revealed that five tectonic stages might have 83 developed before, during, and after, the Triassic Indosinian Orogeny. Only the first three stages pre-84 date the main layer-parallel shortening event. Sone and Metcalfe (2008) modelled a back-arc 85 opening between the Sukhothai volcanic-arc and the Indochina terrane. Hence, we interpreted the 86 first phase of extension as a pre-Indosinian N-S deformation reflecting either pre-Indosinian 87 extension, possibly related to, extension foreland-ward of an evolving contractional orogeny, 88 created due to flexure in the peripheral bulge (Doglioni, 1995; Langhi et al., 2011; Tavani et al., 89 2015), or Permian supra-subduction zone extension. The second stage yields paleostress tensors of 90 both strike-slip and pure compression, which are consistent with a pre-folding compression. This 91 phase described an event that was largely perpendicular to the fold axes of the main structures, 92 while the third stage is associated with an E-W compressional strike-slip phase. A further two stages 93 took place after, or during, the main folding event and correspond to N-S compression and to an E-W 94 composite strike-slip/contractional stage, the latter which is interpreted to represent Cenozoic95 deformation related to the India-Asia collision.

96 Central Thailand and more specifically the KKFTB has a remarkable record of Palaeozoic and 97 Mesozoic sedimentation preserved in a sequence of well-exposed quarries. These rocks have been 98 traditionally lumped together in several formations forming the Saraburi Group. However, until 99 recently, there has been very little sedimentological data with almost no geochronological study 100 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 101 102 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 103 104 models lack essential constraints and, therefore, the significance of this basin for the tectonic 105 evolution of central Thailand is poorly known. Hence, we performed a coupled U-Pb and Lu-Hf 106 isotopic study on 837 detrital zircons from in-situ sedimentary rocks packages within the KKFTB. 107 These analyses revealed that the detrital age spectra spanning from Upper Triassic to 108 Palaeoarchean. The entire dataset have a common age peak at ca. 450 Ma, and all samples contain 109 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. 110 Multidimensional-scaling analysis of detrital zircons from throughout SE Asia demonstrate that the 111 detrital zircon age spectra of the siliciclastic units of the Saraburi Group resemble that of Permian-112 Triassic detritus found elsewhere in the Khorat Plateau and throughout Vietnam and southeast 113 China, implying that these areas share similar sources. These sources may be the, now largely 114 covered, Indochina basement, and/or contiguous continental crust in terranes already amalgamated 115 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 116 117 Triassic. Therefore, we propose a depositional model, for the region, of a Permian rift or passive 118 margin setting that evolved into piggy back and foredeep basins during an extended period of 119 folding and thrusting in the Triassic.

120 The collision between Sukhothai and Indochina is marked by the emplacement of a moderately large 121 igneous and volcanic province on the margin of the Indochina terrane named the Loei volcanic belt. 122 However, the southern portion of the volcanic belt has never been investigated and, here we 123 attempt to bridge this gap of information presenting new geochronological, geochemical and 124 isotopic data. The KKFTB records two different stages of from ca. 250 Ma (Pak Chong granodiorite -125 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 126 127 calc-alkalic in major element compositions, highlighting the possible continental setting. The entire 128 set of mafic dykes can be subdivided in three different volcanic groups; however, all the groups 129 present similar chemical footprints with high LILE and LREE, and low HFSE. This exposes the volcanic 130 arc nature of the Loei volcanic system. Isotopically, the three groups are characterized by subtle differences in ϵ Nd(t) values (from 2.94 to 5.16) and initial 87 Sr/ 86 Sr ratios (from 0.705 ~ 0.706). The 131 132 high levels of NI, Cr and Mg# along with low levels of SiO_2 suggests high inputs from the mantle 133 during their genesis. However, the volcanism is likely to not represent primary melts, as judged from 134 their MgO (average <6.1%), Mg# (0.29–0.99) and Ni contents (1.5–320 ppm). These characteristics 135 suggest that they most likely underwent a degree of fractional crystallization prior to emplacement. 136 All the rocks from the KKFTB show a distinct trend that straddle from MORB to IAT Ti/V fields. These 137 geochemical features might be representative of a tectonic setting where the arc-affine rocks of the 138 KKFTB represent the stage of the subduction of the slab (proximal BAB) between Sukhothai and
139 Indochina. During the Late Triassic the volcanic system evolved, possibly after the Indochina140 Sukhothai slab break-up, in a more MORB-like magma with higher levels of Ti depletion, represented
141 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.

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155	"Science, my lad, is made up of mistakes,
156	but they are mistakes which it is useful to make,
157	because they lead little by little to the truth."
158	
159	-Jules Verne – A Journey to the Centre of the Earth

161	Journal articles
162	Arboit, F., Collins, A. S., King, R., Morley, C. K., & Hansberry, R. (2014). Structure of the
163	Sibumasu-Indochina collision, central Thailand: A section through the Khao Khwang Fold and
164	thrust belt. Journal of Asian Earth Sciences, 95, 182-191.
165	Arboit, F., Amrouch, K., Collins, A. S., King, R., & Morley, C. (2015). Determination of the tectonic
166	evolution from fractures, faults and calcite twins on the south-western margin of the Indochina
167	Block. <i>Tectonics</i> . 34 , 1576-1599.
168	Arboit, F., Collins, A. S., Morley, C., King, R., Amrouch, K. (2016). Detrital zircon analysis of the
169	southwest Indochina terrane, central Thailand: Unravelling the Indosinian orogeny, GSA Bulletin.
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171	Arboit, F., Collins, A. S., Morley, C., King, R., Amrouch, K. (2016). Geochronological and
172	geochemical study of mafic dykes from the Khao Khwang Fold-Thrust Belt: Implications for
173	petrogenesis and tectonic evolution. Gondwana Research. Submitted.
174	Arboit, F., Amrouch, K., Morley, C., Collins, A. S., & King, R. (2016). The effect of active margin
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Signature		Date	15/01/2016

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233	Declaration
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281 **Project Overview**

282 Aesthetically appealing thrust systems and related large-scale anticlines, in both active and fossil 283 foreland fold- thrust belts, and the economic potential associated with them, have captured the 284 interest of structural geologists for many decades. Further, fold-thrust belts are geological 285 archives able to record the most useful information for reconstructing their geodynamic 286 evolution. Here we try to provide a review of the deformation pattern templates from field data 287 within the foreland Khao Khwang Fold-and-Thrust-Belt (KKFTB), with data that aim to show how 288 the KKFTB holds fundamental information necessary to reconstruct the geodynamic evolution on 289 the southwestern margin of the Indochina terrane.

290 This fold and thrust belt is one of the key area for better understanding the various 291 deformational stages of the Indosinian orogeny in central Thailand. The KKFTB was formed 292 during the early phases of the Indosinian event, on the onset of the collision between the 293 Indochina terrane and the Sukhothai volcanic arc (Sone and Metcalfe, 2008). The KKFTB lies on 294 the south-western margin of the Indochina Block and exposes an area of ± 2900 km² of east-295 west trending, polydeformed and slightly metamorphosed Permian and Triassic rocks. The 296 KKFTB is bounded to the east by the Khorat Plateau and to the west by the Nan Suture Zone. 297 Recent studies revealed the extremely complex tectonic framework of the KKFTB and that the 298 large portions of this deformed belt have experienced different stages of deformation and low-299 pressure regional metamorphism (Morley et al., 2013).

300 The Indosinian orogenic belt, within central SE Asia, is characterized by various subduction and 301 collision-related events that span the period from around 260 Ma to 190 Ma (see reviews in 302 Lepvrier et al., 2004; Sone and Metcalfe, 2008 and Barber et al., 2011). In Thailand, the tectonic 303 belts trend predominantly N-S, including the back-arc suture zone (Nan-Uttardit-Sa Kaeo) and 304 the Palaeo-Tethyean sutures (Inthanon Zone). It is commonly accepted that the Nan-Uttardit-Sa 305 Kaeo Suture Zone is related to the closure of the back-arc basin and collision of the volcanic-arc 306 dominated Sukhothai zone with Indochina during the Early to Middle Triassic, and a later 307 collision occurred between the combined Sukhothai-Indochina block with Sibumasu as Palaeo-308 Tethys closed during the Late Triassic-Early Jurassic, (e.g. Fontaine and Workman, 1978; Hahn, 309 1984; Sone and Metcalfe, 2008; Booth and Sattayarak, 2011; Barber et al., 2011). However, the 310 position of these suture zones is cryptic in several areas and working out the timing of their 311 closure has previously proved elusive. The key to unravelling the evolution of central Thailand, 312 and the tectonic architecture of the south-western margin of Indochina lies in the exposed 313 sedimentary and volcanic rocks of the Saraburi Group within the KKFTB. Mixed carbonate-314 siliciclastic Permian to Triassic rocks on the eastern side of the lower Chao Phraya Central Plain 315 from Nakhon Sawan to the Saraburi Province, and on the western margin of the Khorat Plateau 316 from Loei to Chaiyaphum/Phetchabun provinces belong to the Saraburi Group. Bunopas (1981) 317 was the first to propose a separate Indochina Block stratigraphic division (Saraburi Group) for 318 the units in the Saraburi-Pak Chong area. Later Hinthong (1985) and Hinthong et al. (1985) 319 revised the stratigraphy within the KKFTB subdividing the Group in six main formations, namely 320 the: Phu Phe, Khao Khwang, Nong Pong, Pang Asok, Khao Khad, and Sap Bon formations. 321 Originally these formations were thought to constitute a simple upward succession; however, 322 biostratigraphical, structural, and geochronological analyses now show that the extension of the 323 Saraburi Group is not limited to the Permian but gets to the Late Triassic (Norian-Rhaetian) and324 few of the formations are synchronous.

325 Studies of the sedimentology of the Saraburi Group started only in the last decades, and include 326 those by Pendexter (1980), Dawson (1993), Dawson and Racey (1993), Dawson et al. (1993), 327 Charoentitirat (2002), and Udchachon et al. (2007, 2008). The presence of folds and faults within 328 the Saraburi Group was observed for the first time by Dawson and Racey (1993). However, in 329 one of the latest regional geological maps (Ueno and Charoentitirat, 2011) the Phu Phe 330 Formation is the only formation that is shown as being overthrust onto the Khao Khad and Sap 331 Bon formations. Detailed sedimentological and structural analyses of the KKFTB are yet to be 332 established. The known geological architecture shows in the southern portion of the KKFTB more 333 than one carbonate platforms stepping laterally into clastic-dominated depositional 334 environments. Seismic reflection data on the Khorat Plateau show a series of coeval basins, 335 which are E-W striking rift-related Permian basins, controlled by extensional faults, and that carbonates tend to occupy the high, intra-basinal areas, while clastics or mixed clastics and 336 337 carbonates fill the basins (Booth and Sattayarak, 2011).

338 Therefore, it is of fundamental importance to take in account the pivotal role of the KKFTB in 339 order to constraining the compressional events affecting the Sukhothai and Indochina terranes 340 and shed light on the tectonic evolution of the Triassic Indosinian Orogeny in central Thailand. 341 Here we report a sequence of structural, geomechanical, geochronological, isotopic, and 342 geochemical analyses on the tectonic structures, and sedimentary and volcanic rocks of the 343 KKFTB. All the newly discovered data provide an overview on the tectonic framework, 344 Phanerozoic evolution, and palaeogeography of SE Asia, focusing on the tectonic, structural, 345 geochronological, isotopic and geochemical aspects of the rocks lying on the south-western 346 margin of the Indochina Block. Particular emphasis has been placed on the geodynamic 347 evolution of the KKFTB and its importance in reconstructing the evolution of the Indosinian 348 Orogeny during the Permian and Triassic in SE Asia.

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 363 364 365 366 367 368 369 370 	Chapter II	
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375 Thesis Outline

The thesis aims to bring new information on the evolution of the Indosinian orogeny using several methodologies on the rocks and the structures of the KKFTB.

378 Chapter 3- In the last decades the effects of the Indosinian orogeny in Thailand have often been 379 interpreted without considering a detailed structural analysis of the south-western margin of the 380 Indochina Block and the Loei Volcanic Belt in central Thailand. The lack of structural data from 381 central Thailand prompted some reconstruction models to interpret the south-western margin 382 of the Indochina Block as the highly linear boundary of an accretionary complex associated to 383 the closure of the Permian back-arc basin between the Sukhothai and Indochina terranes. 384 Therefore, detailed field-based structural analyses were performed through a sequence of scan-385 areas, scan-lines and geological mapping throughout the best exposed sedimentary sequences 386 of the Saraburi Groups. More than 800 structural features were collected within the Sap Bon, 387 Khao Khad and Nong Pong formations. From south to north several litho-tectonic features were 388 recognised:

- Permian to Triassic volcanic and sedimentary rocks lying east to the cryptic Nan-Uttardit Sa Kaeo Suture Zone;
- the informal unit "alum shale" (Morley et al., 2013) is the only portion within the KKFTB
 that shows folded volcanic units; which suggests the record of Permian stages of the
 early deformation;
- the fold and thrust belt formed by forward (north) propagating deformation in the
 Triassic, consists only of cover strata and has been displaced mainly along weak horizons
 of incompetent shale within the Khao Khad Formation, transported by numerous in sequence thrusts;
- The Khao Khwang represents a thin-skinned fold and thrust belt developed on a detachment that lies between 0.7 and 1.5 kilometres depth which is similar to the stratigraphic thickness of the Khao Khad Formation (Dawson and Racey, 1993; Thambunya et al., 2007, Ueno and Charoentitirat, 2011);
- The in-sequence thin-skinned deformation demonstrates that deformation has migrated
 from S-SSE to N-NNW along a zone as wide as the fold and thrust belt itself, with lateral
 variations probably attributed to lateral facies variations;
- Evidence of lateral structural variations occur along the strike of the fold and thrust belt
 in zones of mechanical weakness in the shale levels, these different rates of strain
 accommodation are probably related to oblique-lateral ramps between thrusts;
- The imbricated thrusts generally cut the forelimbs of folds in the limestone of the Khao
 Khad Formation, suggesting a model where some imbricates were formed during the
 folding, whilst folding continued in the surrounding shales with the development of
 some minor amplitude buckle folding associated with detachment levels.

412 All these data revealed that the KKFTB represents a significant kink in the collision between 413 Sibumasu and Indochina, which may be due to either the original geometry of the Indochina 414 margin, or due to a poorly recognised ocean strand that split Indochina into two or more. 415 Although the dominant structural trend is northwards-verging, interference structures, and late 416 strike-slip faults indicate there is more than one phase of structural development present, with 417 an estimated amount of shortening that affected the KKFTB of \pm 10/15 km.

418 Chapter 4- The structural analyses on the architecture of the large scale deformation revealed 419 the polyphase evolution of the palaeostress that affected the KKFTB from the Permian to the 420 Cainozoic. This composite structural framework is attributed to the complex continental 421 amalgamation that led to the actual SE Asia during the Permian and Triassic stages of the 422 Indosinian orogeny. Therefore, in order to characterize and compare the stress-strain record 423 prior to, during, and just after folding at the macroscopic and the microscopic scales and to 424 provide insights into stress levels sustained by folded rocks; we investigate the relationship 425 between the stress-strain distribution in folded strata derived from fractures, striated micro-426 faults, and calcite twins and the development of the KKFTB. We here focused on the description 427 of the internal deformation of folded strata and characterization of the controlling mechanisms 428 at the microscopic scale, and the mechanical response of rocks during folding and the 429 distribution of strain within the folds. We decided to investigate the stress record through the 430 tectonic phases of the Indosinian orogeny at both microscopic and mesoscopic scales, through a study on the striated micro-faults and calcite twins. Widespread mechanical e-twinning occur in 431 432 the calcite crystals within the carbonate Khao Khad Formation in the southern portion of the 433 KKFTB. One of the advantages of this technique is that the e-twinning requires a low critical 434 resolved shear stress (RSS) (10 ± 4 MPa), which depends on grain size (e.g., Rowe and Rutter, 435 1990) and internal twinning strain (Turner et al., 1954; Laurent et al., 2000; Lacombe, 2001, 2007), and has only a small sensitivity to temperature, strain rate and confining pressure, 436 437 therefore considering the possible slight regional metamorphism that have affected central 438 Thailand during the Indosinian orogeny it is possibly the best tool to evaluate the palaeostress 439 history.

440 The inversion process takes into account both the twinned and the untwinned planes, the latter 441 being those of the potential e-twinning planes that never experienced a RSS of sufficient 442 magnitude to cause twinning. The inverse problem consists in finding the stress tensor that best 443 fits the distribution of twinned and untwinned planes. The basic hypothesis is that the RSS τ_s 444 acting on any twinned e plane is higher than, or at least equal to the critical RSS τ_a .

445 Thus, for twinned planes: $\tau_s \ge \tau_a$ and for untwinned planes: $\tau_s < \tau_a$. The Etchecopar's CSIT allows 446 simultaneous computation of principal stress orientations and differential stresses. The tensor 447 solution is calculated as a normalized reduced stress tensor such as ($\sigma 1 - \sigma 3$) is scaled to [($\sigma 1 - \sigma 3$) 448 σ 3)*=1]. Thus, the value of the RSS τ_s acting on any plane lies between -0.5 and +0.5, that is, -(σ 1 449 - σ 3)*/2 and + (σ 1 - σ 3)*/2 (Jamison and Spang, 1976). Theoretically, all the twinned planes 450 consistent with a given tensor must sustain a τ_s value larger than the one exerted on any 451 untwinned plane. The best tensor solution is searched as to minimize the function f, ideally 452 equal to 0.

453 The optimal tensor is obtained when (I) the maximum of twinned planes are taken into account; 454 (II) the maximum of untwinned planes are taken into account; and (III) the f value is minimal (in 455 practice, one can authorize a weak percentage, 10%–15%, of untwinned planes receiving a RSS 456 larger than the smallest applied τ_a because of measurement uncertainties and local 457 heterogeneities at the grain scale). This process drives through the determination of the orientation of the three principal stresses, we hence used the conjoined analysis of fractures, faults and calcite twins to analyse the paleostresses (both magnitudes and principle stress directions) that affected the area during the Indosinian orogeny from the Permian onward. This multi-methodological study revealed the five tectonic stages that were interpreted to have developed before, during, and after, the Indosinian Orogeny.

Chapter 5- This chapter focuses on characterizing the provenance of the siliciclastic rocks 464 throughout the KKFTB. The study utilises LA-ICPMS U-Pb zircon geochronology and 465 466 multicollector LA-ICPMS Lu-Hf isotopes in zircons to better constraints the provenance, with a 467 particular emphasis placed on the potential source rocks in the adjoining blocks in SE Asia during 468 the Permian and Triassic. The relevance of the information that might come from the 469 stratigraphic control of the Permian and Triassic clastic formations in SE Asia was exposed in the 470 last decades (Bodet and Schärer, 2000; Carter and Bristow, 2003; Carter and Clift, 2008; Li et al., 471 2012; Burrett et al., 2013). The majority of the exposed areas within the KKFTB present rocks of 472 the Permian carbonate and clastic formations of the Saraburi Group, unfortunately no 473 stratigraphic control have ever been applied on the siliciclastic formations such as the Sap Bon, 474 Pang Asok and Nong Pong formations. The clastic formations of the Saraburi Group were used to 475 provide a control on the timing and tectonic setting of the Indosinian orogeny during the 476 Permian and the Triassic. The poor stratigraphic geochronological and provenance constraints 477 left a gap full of uncertainties on the tectonic setting of SE Asia and more specifically on the 478 tectonic framework of Central Thailand during the Triassic. Therefore, a deep geochronological 479 provenance investigation provided a higher level of constrain on the provenance, maximum 480 depositional ages and depositional environment of the south-western margin of the Indochina 481 terrane through the Late Palaeozoic to Early Mesozoic. The analyses revealed detrital age 482 spectra spanning from Upper Triassic to Palaeoarchean. However, there is a loose control on the 483 sedimentary supply and the possible palaeogeography of central Thailand in the Triassic. 484 Therefore, a more robust statistical approach (Multidimensional-scaling) based on the K-S 485 statistic was considered necessary to individuate the possible sedimentary sources (Vermeesh, 486 2013). This study demonstrates that the KKFTB was not experiencing uniform deposition 487 throughout the entire area, and that the detrital zircon age spectra of the siliciclastic units of the 488 Saraburi Group resemble that of Permian-Triassic detritus found NE from the southwestern 489 margin of the Khorat Plateau to the southern margin of the South China Block. New data on the 490 maximum depositional ages of the clastic formations lying within the KKFTB drastically changed 491 the depositional history of the Saraburi Group, which was previously considered extending till 492 the Middle-Late Permian age, and now are no older than Late Triassic.

493 Chapter 6- This chapter investigates the significance of the volcanic rocks that intruded the 494 KKFTB through geochemical and isotopic analyses. The geochemistry of the KKFTB volcanic suite 495 has never been investigated; however, a common conception extends the Loei volcanic belt to 496 the southern portion of the KKFTB. This chapter integrates all the newly acquired zircon U–Pb age data, mica ⁴⁰Ar/³⁹Ar ages, and whole rock isotopic and geochemical analyses in order to: (I) 497 498 characterise the magmatic pulses, and their relevance to the current tectonic models; (II) for 499 better constraining the timing of the Sukhothai-Indochina & Sibumasu-Indochina collisions 500 during the Permo-Triassic stages of the Indosianian orogeny. It is shown that the entire set of 501 mafic dykes can be subdivided in three different volcanic groups on the basis of trace and

502 incompatible element abundances. However, a similar geochemical imprinting is shown with 503 high LILE - LREE, and low in HFSE, highlighting the volcanic arc nature of the system. These 504 geochemical features suggest that the KKFTB mafic dykes and the volcanic rocks in central-505 northern Thailand were likely crystallized in different times and orogenic settings.

506 **Chapter 7**- The concept of stress is of primary importance when dealing with the mechanics of materials. Although the validity of applying concepts of continuum mechanics to natural rock 507 508 masses that are neither continuous nor purely solid may be questioned, in practice the 509 idealisation of reality by the definition of an equivalent continuum has proved very powerful for 510 many mechanical purposes (Lacombe, 2009). There are several reasons for portraying the distribution of stresses in the crust such as geological hazards, engineering activities and 511 512 resource exploration, but also from fundamental geological purposes, such as understanding the 513 mechanical behaviour of geological materials and deciphering the various tectonic mechanisms that led to the investigated structure, from those related to plate motions at a large scale to 514 515 those causing jointing and faulting or even microstructures at a smaller scale. Therefore, in this 516 chapter we tried to integrate geomechanic and microstructural data and hence to deal with the 517 reconstruction of intraplate paleostresses magnitudes.

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Chapter III

572	Arboit, F., Collins, A. S., King, R., Morley, C. K., & Hansberry, R. (2014). Structure of the
573	Sibumasu–Indochina collision, central Thailand: A section through the Khao Khwang Fold and
574	thrust belt. Journal of Asian Earth Sciences, 95, 182-191.
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586 Structural of the Sibumasu-Indochina Collision, Central Thailand: A section 587 through the Khao Khwang Fold and Thrust Belt.

588 ABSTRACT

589 Mainland SE Asia is composed of a number of continental fragments and volcanic arcs, 590 separated by oceanic suture zones, that were accreted to the growing Asian continent during 591 the Triassic Indosinian orogeny. The evolution of this orogeny has always been quite 592 controversial. Indeed, the effects of this orogeny in Thailand have often been interpreted 593 without considering the detailed tectonic evolution of the portion of the Indochina Block's 594 margin formed by Khao Khwang Platform area of the Saraburi group, in central Thailand. This 595 area is unusual because: 1) an extensive area representing a thin-skinned fold and thrust belt is 596 well-exposed due to quarrying and 2) the fold and thrust belt displays a series of E-W and WNW-597 ESE striking thrusts and associated folds that are not easily explained in the context of the 598 traditional interpretation where the terranes have been accreted broadly along N-S striking 599 collisional zones. Detailed structural observations in numerous quarries around Highway 21 in a 600 13 km long dip-direction traverse have revealed that overall the thrust belt is composed of 601 several large thrusts with an approximately northwards transport direction. In the southern part 602 of the area south-verging structures are present. Although the dominant structural trend is 603 northwards-verging, interference structures, and late strike-slip faults indicate there is more 604 than one phase of structural development present.

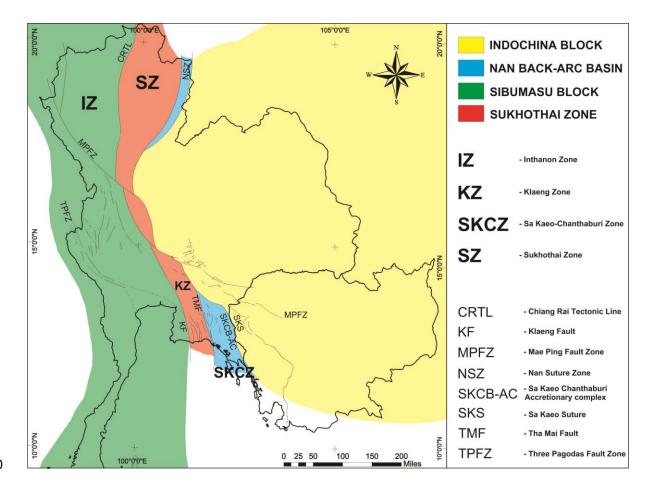
605 **1. Introduction**

Fold and thrust belts are widely studied in the 606 607 geologic record because they are both the 608 most common way the upper crust 609 accommodates shortening and for having a 610 worldwide distribution (Cunningham and 611 Mann, 2007). The interest in this type of 612 structural system goes beyond pure scientific 613 curiosity. The study of fold and thrust belts is 614 essential in developing а complete 615 understanding of the evolution of an orogenic 616 belt. In addition, they commonly trap 617 hydrocarbons, and form major exploration 618 targets (Poblet et al., 2011; Cooper, 1986).

Mainland Southeast Asia is the key area for 619 620 understanding the Permo-Triassic Indosinian 621 orogeny (Fontaine and Workman, 1978, 622 Metcalfe, 2002, 2005, 2011). An orogeny that, 623 in the present use of term, encompasses Late 624 Palaeozoic to Early Mesozoic orogenesis in places as diverse as Korea (Cluzel et al., 1991; 625 626 Metcalfe, 2006), central China (Li et al., 2006),

627 and throughout South-East Asia (Metcalfe 628 2013; Morley et al., 2013). Exposed parts of 629 the orogeny are also key locations to use as 630 analogues to assist in understanding sub-631 surface tracts of Permian-Triassic fold and 632 thrust belts, the main target for hydrocarbon 633 exploitation in northeast Thailand.

634 The case study presented here comes from 635 the Khao Khwang Fold-and-Thrust Belt of 636 central Thailand. This fold and thrust belt lies 637 on the southern edge of the Indochina block 638 (Morley, 2013). Between its Devonian 639 separation from Gondwana, and its Triassic 640 collision with Sibumasu, the Indochina Block 641 records deposition/formation of carbonates, 642 clastic sedimentary rocks, chert and basalt of 643 the Late Carboniferous to Permian Saraburi 644 Group (Hinthong, 1985), in both neritic and 645 pelagic environments (Metcalfe, 1999, 2006; 646 Ferrari et al., 2008, Ueno and Charoentitirat, 647 2011). Among the previously published platetectonic models, the Indosinian orogeny had 648 649 two peaks of activity that have been defined



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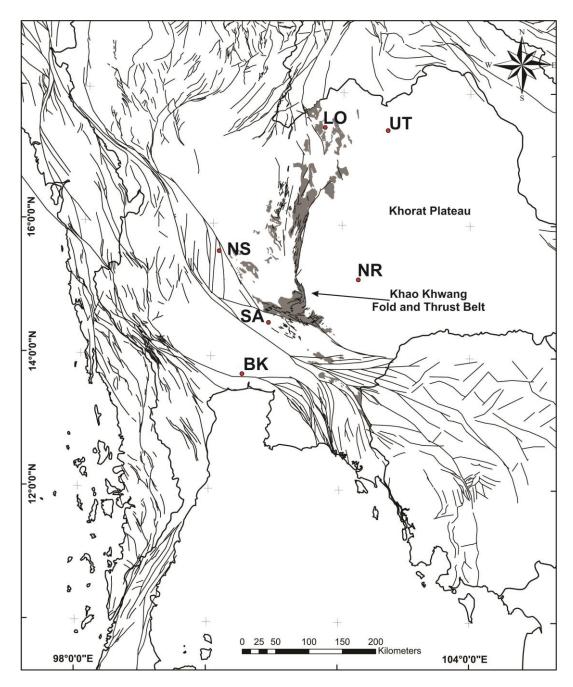
Fig. 1. Geotectonic subdivision of Thailand into main tectonic areas collided during the Indosinian Orogeny (modified fromUeno and Charoentitirat, 2011) and distribution of the major lineaments of the study area.

653 in Thailand as an early stage developed 654 between the Lopingian – Carnian and the late 655 stage during the latest Triassic (Helmcke and 656 Lindenberg, 1983; Sone and Metcalfe, 2008; Morley et al., 2013). The aim of this paper is 657 to analyse and reconstruct the structural 658 659 framework of the Triassic KKF&T Belt in this 660 southern strand of the Indosinian orogen. This 661 reconstruction is based on the analysis of the contractional structures developed in the 662 carbonate rocks of the Khao Khad Formation 663 664 (Saraburi Group) and their interpretation in a 665 regional cross section through the Saraburi region. This cross section is a powerful tool 666 that allows us to (1) define more precisely the 667 668 main architectural elements such as faults, 669 the linkage between low-angle and high-angle reverse faults, propagation mechanisms and 670 associated folding styles and their distribution 671

672 across the KKF&T Belt, (2) propose a
673 kinematic model for the Triassic geodynamic
674 evolution of the south-western margin of the
675 Indochina Block.

676 2. Tectonic Framework of Thailand

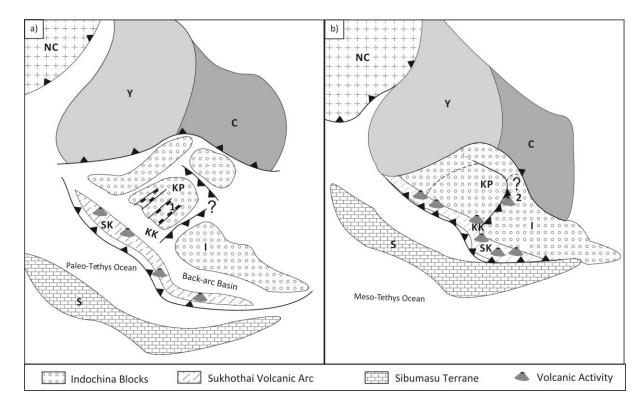
677 Bunopas (1981) was the first person to 678 introduce the plate tectonic concept for the 679 geological evolution of Southeast Asia. Later 680 workers have revealed that the region is made 681 up of a composite puzzle of terranes derived 682 from Gondwana during the Palaeozoic (Devonian - Permian) (Metcalfe, 1988, 1990, 683 684 1991, 1998, 2002, 2005, 2011; Lepvrier, 1994; 685 Morley et al., 2002, 2013). Numerous models 686 have been proposed to unravel the 687 geotectonic evolution across the countries of 688 SE Asia (Metcalfe, 1988, 1990, 2002, 2011;



690 Fig. 2. Map with major lineaments (after Morley et al., 2013) at a regional scale (solid lines), based on Landsat 7 satellite 691 imagery analysis, and distribution of Permian rock in Thailand (grey areas), based on the geological map of Thailand (from 692 DMR, 1999). NR = Nakhon Ratchasima, BK = Bangkok, SA = Saraburi, NS = Nakhon Sawan, PH = Phetchabun, LO = Loei, UT = 693 Udon Thani.

694 695 and Metcalfe, 2008; Ferrari et al., 2008, Ridd 703 Sa Kaeo Chantarburi Accretionary Complex) et al., 2012, Zaw et al., 2013, Burrett et al., 704 (Metcalfe, 2005; Ueno and Charoentitirat, 696 697 2013). Thailand and Malaysia, have often 705 2011; Sone and Metcalfe 2008) (Figure 1), 698 been depicted as two major continental 706 which isolates a domain of central Thailand, 699 masses—Sibumasu and collided 700 during Triassic. the 701 reconstructions have also recognised the Nan 709 previously interpreted as the site of closure of

Ueno, 1999, 2002; Charusiri et al., 2002, Sone 702 Suture Zone (and its southern expression the Indochina-that 707 known as the Sukhothai Arc (Sone and Recent 708 Metcalfe, 2008). The Nan Suture Zone was



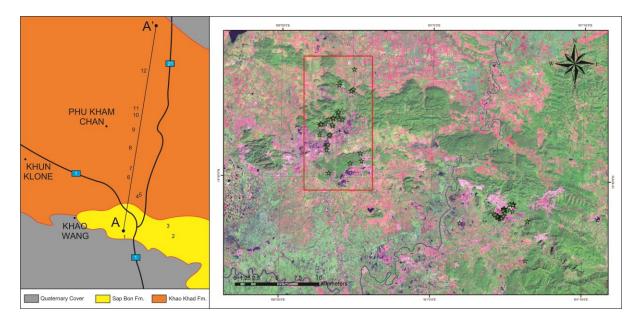
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711 Fig. 3. Map view reconstruction of the plate tectonic evolution of the SE Asia during Early Triassic (A) and Middle Triassic 712 (B). Modified from Morley et al. (2013) and Lepvrier et al. (2004). NC = North China, Y = Yangtze Block, C = Cathaysian 713 Block, I = Indochina Block, KP = Khorat Plateau, KK = Khao Khwang carbonate platform, SK = Sukhothai Terrane, 1 = rift 714 related Permian Basin in the Khorat Plateau, 2 = possible minor suture zone running on edge of the Khorat Plateau.

715 the Palaeo-Tethys Ocean, which, during the 735 Klaeng sutures (Metcalfe, 1999, 2005, 2006; 716 Palaeozoic (Middle Devonian – Early Triassic), 717 spanned the area between the Indochina 718 Block (Cathaysian domain) and the 719 Gondwana-derived Sibumasu Block (Ueno and 720 Hisada, 2001; Ueno et al., 2012, Metcalfe, 2005, 2006, 2011, 2013). Ueno (1999), and 721 successively, Ueno and Hisada (2001) and 722 723 Sone and Metcalfe (2008), used stratigraphic 724 and biostratigraphic evidence to suggest that 725 this suture zone more likely represents the 726 closure of a Late Devonian Late Permian backarc basin related to an extensional regime 727 728 between Indochina to the east and the 729 Permian Sukhothai terrane, to the west (Barr 730 and Macdonald, 1991; Metcalfe, 2006, 2011, 2013; Sone and Metcalfe 2008; Yang et al. 731 732 2009; Barber and Charusiri, 2011). Sibumasu 733 lies to the west of the Sukhothai terrane, and 734 is separated from it by the Chiang Rai and

736 Ueno and Hisada, 1999, 2001; Sone and Metcalfe, 2008) (Figure 1). The Chiang Rai and 737 738 Klaeng sutures are interpreted as being the 739 site of the closure of a second strand of the 740 Palaeo-Tethyan Ocean (Late Triassic - Early 741 Jurassic) (Ferrari et al., 2008; Sone and 742 Metcalfe, 2008; Barber et al., 2011, Metcalfe, 743 2011).

744 Structurally, two sets of major lineaments are 745 seen in north/central Thailand; N-S and NW-746 SE (Figure 2). The N-S trend corresponds to 747 the overall E-W (present coordinates) collision 748 proposed by most workers for the collision of 749 both Sukhothai/Indochina and 750 Sibumasu/Sukhothai (Metcalfe, 1998, 2000, 751 2005, 2011; Sone and Metcalfe, 2008; Ridd, 752 2012), as well as the trends of Cenozoic extensional faults, and some local trends of 753 754 Cenozoic strike-slip faults. The NW-SE trend is



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756 Fig. 4. GPS stops superimposed atop of Landsat 7 satellite images (bands 8-4-2). Geological map of the study area (DMR, 757 1999); 1-2-3 quarries in the southern portion of the cross-section, 4-5 quarries on ridge one, 6 quarry on ridge two, 7 758 quarry on ridge three, 8-9-10-11 quarries on ridge 4, 12 quarry on ridge 6. A-A' length of the cross-section. 1-21 national 759 Thai Highways.

760 seen throughout eastern Myanmar and 784 we use the classification proposed by Ueno 761 western Thailand and could correspond to an 785 extensive network of Cenozoic strike-slip 762 763 faults (Morley et al., 2007), related to Cenozoic continental deformation after the 764 India – Eurasia collision (Tapponnier et al., 765 766 1986). The strike-slip faults commonly combine NW-SE, NNW-SSE, ENE-WSW, E-W 767 768 and N-S trending segments to form 769 horsetailing splays and strike-slip duplexes. One of the major NW-SE striking faults 770 771 running into Thailand is the Mae Ping (also 772 known as Wang Chao) fault zone (Morley et al., 2007; Lacassin et al., 1997; Leloup et al, 773 774 2001; Tapponier, 1986).

775 3. Permian Stratigraphy in Northern 776 and Central Thailand

The Permian carbonates of the Saraburi area 777 778 were once considered part of the Ratburi Limestone (Brown et al., 1951; Toriyama et 779 780 al., 1974; Hinthong et al., 1981, 1985). Subsequently, Bunopas (1985) named all the 781 782 Permian limestones of the Indochina Block in Thailand as the Saraburi Group. In this article, 783

and Charoentitirat (2011) (after Hinthong, 786 1981, 1985), where the Saraburi Group of the southwest Indochina Block (the Khao Khwang 787 788 Platform) is divided into six formations, namely the: Phu Phue, Pang Asok, Khao Khad, 789 790 Sap Bon, Khao Khwang and Nong Pong Formations. The sedimentary cover of the 791 792 carbonate platform does not have a well-793 defined thickness, because of its complex structural framework, but, it has been 794 795 estimated to range from c. 1400 up to c. 3500 796 m (Chutakositkanon et al., 2000; Dawson and 797 Racey, 1993) and spans the Upper 798 Carboniferous to the Lower Triassic. The 799 carbonates of the study area are grouped 800 under the Khao Khad Formation (Bunopas, 801 1985), which has been described as mainly thin- to very thick-bedded limestone with 802 803 chert nodules and locally interbedded 804 argillite, dolomitic shale, siltstone, sandstone and conglomerate (Ueno and Charoentitirat, 805 806 2011). Previous work on the Khao Khad Formation has concentrated on interpreting 807 808 the outcrop facies distribution, primarily by

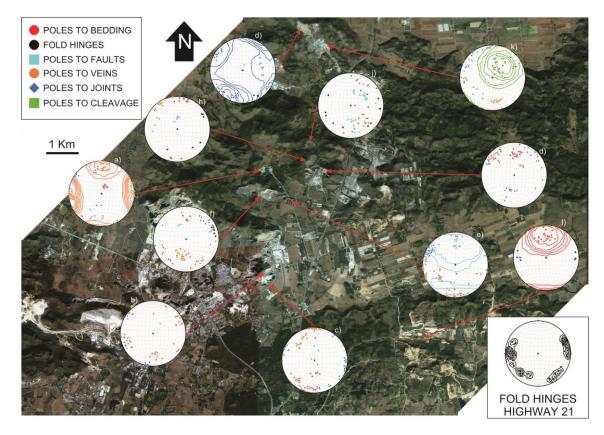


Fig. 5. Satellite photo of the study area and location of the structural stations and relative stereoplot: a-k relative to
 structural data on Khao Khad Fm., I on Sap Bon Fm.

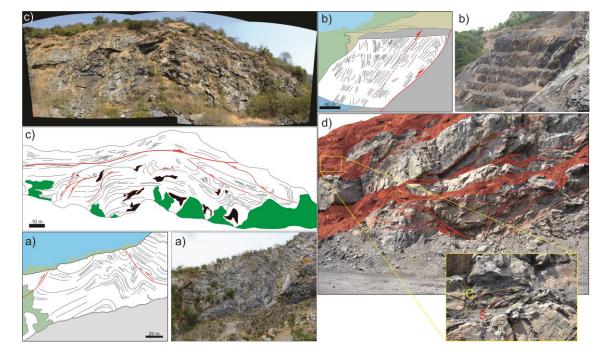


Fig. 6. (a) Photograph and line drawing of the disharmonic folding in Khao Yai Hill on ridge 1. (b) Fault propagation fold and parasitic folding related to the emplacement of two main slip surfaces. (c) Panoramic view of one of the quarries on ridge four and the relative interpretation highlighting the main structural features as faults and bedding. (d) Detachment levels in quarry 12 on ridge 6 and line drawing of the shale (red) with superimposed the C–S fabric. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

818 lateral and vertical lithological changes due to 819 variability in the lateral and temporal depositional environments (Chutakositkanon 820 821 et al., 2000; Thambunya et al., 2007). Only 822 Dawson and Racey (1993) introduced the 823 possibility of structural complication along a 824 particularly well-exposed N-S section along 825 the Thai national Highway 21. These authors 826 documented structural thickening through the 827 section and the presence of a possible vertical 828 alternation of facies due to folding and 829 thrusting. The goal of this project is not to 830 redefine the stratigraphy of the area but to 831 provide a reconstruction of the geodynamic 832 evolution across the Saraburi Region. The 833 most deformed zone along Highway 21 is 834 characterised by the presence of well bedded carbonates - wackestones/packestones plus 835 836 occasional grainstones and boundstones 837 (Dawson and Racey, 1993) - with a notable presence of chert lenses, and dark grey 838 839 limestones with shaly and volcanic-tuffaceous 840 levels. Limitations in this study include 841 uncertainties in detailed stratigraphic columns 842 for these rocks that have been historically 843 attributed to the Mid-Permian. The lack of 844 deep well control and seismic or other 845 geophysical imaging constrain the cross 846 sections (Figures 7) to non-unique solutions. However, the section represents a consistent 847 interpretation of the data on the base of the 848 849 modern concepts of fold and thrust belt 850 interpretations (Mitra and Boyer, 1984; Mitra, 851 2002; Cosgrove, 2000; Poblet and Lisle, 2011; 852 Morley et al. 2011). The cross section 853 therefore has been carried out taking in 896 854 consideration both the available ages (Dawson and Racey, 1993) and the lithological 855 facies distribution along Highway 21. 856

857 4. The Khao Khwang Fold and Thrust858 Belt

859 We have constructed one regional cross 860 section across the Saraburi Region, 861 perpendicular to the trend of the KKF&T Belt.

The lack of subsurface data through the fold 862 863 and thrust belt restricts the subsurface 864 interpretation to being solely based on projection from surface data. This limitation is 865 866 balanced by the excellent exposure of the 867 deformed Permian stratigraphy along the investigated section line. The lack of highly 868 869 exhumed 'basement' thrust sheets, or thrust 870 sheets bearing significantly pre-Permian 871 sequences also constrains us to an 872 interpretation for the thrust belt as a thin-873 skinned belt, where each thrust fault and 874 related folds are linked to major detachments.

875 Along Highway 21 (Figure 4) a sequence of 10 876 quarries and highway 21 road cuts have 877 excavated the Khao Khad and Sap Bon 878 Formations (Hinthong, 1985) to provide the 879 expansive outcrop that has led to a number of 880 publications on the stratigraphy of the area 881 (Dawson and Racey, 1993; Racey et al., 1996; Chitnarin et al., 2008; Fontaine, 2002, 882 883 Thambunya et al., 2007). However, many of have underestimated the 884 these thrust 885 imbricate nature of the fold-thrust belt, which has often been interpreted as an undeformed 886 887 sequence of facies (Thambunya et al., 2007, 888 Chutakositkanon et al., 2000). Lithologically, 889 the KKF&T Belt is dominated by thicklybedded platform carbonates (the Khao Khad 890 891 Formation and the Phu Phe Formation), intercalated with intrabasinal shale and chert 892 893 units that have focussed much of the strain, 894 and acted as detachment horizons (Hansberry et al., in review). 895

5. The Highway 21 section

897 The westernmost cross section was 898 constructed through the KKF&T Belt along 899 Highway 21. The first 10 kms, from Phu Khae 900 to Chong Sarika, exposes an excellent section 901 through the thrust imbricated Permian Khao 902 Khad Formation (Figure 7), which crops out as 903 WNW-ESE ranges in the Saraburi region. Field 904 investigation occurred across 10 limestone

quarries along the western side of Highway 905 906 21, where structural characterization has 907 been carried out. This cross section, and the 908 relative fault and fracture analysis, were 909 constructed through methodologies such as 910 geological mapping, scan lines, scan areas and 911 satellite photomosaic in a GIS environment.

912 The investigated field locations (Figure 4), 913 presented different stages of deformation, 914 including folded regions verging almost 915 entirely north, gently deformed slabs 916 composed of layered carbonate, reverse and 917 thrust faults, back-thrusts, and evidence of 918 strike-slip fault zones. The quarries, where 919 detailed fieldwork (Figure 7) has been 920 undertaken, were selected in order to 921 determine the structural evolution with clear 922 structural and spatial relationships. The study 923 area has been divided into southern and 924 northern areas, the boundary corresponds 925 with the intersection between Highways 1 and 926 21, and approximately with the stratigraphical 927 boundary proposed by Hinthong (1985) 928 between the Khao Khad and Sap Bon 929 Formations (Figure 4). Here, the deformation 930 style also changes drastically.

931 Highway 21 stratigraphy

932 Hinthong (1985) described as conformable the 933 boundary between the Sap Bon and the Khao 934 Khad Formations (Figure 4). Field based 935 observation along Highway 21 revealed the 936 gradational change in the lithology from 937 latitude N 14°42'00" (massive carbonates 938 alternated with thin bedded dark carbonates) 939 to latitude N 14°41'00', where, the presence 940 of cherty carbonates alternates with cm-941 bedded siltstone and fine sandstone. Khao Yai 942 Hill represents the first topographic high along 943 the cross-section (Figure 7). This portion of 944 the KKF&T Belt consists of a stack of thrusts 945 imbricating a sequence of carbonates, 946 characterised by the absence of chert and 947

described this part of the Khao Khad 948 949 Formation as inter-bedded dolomitic algae 950 (stromatolites) and fenestral flats 951 mudstones/wackestones (peritidal 952 facies). However, this interpretation did not 953 take in consideration the structural 954 framework and the consequent stratigraphical 955 implications. The flat area north of Khao Yai 956 Hill (c. N 14°42'31.14" - E 100°53'15.58") 957 shows a sequence of grey, dark grey 958 limestone (mostly mudstone) with chert 959 lenses and nodules, alternating with layers of 960 shale and silt. This part of the KKF&T Belt gets 961 wider on the eastern side of Highway 21 962 making it possible to infer the presence of a 963 lateral facies change of the carbonates of the 964 Khao Yai Hill. A sequence of six ridges 965 characterised by considerable structural 966 complexity governs the topography of this 967 portion of the KKF&T Belt. The stratigraphy in 968 this area has been described by Dawson and 969 Racey (1993) and Thambunya et al., (2007), 970 either without taking in consideration, or by 971 underestimating, the structural framework 972 and the consequent possible repetitions in the 973 stratigraphy. Lithologies to the north are 974 typically composed of bioclastic rocks in the 975 northernmost portion, with boundstone 976 dominated by Tubiphytes and binding algae as 977 Archaeolithoporella (Dawson and Racey, 978 1993), whereas the southern part of this ridge 979 domain largely consists of a platform-derived 980 exoclast in a matrix of mudstone-wackestone 981 (Dawson and Racey, 1993). Dawson and Racey 982 (1993) described the lithology of the northern 983 ridge domain as dominated by silicified 984 mudstone with chert nodules. The upper part 985 of this sequence displays numerous 986 sedimentary structures related to mass transport as turbidites and debris flow 987 988 deposits. The depositional model of the Khao 989 Khad Formation is, therefore, represented by 990 а shallow carbonate ramp prograding 991 northward the (respect to present clastic rocks. Dawson and Racey (1993) 992 orientation), with a protected lagoon and

peritidal depositional environment in the 1036 Ridge 1 993 extreme south (Dawson and Racey, 1993; 994 1037 Chutakositkanon et al., 2000; Thambunya et 995 1038 al., 2007). 996 1039

997 SOUTHERN HIGHWAY 21

998 The southern part of the cross section (Figure 1042 7) consists of highly deformed layers of 999 1043 orange, purple and brownish thinly-bedded 1000 1044 1001 siltstone and mudstone, which vary in 1045 thickness from a few cm up to 1 metre. The 1002 1046 southernmost part of the section solely 1003 1047 consists of siliciclastic material, with no 1004 1048 observable carbonate component. While to 1005 1049 the north, lithologies consist of an alternation 1006 1050 1007 of thin silty sandstone and widespread lenses 1051 and layers of recrystallised carbonate rocks. 1008 1052 The rocks in this region dip south (with a 1009 1053 range of dip directions from 160° to 190°) 1010 1054 (Figure 5), with no major folding and with the 1011 1055 strain accommodated by a pervasive intra-bed 1012 1056 slip and folding at the sub-metric to metric 1013 1057 scale. In the north of this region, near 1014 1058 1015 Highway 21, the alternation of incompetent 1059 mud units and the more competent carbonate 1016 1060 units has contributed to the emplacement of 1017 1061 weakly to intensively folded and deformed 1018 1062 zones. In some of the layers, the shaly units 1019 1063 display extremely narrow zones (from 10 cm 1020 1064 up to about 1 m) of thinly foliated breccia and 1021 1022 fault gouge forming zones of displacement. 1065 1023 These damage zones are characterised by the 1066 1024 presence of calcite veins. It is therefore 1067 1025 possible interpret as low 1068 to these temperature thrust faults (Sibson, 1977). The 1069 1026 pervasive strain observed in the southern part 1070 1027 1028 of this region is interpreted as a region of 1071 distributed shear strain forming a parallel 1072 1029 shear zone (Mitra, 2002). The interlayered slip 1073 1030 1031 in this highly deformed zone is interpreted to 1074 1032 be associated with the presence of a major 1075 basal detachment running at the base of the 1076 1033 1034 clastic unit. 1077

1035 NORTHERN HIGHWAY 21

1040 1041

Quarries number 4 and 5 (Figure 6), lie within Khao Yai Hill, which lies one kilometre east of the Highway 21 and road 3385 intersection. Hinthong (1985) placed the boundary between the Sap Bon and Khao Khad formations three kms south of Khao Yai Hill. This stratigraphic boundary is based on the lithological transition from the southern incompetent carbonate - clastic alternation of the Sap Bon Formation, to the massive competent carbonate of the Khao Khad Formation (Hinthong, 1985). The structural style at Khao Yai Hill is strongly influenced by the mechanical anisotropy of the stratigraphy. Figure 6 shows a sequence of tight chevron disharmonic folds lying in the foot-wall of a major thrust whilst two major folds (fault propagation fold and fault bend fold) occur in the hanging-wall, above a south verging fault. In the south side of Khao Yai Hill this different deformation style probably occurred because of the different competence of the two deformed slabs of rock. The hanging-wall is a slab composed of competent thick layers of carbonate (packestone – wackestone), overthrusting a slab of alternating dark shales and thin-bedded carbonate (packestone wackestone).

The major fault is traceable for a couple of kilometres and parallels bedding in the forelimb of the fold, whilst cutting obliquely through the Khao Khad Formation in the backlimb (Figure 7). Small portions of this ramp are tectonically thickened by a sequence of small duplex structures. The northern part of the hill preserves a major fault with a related detachment fold (Figure 7); the straight bedparallel geometry of this fault suggests that it may have been present before folding. Poles to bedding are bimodal, which is a clear evidence for almost planar fold limbs (Figure 1078 5). The only cleavage exhibited is observed 1079 within the layers of interbedded shale, but in

quarry number 4 it is more pervasive near the 1122 limestone. The bedding within these units is 1080 synclinal hinge. In guarry number 5 (in the 1123) 1081 1082 northern part of the Khao Yai Hill) cleavage is 1124 observed in shale units of the small duplexes. 1125 1083 Cleavage is mostly developed at a high angle 1126 1084 to bedding (75° - 85°) and dips north into the 1127 1085 shale levels of the Khao Khad Formation. This 1128 1086 1087 may be related to the increased deformation 1129 1088 in the damage zone of the major faults. 1130

1089 Ridge 2

1090 Quarry number 6 is on the second ridge, $^{\rm 1133}$ 1091 approximately 500 metres north of Khao Yai ¹¹³⁴ 1092 Hill. It is a prominent structure, five km in $^{1135}\,$ 1093 length and 1 km in width. This ridge is formed ¹¹³⁶ 1094 from a doubly plunging fold, the southern ¹¹³⁷ (backlimb) of the anticline dips uniformly S – 1138 1095 1096 SSE. The northern (forelimb) is vertical to 1139 1097 slightly overturned in places. The shortening 1140 1098 strain is accommodated by a sequence of 1141 1099 folds within the body of a thrust sheet and is $^{1142}\,$ 1100 cored by a sequence of imbricated thrusts 1143 1101 with steep dip angles, ranging from 80° to $^{1144}\,$ about 40° (Figure 7). The folds, related to the 1145 1102 chevron ¹¹⁴⁶ 1103 southernmost thrust, have а 1104 configuration with a box fold geometry at high 1147 1105 levels. The box-fold kink-band axial planes ¹¹⁴⁸ 1149 1106 merge towards the base of the outcrop. 1150 1107 forming chevron folds.

1108 Ridge 3

1109 The third ridge along Highway 21 (Figure 7) ¹¹⁵² 1110 contains a well-exposed fault-propagation ¹¹⁵³ 1111 fold, where the thrust breaks through the 1154 Khao Khad Formation with a moderately 1155 1112 steep angle of dip (47°). Figure 6 shows that $^{\rm 1156}$ 1113 1114 two bright green units of andesite are almost 1157 1158 isoclinally folded and follow the bedding, 1115 1159 suggesting that they may be two sills or tuffs. 1116 In contrast to the Khao Yai folds, this fault- 1160 1117 1118 propagation fold is recumbent with a fold axis 1161 1119 orientation of 25° \rightarrow 270°. Both the limbs are ¹¹⁶² planar with an average angle of ~45°. Units of 1163 1120 shale are interbedded with dark grey 1164 1121 1165

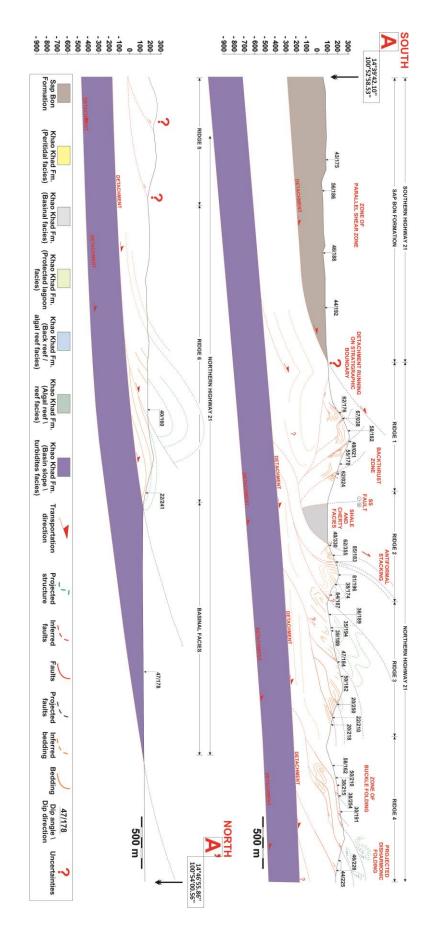
totally overprinted by a pervasive cleavage. The coloured volcanic layers are excellent marker horizons that highlight the complex geometry and deformation in the folds, demonstrating diffuse parasitic folding of second and third order folds (Figure 6). The lowest beds in the northernmost anticline form angular hinges with more rounded hinges in the upper levels. The minor thrusting is restricted to an interbedded unit; therefore strata thickness is expected to be homogeneous without duplications, although, it is possible to observe a slight thickening in the back-limb (c. 5-10%). Vein orientation is rather homogeneous throughout the entire quarry. Whereas, intense fracturing is restricted to the most deformed zones close to the thrust. The homogeneity of veins and joints across the folds is associated with a notable amount of interbedded flexural slip. which used the clastic shaly units to accommodate the strain. Sequences of hilltype meshes (Sibson, 1996), with opened tension gashes in competent carbonate layers alternated with shears along shale beds, have been observed and are interpreted to form due to the extreme shale/carbonate competence contrast.

1151 Ridge 4

1131

1132

Rocks of the fourth ridge are well exposed in two large quarries (Figure 4). Here fold styles differ from the more southerly ridges by having larger wavelengths and wider hinges with 1.6 kilometres between the back- and the front-limbs of the anticline (Figure 7). The southern side of the ridge (back-limb) displays a well-bedded carbonate, folded into a wide syncline – anticline (radius ~ 100m) with a north dipping axial plane (32°/185°) and an east plunging hinge 11° \rightarrow 088°. Further north (Figure 7), the lithology passes from wellbedded carbonate to dark grey massive limestone with an increase of the shale



1167Fig. 7. Regional cross-section A–A0 through the southern portion of the Saraburi Region, the Khao1168Khwang Fold-and-thrust belt (see Fig. 4 for location).

1169 amount (2-5%). The northern part of the 1211 content of shale led to disharmonic folding. hillside along Highway 21 is characterized by 1212 The southern thrust preserves a steeper dip 1170 1171 numerous slip planes that tend to follow bed 1213 parallel fissility. The shale and carbonate 1214 1172 masses are folded with wavelengths ranging 1215 1173 1174 from 1 to 10 m. The folds are disharmonic 1216 1175 (Figure 6). Chevron to isoclinal folds occur 1217 1176 throughout the entire quarry, the 1218 1177 deformation is so intense that the shale has 1219 been displaced from the cores of folds. 1220 1178 Folding was not enough to accommodate the 1221 1179 1180 strain and at some stage (syn- or post-folding) 1222 formed 1181 high-angle reverse faults to 1223 1182 accommodate the displacement, on the scale 1224 of these two quarries. Folds in this part of the 1183 section have a very consistent SW-NE $^{\rm \dot{1}225}$ 1184 direction. The deviation from the E-W fold ¹²²⁶ 1185 hinge trend could be because of later, 1227 1186 possible Cenozoic deformation, or due to 1228 1187 decoupling deformation at the core of a 1229 1188 detachment dying out on a flat level of shale. 1230 1189 Macroscopic observations demonstrate that 1231 1190 calcite veins are most abundant in the 1232 1191 footwall, with a horizontal (en-echelon) 1233 1192 pattern consistent with a horizontal maximum 1234 1193 1194 principal stress.

1195 *Ridge 5*

1237 1196 The fifth ridge from the south is poorly 1238 1197 exposed, therefore, the interpretation in 1239 Figure 7 follows the same structural style of 1198 1240 the other ridges, and is not discussed further 1199 1241 1200 for lack of knowledge. 1242

1201 *Ridge 6*

1244 The northernmost ridge preserves two major 1202 1245 fold propagation faults associated with two 1203 1246 1204 well exposed thrusts running on levels of 1247 1205 shale measuring 1-10 meters in thickness. 1248 These leading edge anticlines formed at the 1206 1249 frontal part of a thrust as a result of thrust 1207 1250 propagation. The southern of the two folds 1208 1251 (Figure 6) has been partially removed by 1209 1252 erosion. Close to the core of the fold, the high 1210 1253

angle (30°/240°) with respect to the northernmost thrust (22°/241° - 25°/190°). Deformation is localized along the cleavage surfaces or shear bands giving a sigmoidal shape fabric to the shale, with two different well-developed cleavage planes resembling a C-S structure (Figure 6). Calcite veins are common in the shales suggesting considerable fluid migration. Within approximately 50 cm of the thrust surface the shale is characterized by intense cataclasis (mesocataclasite with matrix content around 70-80%).

6. The Khao Khwang Fold-and-Thrust **Belt cross section**

The cross section presented here was constructed across the KKF&T Belt in central Thailand, using a combination of 1:250000 geological maps (Hintong et al., 1985), satellite image interpretation (SRTM and Landsat-7 imagery) and field data from exposures across the southern part of the belt.

1235 There are no subsurface data (such as seismic 1236 sections or well-log data) in the area, thus it is difficult to interpret the geometry of the structures at depth within the KKF&T Belt. A variety of structural models are possible to predict the geometry and distribution of folds and thrusts in the subsurface. The observed geometries of folds and thrusts in outcrops best fit a kink-band fold deformational style. Thus, the application of the fault-bend fold or fault-propagation fold modelling technique is here deemed appropriate, since the majority of the folds have been generated in response to faulting (Suppe, 1985; Mitra, 2002). However, there is a component of pure buckle folding mostly related to incompetent layers of shale. The evolution of the KKF&T Belt has been interpreted with a forward (northward) propagating model of staircase imbricated

trajectories with a sequence of three 1297 1254 1255 detachment faults, which have been 1298 positioned at a depth calculated on the base 1299 1256 1257 of the fold geometries, formation thicknesses 1300 and their morphological expression (Epard 1301 1258 and Groshong, 1993) (Figure 7). 1259 1302

1303

Between the Highway 21-1 intersection and 1260 1304 the locality of Phu Kham Chan (Figure 4), the 1261 1305 maximum vertical relief of exposures is 1262 1306 limited to tens of metres, but the horizontal 1263 1307 1264 section is continuous along a sequence of 10 1308 quarries. The overall trend of the imbricated 1265 1309 pre-Permian strata of the carbonate Khao 1266 1310 Khad Formation, have a predominantly N -1267 1311 NNE vergence (Fig. 5). A different imbricate 1268 1312 set, with a S - SSW vergence, has been 1269 1313 identified in the Khao Yai Hill (southernmost 1270 1314 major topographic expression along Highway 1271 1315 21) and recognising that this the only portion 1272 1316 of the belt with south dipping features (Fig. 5), 1273 1317 we interprete this as a back-thrust region (Fig. 1274 1318 1275 7). 1319

Along the entire section there are no $^{\mbox{1320}}$ 1276 1321 1277 exposures of crystalline basement, or any Pre-Permian formations, which suggests that, ¹³²² 1278 1323 there may be a major detachment possibly 1279 coincident with the base of the Khao Khad 1324 1280 Formation. Typically, it is difficult to estimate ¹³²⁵ 1281 1326 the depth of the detachments or identify the 1282 1327 involved stratigraphic level just from the fold 1283 and 1328 1284 geometry (Ramsay, 1974; Escher Watterson, 1974; Epard and Groshong, 1993; ¹³²⁹ 1285 exposed 1330 Mitra, 2002). Therefore, the 1286 boundary between basin depositional facies ¹³³¹ 1287 1332 has been chosen as a detachment, which has 1288 a possible depth of 0.7– 1.5 km according to 13331289 wavelength and amplitude of major anticlines 1290 1291 (Figure 7) (Mitra, 1992; Epard and Groshong, 1334 1292 1993). 1335

1336 1293 Many folding mechanisms have been 1337 1294 observed in the study area, these cross the 1338 1295 entire possible spectrum between the two 1339 1296 end members ranging from buckling to 1340

bending (Cosgrove, 2000). This alternation of geometries has been attributed to the lithological heterogeneity of the Khao Khad Formation that is the prominent deformed lithology in this part of the KKF&T Belt. Folds are the most frequent and best exposed structural feature along Highway 21. The illustrated cross-section (Figure 7) shows an interpretation of the strain distribution throughout the fold and thrust belt within the Formation, Khao Khad where several deformation themes have been observed. The (commonly asymmetric) folds have been classified as features related to bending events (forced folds or fault related folds), while buckle folds are more representative for accommodating the strain at the metric (<10 m) scale. Buckle folding is prevalent where the alternation of clastic basinal and carbonate layers is present. The geometry of the folds and the alternation of basinal with shallow marine carbonate sediments imply the presence of more than a single detachment level. Since the Phu Phe Formation is not seen along the analysed cross section, it is possible to exclude a detachment running at the very base of the Saraburi Group. Instead, the basinal facies within the Khao Khad Formation is taken as the main basal detachment. The distance between the main outcropping thrust and the wavelengths between the anticlines do not change, having the same intensity of deformation across the area and revealing that the detachment could lie at approximately the same depth for the entire length of the cross-section.

7. Discussion

The north-directed regional transport represented by the KKF&T Belt has been accommodated within limestone of the Permian Khad Formation. The Khao mesoscopic structures, including major thrusts, backthrusts, and forced and buckle folds, represent the typical set of structures 1341 observed well-known in boundaries (Morley et al., 2011). In these 1386 1342 structural environments, basal thrusts along 1387 1343 weak horizons confine and define thrust belts, 1388 1344 1345 and relative structural features. The specific 1389 1346 mechanisms of structural development we 1390 1347 present here are similar in carbonate 1391 1348 deformation with shale detachments (Morley 1392 1349 et al., 2011). 1393

1394 1350 Mesoscale analysis revealed both 1395 1351 compression and dilatation widespread 1396 1352 throughout the KKF&T Belt. Several large 1397 contraction faults divide the Khao Khad 1353 1398 Formation in a series of thrust sheets. These 1354 1399 have listric geometries and most likely merge 1355 1400 at depth with a detachment horizon with a 1356 1401 high range of dip angles decreasing to the 1357 1402 direction of propagation as expected in an 1358 1403 imbricate system of a thin-skinned geometry. 1404 1359 Minor reverse faults often truncate large 1360 1405 regional anticlines and synclines and are 1361 1406 refolded throughout the entire cross section. 1407 1362 Mesoscopic contraction faults are visible in 1408 1363 outcrops and have displacement in the order 1364 1409 of several metres. An intense cleavage occurs 1365 1366 in shales, mudstones and siltstones. At the 1410 The roughly N-S Sibumasu – Indochina Block 1367 outcrop scale, joints at an angle with respect 1411 1368 to the bedding are a visible expression of the 1412 cleavage structures, and cleavage appears to 1413 1369 1370 be absent, or generally refracted into thin 1414 1371 layers of limestone beds, due to their higher 1415 1372 competence. The idea of forced folds 1416 1373 generated by the emplacement of major 1417 1374 thrusts throughout the belt is reinforced by 1418 1375 the general dip directions of the pervasive 1419 1376 cleavage in the layers of shale used for the 1420 1377 thrust propagation. Furthermore, the 1421 cleavage being parallel to mesoscopic fold 1422 1378 axial traces also indicates syn-deformational 1423 1379 1380 generation. 1424

Most of the mesoscale fractures and faults 1381 1426 show evidence that they have been used as 14271382 corridors for fluid migration (e.g. Warren et 1428 et al. (2013), it may be the result of the 1383 al., 2014). It is possible to observe a relatively 1384

1425

convergent 1385 high number of bed-parallel stylolites in the footwall and hanging-wall, both which increase towards the thrust surfaces. Often shear surfaces in the thrust have been used as preferential corridors for fluid migration and facilitating solution transfer processes (dissolution and precipitation). Most of the observed veins in the footwall have a subvertical dip (70°/85°) and trend E-W trend. They are notably less abundant that in the hanging-wall. This may indicate that fluids were not present in substantial amounts in the hanging-wall, coupled with the hangingwall experiencing less strain. This is interpreted as being because of stress being guided along the thrust plane and in the adjacent footwall. The N-S extension expressed by the vertical veins with enechelon pattern in the footwall may result from increased hydraulic pressure, caused by the concentration of water in the footwall, bringing the footwall nearer to tensile failure. Clearly, thrusts and shear zones in general, behave differently for fluid flow, depending on lithology, structural setting and geometry.

> convergence has been accommodated in the KKF&T Belt by a combination of (present and NW-SE trending orientation) E-W structures. Elsewhere in Thailand, the same collision is represented by approximately E-W shortening on N-S trending faults and folds. The change in fold strike is notable only in the KKF&T Belt and does not involve a larger portion of the Permian-Triassic collisional belt. This leads to the question as to why does the orogeny bend at the Khao Khwang Belt? The answer may lie in the geometry of the terranes involved in the collision (Sone and Metcalfe, 2008; Ridd et al., 2012; Metcalfe, 2013). This pre-collisional geometry may have been as simple as a bend in the original Indochina margin. Or, as suggested by Morley

1429 Indochina Block itself being split by an 1473 some minor 1430 approximately E-W suture stretching from the 1474 1431 Khao Khwang Platform in the Saraburi Region 1475 1432 of Thailand, along the southern margin of the 1476 1433 Khorat Plateau to central Vietnam. This 1477 1434 interpretation has circumstantial support in 1478 1435 the Permian E-W rift sequence developed in 1479 1436 the southern Khorat Plateau (Hutchison, 1480 1437 1975; Morley et al., 2013), suggesting that 1481 1438 Permian N-S extension occurred in the area, 1482 1439 but it is unknown whether this is related to an 1440 oceanic margin to the south.

1441 8. Conclusions

1442 The fold and thrust belt formed by forward 1486 1443 (north) propagating deformation in the 1487 1444 Triassic, consists only of cover strata and has 1488 1445 been displaced mainly along weak horizons of 1489 1446 incompetent shale within the Khao Khad 1447 Formation, transported by numerous in- $^{\rm 1490}$ 1448 sequence thrusts. The KKF&T Belt represents 1491 1449 a thin-skinned fold and thrust belt developed 1492 1450 on a detachment that lies between 0.7 and 1493 1451 1.5 kilometres depth that is similar to the 1494 1452 stratigraphic thickness of the Khao Khad 1495 1453 Formation (Dawson and Racey, 1993; 1454 Thambunya et al., 2007, Ueno and 1496 1455 Charoentitirat, 2011). The in-sequence, thin- 1497 1456 skinned, deformation demonstrates that 1498 1457 deformation has migrated from S-SSE to N- 1499 1458 NNW along a zone as wide as the fold and 1500 1459 thrust belt itself, with lateral variations 1501 facies attributed lateral 1460 probably to 1502 1461 variations. Evidence of lateral structural 1462 variations occur along the strike of the fold 1503 1463 and thrust belt in zones of mechanical 1504 1464 weakness in the shale levels, these different 1505 1465 rates of strain accommodation are probably 1506 1466 related to oblique-lateral ramps between 1507 1467 thrusts. The imbricated thrusts generally cut 1508 1468 the forelimbs of folds in the limestone of the 1469 Khao Khad Formation, suggesting a model 1509 1470 where some imbricates were formed during 1510 1471 the folding, whilst folding continued in the 1511 Government Printing Office, Vol. 984. 1472 surrounding shales with the development of

amplitude buckle folding associated with detachment levels. The KKF&T Belt represents a significant kink in the collision between Sibumasu and Indochina, which may be due to either the original geometry of the Indochina margin, or due to a poorly recognised ocean strand that split Indochina into two or more late Palaeozoic continents (Fig. 3).

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Determination of the tectonic evolution from fractures, faults and calcite twins on the south-western margin of the Indochina Block

1869 ABSTRACT

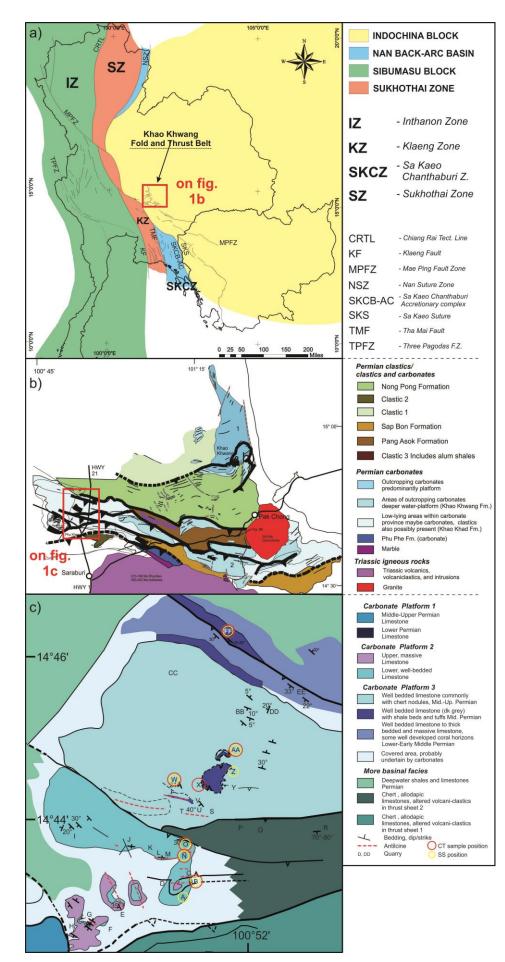
In polyphase tectonic zones, integrating a study of fault and fracture with calcite twin analysis can 1870 1871 determine the evolving paleo-stress magnitudes and principle stress directions that affected the 1872 area. This paper presents the results of the analyses of fractures, striated faults and calcite twins 1873 collected within the Khao Khwang Fold-Thrust Belt (KKFTB) in central Thailand (SE Asia). Here we 1874 attempt to reconstruct the orientation of the principal stresses that developed during the tectonic 1875 evolution of this highly deformed, polyphase orogen. Tectonic data were collected in the Permian 1876 carbonates of the Khao Khad Formation of the Saraburi Group, and five successive tectonic stages 1877 are determined that are interpreted to have developed before, during, and after, the Triassic 1878 Indosinian Orogeny. The first three stages pre-date the main deformation event: the first stage is 1879 interpreted as a pre-Indosinian N-S extensional stage, the second stage described a N-S strike-slip 1880 and compressional regime, largely perpendicular to the fold axes of the main structures, while the 1881 third stage is associated with an E-W compressional strike-slip phase. A further two stages took place 1882 after, or during, the main folding event and correspond to N-S compression and to an E-W 1883 composite strike-slip/contractional stage, the latter which is interpreted to represent Cenozoic deformation related to the India-Asia collision. 1884

1885 Introduction 1.

1910 South East Asia is formed from a number of 1911 1886 continental fragments and volcanic arcs, 1912 1887 separated by oceanic suture zones, which 1888 accreted to the growing Asian continent 1913 1889 1890 during the latest Paleozoic-early Mesozoic 1914 Indosinian Orogeny. In Thailand, this tectonic 1915 1891 1892 event, developed mainly during the Triassic 1916 1893 (Sone and Metcalfe, 2008; Metcalfe, 2011) 1917 1894 and is the result of the collision between the 1918 Sibumasu, Sukhothai and Indochina Terranes 1919 1895 1896 (Figure 1a, b). Models for the tectonic 1920 1897 evolution of Thailand from the Indosinian 1921 1898 Orogeny to the present have been defined 1922 1899 using petrological, 1923 biostratigraphical, 1900 structural geochronological data 1924 and 1901 (Metcalfe and Sone, 2008; Sone and Metcalfe, 1925 1902 2008; Ridd and Morley, 2011; Morley et al., 1926 1903 2013; Arboit et al. 2014; Hansberry et al. 1927 1904 2014) and involve broadly N-S trending 1928 1905 tectonic domains converging in E-W directions 1929 1906 (with respect to the present-day orientation) 1930 (Sone and Metcalfe, 2008; Morley et al., 1931 of the region, we took advantage of the rocks 1907 1908 2013). However, these are based on the 1932 of the Khao Khad Formation (Ueno and

present day orientations of the tectonic 1909 domains and little constraints on the original orientations or paleo-stress determinations have been previously attempted.

> Central Thailand, and more specifically the Khao Khwang Fold-Thrust Belt (KKFTB), provides a natural laboratory to obtain the necessary information, with many well exposed quarries along Highway 21 (Table 1, Figure 1c). The complex structural architecture in the KKFTB evolved from the Permian, mainly with the growth of E-W to **ENE-WSW** striking reverse faults and associated drag-folds that developed in this thin-skinned fold and thrust belt (Morley et al., 2013; Arboit et al., 2014). Associated with this deformation, there are a number of N-S to E-W trending sets of fractures that developed before, during, and after, the main Layer-Parallel Shortening (LPS) event of the Indosinian Orogeny. In order to develop a permissive model for the dynamic evolution



1934 Fig 1. (a) Subdivision of Thailand into main tectonic terranes that amalgamated during the Indosinian Orogeny (modified 1935 from Ueno and Charoentitirat [2011]) and distribution of the major lineaments of the study area [after Arboit et al., 2014]. 1936 (b) Geological map of the Khao Khwang Fold-Thrust belt region [from Morley et al., 2013]. (c) Detailed description of the 1937 western portion of the Khao Khwang Fold-Thrust belt [from Warren et al., 2014]. The described lithologies are "informal 1938 units" based on the description from Hinthong [1981]. The red circles show the location where the samples have been 1939 collected, and the yellow circles where data for structural stations have been taken, coordinates on Table 1.

1987

1988

1940 Charoentitirat, 2012) to compare fracture 1966 1a) (Sone and Metcalfe, 2008; Metcalfe, 1941 and fault sets with a paleostress analysis 1967 1942 carried out using calcite twins (Lacombe et al., 1968 1992; Lacombe et al., 2007; Amrouch et al., 1969 1943 1944 2010a, b). In combination, these data provide 1970 an accurate estimate on the evolving stress 1971 1945 1946 orientation and resulting deformation before, 1972 during, and after, the Indosinian Orogeny. 1947

		19/2
Latitude	Longitude	1974
14° 42' 01.40"N		1975
		1976
14 42 00.45 1	100 33 08.45 L	1977
14° 44' 12.08"N	100°53'43.33"E	1978
14° 46' 07.13"N	100°53'33.67"E	1978
14° 43' 27.09"N	100°52'54.27"E	1980
14° 43' 16.51"N	100°53'25.40"E	1981
14° 43' 41.22"N	100°53'03.66"E	1982
14° 43' 46.02"N	100°53'44.55"E	1983
14° 53' 58.18"N	100°53'48.67"E	1984
	14° 42' 01.40"N 14° 42' 06.45"N 14° 44' 12.08"N 14° 46' 07.13"N 14° 43' 27.09"N 14° 43' 16.51"N 14° 43' 41.22"N 14° 43' 46.02"N	14° 42' 01.40"N 100°53'20.28"E 14° 42' 06.45"N 100°53'08.49"E 14° 44' 12.08"N 100°53'33.67"E 14° 46' 07.13"N 100°52'54.27"E 14° 43' 27.09"N 100°53'25.40"E 14° 43' 41.22"N 100°53'03.66"E 14° 43' 46.02"N 100°53'44.55"E

1948 Table 1. List of the Quarries With Location Coordinates 1985 1949 Quarry 1986

1950 2. Geological setting

The study area has undergone a complex ¹⁹⁸⁹ 1951 geological history, which mainly developed 1990 1952 during the Indosinian tectonic event, this is 1991 1953 characterised by different subduction and 1992 1954 collision episodes that covered the period 1993 1955 1956 from ca. 260 to 200 Ma (Late Permian to Late 1994 Triassic) (Sone and Metcalfe, 2008; Morley, 1995 1957 2007; Morley et al., 2013). The resulting ¹⁹⁹⁶ 1958 tectonic belts and suture zones in Thailand 1997 1959 have a dominant N-S trend. The Indosinian 1998 1960 1961 orogeny in Thailand has been considered to 1999 1962 involve two stages of collision during the 2000 1963 Triassic-Early Jurassic between the three main ²⁰⁰¹ terranes, which, from east to west, are: 2002 1964 Indochina, Sukhothai and Sibumasu (Figure 2003 1965 2004

2013). Additionally, beyond Thailand, to the NE, coeval Triassic collision also occurred between both the Indochina/ South China Blocks (Cai and Zhang, 2009; Halpin et al. in press) and the South/North China Cratons (Dong et al. 2015)..

1973 The Sukhothai Terrane is believed to have been a volcanic arc that rifted away from the south-western margin of Indochina in the Early Permian, as consequence of rollback above the subducting Paleo-Tethys, and opening of the back-arc basin between the volcanic arc (Sukhothai) and the Indochina Terrane (Sone and Metcalfe, 2008). The first 1 tectonic event is commonly interpreted as resulting from the Early Triassic collision as the Sukhothai Terrane re-amalgamated with Indochina, with the related closure of the Permian back-arc basin (Metcalfe, 2005; Sone and Metcalfe, 2008; Metcalfe, 2013). Subsequently, in the Late Triassic, during the late stages of the Indosinian collision, the Sibumasu Terrane is thought to have collided with the now combined Indochina/Sukhothai Terrane, causing the complete closure of the Paleo-Tethys in this region. The Indosinian orogeny has usually been thought as resulting from the collisions between these two strongly linear terranes and Indochina. However, despite the common N-S trend of the suture zones (Nan-Sra Kaeo and Changning-Menglian S.Z.) (Figure 1a) between the blocks involved in the collision, in some areas the tectonic trend diverges from simply N-S to NW-SE and E-W trends. The most prominent of these regions is the Saraburi region (Morley et al., 2013; Arboit et al., 2014). One explanation for the different trend

2005 is that the belt was rotated from a N-S 2049 2006 direction to a more E-W orientation by motion 2050 2007 along the NW-SE trending Cenozoic Mae Ping 2051 2008 Fault Zone; Tapponier et al. (1986) proposed 2052 2009 sinistral displacement of about 150 km on this 2053 2010 fault. However, even after restoring this 2054 2011 offset, and applying a relative clockwise 2055 2012 rotation of about 25°-30° (Charusiri, 2006; 2056 2013 Cung and Geissman, 2013; Singsoupho et al. 2057 2014 2014) to the northern side of the fault, the 2058 2015 boundary does not restore to a N-S 2059 2016 orientation (Anchuelas et al., 2012; Mochales 2060 2017 et al., 2012; Morley et al., 2013). Alternatively, 2061 2018 the deflection may be due to the original 2062 2019 orientation of the continental margins, or 2063 2020 possibly due to a poorly documented intra- 2064 2021 Indochina suture, that strikes east-west, and 2065 2022 lies close to the southern margin of the Khorat 2066 Plateau (Hutchinson, 1975; Morley et al. 2067 2023 2024 2013). 2068

2025 The KKFTB lies in the Saraburi Province in 2069 2026 central Thailand, and it is tectonically located on the SW margin of the Indochina Block 2070 2027 (Bunopas, 1982; Metcalfe, 2011; Morley et al., 2071 2028 2013). It is bounded to the north and to the $_{2072}$ 2029 2030 east by the Khorat Plateau, which trends NW- 2073 2031 SE, and to the south by the Cenozoic Mae Ping 2074 strike-slip fault (Morley, 2007; Morley et al., 2075 2032 2013). Bunopas (1981) was the first to 2076 2033 propose a separate Indochina Block by 2077 2034 stratigraphic division (Saraburi Group) of the $_{2078}$ 2035 lithological units in this province. A few years 2079 2036 later, Hinthong (1981) and Hinthong et al. 2080 2037 (1985) defined the stratigraphy that is still 2081 2038 2039 used today and described three main 2082 carbonate formations, the Phu Phe, Khao 2083 2040 Khad and Khao Khwang formations, that 2084 2041 2042 formed platforms, 2085 Permian carbonate separated by clastic and mixed clastic and 2086 2043 carbonate facies formations (Sap Bon, Pang 2087 2044 2045 Asok. and Nong Pong) (Ueno and 2088 2046 Charoentitirat, 2011; Morley et al., 2013). 2089

2047 The thickest and most deformed formation ²⁰⁹⁰ 2048 exposed within the KKFTB is the Khao Khad ²⁰⁹¹

Formation, which tectonically underlies the Sap Bon Formation and is thrust over the Nong Pong Formation to the north. In the Saraburi area of the KKFTB, the Khao Khad Formation consists of approximately 1400 m of tectonically thickened Permian carbonate platform facies (Dawson and Racey, 1993; Morley et al., 2013; Warren et al., 2014; Arboit et al., 2014) (Figure 1). The present trend of the belt (from E-W to ENE-WSW) lies at a high angle to the interpreted orientation of the approximately N-S Indosinian suture zones that run throughout SE Asia. The study region represents a natural laboratory to investigate the processes that affected the general kinematic framework on the southwestern margin of the Indochina Block; and thus contributing to better illustrate the Permo-Triassic phases of the paleostress evolution during the Indosinian Orogeny.

3. Methodology

3.1. Field and mapping methods

Fractures were measured on, and normal to, bedding surfaces along the length of the folds, mainly in a direction perpendicular to thrust vergence, or in single positions in order to decrease the level of bias due to the orientation of the outcrop. Analyses were carried out with detailed mapping of structural stations at a few, well-exposed, surfaces, of the thickly bedded limestone of the Early - Middle Permian Khao Khad Formation (Ueno and Charoentitirat, 2012), in a number of quarries exposed along highway 21 in the Saraburi region, as well as in oriented thin-sections. As fracture sampling was undertaken unsystematically through the region, due to outcrop availability and access, density distributions and relative clusters have not been filtered to avoid any possible bias to the data. Fracture orientations, lengths and modes of deformation (opening and sliding) were recorded as well as cross-cutting

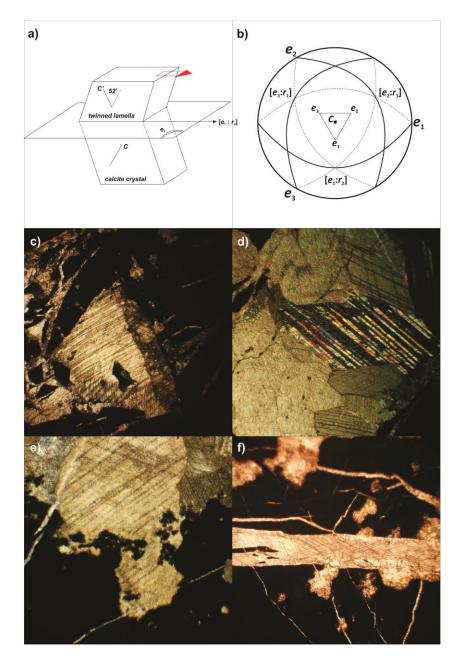
relationships. This information has been 2132 techniques have been applied to non-2092 2093 collected in order to provide new data on the 2133 geometries and chronologies of fracturing 2134 2094 that affected the western portion of the 2135 2095 2096 KKFTB since the Permian stage of the 2136 2097 Indosinian Orogeny. According to the quality 2137 of the exposure, from 30 to 80 fractures were 2138 2098 2099 measured for each stop, in order to 2139 2100 statistically identify the orientation of the 2140 2101 main fracture families. Facies variations within 2141 the rocks of the KKFTB have not been taken in 2142 2102 2103 consideration, although these are certainly 2143 present and are likely to affect the mechanical 2144 2104 2105 properties of the rocks. Despite this, no large 2145 2106 variations in the orientations of the fracture 2146 2107 sets have been noticed throughout the 2147 2108 western portion of the KKFTB. Here the term 2148 "fractures" is used in general to describe 2149 2109 either opening-, sliding-, or closing-mode 2150 2110 2111 discontinuities, such as pressure-solution 2151 seams, joints and veins. Small faults, with 2152 2112 2113 negligible offset (less than 10 mm), have here 2153 been referred as fractures when kinematic 2154 2114 2115 indicators were lacking (Pollard and Aydin, 2155 2116 1988). Structural and geological maps have 2156 2117 been constructed using a variety of methods, 2157 2118 including scan lines, scan areas with a 1 – 1 m 2158 2119 resolution combined with Landsat and SRTM 2159 2120 orthorectified photomosaic satellite images 2160 and topographic data in ArcGIS® environment. 2161 2121 2162

2122 3.2. Calcite twin analysis

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Over the last 50 years many different 2164 2123 methods for inferring certain elements of the ²¹⁶⁵ 2124 stress tensor from fault populations have 2166 2125 been used (Ramsey, 1962; Angelier and ²¹⁶⁷ 2126 Mechler, 1977; Angelier, 1984). In order to 2168 2127 inspect the stress history before and after ²¹⁶⁹ 2128 folding at both meso- and micro-scale, we ²¹⁷⁰ 2129 carried out an analysis of fractures and calcite ²¹⁷¹ 2130 2131 twins. Several calcite twinning and inversion 2172 twinned planes in a sample are not explained

metamorphosed to weakly metamorphosed carbonate rocks to obtain regionally meaningful paleostress tensor orientations (Etchecopar, 1984; Tourneret and Laurent, 1990; Lacombe et al., 1992, 2007; Lacombe, 2001). The geometry of calcite twinning has been exhaustively described by Handin and Griggs (1951). Mechanical e-twinning (Figure 2) often occurs in calcite crystals deformed at low temperatures (Burkhard, 1993) (Figure 2). In terms of deformation, an individual e-twin can be considered as a zone of perfect simple shear resulting from the slide of the position of the atoms in the crystal lattice along a plane (e); which for unmetamorphosed calcite are e_i :{0112}, and these three e planes are geometrically forced around the optic axis C (Figure 2). Twin gliding in calcite requires a resolved shear stress (RSS) that exceeds the yield stress value for twinning (τ_s) of 10±4 MPa in order to develop (Turner et al., 1954; Lacombe and Laurent, 1996; Ferrill, 1998; Laurent et al., 2000; Lacombe, 2007, Lacombe 2010). Resolved shear stress is the component of stress that is aligned with the twinning direction. The yield stress value has a very small sensitivity to temperature and confining pressure but depends mainly on grain size and internal twinning strain (Tullis, 1980; Rowe and Rutter, 1990; Lacombe et al., 2007). The inversion process takes into account both the twinned and untwinned planes, the latter of which are those of the potential e-twin planes that never experienced a resolved shear stress of sufficient magnitude to cause twinning (Tourneret and Laurent, 1990). The inverse problem consists in finding the stress tensor that best fits the distribution of twinned and untwinned planes. If more than 30% of the



2174 Figure 2. a) Schematic sketch of a twin lamella {0112} in a calcite crystal (after Bukhard, 1993). The twinning direction 2175 $[e_1:r_2]$ corresponds to the direction of movement of the atoms situated above the twin plane. The sense of shear is 2176 indicated by the arrow and is imposed by the crystal geometry. b) Stereographic projection (lower hemisphere, equal area) 2177 of the calcite twin planes. The optic axis C, at the centre of the diagram is vertical. The poles to the three sets of twin 2178 planes e₁, e₂ and e₃ are at 26.5° to the C axis. The planes of twinning are the three great circles containing the three 2179 directions of twinning $\{01\overline{1}2\} - [e_i:r_i]$ (modified from Evans and Groshong, 1994). The lower images describe samples of 2180 twinned crystals from veins and matrix of the Khao Khad Fm. All the crystals show type I & II geometry (Burkhard, 1993). 2181 Most of the deformation describes a low temperature deformation environment (from <200° C up to 300° C) with 2182 deformation varying from low to high degrees. c) Twins deformed by intense shear, d) thick twins (>>1µm), e) thin twins in 2183 matrix, f) vein filled with large sparry calcite crystals in the centre and untwinned calcite crystals on the walls.

by a unique tensor, the inversion process is 2188 Several methods for determining stress or 2184 2185 repeated with the uncorrelated twinned 2189 strain components from calcite twin lamellae 2186 planes and the whole set of untwinned 2190 have 2187 planes.

been proposed (Groshong, 1972; 2191 Etchecopar, 1984). For this study we used 2192 Etchecopar's calcite stress inversion technique 2193 (CSIT) (Etchecopar, 1984) to obtain the stress 2233 corresponds to the critical RSS for the 2194 tensor, while other methods such as the 2234 2195 Groshong's calcite strain gauge technique 2235 2196 (CSGT) (Groshong, 1972) allow production of a 2236 2197 strain ellipsoid. The CSIT applies to small 2237 2198 twinning strains that can be approximated by 2238 coaxial conditions, so orientation of the 2239 2199 2200 twinning strain can be correlated with 2240 2201 paleostress orientation (Amrouch et al., 2241 2202 2010a) [see details in works by Lacombe, 2242 2203 2001, 2007]. 2243

2244 Etchecopar's CSIT leads directly to the 2245 2204 simultaneous computation of principal stress 2205 2246 orientations (with: σ_1 - maximum principal 2206 2247 stress; $\sigma_{2^{-}}$ intermediate principal stress; $\sigma_{3^{-}}$ 2248 2207 minimum principal stress) and differential 2208 2249 2209 stresses (Tourneret and Laurent, 1990; 2250 Lacombe and Laurent, 1992; Amrouch et al., 2210 2251 2010a), which also yields data on the ellipsoid 2211 2252 2212 shape ratio $\Phi = (\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$, and the peak 2253 2213 differential stress (σ_1 - σ_3) (with $\sigma_1 \ge \sigma_2 \ge \sigma_3$ as a 2254 2214 compressive stresses, positive in value). The 2255 2215 tensor solution is calculated as a normalised 2256 reduced stress tensor, such that (σ_1 - σ_3), and 2216 2257 2217 is scaled to $[(\sigma_1 - \sigma_3)^* = 1]$. 2258

2218 Thus, the value of the RSS τ_s acting on a plane 2259 2219 lies between -0.5 and +0.5, that is $-(\sigma_1 - \sigma_3)^*/2$ 2260 2220 and $+(\sigma_1 - \sigma_3)^*/2$ (Jamison and Spang, 1976).

2221 Theoretically, all the twinned planes 2261 2222 consistent with a given tensor must sustain a 2262 2223 τ_s value larger than the one exerted on any 2263 2224 untwinned plane. The best tensor solution is 2264 2225 searched in order to minimize the function *f*, 2265 2226 which is ideally equal to 0, and is defined as: 2266

$$f = \sum_{j=1}^{N} (\tau_{sj} - \tau_{a'})$$
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2269

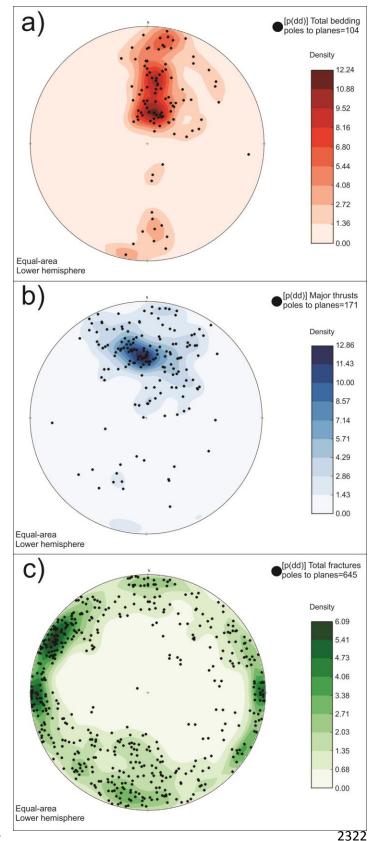
2267

2227 Where $\tau_{a'}$ is the smallest RSS applied on the 2270 2228 twinned planes compatible with the tensor 2271 2229 and τ_{sj} are the RSS applied on the *N* 2272 2230 untwinned planes *j* such that $\tau_{sj} > \tau_{a'}$ 2273 2231 (Etchecopar, 1984; Laurent, 1984). The $\tau_{a'}$ 2274 2232 value is deduced from the inversion and 2275 2276

normalised tensor used for the calculation. The best fitting tensor is obtained when (1) the maximum of the twinned planes are taken into account; (2) the maximum of the untwinned planes are taken into account; and (3) the f value is minimal (in practice, one can authorise a weak percentage, 10% - 15%, of untwinned planes receiving a RSS larger than τ_{ai} because of measurement uncertainties and local heterogeneities at the crystal scale). Therefore, the quality of the calcite twin data has a further control with the penalization function "f", this parameter indicates the quality of the arrangement of the whole measured e planes (Lacombe and Laurent, 1996). This process leads to the determination of the orientation of the principal stresses σ_1 , σ_2 and σ_3 and the stress ellipsoid shape ratio $\Phi = (\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$ being between 0 and 1 (Etchecopar, 1984; Laurent, 1984). If polyphase deformation has occurred, this provides an efficient way of separating superimposed twinning and therefore deformation events (Etchecopar, 1984; Lacombe et al., 2007).

4. Overview of fracture-deformation framework

Interpretation on the structural framework development within the KKFTB is here based on the statistical analysis of fracture orientations and their relative ages. The analysis of these fractures was carried out both with a field based study at the mesoscale, and at the micro-scale in 27 thin sections. Fracture populations in the field have been sampled along Highway 21 (Figure 1b), along a N-S oriented section within the KKFTB where the Khao Khad Formation crops out. The Permian carbonate of the Khao Khad Formation contains a great variety of fractures, many filled with calcite, which developed during the Indosinian Orogeny (Warren et al., 2014). The term "fractures" is



23232278Fig 3. Stereographic plot (equal-area, lower hemisphere
projection) showing the attitude of the (a) bedding, (b)
major faults, and (c) fractures. Cluster analysis shows
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23252281main E-W strike of both bedding and thrusts indicating a
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principal northerly vergence in the western part of the Khao Khwang Fold-Thrust belt. Contouring operations performed with the aid of Openstereo software [Grohmann and Campanha, 2010].

here used in a general sense to refer to either (Type I) opening-, (Type II & III) sliding-, or closing-mode displacement discontinuities along surfaces; such as planar surfaces, pressure-solution seams, joints, and veins (Pollard and 1988). Tectonic Aydin, pressuresolution surfaces (Figure 5e) or stylolites comprises bed-perpendicular surfaces with an average direction of 100°, these are the less frequent structural features, and are not present in many of the investigated guarries. It is well known that analysis of the distribution of such structural features has the potential to increase the constraints on the fold kinematic (Gutierrez-Alonso and Gross, 1999; Tavani et al., 2006, 2015), and therefore on the geodynamic evolution of the KKFTB. But here, considering their statistically irrelevant numbers (6/675), they have been excluded from the analysis. However, the stylolite 'teeth' are aligned normal to the pitted solution surface, implying the σ_1 during stylolite development was parallel to the pole of the stylolite surface (Choukroune, 1969; Eyal and Reches, 1983). Major features, such as bedding and faults, show a preferential E-W trend, while fractures display a wide range of strike orientations from E-W to N-S (Figure 3) with the highest frequency corresponding to fractures 2322 almost perpendicular in strike to the

direction of major structures. We differentiate five major regionally systematic phases of deformation, composed of 12 fracture sets. The fracture sets form at both low and high 2327 angles to bedding (NE-SW and NW-SE) (Figure 2371 3c) and occur in all the sites over the quarries 2328 within the Khao Khad Formation. When 2372 2329 2373 plotted (Figure 4), the data reveal two main 2330 2374 arrays, one with a high-angle to the average 2331 dip direction of bedding, and a second array, 2375 2332 oblique to the average dip direction of 2376 2333 bedding. When close to inter-layered shale, it 2377 2334 is difficult to identify clear patterns in the 2378 2335 fracture orientations throughout the KKFTB, 2379 2336 or, at a smaller scale, to follow them over the $_{2380}$ 2337 same layer, because of intensive dissolution 2381 2338 (burial pressure-solution), which significantly 2382 2339 affected the thickness of the bedding. In some $_{2383}$ 2340 areas, the relationship to local and regional 2384 2341 structures is uncertain as a result of these 2385 2342 conditions. Field evidence also shows that the 2386 2343 carbonate layers of the Khao Khad Formation 2387 2344 are often interlayered with thin shale layers. $_{\ensuremath{\text{2388}}}$ 2345 In these cases, veins and joints developed 2389 2346 2347 within a single bed and joint/vein spacing 2348 increases with the increasing bed thickness. 2390 We observe two systematic fracture sets 2391 2349 2350 trending 015° to 050° (Figure 4) throughout 2392 2351 the entire area, both before and after 2393 2352 unfolding. 2394

2353 4.1. Fracture data processing

2397 Regional fracture sets were identified based 2354 2398 on common ranges of strike and dip angle 2355 2399 from 7 processed and interpreted guarries. 2356 2400 2357 Fracture data were isolated to time and space 2401 clusters to reveal natural fracture trends that 2358 2402 were not easily identified in a single stereonet 2359 2403 (Figure 3c) with all fracture data. A large 2360 2404 number of natural fractures appeared to 2361 2405 converge to the same direction after isolating 2362 2406 data by quarry; however, in each stereonet 2363 by ²⁴⁰⁷ removed 2364 bedding dip angle was 2408 stereographic rotation to align fracture planes 2365 2409 with a specific fracture set geometry. The 2366 2410 members of a fracture set share a similar 2367 2411 2368 strike and dip relative to the bedding, each 2412 group has been estimated using a normalised 2369 2413 kernel (Long and Billaux, 1987). 2370

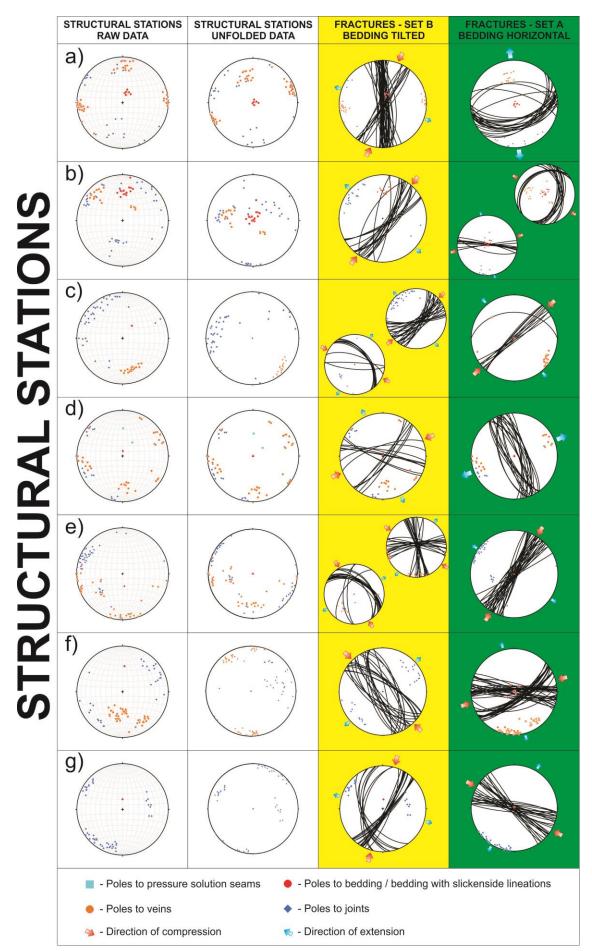
4.2. Sequence of fracture development

Here we illustrate the analyses of the fracture data, the raw data along with their description in terms of statistically defined mean sets.

The first deformational phase is composed of Set-AI (65°/150°) and Set-AII (65°/175°) (Figure 4d). These two fracture sets have a more restricted occurrence than other sets, they trend 160° are at a high angle to bedding, and are mostly joints that are partially to totally (veins) filled with coarse calcite. Evidence of fracturing or shearing are both present in thin sections, probably indicative of a Type I opening mode later reactivated with shearing. The relatively narrow strike distribution for fracture Set-AI and AII implies a uniform distribution of minimum stress and a constant position through time of σ_1 .

The second phase of deformation is the most prevalent high-angle array, occurring on most of the ridges on the analysed portion of the KKFTB. Phase 2 consists of two fracture sets: Set-AIII (80°/050°) and Set-AIV (90°/080°) (Figure 4c, e, f). These fracture sets commonly consist of fractures that are several meters long and have high angles of dip. In the field, their deformation mode is quiet difficult to determine, as different fractures show characteristics of either joint and shear band morphology. In some cases, the fractures are open, with or without mineral fillings, and in other cases they stand up from the outcrop with small positive relief. This latter attribute may be related either to cementing (for the case of joints or dilational bands) or tighter packing of calcite grains within the fracture during the shear (for the case of deformation bands). As for fracture sets of the Phase 1, the deformation mode remains uncertain, but in thin section, they appear to have initiated either as simple shear-related deformation bands, or as extensional joints with simple

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2415 Fig 4. Stereonets (performed with Stereonet software [Allmendinger, 2005]) describing the position of the most relevant 2416 structural stations collected in the western portion of the KKFTB (see Figure 1c for location). Each stereonet has been 2417 unfolded for the bedding where the structural station was located. Those unfolding operation revealed clusters of data 2418 with high (green column) and low angle (low angle) with respect to the average bedding. The analyses of the poles to the 2419 main fractures detected within the Khao Khad Fm. show the horizontal and tilted emplacement of the main sets (from NE-2420 SW to NW-SE). The red thick arrows indicate directions of compression (parallel to σ 1), while the blue thick arrows indicate 2421 direction of extension (parallel to σ 3) (a) Quarry W-Bedding 188°/21°, two clear sets: N025° (postfolding SS regime) and 2422 N352° (prefolding extensional regime). (b) Quarry X-Bedding 53°/192°, two sets: N055° (oblique postfolding SS regime) and 2423 N325° (prefolding thrust regime). (c) Quarry FF-Bedding 24°/227°, two sets both prefolding and postfolding N058° SS 2424 regime. (d) Quarry A-Bedding 10°/181°, two clear sets: N051° (postfolding SS regime) and N053° (prefolding extensional 2425 regime). (e) Quarry Z-Bedding 22°/351°, N331° (postfolding SS regime) and N028° (prefolding SS regime). (f) Quarry N-2426 Bedding 49°/185°, N339° (postfolding SS regime) and N078° (prefolding SS regime). (g) Quarry FF-Bedding 20°/179°, N019° 2427 (postfolding SS regime) and N318° (prefolding SS regime).

shear superimposed. Fracture Set-AIII and AIV 2460 1988). In most of the back-limbs their 2428 2429 cross cuts Set-AI and AII in thin section in both 2461 sliding- (Figure 6a) and opening-mode. 2462 2430 Fracture sets of both Phase 1 and 2 range 2463 2431 2432 from being perpendicular to slightly oblique 2464 2433 to the axial trend of the major folds. The 2465 observed partial overlay between joints and 2466 2434 2435 veins (Figure 4b, d) also implies that these 2467 2436 fractures may have initiated as open 2468 2437 fractures, later filled and reactivated as 2469 sheared veins (Figure 6). 2438 2470

2471 2439 The third phase of deformation is not as 2472 2440 pervasive as Phases 1 and 2. The fractures 2473 related to this phase are fracture Set-AV 2441 2474 (40°/050°) and AVI (25°/130°) (Figure 4b, g). 2442 2475 Fracture sets AV and AVI are often associated 2443 2476 with tail cracks (Figure 5d) and Riedel arrays 2444 2477 2445 (R and R'). Those fractures resemble both 2478 2446 joints and deformation bands.

2479 Fracture sets associated with the fourth phase 2447 2480 of deformation are Set-BVII (90°/355°) and 2448 2481 Set-BVIII (85°/030°) (Figure 4a, b, c, d, g). 2449 2482 2450 These fracture sets have similar geometries to 2483 fracture Set-AI and AII, with several meters 2451 2484 long fractures closely spaced and cutting 2485 2452 2453 though several layers of the thick bedded 2486 Khao Khad Formation. Fracture Set-BVII and 2454 2487 BVIII present a steeper dip angle (~85°), are $_{
m 2488}$ 2455 located mostly in highly deformed zones with 2456 2489 linear fracture traces, and they lack tail cracks 2457 2490 and Riedel fractures or other shearing-related 2458 2491 secondary structures (Pollard and Aydin, 2492 2459

deformation mode is difficult to determine in the field. They look like joints in some sites, yet in other sites resemble deformational bands. Several additional sets of veins, mainly bed parallel (flexural slip, reactivation of bedparallel stylolites) or veins associated with enhanced deformation in fold cores (Figure 5a, a'), are associated with folding. The link between high rates of deformation on the hinges, shear and slip along bed-parallel surfaces and compression in non-horizontal layers during folding could be associated with Set-BVIIa striking 250°, dipping 50°, and Set-BVIIIa striking 080° and dipping 60° (Figure 4a). Fractures associated with those two sets are mostly located on the hinges of the folds developed in the KKFTB.

Deformation Phase 5 is associated with two fractures sets; Set-BIX trending 330° and dipping 85°, and Set-BX trending 290° and dipping 80° (Figure 4e, f). These fracture sets are commonly associated with the steeplydipping layers, which are interpreted as the forelimbs of fault-propagation folds (Morley et al., 2013; Arboit et al., 2014). These fracture sets are present in low abundance in the sub-horizontal southern-limbs of the north verging drag folds, with the longest wavelengths, where the bedding curvature or fold amplitude are at a minimum (Figure 7 in Arboit et al., 2014). While the forelimbs preserve the highest frequency of fractures,

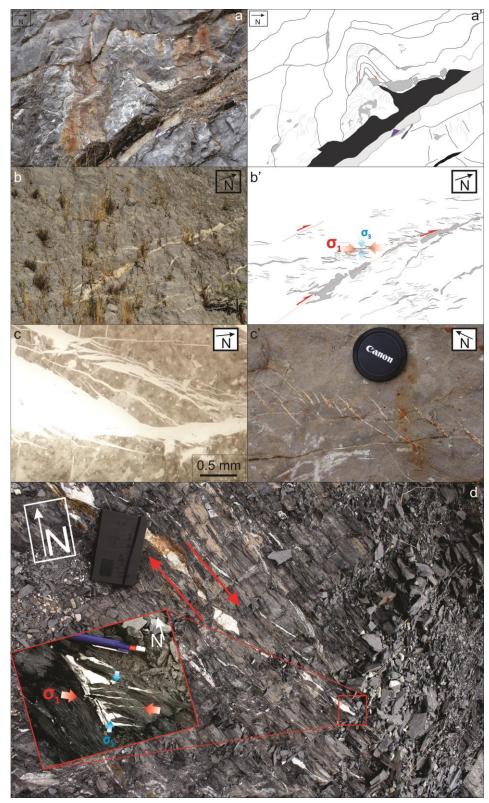


Fig 5. (a) Example of mesoscale chevron fold with veins relative to fold tightening, (a') detail of the deformation: geometries here agree with a progressive evolution of deformation affected a multilayered (fixedhinge) fold, where tangentiallongitudinal strain accumulates in the fixed hinge region and only in the thickest and more competent mechanical layer, while thinnest layers show an higher level of flexural-slip in the libs of the fold. (b) Subhorizontal en-echelon veins possibly occurred during late stage of propagation of the resulted thrust, probably reactivated (188°/47°) during phases of fold tightening (Stage 4); (b') detail of the veins pattern with a subhorizontal σ 1. (c and c') Two examples of shearing at the microscale and macroscale, with respectively sinistral movement lined up on N-S direction showing а crosscutting relationships with NW-SE oriented veins attributable to the fourth deformation phase and a leftstepping tensional gashes showing a dextral movement developed during the fifth deformation phase. (d) Linkage of a sequence of enechelon veins into a shear zone crosscutting N-S oriented veins with NW-SE oriented wing-cracks.

2537 inferring that the fracture sets are induced or 2543 echelon tension gashes (forming a conjugate 2538 at least initiated by folding (Price and 2544 Cosgrove, 1990) (Figure 5c, d). Where possible 2539 2545 2540 to observe, fractures associated with the fifth phase of deformation are represented by $^{\mbox{2546}}$ 2541 2547 right (higher frequency) and left stepping en-2542 2548

pattern).

Fractures that met the geometric criteria (dip angle range/strike) of a given pervasive fracture set before and after stereographic rotation (Figure 4), are often used to relate 2549 the fractures to a pre- and post- tilting origin

(Hancock, 1985; Bellahsen et al., 2006). The 2594 2550 derived sequence of fracturing relies upon 2595 2551 abutment and crosscutting relationships both 2596 2552 2553 at the meso- and micro-scale, starting from 2597 those that apparently initiated before the 2598 2554 early stages (Figure 4, horizontal bedding- 2599 2555 related), and those that developed during and 2600 2556 2557 after the Indosinian Orogeny (Figure 4, tilted 2601 2558 bedding-related). We identify six sets of 2602 fractures that formed when bedding was 2603 2559 horizontal, Set-AI/AII preceding Set-AIII/AIV 2604 2560 2561 and AV/AVI, which clearly abut on, and hence 2605 post-date, sets AI and AII. We also identify 2606 2562 Set-BVII/BVIII as formed during the various 2607 2563 stages of folding and Set-BVIIa/BVIIIa during 2608 2564 2565 late stage of folding. These sets are present 2609 2566 throughout the entire length of the folds but 2610 have the highest frequency in the forelimbs 2611 2567 and in the hinges. Some of the BVII/BVIII 2612 2568 2569 fractures were later reactivated as strike-slip 2613 faults. Set-BIX/BX are sub-vertical in their 2614 2570 2571 present orientation (folded) and cut across all 2615 the previous sets except BVIIa/BVIIIa (where a 2616 2572 2573 relationship isn't seen). Hence, sets BIX/BX 2617 2574 are treated as the youngest set cutting the 2618 2575 carbonates of the Khao Khad Formation 2619 2576 (Figure 6). Fractures associated with shear 2620 2577 displacements in the field, or thin section 2621 (Figure 5c, c', d) demonstrate a bimodal 2622 2578 2579 distribution (Figure 4), suggesting that the 2623 fracture sets in the western portion of the 2624 2580 2581 KKFTB are conjugate arrays (Figure 4). 2625

2582 5. Analysis of fault slip data

The kinematics of the fault population (140 $^{\rm 2628}$ 2583 faults) is described using the calcite and rock $^{\rm 2629}$ 2584 striations and steps observed on the slip $^{
m 2630}$ 2585 planes in several locations across the study ²⁶³¹ 2586 area at various scale (10 cm to 100 m). Their $^{\rm 2632}$ 2587 distribution throughout the western part of 2633 2588 the KKFTB is heterogeneous both in terms of 2634 2589 size and frequency and therefore, to avoid $^{\rm 2635}$ 2590 local heterogeneities, all the slip events have 2636 2591 2637 been grouped in a single stereonet in order to 2592 identify their significance in relation to $^{\rm 2638}$ 2593

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regional-scale stress regimes. As we are attempting fault slip inversion а few assumptions are required. Firstly, the analysed rocks hosting the fractures are considered physically homogeneous and isotropic; i.e., the rock behaves as a rheologically linear material (Twiss and Unruh, 1998). Secondly, displacements on fault planes are assumed to be small with respect to the fault length and there is no ductile deformation of the material and thus no rotation of the fault planes. Thirdly, each tectonic event is assumed to be characterised by a single stress tensor. Finally, the orientation of slip occurs in the sense of the maximum resolved shear stress in order to explain the presence of oblique slip faults, which are incompatible with Anderson's theory. After measuring fault data in the field, this raw assemblage of data (or pattern following the terminology proposed by Angelier, 1994), was divided into sub-sets and used as a starting point for stress inversion. Each sub-set is here defined as a group of faults that moved or have been generated during the same tectonic event. Following Angelier (1994), sub-sets are formed by more than two families of data and each family has been considered a group of brittle data of the same type and with similar geometric characteristics. These preconditions have been necessary in order to find the best solution fitting the observed slip directions and the possible stress tensors that induced these faults. Considering all these preconditions, we carried out a quantitative inversion of all the fault slip data collected within the Khao Khad Formation (Angelier and Mechler, 1977, Lacombe, 2012; Celerier et al., 2012) using the Win-Tensor Software (Delvaux and Sperner, 2003). This inversion has been done in order to obtain data on the stress model (three principal stress axes $\sigma_1 \sigma_2 \sigma_3$ and on the stress ratio 'R'), which minimizes the differences between the observed and the

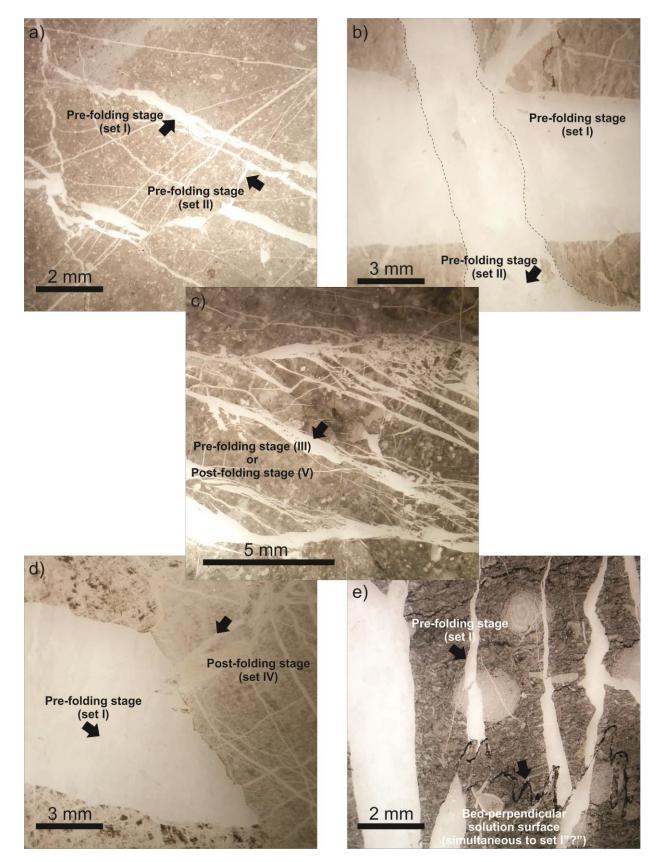


Fig 6. Photomicrographs illustrate the main sets of veins lying within the Khao Khad Formation. It is possible to observe that set I, set III, and dissolution surfaces form crosscutting relationships, their relative ages to be determined. The deformation mode of these fractures remains uncertain, but in thin sections it is possible to observe that they initiated either as simple shear deformation bands (sets II and III) or as extensional joints (set I) later reactivated by shear.

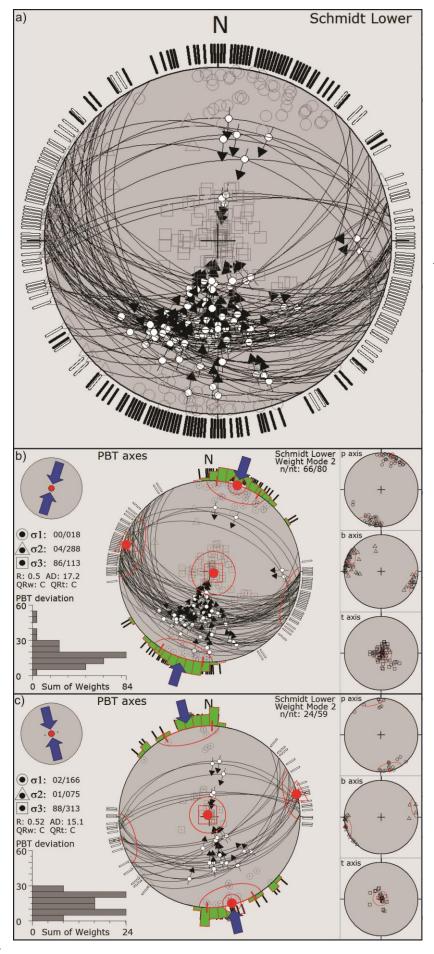


Fig 7. Stereonet (lower hemisphere, equal area projection) (a) illustrating the structural and kinematic data of faults detected in the most significant structural stations in the western portion of the Khao Khwang Fold-Thrust belt. Cluster analysis of the stress axis shows very similar angular deviations and also the presence of two major sets of conjugate compressive faults (both with major compressional and minor strike-slip fault stress regimes) with (b) WNW-ESE and (c) ENE-WSW orientations

predicted slip directions on a set of fault planes. The best fitting models and therefore the quality of the calculated tensors have been chosen based on the minimum difference between the computed shear stress and observed the kinematic indicators on the fault planes. The deformation in the study has been area accommodated by a large number of slip events (140), which have been grouped different into fault populations. The dataset for each fault includes the strike, dip and dip direction of the fault plane; the plunge the azimuth and the sense of shear of the slip lines.

The overwhelming majority of faults (98.8 %), presented here, infer a compressive regime and are observable throughout the entire KKFTB. Fault striae, where observed, indicate a dominant dip-slip sense of movement with reverse offset. Faults cluster 2691 into two distinct populations based on 2714 deformation-twinning in the matrix. In the 2692 orientation and kinematic attitude, striking 2715 2693 from WNW-ESE to ENE-WSW (mean 096°, 2716 range from 053° to 165°), each with dip angles 2717 2694 ranging from quite shallow to steep (30° - 2718 2695 2696 80°). Inversion of the 140 fault slip planes 2719 presented here (Figure 7a) yields two reliable 2720 2697 2698 stress tensors (a) $\sigma_1 = 00/018 - \sigma_2 = 04/288 - 2721$ 2699 σ_3 =86/113, R=0.5 and a "C" quality ranking 2722 2700 with an angular deviation of 17.2° ± 8.6° 2723 2701 (Figure 7b); (b) $\sigma_1=02/166 - \sigma_2=01/075 - 2724$ 2702 σ_3 =88/313, R=0.52, and a "C" quality ranking 2725 with an angular deviation of 15.1° ± 7.5° 2726 2703 2704 (Figure 7c) (Delvaux and Sperner, 2003). 2727

2705 6. Calcite twin data processing

Microstructural analysis has been performed ²⁷³⁰ 2706 on nine oriented samples collected in the ²⁷³¹ 2707 the 2732 Following 2708 Khao Khad Formation. Etchecopar (1984) method, five of these ²⁷³³ 2709 Khad 2734 2710 samples, collected in the Khao Formation, have been used to carry out ²⁷³⁵ 2711 2736 2712 calcite twin analysis. In only two samples is 2737 2713 the cement coarse enough to observe

rest of the samples, data were obtained exclusively from the vein systems cutting the host limestone. For each sample, approximately 100 to 250 calcite grains were studied with the aid of the universal stage microscope. In all the observed twins, the internal twinning deformation occurred in a thin-twin regime (Figure 2), suggesting that temperature remained lower than ca. 150-200 °C, and that internal strain did not exceed 3-4% (Burkhard, 1993). In each of the three perpendicular thin sections per specimen, twinned calcite grains were measured along random traverses of unit length. When more than 30% twinned planes in a sample are not explained by a unique stress tensor, the inversion process is repeated ("b" samples in Table 2) with the uncorrelated twinned planes and the whole set of untwinned planes. This procedure provides an efficient way to separate superimposed twinning events and to calculate related stress tensors where polyphase deformation has occurred 2738 (Amrouch et al., 2010a).

				Trend of the Principal Stress Ax			Ratio					
Stress Stage	Sample Number	Bedding Dip Dir Dip	Vein Dip Dir Dip	σ	σ₂	σ	Between Differential Stress Φ	Number of T/UT Data	Number of Data Consistent with the Tensor T/UT	Quality Estimator function " f "	Pre/Post Folding Setting	Orientation Stress Regime
	T_14_020	174/14	068/88	321/58 302/69*	115/29 121/21*	211/12 210/01*	0.6	211/065	100/016	0.37	Ť	>
I.	T_14_029	352/39	235/80	181/53 285/84*	316/28 321/-01*	058/22 050/03*	0.3	365/106	182/092	0.76		
	T_14_019b	160/40	251/72	283/55 219/56*	139/29 142/-09*	039/17 103/00*	0.4	186/081	052/073	0.50	ŊĊ	
	T_14_029b	352/39	358/82	023/16 023/-18'	290/13	163/69 002/72*	0.4	183/106	069/084	1.80	-FOLDING	M
н	T_14_083b	175/59	HOST	272/33 239/22*	037/41 113/55*	159/31 160/-26*	0.9	166/087	056/080	0.30	ō	
	T_14_018v	160/40	138/25	244/27 228/17	006/47 070/73	136/32 140/-05*	0.8	152/068	057/059	0.67	ш	
	T_14_011b	178/60	HOST	110/33 127/00*	353/36 212/83*	230/38 217/-06*	0.5	249/086	094/075	0.65	PRI	
	T_14_019	160/40	322/71	133/49 142/12*	037/05 047/25*	303/41 255/63*	0.2	273/081	087/069	0.96		
	T_14_018v	160/40	322/71	112/33 121/03*	004/24 025/58*	246/47 213/32*	0.5	223/068	071/057	0.91		
	T_14_011	178/60	HOST	107/34 126/02*	355/29 289/87*	234/42 216-02*	0.5	259/086	103/072	0.85	ļ	~
	T_14_081	175/59	140/78	035/20	275/54	136/29	0.3	306/084	128/068	1.03	, †	K
IV	T_14_082	175/59	217/75	028/08	293/30	131/59	0.1	294/078	117/066	0.81	NG	
	T_14_080b	175/59	255/52	282/36	047/38	165/31	0.8	188/084	072/073	0.53	-FOLDING	
	T_14_081b	175/59	281/42	140/15	024/58	238/28	0.4	178/084	089/076	0.92	ОГ	
v	T_14_082b	175/59	261/49	126/09	351/77	217/09	0.3	177/078	081/072	0.47	Щ,	$\langle \rangle$
v	T_14_083	175/59	045/87	160/15	064/20	284/64	0.6	276/087	110/071	0.95	ISI	
	T_14_080	175/59	337/85	154/26	057/13	303/61	0.7	303/084	115/073	1.14	PO	

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2783 2742 The rocks are effectively unmetamorphosed 2784 2743 and were deformed within five km of the 2785 surface (Morley et al., 2013, Arboit et al., 2786 2744 2745 2014). Therefore a principal stress is required 2787 to be vertical (Anderson, 1905). To satisfy 2788 2746 2747 these criteria, we examined all calculated 2748 tensors in a) their present orientation, and, b) 2789 2749 after bedding was rotated to horizontal. In 2790 2750 cases where unfolding resulted in a principal 2791 2751 stress becoming vertical we assigned the RST 2792 2752 as being active before tilting. In cases where 2793 2753 unfolding resulted in no vertical principal 2794 stress we assigned the RST as being active 2795 2754 2755 after folding. These bed-unfolding calculations 2796 2756 lead us to resolve five different stress tensors 2797 2757 (Table 2); three in a horizontal bedding- 2798 2758 related position and two in the present 2799 2759 position. 2800

2760 6.2. Horizontal-bedding related stress 2802 2761 tensors 2803

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The first calculated tensor (Figure 8T1) found ²⁸⁰⁴ 2762 in samples: T_14_020 / 029 / 019b is related $^{\mbox{2805}}$ 2763 2806 to an extensional event. All the samples 2764 present a vertical σ_1 , the minimum (σ_3) and 2807 2765 2766 intermediate (σ_2) principal stress axes are 2767 approximately bedding parallel, respectively 2808 2768 trending NE-SW and NW-SE. This stress 2809 2769 regime was reconstructed from twinned 2810 2770 calcite collected within bed-perpendicular 2811 2771 veins striking 150° (Set-AI), 170° and 335° 2812 2772 (Set-All) coming from guarries A and N (Figure 2813 2773 1c). 2814

The second RST (Figure 8T2) has been 2774 2816 recorded in samples (T_14_029b / 083b / 2775 2817 018v) collected in quarries B, X, Y in (Figure 2776 2818 1c). This stress tensor corresponds to a strike-2777 2819 slip and compressive regime, both with a 2778 2820 horizontal σ_1 axis oriented NE-SW that trends 2821 2779 2780 ~30° to the mean fold hinge orientation. The 2781 stress tensor corresponding to the third

6.1. Stress tensors from calcite twin data 2782 tectonic event has been recorded by twinned calcite in bed-perpendicular veins striking 050°, 065° (Set-AIII) and 110° (Set-AIV). Sample T_14_029b is the only sample presenting a pure compressive stress regime and has the lowest value of differential stress $(\Phi = 0.368).$

> The last of the bedding-related stress regimes (Figure 8T3) was reconstructed in samples coming from quarries AA and FF (Figure 1c). This RST has been reconstructed including both strike-slip and compressional regimes, it shows a consistently horizontal σ_1 oriented approximately 300°, a horizontal σ_3 in samples T_14_011b / 011 / 018v oriented 215°, and a horizontal σ_2 in sample T 14 029 trending 255°. This stress tensor has been recorded in both the matrix of the Khao Khad carbonates and from veins striking 050° (Set-AV) and 145° (Set-AVI). The stress ellipsoid shape ratio (Φ) in sample T 14 019 is close to 0, this indicates similar magnitudes for σ_2 and σ_3 , hence stress permutations are likely, swapping between compressional and strikeslip regimes

6.3. Tilted bedding related stress tensors

The fourth twinning event (Figure 8T4) is related to both a compressional and a strikeslip regime with a low-angle σ_1 axis trending NE-SW. This RST was found in bedperpendicular veins striking 355° (samples T 14 082 / 080b, Set-BVII) and 045° (sample T 14 081, Set-BVIII). The ellipsoid shape ratio in sample T_14_082 has a value close to zero (Φ =0.135), which indicates that σ_2 and σ_3 are similar magnitudes. Therefore little stress permutations are required to switch between strike-slip and compressional regimes. The σ_1 axis in the fourth tensor is oriented NE-SW (similarly to the second stress regime), which

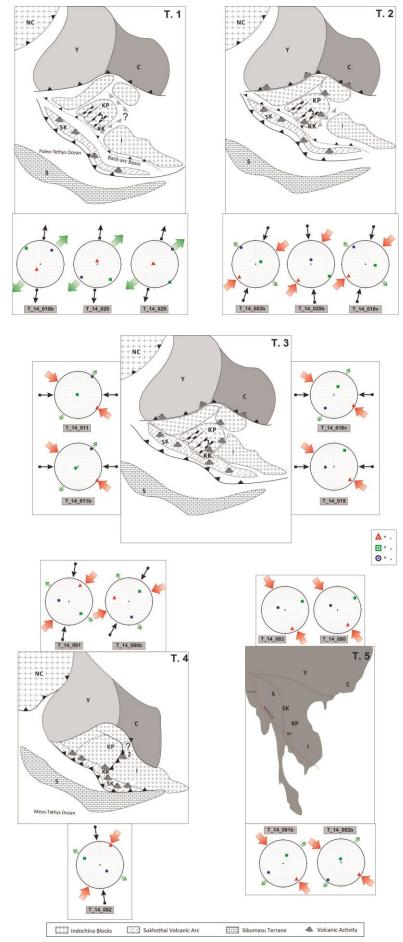


Fig 8. Paleostress orientations related to the Indosinian Orogeny derived from calcite twins. Image illustrates the five different stages of deformation inferred from the twins, The thick arrows reveal the actual calculated stress orientation, and the thin (black/white) arrows display the data corrected to an interpreted original orientation prior to the Late CretaceousPaleocene rotation. Stress data are superimposed on the reconstruction of the plate tectonic evolution of the SE Asia during Late Permian-Early Triassic (T1, T2, and T3) and Mid-Late Triassic (T4), and Late Mesozoic-Early Cenozoic (T5). Modified from Arboit et al. [2014] and Morley et al. [2013]; NC = North China, Y = Yangtze Block, C = Cathaysian Block, I = Indochina Block, KP = Khorat Plateau, KK = Khao Khwang carbonate platform, SK = Sukhothai Terrane, 1 = rift related Permian Basin in the Khorat Plateau, 2 = possible minor suture zone running on edge of the Khorat Plateau.

is almost perpendicular to the fold axes of the major folds. The samples that yield this tensor occur where macroscopic deformation is most intense, such as between closely spaced thrusts and on the steep forelimbs of tight fault-propagation folds or buckled chevron folds (Arboit et al., 2014).

The last of the tilting-related stress tensors (Figure 8T5) has yielded both strike-slip and compressional stress regimes, with a horizontal σ_1 oriented ~145°. The compressional regime was reconstructed in veins striking 330° (samples T_14_081b / 082b, Set-BIX). The strike-slip regime was found in bedperpendicular veins 2870 **7. Discussion**

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7.1. Comparison of macroscopic

microscopic paleostress analysis

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and

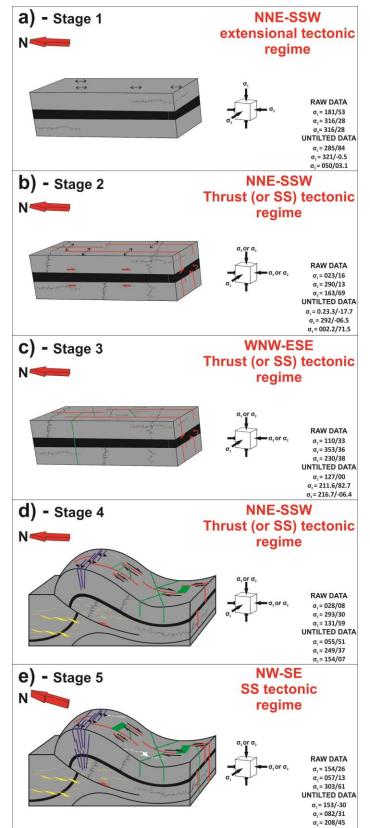
The inversion, and the efficiency of the $^{\ensuremath{\text{2918}}}$ 2873 2919 inversion, of fault slip data have been 2874 2920 extensively debated by several authors (e.g. 2875 2921 Angelier, 1984, 1990; Lacombe, 2012). In 2876 2922 order to make a comparison between the 2877 2923 stress tensor calculations from fault-slip 2878 inversion and calcite twin analysis, it is 2924 2879 needed to estimate the possible margin of ²⁹²⁵ 2880 error in both paleostress determination 2926 2881 2927 techniques. The major source of uncertainties 2882 for striated faults lies in the data acquisition, ²⁹²⁸ 2883 it is important that the number of faults per $^{\mbox{2929}}$ 2884 station is large enough (15-200), and fault ²⁹³⁰ 2885 orientations are sufficiently variable to be ²⁹³¹ 2886 statistically valid. Conversely, for calcite twin $^{\ensuremath{\text{2932}}}$ 2887 analysis, Lacombe et al. (1990) demonstrated ²⁹³³ 2888 that 90 twins per sample is required to ²⁹³⁴ 2889 2935 remove the possibility of any inversion error 2890 and that the main source of error of this 2891 2936 technique lies in the preparation of the thin-2892 2937 2893 section and U-stage measurements. We 2938 therefore assert that, considering the quantity 2939 2894 and quality ("f" function ranging between 0.3 2940 2895 and 1.8 in Table 2) of the data presented here, $_{2941}$ 2896 the calculated paleostress tensors from the 2942 2897 calcite twin analysis are likely to be reliable 2898 2943 (Table 2). Following the previous works of 2944 2899 Lacombe et al. (1992; 2007) and Amrouch et 2900 2945 al. (2010), calcite twins and mesoscale 2901 2946 kinematic features, such as faults, veins, joints 2947 2902 and cleavage surfaces, are expected to show 2903 2948 regionally consistent results in term of 2904 2949 2905 paleostress-orientation. To test this assertion, 2906 we calculated the misfit angles between the 2950 2907 best-fitting shear stress direction and the 2951 2908 measured lineation for each of the considered fault planes, the ratio between the number of $^{\rm 2952}$ 2909 data used to generate the tensor versus the $^{\ensuremath{\text{2953}}}$ 2910 number of inputted data—"n/nt" (0.90 in $^{\rm 2954}$ 2911 Figure 7b) (0.41 in Figure 7c), the dispersion of 2955 2912 planes— "Plen" (0.91 in Figure 7b) (0.83 in $^{\rm 2956}$ 2913

Figure 7c), and the dispersion of slip-lines-"Slen" (0.9 in Figure 7b) (0.84 in Figure 7c) for each identified stress state. To calculate the RSTs using the calcite twin inversion method, we considered different parameters in order to evaluate the reliability for each RST. In particular, we used the ratio of the number of twinned and untwinned planes consistent with the stress state of interest compared to the total number of twinned and untwinned collected for each sample. If this ratio gets large (Jaya and Nishikawa; 2013), then the proposed RST is viable. Twinned planes (up to 51%) and untwinned (up to 92%) are compatible with the proposed stress state, while 40-83% of the total number of faults are suitably oriented for motion under the identified stress state. The high number of untwinned planes consistent with the tensor in sample T_14_029b (Table 2) is most likely the reason behind the high value of the quality factor.

Taking into account the uncertainties inherent in paleostress orientation determination (5-10°) (Lacombe et al., 1992), the deviation in order of ~5°-15° between the meso- and micro-scale paleostress inversion presented in this study is considered acceptable and may be justified in terms of local stress perturbations or inhomogeneities in the rocks. Figure 9 illustrates that, despite the complexity of the tectonic framework within the KKFTB, all the paleostress indicators, from fault striae, fractures, and calcite twin analysis, yield very similar σ_1 orientations supporting the validity of the approach.

7.2. Reconstruction of pre-deformation tensor orientation

The paleostress tensors determined here are reconstructed in their present-day orientation. However, in this tectonically active region, rotations of the analysed terranes are likely to have occurred since



2957Figure 9. Conceptual models of deformation stages and
fracture formation within the Khao Khad Formation
compared with the orientation and regimes of the
calculated stress tensor for each stage of deformation,
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involving prefolding and postfolding structural element
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formation of the rock. Recent results on the geodynamic evolution in SE Asia, demonstrates that the block north of the Mae Ping Fault (including the KKFTB) underwent approximately 150 km sinistral translation after Late Cretaceous times; an amount consistent with paleomagnetic results obtained from the Khorat Plateau that demonstrate a clockwise rotation of about 25° - 30° (Charusiri, 2006; Cung and Geissman 2013; Morley et al., 2013; Singsoupho et al. 2014). To account for this, the subsequent discussion, on the fractures, faults and calcite twins derived RSTs (including Figures 8 and 9) will take this 25° - 30° rotation into account.

7.3. Correlating palaeostress determinations with tectonic environment

Based on the results of previous studies regional tectonics and on paleogeographic reconstructions of SE Asia (Helmke and Lindenberg, 1983; Helmke, 1985; Mitchell, 1989; Metcalfe, 1990; Metcalfe, 1991, Metcalfe, 2000; Metcalfe and Sone, 2008; Metcalfe, 2011; Morley, 2002; Morley, 2004; Morley et al., 2007, Morley et al., 2013), the Permian-Recent history of Thailand with Early-Mid began Permian subduction of Paleo-Tethys underneath the south-western margin of Indochina. This initiated upper-plate extension and subsequent contraction as a back-arc basin first opened, then closed as the arc (represented by the Sukhothai terrane) collided with Indochina. This

3002 contractional event was followed by the Late 3003 Permian – Early Triassic collision between 3004 Sibumasu and the Indochina Block, which 3005 during the Mid-Late Triassic itself collided 3006 with South China (Cathaysia) to form a large 3007 amalgamated continent. The next major 3051 acted in a more ductile manner, dominantly deformation to affect the region after the 3052 3008 3009 Indosinian occurred in the Cenozoic, where 3053 3010 extensive Cretaceous-Paleocene 3054 S-type 3011 granites in Myanmar and Thailand (Morley, 3055 3012 2004) are associated with upper-crustal 3056 3013 deformation (Mae-Ping and Three Pagodas 3057 3014 fault zones). The KKFTB lies close to the trace 3058 3015 of the Mae-Ping Fault, so we expect to see 3059 3016 deformation, in the form of meso-scale faults

3060 and calcite twins, in the KKFTB limestones. 3017 3061

3018 The stress states determined here are 3062 3019 characterised by an initial NE-SW oriented σ_3 3063 3020 with a vertical σ_1 , followed by four later stress 3064 3021 tensors that share a horizontal σ_1 direction 3065 3022 (oriented variously NE - SW to WNW - ESE) 3066 3023 and vertical to moderately plunging σ_2 and σ_3 3067 3024 with variable stress ratios. These stress states 3068 3025 are consistent with an early extensional event 3069 3026 followed by contractional (thrust or strike- 3070 3027 slip) tectonic regimes. Between these five 3071 3028 different tectonic regimes; four are 3072 3029 interpreted to belong to the Indosinian 3073 3030 Orogeny, while the fifth has been attributed 3074 3031 to Cenozoic deformation that affected SE Asia 3075 3032 during the India-Asia collision. These five 3076 3033 tectonic systems have been recorded by 3077 3034 structures both at the macro- and micro-scale, 3078 3035 which are respectively represented as major 3079 3036 anticlines and calcite twins. We present 3080 3037 conceptual block models to illustrate the 3081 3038 fracture evolution within the KKFTB (Figure 9). 3082 3039 These models are composed of three layers, 3083 3040 idealized from the stratigraphy of the Khao 3084 3041 Khad Formation (Figure 1), including a black 3085 3042 layer representing the shale between two 3086 gray layers representing limestone, which, 3087 3043 3044 being relatively stiffer (higher Young's 3088 3045 modulus), can support greater amounts of 3089 3046 stress than softer layers when subject to same 3090 3047 effective stress. The limestone layer of the 3091 3048 Khao Khad Formation responded to the stress 3092 by fracturing (Figure 6a, b and e) and shearing 3093 3049 3050 (Figure 6a, c and d), while the black layers 3094

by plastic flow (detachments), resulting in a less fractured framework (Nelson and Hillis, 2005). The bedding parallel slip at the interfaces between the ductile and brittle layers played an important role for the stress distribution (Cooke and Underwood., 2001; Sanz et al., 2008). The stress tensors that resulted in the deformation observed are:

1- Fracture Set-AI/AII (Figure 4d Set-A) along with RST obtained from samples T_14_020/029/019b are consistent with a pre-folding extensional stage (Figure 9a) with a vertical σ_1 and an almost N-S oriented σ_3 . The minimum principal stress lies in the plane of the bedding and is oriented ~N-S, subperpendicular to the trend of the KKFTB (T1 in Figure 8). These fracture sets pre-date all the other detected fracture sets as suggested by few macroscopic and microscopic observations along with calcite twin analysis. We suggest that this deformation reflects 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 KKFTB lies close to the Nan Suture (Figure 1a), which is a narrow zone of Permian ophiolites and melange, and is associated with the back-arc basin between the Sukhothai and Indochina terranes. A K/Ar actinolite age of 269 ± 12 Ma (i.e., Middle/Late Permian) (Barr and Macdonald, 1987) was obtained from mafic schists in the Pha Nom Complex, within the Nam Suture (Barr et al., 1985; Singharajwarapan and

3095 Berry, 1993, 2000; Sone and Metcalfe, 3139 3096 2008). This infers that the back-arc 3140 3097 basin related extension predated ca. 3141 3098 269 Ma. 3142 3143 2- Fracture Set-AIII/AIV (Figure 4c, e, f 3099 3144 Set-A) along with some calcite twin 3100 3145 results, yielding paleostress tensors of 3101 3146 both strike-slip and pure compression, 3147 3102 3103 from the samples 3148 T_14_029b/083b/018v are consistent 3104 3149 3105 with а pre-folding compression 3150 3106 (Figure 9b). These yield N-S oriented 3151 σ_1 that is perpendicular to the fold-3107 3152 axis and is interpreted as related to 3108 3153 the first phase of the Indosinian 3109 3154 3110 collisional event (Indosinian ^{I)} 3155 between the Sukhothai and Indochina 3156 3111 terranes. This tectonic phase is 3112 3113 interpreted to represent the main 3157 3114 layer-parallel shortening event, and 3158 therefore to be the stress state 3159 3115 3116 responsible for the emplacement of 3160 3117 the KKFTB. The range of orientations 3161 3118 of fracture of Set II is in very good 3162 3119 agreement with both the fault-slip 3163 3120 and calcite derived stress state. These 3164 3121 suggest a range of shortening 3165 3122 direction from 020° to 340° with a 3166 3123 mean shortening direction of 005°, 3167 3124 which is quite consistent with the 3168 3125 general trend of the major folds in the 3169 3126 western portion of the KKFTB. 3170 3127 Andesite intrusions in the Saraburi - 3171 3128 Khao Yai area post-date major KKFTB 3172 3129 deformation and have recently been 3173 3130 dated as crystallising between 250 3174 3131 and 240 Ma (Morley et al., 2013). This 3175 3132 constrains the timing of this stress 3176 3133 tensor to occurring in the Late 3177 3134 Permian-Early Triassic. This collision is 3178 3135 thought to have affected the entire 3179 Indochina Block. In the sub-surface of 3180 3136 3137 NE Thailand there is a major regional 3181 3138 unconformity, which was clearly 3182

established by the uplift and the consequent erosion associated with major compressional deformation of the Saraburi Group (Booth and Sattayarak, 2011) at around the Permian – Triassic boundary. The RST is here presented by three tensors, two of them with σ_2 close to vertical, indicating a strike-slip fault stress regime. The apparent interchange between the vertical stress being σ_2 or σ_3 is likely due to the similarity in magnitude of these stresses during the Indosinian I event. Similar results were found in the calcite twin analysis study of the Sheep Mountain Anticline (Wyoming, U.S.A.; Amrouch et al., 2010a).

3- Fracture Set-AV/AVI is represented by veins and joints that formed in both pure compressional and strike slip regimes (Figure 4b, g Set-A). These E-W represent an oriented compressional (Figure 9c), strike-slip fault stress regime, which could represent either a pre- or syn-folding event. The σ_1 direction is almost parallel to the main fold axes of the KKFTB. This regime may reflect stress evolution during the early Indosinian Orogeny. However, Lepvrier et al. (2004) and Morley et al. (2013) suggested the possibility that the Indochina Block was actually more than one continental terrane before the "Indosinian I" Orogeny. They suggested that an intra-Indochina ocean may have closed during the main phase of the "Indosinian I". The tensor described here would be in a favourable orientation to result from the closure of this proposed ocean. Clearly a wider, more regional, view is needed before this RST is attributed

3183 to a specific tectonic event. The Ailao 3227 Shan region lies 800 km NE of the 3228 3184 3185 KKFTB. Here, outcrops of mafic and 3229 ultramafic rocks have led various 3230 3186 3187 authors to interpret this as a suture 3231 al., 3188 zone (Tapponier et 1990) 3232 3189 associated with the collision between 3233 3190 Indochina and South China (Cai et al., 3234 3191 2009). This collision is thought to have 3235 3192 started as a south-directed oceanic 3236 3193 subduction beneath Indochina, which 3237 3194 has been interpreted to have been 3238 3195 active at ca. 236 Ma, based on 3239 ⁴⁰Ar/³⁹Ar dating (Maluski et al., 2001). 3240 3196 3197 Syn- to post-tectonic granites have 3241 been U-Pb zircon dated to ca. 252-245 3242 3198 3199 Ma dating the major compression in 3243 the region (Halpin et al. in press). This 3244 3200 3201 is consistent with the orientation and 3245 3202 timing of the third RST. 3246 3247

4- The Indosinian event also probably 3248 3203 marked the emplacement of fracture 3249 3204 fractures, 3250 3205 Set-BVII/BVIII. These 3206 ranging in orientation between 355° 3251 and 030°, are similar in orientation to 3207 3252 3208 Sets-AI/AII. However, these fractures 3253 are clearly shear fractures (Type 3). 3254 3209 The similarity between these fracture 3255 3210 3211 sets suggests that many of the 3256 fractures belonging to Set-AIV are 3257 3212 reactivated fractures emplaced during 3258 3213 the early stages of the Indosinian 3259 3214 orogeny. In such a case, sets of the 3260 3215 fourth deformation phase in those 3216 3261 3217 parts of the KKFTB with near 3262 horizontal bedding could not always 3218 3263 be distinguishable from fractures 3264 3219 active during the second phase of the 3265 3220 Indosinian orogeny. In most cases, 3266 3221 fractures 3267 3222 though, Set-BVII/BVIII consistently abut fractures of the 3268 3223 second deformational phase. This 3269 3224 later stage of the Indosinian Orogeny 3270 3225 is further represented by fracture Set- 3271 3226

BVIIa/BVIIIa (Figure 4a Set-A); indeed, these fractures reflect the increasing intensity of folding. Fracture sets developed during the fourth stage of deformation are interpreted to be associated to the syn-folding bending of the layers. This is because they strike almost parallel to the fold axes and are most abundant in the hinge zones of the tight chevron folds in the core of north-verging faultpropagation folds. There is no clear calcite twin regime detected with this orientation but permutations of σ_1 and σ_2 axes in some of the samples provide an extensional stress regime with a horizontal σ_3 axis oriented at high angle to the major fold hinges T 14 083b/018b). (samples We interpret this resumption of ~N-S compression to correspond to the latest Indosinian Orogeny (Indosinian II). Macro deformation associated with this phase is responsible for the tightening of pre-existing faultpropagation folds and partial of the reactivation fractures developed during the earlier event (i.e. SeAII/AIII fractures). During the latest Triassic, the half-graben basins in the Khorat Plateau (NE Thailand) containing the Kuchinarai Group (Late Triassic) ceased to subside and were structurally inverted. The degree of deformation associated with this event is very much less than that which took place during the earlier Indosinian I event. The conceptual model in Figure 11d shows most of the structural events that occurred in the latest stages of fold growth. Indeed as the dip of the fold limbs increased, flexural-slip processes are interpreted to decrease until fold curvature could not accommodate

3272 more shortening. When limb dips 3316 3273 increase to a maximum for flexural 3317 3274 slip amplification (almost 60° as in 3318 Figure 5a and a'), further stress and 3275 3319 on slip 3276 shortening driven bv underlying thrust faults (Figure 5b and 3277 3320 3278 b') is accommodated by deformation 3321 3279 structures cross-cutting the layers. 3322

3323 3280 5- The last fracture Sets BIX/BX are 3324 interpreted as the only fracture sets 3281 3325 not related to the Indosinian event. 3282 3326 Both fractures and calcite twins 3283 3327 recorded a consistent post-folding 3284 3328 relationship for the RST. The vertical 3285 3329 stress vector was σ_2 and σ_1 was 3286 3330 oriented NW-SE, consistent with the 3287 3331 rupture of post-folding E-W oriented 3288 3332 strike-slip faults (Figure 9e). These 3289 3333 strike-slip faults were detected in the 3290 3334 field (Figures 5d; 6c), and calcite twins 3291 3335 from ~150° striking veins, (samples 3292 3336 yielded T 14 081b/082b/08/080) 3293 3337 results consistent with this stress 3294 3338 state. We consider that these fracture 3295 3339 sets represent the last event because 3296 3340 3297 of the strike slip faults deforming the 3341 region, which have similar orientation 3298 3342 3299 to Sets-BIX/BX, and cross-cut previous 3343 3300 structures emplaced during the main 3344 Orogeny. These age 3301 Indosinian 3345 constraints limit these sets and their 3302 3346 relative stress field to being post-3303 3347 Triassic). 3304 Indosinian (i.e. post 3348 However, the modern stress tensor 3305 3349 has a similar orientation to the fifth 3306 3350 RST detected by calcite twin analysis, 3307 3351 with the modern maximum horizontal 3308 3352 stress ranging from N-S to NW-SE 3309 3353 (Tingay et al., 2010). The modern 3310 3354 stress field has been responsible for 3311 3355 the nearby continental-scale NW-SE 3312 3356 to NNW-SSE oriented Mae Ping Fault. 3313 3357 We therefore assert that this stress 3314 3358 tensor might represent Cenozoic 3315 3359

deformation related to the India-Asia collision.

7.4. Variations in the ellipsoid stress ratios 'Φ'

There are a variety of phenomena which may be invoked in order to account for variability of the ellipsoid stress ratio. Stress permutations (between σ_1 and σ_2 , or σ_2 and σ_3) are common in brittle tectonics at local and regional scales (Angelier et al, 1984; Angelier, 1994; Hu and Angelier, 2004; Amrouch et al., 2010a; Tavani et al., 2015). The results shown in Table 2 illustrate such interchangeable position between σ_2/σ_3 ($\Phi <$ 0.3) and between σ_1/σ_2 (Φ < 0.7). Such permutations may induce apparent complexity with several paleostress patterns for a single tectonic event. The origin of these permutations may result from a variety of causes, which can be classified into two groups. The first group involves actual modifications in the stress field induced by far-field changes; e.g., plate motion changes, or local conditions that affect the vertical stress (erosion, burial, elastic rebound, Garcia et al., 2002) and stress relaxation (Du and Aydin, 1996). The second group involves little change in tectonic environmental conditions and is mainly controlled by ongoing brittle deformation inducing stress changes; e.g., stress drop, which may depend on the rheological properties of the affected rock masses (Hu and Angelier, 2004) or an abundance of meso-scale reverse faults versus strike slip faults, pressure solution cleavages and veins (Tavani et al., 2006, 2015), dike injections, and accommodation around tilted blocks. Another possible interpretation is an evolution of the same stress tensor, with the conversion from σ_3 and σ_2 as an effect of transpressive stress partitioning related to the opening of the veins with an orientation of about 50° (80°-90°) with respect to the orientation of σ_1

3360 (Evans and Dunnet, 1991; Jones and Tanner, 3403 In this study, we have performed qualitative3361 1995).3404 and quantitative tectonic analysis of the

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33627.5. Localstressperturbationand34063363regional stress orientations3407

3408 As discussed above all the analysed structural 3364 features (fractures, faults and calcite twins) $^{
m 3409}$ 3365 provide related information on the stress 3410 3366 evolution history of the western portion of $^{\rm 3411}$ 3367 the KKFTB, revealing predominant pre-folding $^{\rm 3412}$ 3368 compressional stress regimes and post-folding ³⁴¹³ 3369 strike-slip regime. The ellipsoid shape ratio of 3414 3370 3371 the two stress tensors reconstructed from $^{\rm 3415}$ fault-slips are near homogeneous; however, ³⁴¹⁶ 3372 3417 some of the samples used for the calcite twin 3373 analysis show stress permutations, this ³⁴¹⁸ 3374 suggests that these RST calculated with calcite $\,^{3419}$ 3375 3376 twins, using different samples, for the same 3420 event might have recorded different stress $^{\rm 3421}$ 3377 σ₂-σ₃). 3422 (permutation 3378 regimes $\sigma_1 - \sigma_2;$ Consideration should be paid to the change in 34233379 scale, indeed the volume of rock examined 3424 3380 using fault-slip analyses is much higher (10^3 to 3425 3381 $10^6\mbox{ m}^3\mbox{)}$ than the volume of rock used for 3426 3382 reconstructing paleostress using calcite twins ³⁴²⁷ 3383 (10^{-3} m^3) (Lacombe et al., 1992). Barquins et 3428 3384 al., (1989a) and Petit and Barquins (1990) 3429 3385 demonstrated that the shape ratio may vary 3430 3386 near to pre-existing defects. Hence, stress ³⁴³¹ 3387 methodological 3432 perturbation and the 3388 uncertainties discussed above, may justify the ³⁴³³ 3389 differences in the values of ratio (Φ) obtained ³⁴³⁴ 3390 from fault slips and calcite twin analyses, in a 3435 3391 given site for a specific tectonic event in a 3392 3436 complex structural setting. Fortunately, this 3393 3437 variability does not reduce the efficiency of 3394 3438 paleostress indicators in terms of orientation, 3395 3439 because it has almost no influence on the 3396 3440 orientations of the reconstructed 3397 RSTs 3441 (Lacombe et al., 1992). Thus the regional 3398 3442 stress history reconstructed and obtained 3399 3443 3400 from calcite twins and fault-slips can be 3444 3401 considered reliable. 3445

and quantitative tectonic analysis of the brittle deformation at meso- and micro-scales in order to unravel the distribution of the stress in space and time before and after the main folding event in the KKFTB. This has been possible due to the strain acquisition in the folded strata and the stress build-up in the carbonate layers of the Khao Khad Formation. The analyses yielded reliable paleostress states similar and consistent with those from and fracture data collected fault-slip throughout the western margin of the KKFTB. At the meso-scale, the observed fracture population are gathered into six different sets formed during five main events that are interpreted to be developed during the Indosinian I & II tectonic events and subsequent Cenozoic deformation. At the scale of the western margin of the KKFTB, the comparison of major structures, such as major folds, fracture patterns, and the RSTs derived from the calcite twin inversion for each of the detected events demonstrate a consistent record of the tectonic stresses at the scale of the entire KKFTB. Dominant and common stress states throughout the whole study area are characterised by a N-S trending σ_1 and vertical, to ENE-WSW plunging, σ_3 with variable values of stress ratio Φ ; which made it possible to link different RSTs obtained with stress tensors coming from distinct samples through σ_1 - σ_2 and σ_2 - σ_3 permutations.

Unfortunately, there synare no deformational sedimentary rocks preserved in the region, restricting the resolution of more precise age constraints on the age of the various deformations. Notwithstanding this, the characteristics of the paleostress regimes, from the calcite twins, and the very good correlation with the distribution of the overall deformation, allowed us to provide a relative chronology of the tectonic events. Calcite 3446 twins revealed significant variations of 3447 paleostress orientation and regime across the 3488 physical properties: a case study at Sheep providing a reliable picture of 3489 3448 KKFTB, paleostress distribution on the edge of the 3490 3449 3450 southern Indochina Block. Beyond regional 3491 1105-1123. 3451 implications, this study enhance the potential 3492 3452 of an analysis based on fault and calcite twin 3493 3453 observations which has the potential to lead 3494 3454 to a more exhaustive understanding of 3495 3455 regional and local stress and stress patterns.

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Detrital zircon analysis of the southwest Indochina terrane, central Thailand: Unravelling the Indosinian orogeny

4001 ABSTRACT

4002 The Khao Khwang Fold-Thrust Belt (KKFTB), central Thailand, developed within a basin that formed 4003 on the southwestern margin of the Indochina block. Because of limited geochronological and 4004 provenance constraints the time of deposition, sediment source location, and tectonic significance 4005 of the basin have been uncertain. Here, we present 837 U-Pb detrital zircon ages and 271 Hf isotope 4006 in-situ analyses from Permian-Triassic clastic units within the KKFTB in order to constrain the 4007 provenance, maximum depositional ages, and depositional environment of the southwestern margin 4008 of the Indochina terrane through the Late Palaeozoic to Early Mesozoic. The key lithological units, 4009 the Sap Bon, Pang Asok, and Nong Pong formations, are part of the Saraburi Group and have detrital 4010 age spectra spanning from Upper Triassic to Palaeoarchean. The entire dataset has a common age 4011 peak at ca. 450 Ma, and all samples contain grains with ages of 0.2-0.3, 0.4-0.6, 1.0-1.3, 1.7-1.8, 2.2-4012 2.7 Ga. A few grains predate 3.0 Ga. Multidimensional-scaling analysis of detrital zircon ages from 4013 throughout SE Asia demonstrate that the age spectra of the siliciclastic units of the Saraburi Group 4014 resemble those of Permian-Triassic detritus found elsewhere in the Khorat Plateau and throughout 4015 Vietnam and southeast China, implying that these areas share similar sources. These sources may be 4016 the, now largely covered, Indochina basement, and/or contiguous continental crust in terranes 4017 already amalgamated to Indochina at that time. Detrital zircons as young as 205 ± 6 Ma show that 4018 some formations of the Saraburi Group, previously considered to be of Middle-Late Permian age, are 4019 no older than Late Triassic. We propose a depositional model, for the region, of a Permian rift or passive margin setting that evolved into piggyback and foredeep basins during an extended period of 4020 4021 folding and thrusting in the Triassic

4022 1. Introduction

4023 The amalgamation of much of east Asia $_{4043}$ occurred in the Permian-Triassic along a series 40444024 4025 of arc-continent and continent-continent 4045 4026 collisions that are collectively known as the $\frac{1}{4046}$ 'Indosinian orogeny' (Carter & Clift 2008). 4047 4027 New work in the region is teasing out the $_{4048}$ 4028 timing and nature of plate interactions 4049 4029 through this period and demonstrating that $_{\rm 4050}$ 4030 the times were particularly dynamic along the $_{4051}$ 4031 west proto-Pacific from Australia to Korea $_{4052}$ 4032 (Cho et al. 2013; Shaanan et al. 2014; Halpin $_{
m 4053}$ 4033 et al. 2014; Dong et al. 2015). Southeast Asia $_{4054}$ 4034 forms part of this end Palaeozoic, earliest 4055 4035 Mesozoic tectonic collage. It is a composite 4056 4036 region of continental crustal segments (Figure 4057 4037 1) that originated along the northern (with $_{\rm 4058}$ 4038 respect to present-day Australia) Gondwana 4059 4039 margin (Cocks and Torsvik, 2013; Metcalfe, 4060 4040

4041 2011). These continental fragments rifted off 4042 Gondwana in the Palaeozoic and were accreted to the growing Asian continent from the Mid Permian to the Late Triassic (Metcalfe, 2013; Morley et al., 2013). The terranes that make up mainland SE Asia, east of Myanmar, include Indochina, Sukhothai, Sibumasu, and South China. In previous studies, early Palaeozoic reconstructions of these terranes were primarily based on magnetic data, palaeo-biogeography, and stratigraphic correlations (Burrett et al., 1990; Metcalfe and Sone, 2008; Sone and Metcalfe, 2008). The different approaches have resulted in significant ambiguity in the tectonic geography of the region throughout this time. For example, the position of Indochina during the Early Palaeozoic differs widely between reconstructions. Torsvik and Cocks (2009) came to the conclusion that both Indochina

4061 and South China were not part of the 4104 4062 Palaeozoic Gondwana margin and already 4105 4063 existed as isolated terranes during the 4106 Cambrian, whereas Burrett et al. (1990), 4107 4064 4065 Metcalfe (2006, 2011a, 2011b) and Usuki et 4108 4066 al. (2013) adhered to an interpretation where 4109 4067 Indochina remained a part of Gondwana until 4110 4068 rifting off in the Palaeozoic. This uncertainty in 4111 4069 the origin of the SE Asian terranes is mirrored 4112 by controversy as to the timing and nature of 4113 4070 4071 the 'Indosinian orogeny', the pan-East Asian 4114 4072 orogeny that evolved during the Late 4115 4073 Palaeozoic and Early Mesozoic and led to the 4116 4074 formation of much of East Asia (Lepvrier et al., 4117 4075 2004; Morley et al., 2013). These issues arise 4118 4076 from the paucity of constraints on the palaeoposition of the SE Asia terranes, the lack of 4119 4077

4120 detailed structural studies regarding thrust 4078 4121 and 4079 direction and timing, transport 4122 uncertainties regarding the dating, location, 4080 4123 4081 tectonic significance and even existence of 4124 suture zones (Metcalfe, 2013; Morley et al., 4082 4125 4083 2013; Gardiner et al., 2015). 4126

4084 The integrated analysis of U-Pb ages and Hf 4127 4085 composition of detrital zircons collected from 4128 4086 clastic sedimentary rock derived from 4129 4087 plutonic, volcanic, metamorphic, or pre- 4130 4088 existing sedimentary rocks, can be used as a 4131 4089 palaeogeographic tool by depositionally 4132 4090 linking a basin to a source region that contains 4133 4091 rocks (or at least minerals) of correlatable 4134 4092 ages and chemistries (Pettijohn et al., 1987; 4135 4093 Collins et al., 2015). This approach, in the SE 4136 4094 Asian region, has been successfully used for 4137 4095 tracing sediment pathways (van Hattum, 4138 4096 2005; van Hattum et al., 2006, Hall et al., 4139 2008; Sevastjanova et al., 2011, Burrett et al., 4140 4097 4098 2014) with the aim of revealing the geological 4141 evolution of the sediment source areas and 4142 4099 4100 constraining the tectonic setting of the 4143 4101 depositional basins. In addition, this approach 4144 4102 provides maximum depositional ages of the 4145 4103 sedimentary rocks in question, constraining 4146

the stratigraphy of the region. The margin of Indochina contains extensively deformed Permian-Triassic carbonates and associated siliciclastic and volcanic horizons (Ueno and Charoentitirat 2011) that were deposited on the passive margin of Indochina as it was inverted and buried by syn-contractional basins (Arboit et al., 2015). Here, we examine the detrital zircon record preserved within siliciclastic units from the fold-and-thrust belt and from directly north of this region, on the southern margin of the Khorat Plateau (Figure 1), to achieve a better understanding of the tectonic geography of this region through its evolving provenance record.

The Saraburi Group comprises a number of formations that are either dominated by carbonate platform deposits (Khao Khad and Khao Khwang formations), or deeper water deposits comprising a mixture of interbedded shale, sandstone, chert, and limestone (Sap Bon, Pang Asok, and Nong Pong formations (Figure 2a). The Permian limestone has been the subject of extensive palaeontological investigations and is well dated (e.g. Toriyama et al., 1974; Toriyama, 1975; Toriyama and Kanmera, 1979; Udchanon et al., 2007; Ueno and Charoentitirat, 2011). However, there has been less success in dating the clasticdominated formations, and their provenance has not been investigated in detail, although the continuation of the Permian units to the north (Nam Duk Formation) was investigated by Malila et al. (2008). Indeed, until now, very little has been known about the provenance and ages of detrital zircons and the change of provenance through time of the basinal formations of the Saraburi Group. In this paper, we discuss U-Pb and Hf-isotope data in detrital zircons from 6 samples collected in the Sap Bon, Pang Asok and Nong Pong formations. We seek to provide a better constraint on the tectonostratigraphic

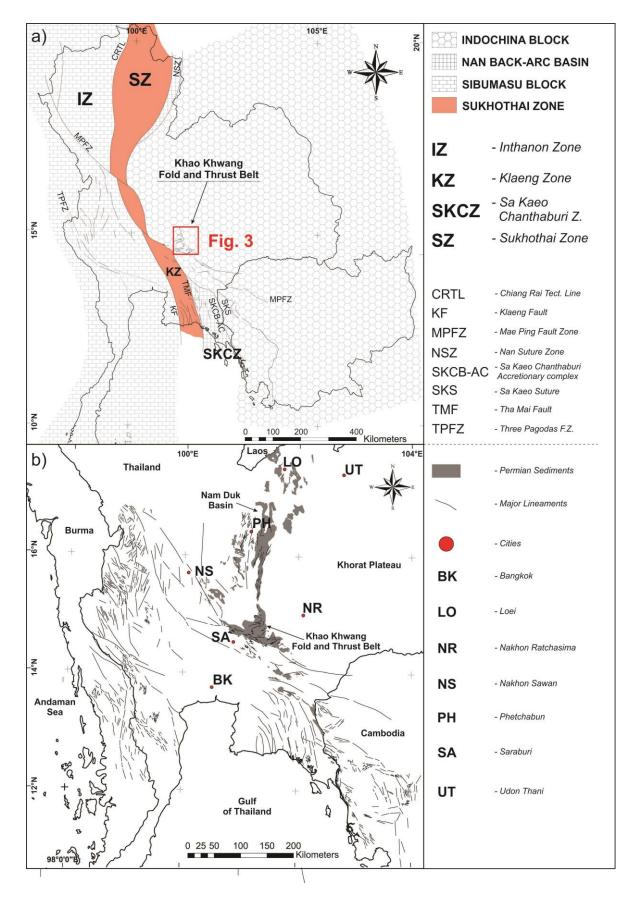




Figure 1. a) Subdivision of Thailand into main tectonic terranes, that amalgamated during the Indosinian Orogeny (modified from Ueno and Charoentitirat, 2011), b) distribution of the major lineaments of the study area (after Arboit et al. 2014).

evolution of the basin that lay in a marginal 4195 the Inthanon Terrane. The Sukhothai Terrane,
position on the Indochina terrane. We go on 4196 which largely corresponds to the Sukhothai
to discuss the implications of these finding on 4197 Zone of Barr and Macdonald (1991) and the
the tectonic and paleogeographic 4198 Sukhothai Fold-Thrust Belt of Bunopas (1982),
reconstructions for Thailand in the context of 4199 is dominated by deformed Palaeozoic to
the overall SE Asia amalgamation.

2. Geological and stratigraphical setting

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of Northern and Central Thailand

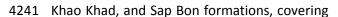
4204 Ueno (1999) and Ueno et al. (2002) proposed 4159 four geotectonic units for northern Thailand $^{\rm 4205}$ 4160 4206 (from west to east): the Sibumasu, Inthanon, 4161 Sukhothai, and Indochina terranes, separated 4207 4162 by the Mae Yuan Fault, Chiang Rai Tectonic $^{\rm 4208}$ 4163 Line, and Nan Suture, respectively (Figure 1a). 4209 4164 Sone and Metcalfe (2008) suggested a similar ⁴²¹⁰ 4165 tectonic scheme. The Sibumasu Terrane is ⁴²¹¹ 4166 Palaeozoic 4212 characterized by an upper 4167 stratigraphy similar to that seen in much of ⁴²¹³ 4168 Gondwana, including a Lower Carboniferous 4214 4169 Lower 4215 4170 Upper Carboniferous to hiatus, with 4216 4171 Permian glaciogenic diamictites 4172 Gondwanan fauna and flora, and Middle– $^{\rm 4217}$ Upper Permian platform carbonates (Ueno et 4218 4173 al., 2010). The Inthanon Zone, originally ⁴²¹⁹ 4174 proposed by Barr and Macdonald (1991), is 4220 4175 characterized by Palaeo-Tethyan oceanic 4221 4176 rocks, pre-Devonian basement rocks, and Late 4222 4177 Triassic and Early Jurassic granitoids, often 4223 4178 deformed into gneiss. The Palaeo-Tethyan 4224 4179 rocks consist of pelagic Carboniferous- 4225 4180 Permian carbonate rocks (the Doi Chiang Dao 4226 4181 Limestone) associated with basaltic rocks (the 4227 4182 basalts and carbonates have been interpreted $_{4228}$ 4183 as forming on seamounts) and Middle 4229 4184 Devonian-Middle Triassic radiolarian chert 4230 4185 (Ueno, 1999; Ueno and Hisada, 2001; Ueno et 4231 4186 al., 2010). The pre-Devonian basement rocks 4232 4187 consist of metamorphic rocks (Dunning et al., 4233 4188 1996), Cambrian sandstone, and Ordovician 4234 4189 limestone, corresponding to component rocks 4235 4190 of the Sibumasu Terrane. The Cambrian 4236 4191 sandstone and Ordovician limestone indicate 4237 4192 that sediments of the Sibumasu Terrane are $_{\ensuremath{4238}}$ 4193 imbricated with Palaeo-Tethyan rocks within 4194

which largely corresponds to the Sukhothai Zone of Barr and Macdonald (1991) and the Sukhothai Fold-Thrust Belt of Bunopas (1982), is dominated by deformed Palaeozoic to Mesozoic sedimentary rocks, volcanic rocks, and Early-to-Late Permian granitoids. The Sukhothai Terrane has been interpreted to represent a volcanic arc developed along the margin of the Indochina Terrane, related to subduction of the Palaeo-Tethys (Metcalfe, 2005; 2006; Sone and Metcalfe, 2008). The Indochina Terrane has remained within the palaeo-equatorial region since its probable Early to Mid-Palaeozoic breakaway from Gondwana. In eastern Thailand, Upper Palaeozoic shallow-marine carbonate rocks, are widely distributed along the margin of the Indochina Terrane. The Nan Suture Zone, besides being considered the closure of the back-arc basin dividing the Sukhothai and the Indochina terranes, hosts the majority of the Permian clastic sedimentary rocks in Thailand, which within the KKFTB are part of the Saraburi Group (Hinthong et al., 1985; Ueno, 1999; Ueno and Hisada, 2001; Ueno and Charoentitirat, 2011).

The basic depositional setting of the Saraburi Group is interpreted as a suite of Permian rift basins on the southern margin of the Indochina Terrane controlled by extensional faults (Booth and Sattayarak, 2011; Morley et al., 2013). These basins have been viewed as simple, large basins and platforms based on outcrop data (Wielchowsky and Young, 1985), but seismic reflection data from the Khorat Plateau area suggests that the stratigraphy is more complex, with rift basins filled with clastics and mixed clastic and carbonate sediments, and small carbonate platforms developed on the intra-rift basin highs (Booth and Sattayarak, 2011). Hinthong et al. (1985) subdivided the rocks, based on stratigraphic relationships, fossils and structures, into six

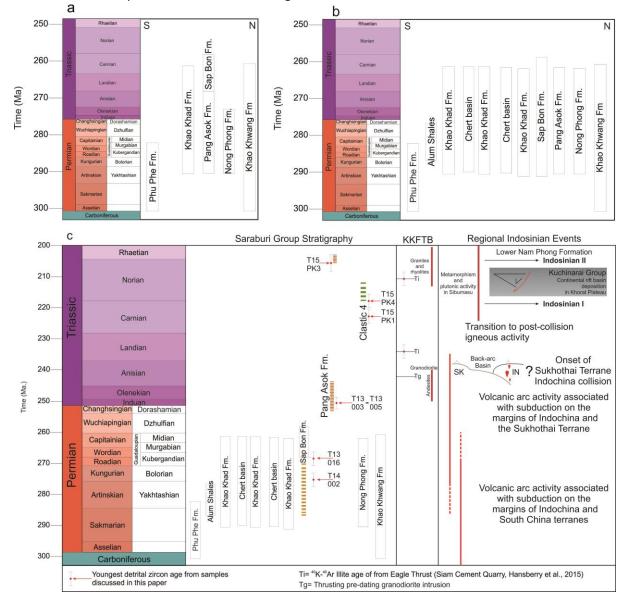
formations, from older to younger, as the Phu 4242 the entire southern limit of the Phetchabun-4239

Phe, Khao Khwang, Nong Pong, Pang Asok, 4243 Saraburi trend (Figure 2a, b).



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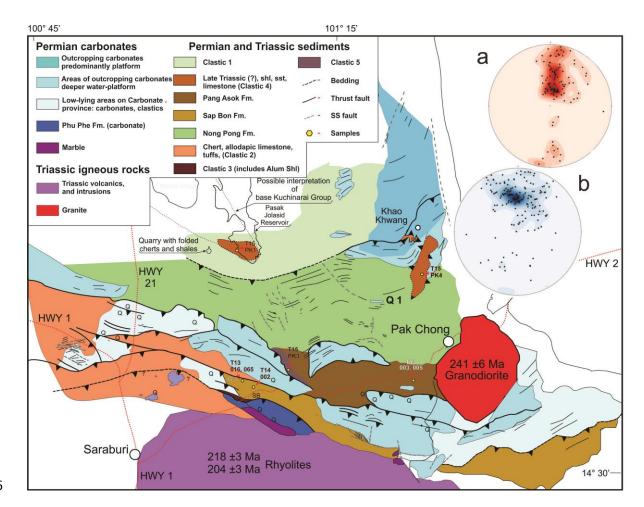
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4245 Figure 2. History of the Saraburi Group stratigraphy. a) Stratigraphy based on Ueno and Charoentitrat (2011), b) Working 4246 stratigraphic model based on fieldwork. c) Modified working stratigraphic model based on the detrital zircon data 4247 discussed in this paper.

4248 Field mapping (Figure 3) shows that the 4257 flow deposits within the deep-water basins. 4249 carbonate platforms pass laterally into the 4258 These relationships indicate that the basinal 4250 mixed clastic and carbonate basinal areas, but 4259 4251 also in places the platforms overthrust the 4260 4252 basinal sequences, and in other places the 4261 4253 basinal sequences overthrust the platforms 4262 clearly more complex than is shown in the 4254 (Morley et al., 2013, Warren et al., 2014; 4263 published stratigraphy (Figure 2a, b), but 4255 Arboit et al., 2014). Permian fusulinid-rich 4264 determining the nature of those relationships 4256 carbonates were also re-deposited as debris 4265 has been problematic due to issues with

areas and carbonates are of approximately the same age, and were stacked up by thrusting. The stratigraphic relationships are



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4267 Figure 3. Geological map of the Khao Khwang Fold and Thrust Belt. It has been modified from Warren et al., (2014) to show 4268 possible interpretations of the stratigraphy as a consequence of this study. (a) Stereonet of poles to bedding for the region, 4269 (b) Stereonet of poles to main thrusts along Highway 21.

4270 dating the clastic sequences. There are two 4286 Zircons grains were separated from six-kg rock distinct kinds of basinal sequence, one is 4287 4271 4272 dominated by chert, with allodapic limestone, 4288 4273 tuff levels and, as described above, it is clearly 4289 4274 contemporaneous with the Permian 4290 4275 carbonate platforms. The other 4276 sequences in the area comprise shale, 4292 sandstone, and in places carbonate rocks and 4293 4277 4278 chert and are not well dated (the Pang Asok, 4294 4279 Sap Bon, and Nong Pong formations). The 4295 cathodoluminescence analyser attached to a 4280 sandstone in these sequences was sampled 4296 Phillips XL20 scanning electron microscope. 4281 for the provenance analysis described here. 4297

4282 **3**. Methodology

4283	3.1.	U-Pb	laser-ab	lation	inductively	4500
4284		coupled	plasma	mass	spectrometry	4301
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samples using standard separation techniques, such as specific-gravity liquid $(\rho \ge 3.2)$ and a Frantz magnetic separator. Hand-picked zircons were then mounted on mixed 4291 2.5 cm-diameter circular epoxy mounts and then polished to expose a section at their inner core. Prior to their analysis the grains imaged Gatan were using а Zircon U-Pb isotope analysis was performed 4298 using LA-ICP-MS at The University of Adelaide 4299 following the method of Payne et al. (2010). 4300 Zircons were ablated with a New-Wave Research UP-213 laser using a spot-size of 30 μ m, a frequency of 5 Hz and intensity of 8-10 4303 J/cm^2 . Isotopic data were acquired with the

4304 Agilent 7500 series Inductively Coupled 4348 Plasma Mass Spectrometer on eight masses: 4349 4305 ²⁰⁶Pb/²³⁸U: ²⁰⁷Pb/²³⁵U: ²⁰⁷Pb/²⁰⁶Pb: ²⁰⁸Pb/²³²U. 4350 4306 Mass discrimination of the mass spectrometer 4351 4307 and elemental fractionation during laser 4352 4308 ablation were corrected by calibration against 4353 4309 4310 the GEMOC GJ-1 zircon with thermal ion mass 4354 spectrometry (TIMS) normalising ages of 4355 4311 207 Pb/ 206 Pb = 607.7 ± 4.3 Ma, 206 Pb/ 238 U = 4356 4312 600.7 ± 1.1 Ma and 207 Pb/ 235 U = 602.0 ± 1.0 4357 4313 Ma (Jackson et al. 2004). The Plešovice zircon 4358 4314 internal standard (ID TIMS ²⁰⁶Pb/²³⁸U age = 4359 4315 4316 337.13 ± 0.37 Ma, Sláma et al., 2008), was 4360 used to assess accuracy before and during the 4361 4317 analysis of the unknowns. Over the course of 4362 4318 4319 the laser session, a total of 110 Plešovice 4363 4320 internal standards analyses were carried out, 4364 and gave a weighted average $^{207}Pb/^{206}Pb = 4365$ 4321 4322 338 ± 18 Ma (MSWD = 0.93), and a weighted 4366 average 206 Pb/ 238 U age = 338 ± 2.7 Ma (MSWD 4367 4323 = 0.95). Data were collected, corrected and 4368 4324 filtered in the GLITTER version 3.0 (Van 4369 4325 Achterbergh et al., 2001) software package. 4370 4326 4327 Concordia diagrams and weighted averages 4371 4328 were calculated using ISOPLOT 4.11 for Excel 4372 4329 (Ludwig, 2009), while probability density and 4373 4330 kernel distributions were created using 4374 DensityPlotter 2.4 (Vermeesch, 2012). 4331 4375

43323.2.Lu/Hf isotopes by laser ablation43764333multicollector inductively coupled43774334plasma mass spectrometry (LA-MC-43794335ICPMS)4380

Lu and Hf isotopic ratios were determined for ⁴³⁸¹ 4336 many of the dated zircon grains using the 4382 4337 (MC)-ICP-MS 4383 multicollector 4338 laser-ablation technique at the Waite (CSIRO) Campus, 4384 4339 South Australia. The laser-ablation system and 4385 4340 4341 procedure for Hf analysis were carried out 4386 4342 only on grains with U-Pb LA-ICP-MS analysis 4387 greater than 90% concordance. Zircons were 4388 4343 ablated within the same CL zone as the U-Pb 4389 4344 data were collected, with a New Wave UP-193 4390 4345 4346 Excimer laser (103 nm) using a spot size of 50 4391 µm, a frequency of 5 Hz, a 4 ns pulse length 4392 that was derived from a depleted mantle. For 4347

and an intensity of 8-10 J/cm². Zircons were ablated in a helium atmosphere, which was then mixed with argon upstream of the ablation cell. The attached Thermo-Scientific Neptune Multi-Collector ICP-MS measured ¹⁷¹Yb, ¹⁷³Yb, ¹⁷⁵Lu, ¹⁷⁶Hf, ¹⁷⁷Hf, ¹⁷⁸Hf, ¹⁷⁹Hf and 180 Hf on Faraday detectors with 1011 Ω amplifiers. A 0.232 s integration time was used with a total analysis time of 1-3 minutes. Hf mass bias was corrected using an exponential fractionation law with a stable ¹⁷⁹Hf/¹⁷⁷Hf ratio of 0.7325. Yb and Lu isobaric interference on ¹⁷⁶Hf were corrected by using the methods of Woodhead et al. (2004). ¹⁷⁶Yb interference on ¹⁷⁶Hf was corrected for direct measurements of the Yb fractionation using measured ¹⁷¹Yb/¹⁷³Yb with the Yb isotopic value of Segal et al. (2003). The applicability of these values were verified by analysing JMC 475 Hf solution doped with varying levels of Yb with interferences up to 176 Yb/ 177 Hf = 0.5. isobaric interference on ¹⁷⁶Hf was Lu corrected using a $^{176}Lu/^{177}Lu$ ratio of 0.02655 (Veevort et al., 2004) assuming the same mass bias behaviour of Yb (Payne et al., 2010). Zircon standards (Mudtank/ Plešovice) were routinely analysed during the analytical session of the unknowns, in order to monitor the accuracy, stability and repeatability of the instruments throughout the session. To calculate model ages (t_{DM}) based on a depleted-mantle source, we have adopted a model with 176 Hf/ 177 Hf= 0.282785 ± 11 and ¹⁷⁶Lu/¹⁷⁷Hf= 0.0336 ± 1; this produces a present-day value of ¹⁷⁶Hf/¹⁷⁷Hf (0.283251). The measured ¹⁷⁶Lu/¹⁷⁷Hf of the zircon are used to calculate the " t_{DM} " ages. These can only give a minimum age for the source material of the magma from which the zircon crystallised. Therefore, we have also calculated, for each zircon, a "crustal" model age (t_{DM}^{C}) in Supplementary Data 2), which assumes that its parental magma was produced from an average continental crust

4393 the calculation of εHf values, we have 4437
4394 adopted the chondritic values of Bouvier et al. 4438
4395 (2008). 4439

43963.3.Multi-dimensional scaling test (MDS)44404397for comparison of the detrital ages4442

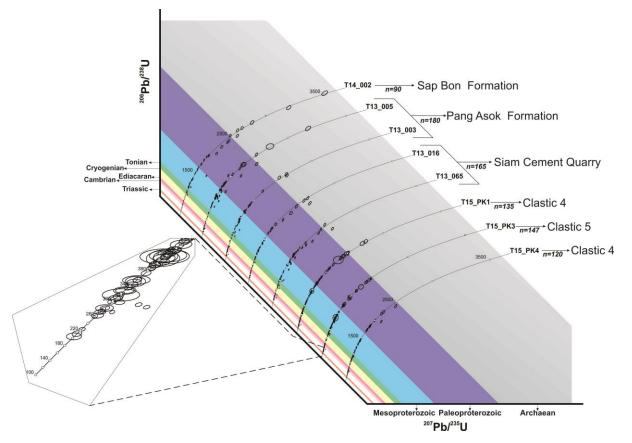
All the samples have been compared with $^{\rm 4443}$ 4398 compatible published databases (Carter and $^{\rm 4444}$ 4399 4445 Bristow, 2003; Li et al., 2012; Hara et al., 4400 2013; Burrett et al., 2014) of detrital zircons ⁴⁴⁴⁶ 4401 from different terranes surrounding the 4447 4402 4448 KKFTB from all over SE Asia, using the 4403 test 4449 (MDS) 4404 Multidimensional Scaling (Vermeesch, 2013). Only compatible samples 4450 4405 4406 of Permian-Triassic age measured with the 4451 same, or similar, techniques (e.g. SHRIMP, LA- 4452 4407 ICP-MS) have been chosen, in order to reduce 4453 4408 analytical uncertainties. The MDS is based on ⁴⁴⁵⁴ 4409 the Kolmogorov-Smirnov (KS) test, which 4455 4410 probability 4456 4411 calculates the maximum dissimilarity between two or more cumulative 4457 4412 distribution functions (Barbeau et al., 2009; 4458 4413 Vermeesch, 2013). Often detrital zircon 4459 4414 analyses are represented by age spectra of $^{\rm 4460}$ 4415 hundreds of zircons, and when numerous ⁴⁴⁶¹ 4416 samples are plotted together, the level of ⁴⁴⁶² 4417 information to process can become unwieldy. 4463 4418 One of the main advantages of the MDS tool 4464 4419 is to provide an objective and straightforward $^{\rm 4465}$ 4420 representation of the degree of dissimilarities 4466 4421 between samples. This comparison is assessed 4467 4422 on a qualitative basis by plotting together 4468 4423 4424 their respective age spectra. The MDS maps group samples with similar age distributions, 4469 4425 4426 and scatter samples with different ages based 4470 on the matrix of KS dissimilarities, while solid 4427 4471 and dotted lines are just a useful graphical 4428 4472 representation to highlight the least dissimilar 4429 4473 samples 4430 and second least dissimilar 4474 (Vermeesch, 2013). The KS statistic can be 4431 4475 considered less sensitive at the extreme ends 4432 4476 4433 of the distributions (Sircombe and Hazelton, 4477 2004), and it can be biased by near-unimodal 4434 4478 distributions. However, Vermeesch (2013) 4435 4479 argued that it is more reliable in distinguishing 4436

provenance similarities than other dissimilarity statistics. Lower KS values suggest relatively low distribution dissimilarities and may be used as support for common source regions. This statistical technique provides quantitive support for visual curve matching. But, we caution using the technique in isolation as the MDS technique is relative to the distributions being compared; i.e. one pair of distributions will always have the lowest dissimilarity. Also, the technique weights the gaps in the data as significantly as the peaks. This would be fine if the process of sedimentation and of sample collection, preparation and analysis were random (Vermeesch 2013). We suggest that trulv random data are intrinsically unobtainable, meaning that the MDA technique, and other similar techniques, be used only in combination with visual analysis and as a broad comparison tool. In this study, we have combined data collected from the KKFTB to samples from other studies (Carter and Bristow, 2003; Li et al., 2012; Hara et al., 2013; Burrett et al., 2014). In order to limit bias only data with similar maximum depositional ages (Permian-Triassic), and that are not likely to be from terrane boundaries, have been chosen from each specific database.

4. Analytical geochronological and isotopic analyses

4.1. U-Pb analyses

Samples used in this study were collected throughout the KKFTB. Eight hundred and thirty seven U-Pb zircon ages were analysed from six samples collected in the arenaceous formations of the Saraburi Group (Table 1; Supplementary data – Appendix B). The results of the U-Pb dating in this study are shown on concordia diagrams (Figure 4) and relative age probability spectra (Figure 5), U-Pb and Hf data are summarised in the 4480 supplementary data that accompanies this 4486 Zircons are generally small (< 80-100 μm) 4481 paper. The analytical errors are presented at 4487 reflecting the fine-grained nature of the 4482 the 2σ level and only data within 10% of 4488 clastic formations in the Saraburi Group. 4483 concordance were plotted on the density 4489 Grains are predominantly translucent and plots. Data quality is generally good, with a 4490 colourless, but have a wide range of 4484 few grains displaying evidence of Pb loss. 4491 morphologies. 4485



4492

4496 4.1.1. Southern part of the Khao Khwang 4509 These represent the maximum depositional 4497 Fold-Thrust Belt 4510 4511 One hundred and eighty zircon grains were 4512 450, 750, 1200, 1425 and 1725 Ma. 4498 4499 analysed for U-Pb from two samples 4500 (T13_003, T13 005) taken from 4501 sandstones that are interbedded with slates 4514 4502 of the Pang Asok Formation. One hundred and 4515 4503 twenty of these grains yielded results that 4516 KKFTB, but elsewhere is overlain by the same 4504 were within 10% of concordance (Table 1 and 4517 4505 Figure 4) with a ²⁰⁷Pb/²⁰⁶Pb age maxima at ca. 4518 2007; Warren et al., 2014). It is characterised 4506 3211 Ma, while the youngest ²⁰⁶Pb/²³⁸U ages 4519 4507 retrieved from T13_003 and T13_005 are 251 4520 sharp increase of carbonate beds occurring 4508 \pm 3 Ma and 262 \pm 4, respectively (Table 1). 4521 towards the north, where it laterally grades

ages of these samples. Age distribution maxima from those two samples are ca. 250,

the 4513 The fine sandstone/siltstone-dominated Sap Bon Formation is thrust over the carbonate Khao Khad Formation in the south of the Khao Khad Formation (Thambunya et al., by interbedded sandstone and shale, with a

⁴⁴⁹³ Figure 4. U-Pb concordia diagram of ages (in Ma) obtained from zircon grains in each sample by U/Pb detrital zircon laser-4494 ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Inset showing MDA with 2 σ error of sample T15 PK3 4495 from 100 to 450 Ma.

up into the Khao Khad Formation. Ninety 4553 4522 zircons from the sample collected in the Sap 4554 4523 4524 Bon Formation (T14_002), define distinctive 4555 4525 concordant age groups (Figure 5), with broad 4556 populations between 2480 and 2830 Ma, 4557 4526 1580 and 1380 Ma, 1270 and 1080 Ma, 980 4558 4527 and 910 Ma, 630 and 430 Ma, and 380 and 4559 4528 4529 270 Ma. The oldest near concordant 4560 ²⁰⁷Pb/²⁰⁶Pb age was 3508 ± 19 Ma, whereas 4561 4530 the youngest ≤ 10% discordant analysis 4562 4531 vielded a 206 Pb/ 238 U age of 275 ± 4 Ma (Table 4563 4532 1), which is interpreted as the maximum 4564 4533 4534 depositional age for this sample. 4565

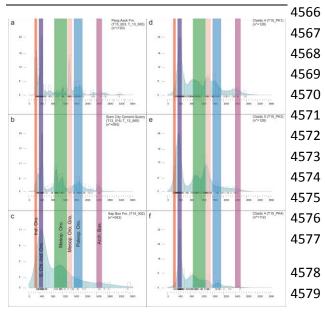


Figure 5. Kernel density estimation (KDE) plots of detrital 4580 4536 4537 zircon ages from each clastic unit. Light-cyan shading 4581 represents detrital grains between 90% and 110% 4582 4538 concordant. Open circles below the KDE represent single 4583 4539 4540 analyses. Ind. Oro.: Indosinian Orogeny; S. Chi.-Ind. Oro.: Oro.: 4584 4541 China _ Indochina Orogeny; Mesop. S 4542 Mesoproterozoic Orogens; Mesop. Oro. Gra.: 4585 4543 Mesoproterozoic Orogens Granites; Palep. Oro.: 4586 Archean 4587 4544 Paleoproterozoic Orogens; Arch. Bas.: 4545 Basement. - 4588

4535

4546 Recent papers on the Saraburi Province 4589 4547 (Hansberry et al., 2014, 2015) have described 4590 4548 an upper-level detachment zone within the 4591 4549 KKFTB. This is well exposed in the Siam City 4592 4550 Cement Quarry, where the northernmost of 4593 4551 two large, northward-verging thrusts that 4594 4552 crop out in the quarry forms a thrust contact 4595 4596

between a sandy silty unit (possibly the Sap Bon Formation, Hansberry et al., 2014) and the carbonate Khao Khad Formation. Two samples were collected within this deformed clastic shale-sandstone unit (T13 016, T13_065). Sample T13_016 from the basal (southern) and less deformed part of the section, while T13_065 from the uppermost (northern) part of the section, close to the north-verging shale detachment. Zircon grains in the samples from this clastic unit are mostly stubby with few elongate grains. Zircon size varied considerably, with an average length of ca. 50 µm. Forty-six of the 90 analysed grains from sample T13 016 yielded ≤ 10% discordant data, whereas 49 of the 75 analysed grains from sample T13 065 were ≤ 10% discordant (Table 1). As a result of this similar discordance (T13 016-65%, T13 065-51%) both samples are plotted together (Figure 5). The oldest analysis in this combined dataset vielded a ²⁰⁷Pb/²⁰⁶Pb age of 2522 ± 20 Ma (T13_065) and the youngest ²⁰⁶Pb/²³⁸U age (taken to be the maximum depositional age) was 268 ± 4 Ma (T13_016).

3 4.1.2. Northern part of the Khao Khwang 9 Fold-Thrust Belt

Generally little information is available on the sandstone in the central and northern section of the KKFTB. The paucity of the sandstone exposure has limited work in this key area directly to the foreland of the highly deformed zone of the KKFTB. Sample T15_PK1 was collected close to the Pasak Jolasid Dam and was exposed during excavation to create the foundations of the dam. This is the northernmost exposure of the mapped Nong Pong Formation. The age of the Nong Pong Formation is uncertain, but is usually assigned to the Permian. One-hundred and thirty-five zircons were selected for U-Pb analysis, and of these 128 grains yielded age data \leq 10% discordant (Figure 3). The ²⁰⁷Pb/²⁰⁶Pb ages of these data date back to 2790± 30 Ma, with

the youngest 206 Pb/ 238 U age of 224 ± 4 Ma 4641 yielded age data \leq 10% discordant (Figure 3). 4597 interpreted as indicating a Triassic maximum 4642 The oldest ²⁰⁷Pb/²⁰⁶Pb age obtained is 2578 ± 4598 depositional age. The most prominent age 4643 21 Ma, while the youngest ²⁰⁶Pb/²³⁸U age is 4599 peak is at ca. 430 Ma with a distinct secondary 4644 4600 peak at ca. 1400 Ma and two less prominent 4645 4601 peaks at ca. 900 and ca. 1650 Ma. 4602 4646

4647 Sample T15_PK3 was collected close to the $\frac{1}{4648}$ 4603 town of Muak Lek (Figure 3). A ca. 500 m long 4649 4604 4605 olistolith of Middle Permian Khao Khad Formation fossiliferous limestone occurs in 4650 4.2. 4606 4607 the quarry from where this sample was taken. 4651 4608 This is slumped into deeper water clastic 4652 sedimentary rocks that are considered to be 4609 4653 part of the Pang Asok, or Nong Pong 4610 4654 formations. One-hundred and forty-seven 4611 4655 analyses were carried out, with 136 zircons 4612 4656 yielding data within 10% of concordance. The 4613 4657 oldest 207 Pb/ 206 Pb age is 2478 ± 21 Ma and the 4614 4658 youngest 206 Pb/ 238 U age is 205 ± 6 Ma, again 4615 4659 implying a Triassic maximum depositional age. 4616 4660 The ²⁰⁶Pb/²³⁸U ages of these zircons range 4617 4661 nearly continuously between ca. 205 and ca. 4618 4662 565 Ma with a few ages around ca. 700 and 4619 4663 ca. 900 Ma. For the older zircons. Most of the 4620 4664 207 Pb/ 206 Pb ages range from 1000 to 1550 Ma 4621 with a few dates extending to around 2450 $_{
m 4665}$ 4622 Ma. A distinct peak occurs at ca. 1400 Ma 4666 4623 4624 (Figure 5).

4667 Sample T15_PK4 is a sample of sandstone $_{4668}$ 4625 4626 from the Nong Pong Formation. The deep- 4669 water siliciclastic deposits of the Nong Pong $_{
m 4670}$ 4627 Formation probably correlate with the Nam $_{
m 4671}$ 4628 Duk Formation, found further north in the $_{\rm 4672}$ 4629 Khorat Plateau, forming a N-S oriented 4673 4630 depositional basin (Ueno and Charoentitirat, 4674 4631 2011). Sandstones are rare in the Nong Pong 4675 4632 Formation. Sample T15_PK4 has evident sole- 4676 4633 marks at its base, and is interpreted as a 4677 4634 4635 turbidite. In one small excavated pit (14°53'17.17" N, 101° 22' 21.17" E), north of 4678 4636 the sample location, Khao Khwang Formation 4679 4637 carbonates are thrust over Nong Pong 4680 4638 4639 Formation shale. One hundred and twenty 4681 grains were analysed for U/Pb, 112 of which 4682 and Hf crustal model ages from 1.26 to 2.03 4640

217 ± 4 Ma, which is interpreted as the maximum depositional age of this sample. The most prominent peak in the age profile occurs at ~430 Ma with a second major peak at ~900 Ma; while older age, less prominent, peaks occur at ~1220 Ma and ~1450 Ma.

Hf isotope analyses

The results are listed in Supplementary Table 2. The data show that the $^{176}Lu/^{177}Hf$ ratios are less than 0.002 (only 4.4% of the data have higher values), indicating the absence of any major enrichment of radiogenic Hf after the formation of the zircons. Thus, the initial ¹⁷⁶Hf/¹⁷⁷Hf ratios can be used as a robust evaluate the reference to source characteristics of these zircons (Wu et al., 2007). A total of 271 zircon grains were analysed, and the results show EHf (t) values in the range of -31.34 to +35.31 and Hf crustal model ages in the range of 0.63 Ga to 3.98 Ga.

4.2.1. Southern part of the Khao Khwang Fold-Thrust Belt

One hundred and ten <10% concordant zircons were analysed for in situ Lu-Hf isotopic composition (Figure 6a), and the results show (¹⁷⁶Hf/¹⁷⁷Hf); (initial ratio) values ranging from 0.28053826 to 0.282853625 (Supplementary Table 2) and a large range in εHf (t) values varying from -29.52 to +35.31 (although all but 5 analyses yield values >-15), inferring complex sources. The Hf (t_{DM}^{C}) of zircons ranges from 0.63 Ga to 3.91 Ga (Supplementary Table 2).

The eight youngest Permian zircons (ca. 299-252 Ma) are dominated by negative ɛHf (t) values (-12.15 to +0.20) with (¹⁷⁶Hf/¹⁷⁷Hf) ranging from 0.282278213 to 0.282622441 4683 components of Mesoproterozoic or older 4727 complex sources. The Hf (t_{DM}^{C}) of zircons 4684 4685 crust. 4728

4729 The highest number of concordant zircons 4686 recovered within the southern portion of the 4730 4687 KKFTB range in age from ca. 500-400 Ma, 4731 4688 many of these analyses yield positive EHf 4732 4689 (Figure 6A) and a lower (176 Hf/ 177 Hf) average 4733 4690 value (0.282586, which is similar to the value 4734 4691 for depleted mantle at that time), and yield 4735 4692 4693 crustal model ages (t_{DM}^{C}) ranging from 0.57 to 4736 4694 1.97 Ga, implying that significant mantle- 4737 4695 derived melt was involved in the parental 4738 4696 magma from which these zircons grew. 4739 Zircons that yielded ages between ca. 850 Ma 4740 4697 4698 and 600 Ma have noticeably evolved *ɛ*Hf(t) indicating a lack of juvenile 4741 4699 values, magmatism in the source region at this time. ⁴⁷⁴² 4700 Zircons that crystallised between ca. 2200 and $\ensuremath{^{4743}}$ 4701 younger 4744 4702 850 Ma contrast with the Neoproterozoic grains in that their $\epsilon Hf(t)$ 4745 4703 4704 values include significantly positive values 4746 (<+12), in addition to the more evolved ⁴⁷⁴⁷ 4705 4706 values, although no values go lower than -12; 4748 again, in contrast to the succeeding later 4749 4707 Neoproterozoic zircons. In fact, 2050-1800 Ma 4750 4708 4709 (Orosirian) zircons appear to mark a change in 4751 4710 the nature of the source-region magmatism 4752 4753 4711 from pre-existing εHf(t) values close to zero, 4712 to a much wider range in values, especially $^{\rm 4754}$ towards values close to those of the 4755 4713 contemporary depleted mantle (Figure 6a). 4714 4756 Small exceptions to this are the two analyses 4715 4757 of ~2500 Ma zircons with highly juvenile 4758 4716 4717 values. 4759

4760 Northern part of the Khao Khwang 4718 4.2.2. 4761 4719 Fold-Thrust Belt 4762

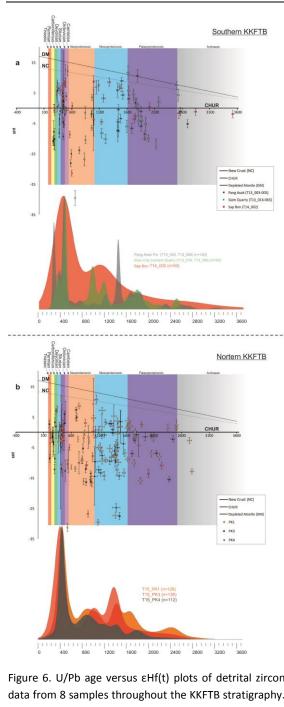
4720 One hundred and sixty-one <10% concordant 4763 zircons were analysed for in-situ Lu-Hf 4764 4721 isotopic composition (Figure 6a), and the 4765 4722 results show ¹⁷⁶Hf/¹⁷⁷Hf values ranging from 4766 4723 4724 0.280644017 to 0.282842605 (Supplementary 4767 Hadaean crust in the source magmas. Only 4725 Table 2) and a large range in ε Hf (t) values

Ga, implying a magma source that involved 4726 varying from -31.34 to +23.07, suggesting Ga ranges from 0.68 to 3.98 Ga (Supplementary Table 2).

> The majority of the youngest Triassic zircons are too small for Hf-isotope analysis; only six Triassic zircons could be analysed. These analysed zircons show similar ¹⁷⁶Hf/¹⁷⁷Hf values to 0.28273563) (0.28241456 (Supplementary Table 2), largely negative ɛHf (t) values (-8.59 to +2.67, average -2.53), and with Hf (t_{DM}^{C}) ranging from 1.05 Ga to 1.76 Ga, indicating that the parent magmas for these young grains contained Mesoproterozoic or older crustal material.

> The Palaeozoic zircons show a similar range of εHf(t) values to those from the southern KKFTB, with values stretching up toward the contemporaneous depleted mantle (and close to those for the contemporaneous 'new crust' curve of Dhuime et al., 2012), to values <-14 (Figure 6a). The data spread implies that two populations may be present, one with EHf(t) values of -8 to -14, and a second, larger population, with ϵ Hf(t) values between +12 and -5. Data collected from the south KKFTB do not show this bimodal distribution, EHf(t) values also range to considerably more evolved values.

> Neoproterozoic zircons do not record the distinct dearth of juvenile EHf(t) values seen in the southern KKFTB, but rather appear to have similar values (approximately between -18 to +13) to those seen in ca. 2200-850 Ma zircons in both the north and south KKFTB (Figures 6a, b). A notable feature of the northern KKFTB detritus, is that between ca. 1500 and 550 Ma there are a number of highly negative EHf(t) zircons (values between -24 to -32) that indicate the presence of Palaeoarchaean, Eoarchaean, or even



4769 εHf(t) such extreme negative values.

4771 Figure 6. U/Pb age versus ɛHf(t) plots of detrital zircon 4815 4772 data from 8 samples throughout the KKFTB stratigraphy. a) southern portion of the KKFTB, b) northern portion of 48164773 the KKFTB. The kernel density estimate distribution for 4817 4774 the samples are plotted below the U/Pb age versus 48184775 4776 epsilon Hf plots to provide a measure of the importance 4819 4777 of each clastic unit. 4820

4770

Zircons that crystallised between ca. 2700 and 4821 4778 4779 1600 have distinctly evolved ε Hf(t) values 4822 varying from -16 to +3 (Figure 6b), indicating a 4823 Arboit et al., 2014; 2015). Morley et al. (2014), 4780 lack of juvenile magmatism in contrast to 4824 and Arboit et al. (2014) constructed structural 4781

4768 one zircon from the southern KKFTB yielded 4782 1800-1600 Ma (Statherian) zircons from the southern portion of the KKFTB that show a 4783 4784 much wider range in values (+2 to +14) especially 4785 close to the earliest Neoproterozoic. 4786

Discussion 4787 5.

4788 5.1. Saraburi Group Stratigraphy

4789 The present knowledge of the Saraburi Group 4790 stratigraphy was recently reviewed and 4791 summarised by Ueno and Charoentitirat 4792 (2011). In their stratigraphic scheme the Khao 4793 Khwang, Phu Phe, Khao Khad, and Tak Fa 4794 formations are all part of one carbonate 4795 platform; the Pang Asok and Nong Pong formations are clastic-dominated lateral 4796 4797 equivalents of the platform of Lower to Middle Permian age, whereas the Sap Bon 4798 4799 Formation is Midian to Dzhulfian (Mid-4800 Capitainian to Wuchiapingian in the 4801 International Commission of Stratigraphy chronology; Cohen et al., 2015) in age (Figure 4802 4803 2c), and was thought laterally equivalent to, and younger than, the youngest part of the 4804 4805 Khao Khwang Formation. Figures 2a and 2b 4806 are simplified versions of the stratigraphic 4807 scheme in Ueno and Charoentitirat (2011). 4808 While dating of the Permian carbonate 4809 platforms in the Saraburi Group has been well established in the last decade using the 4810 abundant fusulinid foraminifera, the clastic 4811 4812 sediments of the Pang Asok, Nong Pong, and the Sap Bon formations are poor in fossils and 4813 4814 correspondingly poorly dated (e.g. Dawson, 1993; Dawson and Racey, 1993; Charoentitirat, 2002; and Udchachon et al., 2014). The problem with this stratigraphic scheme is that the area of exposure of the Saraburi Group is strongly deformed by folding and thrusting, making it difficult to identify coherent stratigraphic packages (e.g. Morley et al., 2013, Hansberry et al., 2014,

sections through the Khao Khwang Fold and 4867 4825 4826 Thrust Belt and used these to recognise that 4868 4827 the Saraburi Group represented multiple 4869 4828 carbonate platforms separated by a series of 4870 4829 deeper water basins (Warren et al., 2014). 4871 4830 These deeper water basins (perhaps reflecting 4872 differences in water depth of hundreds of 4873 4831 4832 metres), contain either shale and sand (Sap 4874 4833 Bon Formation), black shale (Alum Shale), or 4875 chert, shale, sand, and allodapic limestone 4876 4834 4835 (Nam Phong Formation). Not all these 4877 4836 deposits are easily linked to existing 4878 4837 formations, and in the absence of a rigorous 4879 4838 understanding of the stratigraphy, Morley et 4880 4839 al. (2013) used informal nomenclature (Clastic 4881 4840 1, Clastic 2, Clastic 3) to indicate where 4882 4841 revisions to the stratigraphic scheme were 4883 needed (Figure 3). Figure 7 shows a 4884 4842 4843 conceptual modification of the depositional 4885 4844 system and the relative stratigraphic scheme 4886 that reflects the changing view of the Saraburi 4887 4845 4846 Group stratigraphy. 4888

4847

48485.2.Impact of detrital zircon ages on48914849interpretations of structure and48924850stratigraphy489348944894

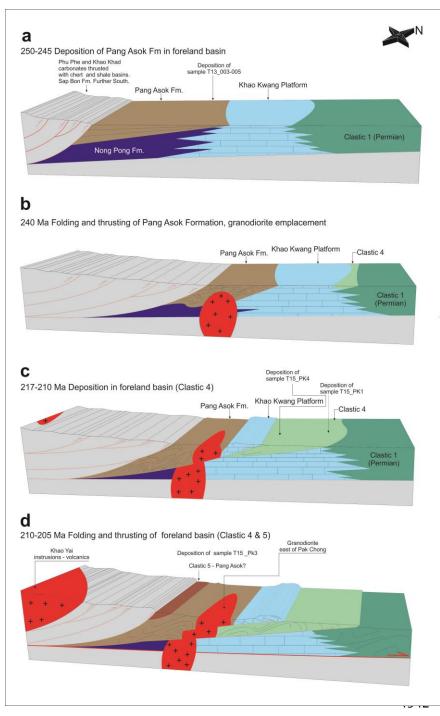
4851 The analysed zircons in this study were 4895 4852 collected from sedimentary rocks in the 4896 4853 KKFTB, previously mapped as being of Mid- 4897 4854 Late Permian age. The new detrital zircon data 4898 4855 require modification of these ages as the 4899 4856 rocks cannot be older than the youngest 4900 4857 detrital zircon. We have used only zircons 4901 4858 with ages within 10% of concordance to 4902 4859 provide a maximum depositional age (MDA) 4903 4860 for each specific formation (Table 1). 4904

4905 The maximum depositional ages impact the 4861 4906 4862 stratigraphy by shifting the age of the Saraburi 4907 4863 Group to the latest Triassic (Figure 2c). The 4908 new MDA for the Sap Bon Formation (275 ± 4 4864 4909 Ma) is close to the published depositional age 4865 4910 4866 (Hinthong et al., 1985), suggesting erosion 4911

and deposition of newly formed source region (McGee et al., 2012); consistent with volcanic source regions such as the Loei volcanic belt and the Sukhothai volcanic arc. However, the Pang Asok Formation is traditionally placed below the Sap Bon Formation (Figure 2a), but now must be younger and, at the most, Early Triassic age (Figure 2c). This is possible as no mapped relationship between these units is known. The Pang Asok Formation is cross-cut by a small granodiorite pluton (Figure 3, Figure 7b), which has been dated at 241 ± 6 Ma (U-Pb on zircon dating by S. Meffre reported in Morley et al., 2013). This leaves a window between 251 ± 3 Ma and ca. 240 Ma during which time the Pang Asok Formation was deposited, and deformed by folding and thrusting (Figure 7c). Sample T15_PK3 is from an area thought to be in continuity with the Pang Asok Formation, and was assumed to be from the Pang Asok Formation prior to the detrital zircon dating. The sample came from a quarry, which lies adjacent to an area about 500 m wide, where fossiliferous shallow water Permian carbonates are present that include boundstones, as well algal as slope conglomerates and crinoidal rudstones. A contact is exposed in the quarry, where the limestone passes abruptly into folded shale that contains small limestone blocks. It is very clear from the relationships that the limestone slid, probably as a coherent rigid block, into deep water environment represented by shale and thin sandstone. Initially it was inferred that the limestone slide was contemporaneous with Permian carbonate platform development, and that the clastic deposits are Permian in age. However, the minimum zircon age from T15 PK3 of 205 ± 6 Ma implies a different scenario (Figure 2c). The implication is that late thrusting caused a lithified block of Permian carbonate to slide into, either on top of a moving single thrust sheet (piggyback basin), or a foredeep basin (Figure 7d), which

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formed during a late phase of thrusting. This requires a separate basin to be developed some 35 My later than deposition of the Pang Asok Formation (referred to informally as Clastic 5). Possibly deposition was freshwater in а environment, since, at this time, regional continental rift basins have been established (Booth and Sattayarak, 2011). Some of the rift basins are inverted both during the late stage of the Indosinian deformation, and during Paleogene (Booth the and Sattayarak, 2011). Consequently despite the Triassic Late age, deformation of the basin could have occurred.

Figure 7. Schematic sequential evolution of

4943 the depositional model within the KKFTB from Early to Late Triassic, based on the modified 4944 stratigraphy shown in Figure 2c and Figure 3.

4945 The samples from the northernmost portion 4953 of the KKFTB are represented by T15 PK1 and 4954 4946 4947 T15 PK4. Sample T15 PK4 was taken from an 4955 4948 area that was mapped as Nong Pong 4956 4949 Formation (based on the map in Ueno and 4957 4950 Charoentitirat, 2011) (Figure 3). This sample is 4958 4951 an extensively burrowed sandstone with flute 4959 marks, and appears to be a marine sandstone. 4960 Sandstone is not normally present. Hence the 4952

Typically, the Nong Pong Formation comprises shale, chert and deepwater limestones. Some of the deepwater limestones are fusulinid grainstone debris flows (i.e. at location Q1, Figure 3), which demonstrates they are Permian in age, and were deposited in deeper water basins adjacent to the platforms. 4961 sandstone sampled represents an unusual 5004 The early stages of the Indosinian orogeny are occurrence. The youngest age from the 5005 4962 sample of 217 ± 4 Ma is Late Triassic 5006 4963 4964 indicating the formation sampled is not 5007 actually Nong Pong Formation, but a new, 5008 4965 undescribed formation (referred to informally 5009 4966 4967 as Clastic 4). This raises the question of 5010 4968 whether the Clastic 4 unit depositionally 5011 4969 overlies the Nam Pong Formation and is 5012 4970 preserved in a syncline, or is overthrust by the 5013 Permian sequences and exposed in a tectonic 5014 4971 4972 window (Figure 7c). The thrust window 5015 4973 interpretation is preferred because to the 5016 4974 north of the sample location is a small pit 5017 4975 where shales that are below a sub-horizontal 5018 4976 thrust and overlain by Khao Khwang 5019 4977 carbonates. The minimum implied amount of 5020 4978 overthrusting, assuming NNW thrust 5021 4979 transport, is 9 km (Figure 3). 5022

Sample T15_PK1 is a sandstone that does not 4980 5024 occur in natural outcrops, but was dug from 4981 5025 the foundations of the Pasak Jolasid Dam 5026 4982 (Figure 3), and hence it was not possible to 4983 5027 obtain data on the relative depositional 4984 5028 environment. The nearest outcrops to the 4985 5029 dam are 5 km away in an extensively quarried 4986 5030 section that comprises mostly cherts and 4987 5031 4988 shales, and no sandstone. This unit was 5032 4989 originally referred to as Clastic 1 (Morley et 5033 al., 2013). However, the minimum zircon age 50344990 for the sandstone is 224 \pm 4 Ma, and on both 4991 5035 a lithology and age basis, sample T15_PK1 is 5036 4992 now considered to represent a different unit 5037 4993 from Clastic 1. The similar MDA of samples $_{5038}$ 4994 PK1 and PK4 opens to a possible affinity 5039 4995 between the two clastic units where the 5040 4996 samples were collected, and on Figure 3 they 4997 4998 are both mapped as the same unit (Clastic 4). 5041 4999 However, given the proximity of the Khorat 5042 5000 Group to the Pasak Jolasid Reservoir the 5043 5001 sandstones could also be part of the 5044 Kuchinarai Group (Figure 3, Figure 2c). 5002 5045

5003 5.3. Evolution of the basin

poorly dated, and the timing of the continental collision remains uncertain. Ophiolitic sequences along the Nan Suture Zone extend back to ca. 270 Ma (Barr and Macdonald, 1987). However, the onset of collision between the Sukhothai Terrane and Indochina, which triggered N-S thrusting and folding (Arboit et al., 2014; 2015) in the KKFTB, is poorly established (Sone and Metcalfe, 2008; Booth and Sattayarak, 2011; Barber et al., 2011; Morley et al., 2013). The Permian represents pre-collision deposition on the Indochina margin that was possibly undergoing extensive rifting and post-rift subsidence (Booth and Sattayarak, 2011). The width of the basin is uncertain because of: 1) the considerable shortening exhibited within the exposed basins; 2) the unknown amount of eroded material; 3) the uncertain extent of the basins to the south, where exposures are very poor. The minimum width is in the order of 10s of kilometres, but widths in excess of 100 km are possible. The basin comprises a number of highs, on which relatively small, isolated, carbonate platforms were developed, surrounded by deeper water basins dominated by chert deposition with allodapic carbonates. Probably to the north, and possibly to the west, of the chertdominated basin, the more shale and sandstone-dominated sequence of the Sap Bon Formation is present. South of the chert basin-Khao Khad Formation depositional area lies the region of the Phu Phe Formation, which includes a black (alum) shale clastic unit.

5023

5041 During the latest Permian to Early Triassic the 5042 convergence of the Sukhothai Terrane with 5043 Indochina would have led to the development 5044 of a foredeep basin on the old passive margin. 5045 Possibly, the Sap Bon Formation marks the 5046 initiation of foredeep basin deposition after 5047 ca. 268 Ma. This basin, or a succession of 5048 5049 towards the north (Morley et al., 2013; Arboit 5093 come from the colliding Sukhothai Arc. 5050 et al., 2015). The Pang Asok Formation may 5094 5051 mark a shift in foredeep basin location in front 5095 5052 of the thrusted Phu Phe and Khao Khad 5096 5053 carbonate platforms and intervening basins 5097 around 250 Ma. This basin was deformed and 5054 5098 incorporated into the fold and thrust belt by 5055 5099 240 Ma (Figure 7). Direct evidence of mid-5056 5100 Triassic deformation is also preserved in ca. 5057 5101 235 Ma K-Ar ages of syn-shearing illite 5058 5102 preserved in shale detachment faults in the 5059 Siam City Cement Quarry (Hansberry et al., 5103 5060 2015). No record of any sedimentation after 5104 5061 the Early Triassic has been recovered from the 5062 5063 samples collected throughout the southern 5105 5064 portion of the KKFTB. Further north, the 5106 advancing thrust front of the orogen is 5107 5065 5066 interpreted to be still active at this time. The 5108 Middle-Late Triassic foreland basin (Clastic 4, 5109 5067 5068 Figure 7) was feasibly tectonically segmented 5110 5069 into satellite basins, such as piggyback or 5111 5070 thrust top basins (Ori and Friend, 1984). Based 5112 5071 on the new data presented here, it is possible 5113 to assume that the sedimentation in the 5114 5072 5073 northern portion of the basin might have 5115 5074 lasted till the latest Triassic-Early Jurassic 5116 5075 (after 205 ± 6 Ma). These data are consistent 5117 5076 with Hirsch et al. (2006) who suggested a 5118 5077 Sibumasu-East Malaysia collision at the same 5119 time, and with the hiatus associated with the 5120 5078 5079 Indosinian II event. This unconformity surface 5121 5080 underlies the lowermost portion of the 5122 5081 Rhaetian (~208-201 Phong 5123 Ma) Nam 5082 Formation further north in the subsurface of 5124 5083 the Khorat Plateau. Having such a short lapse 5125 5084 of time between the youngest MDA and the 5126 5085 documented Lower Nam Phong Formation, 5127 5086 the Late Triassic zircons must be close to the 5128 5087 real depositional age of the sandstones in the 5129 5088 northern portion of the KKFTB, hence, it is 5130 possible to assume that there were some 5131 5089 5090 significant igneous activities nearby during the 5132 latest Triassic that were not recorded by the 5133 5091 5134

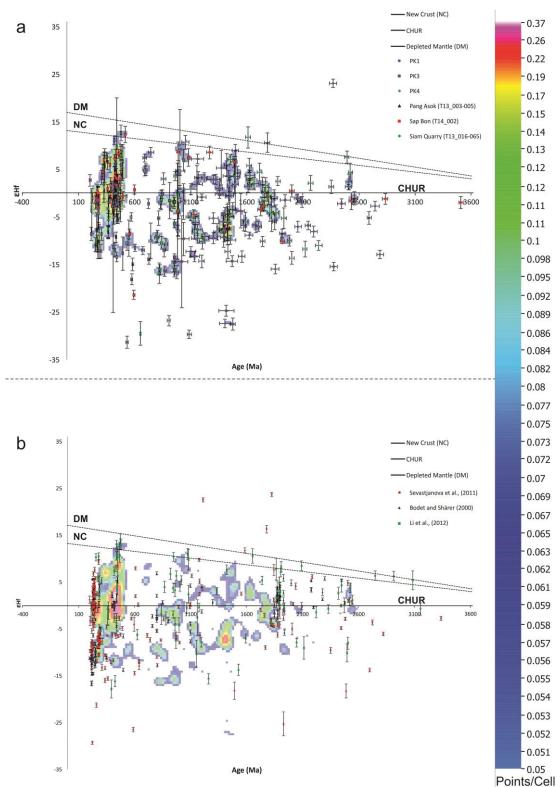
basins, was characterised by propagation 5092 southern part of the KKFTB, but may have

The topography during the Rhaetian is hence interpreted to be the result of the end of the Indosinian contractional event and it is well represented by the overlying Nam Phong Formation, which represents depositional environments, such as fluvial channels (braided and meandering) interbedded with lacustrine or floodplain sequences (Racey and Goodall, 2009).

5.4. Regional correlations and possible tectonic implications

All the samples looked at in this study have appreciable numbers of detrital zircons that yield late Triassic to Palaeoarchean ages (Figure 4, Figure 5). When combined, the data set includes $642 \leq 10\%$ discordant zircons, with ages that range between ca. 201 Ma and 3508 Ma. U-Pb data presented here reveal two distinct episodes of magmatism at ca. 250-200 Ma and ca. 450 Ma. Palaeozoic magmatism that may be the origin of the ca. 450 Ma zircons, is found in the Kon-tum Massif of central Vietnam, coeval Late Ordovician-Silurian metamorphic activity also occurs along the Phuoc Son-Tam Ky Suture Zone of northern Vietnam (Tran et al., 2014). Late Carboniferous to Permian detrital zircons found in the modern Mekong River and Red River (Bodet and Shärer, 2000) (Figure 8) that drain Indochina and the margin of South China (Figure 10) preserve similar U-Pb and Hf isotopic ratios to those from the KKFTB, with ϵ Hf(t) values close to the CHUR. Similar ϵ Hf(t) values are also found in coeval detrital zircons preserved in Permian sedimentary rocks in South China (Li et al., 2011; Figure 8). We suggest that these may be all sourced from granites and granodiorites emplaced across Myanmar and NE Vietnam in a syn- to postcollisional setting during the latest stages of the Indochina-South China collision (Gardiner

5135 et al., 2015; Halpin et al., 2015). Zircons that 5137 also show similar ϵ Hf(t) values to modern 5136 date from the 200-250 Ma magmatic phase 5138 river systems and South China (Figure 8).



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Figure 8. a) U/Pb age versus epsilon Hf plot of all the data from the KKFTB and relative density contour. b) U/Pb age versus
epsilon Hf plot of published hafnium isotopic data from zircons from the Mekong River and Red River (replotted from
Bodet and Shärer, 2000), from Permian sediments in southeast China (replotted from Li et al., 2012), and the Malaya
Peninsula river systems (replotted from Sevastjanova et al., 2011); compared with density contour of all the Hf isotopic
data collected within the KKFTB.

5145 5146 systems, from the Permian of South China (Li 5190 5147 et al. 2012) and from the Indochina part of 5191 5148 the Malay Peninsula (Sevastjanova et al., 5192 5149 2011) share several similarities with zircons 5193 5150 from the KKFTB (Figure 8). In particular, the 5194 wide range of ϵ Hf(t) values of the latest 5195 5151 5152 Mesoproterozoic-Neoproterozoic zircon, and 5196 5153 the Neoarchaean juvenile values (Figure 8). 5197 5154 This not only implies that pre-Carboniferous 5198 rocks occur in the sources to the sedimentary 5199 5155 5156 rocks of the KKFTB, S China and Malay 5200 5157 Peninsula, but that at least by the Permian, 5201 5158 regions as far-flung as South China, central 5202 5159 Thailand and Malaya shared similar 5203 5160 sedimentary sources. Significant differences 5204 5161 do occur, particularly at ca. 1.8-1.9 Ga in 5205 5162 South China (Li et al., 2011) and in the dearth 5206 5163 of early Mesoproterozoic zircons from the 5207 modern rivers and the Permian of South China 5164 5208 (Bodet and Shärer, 2000; Sevastjanova et al., 5165 5209 2011). In the latter case, this difference may 5166 5210 be attributed to KKFTB Triassic rocks being, at 5167 5211 5168 least partially, sourced from the western 5212 Sibumasu Terrane, which preserves distinct 5169 5213 populations of ca. 1.3-1.4 Ga detrital zircons 5170 5214 5171 with negative ϵ Hf(t) values (average -6.83) 5172 (Figure 8, Supplementary Table 2) (Burrett et 5215 al., 2014). This would support a Middle-Late 5173 5216 Triassic age for the collision (Booth and 5217 5174 5175 Sattayarak, 2011). 5218

5176 5.4.1. Multidimensional scaling analysis

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5177 After MDS statistic calculations performed in 5221 5178 MATLAB, all the databases used in this study 5222 5179 clustered in three different groups of 5223 5180 terranes, each cluster contains the samples 5224 with the lowest dissimilarity values (Table 2; 5225 5181 5182 Supplementary data – Appendix B). Figure 9 is 5226 5183 only the visual representation of this 5227 5184 clustering based on the values of the 5228 dissimilarity matrix. Figure 10 depicts the 5229 5185 geographical position of each sample and 5230 5186 5187 relative cluster category, throughout the 5231 5188 terrane of SE Asia. All the samples collected 5232 Khorat Plateau in the north and Cambodia in

Pre-Carboniferous detritus of these river 5189 within the KKFTB have very low dissimilarity values with an average of 0.14416 (Table 2). Similar values occur between the KKFTB and the samples representing sedimentary rocks from the Khorat Plateau (0.2383), Truong Son (0.2233), NE Vietnam (0.1921), and partially with South China (0.3129). The quality of the numerical approximation of the MDS fit is evaluated by the stress parameter "S" that appear to be fairly good (0.1002) (Kruskal, 1964, Vermeesch, 2013). It is hence possible to assume that these values do not indicate statistically significant differences among the above terranes, and they suggest that the zircons were derived from a common underlying population.

> All the zircons from western SE Asia are much less similar to those samples from the KKFTB. The significant mismatch with the terranes in the west, such as Sibumasu, Phuket, and Inthanon, is demonstrated by KS values ranging from 0.4239 to 0.4932. This shows that the detrital age spectra are distinctly different, and implies that these terranes were not sourced from similar-aged areas during the Late Palaeozoic.

> The KS results for central Vietnam, Loei, Indochina (samples from Cambodia), Ε Malaysia, and Sukhothai, show little or no links with other data in this study, having disparity of values ranging between 1.0 and 0.5545 (Table 2). The Sukhothai, Loei, and Indochina terranes are interpreted as being separated by a back-arc basin (Sone and Metcalfe, 2008). The low KS dissimilarity (0.1974) (Table 2; Figure 9) between the Permian samples of these terranes appears to confirm the possibility that they shared sediment source regions in the latest Palaeozoic before the opening of the back-arc basin in the Early Permian. Further, the KS dissimilarity value (0.3957) highlights the mismatch within Indochina between the

5233 the south. It has been previously suggested by 5277 several authors that the Indochina Terrane 5278 5234 5235 itself may not have been one single terrane 5279 5236 but might have had a more complicated 5280 geometry (Lepvrier et al., 2004; Morley et al., 5281 5237 2013). No fewer than 20 belts of mafic- 5282 5238 ultramafic assemblages have been named 5283 5239 5240 "ophiolite" in the complex SE Asia region of 5284 5241 Sundaland, but fewer than half of these can 5285 be confidently classified as "ophiolite" 5286 5242 5243 (Hutchison, 1975). However, a few previous 5287 authors (Fromaget, 1941; Fromaget et al., 5288 5244 5245 1971; Hutchison, 1975) highlighted the 5289 5246 presence of the Siem Reap-Stung Treng Line, 5290 5247 which consists of gabbro, peridotite and 5291 5248 dolerite bodies, trending roughly E-W, south 5292 5249 of the Khorat Plateau, and occurring in a large 5293 5250 elongate mass in Permian to Triassic 5294 5251 sedimentary rocks. The rocks within this line 5295

5252 shows similarities with the rocks of the coeval 5253 Uttaradit-Luang Prabang-Pak Lay Line 5254 (Fromaget, 1941; Baum al., 1970; et 5255 Hutchison, 1975) that consists of 5256 serpentinized pyroxenite, gabbro, diorite and 5257 dolerite and is associated with the suturing of 5258 the Sukhothai and Indochina terranes. Given 5259 our findings, the two terranes displaying 5260 different age spectra, and combining those 5261 with observations of Hutchison (1975), we support the idea of an intra-Indochina suture 5262 5296 along the Siem Reap-Stung Treng Line (Figure 5263 5264 10). 5297 5298

Several factors associated with detrital U-Pb 5299 5265 5300 analysis could alter the statistics, and thus, 5266 5301 our interpretation. Firstly, we took into 5267 5302 consideration the number of zircons sampled. 5303 5268 It has been argued that > 100 analyses are 5304 5269 5270 needed to be 95% confident that no fraction 53055271 >5% of the population is missed (Vermeesch, 5306 5272 2004), although previous authors suggested 5307 5273 that at least 40-60 randomly selected grains 5274 are sufficient to reduce the probability of 5308 This study reports a new dataset of zircon Umissing this component to 5% (Dodson et al,. 5309 Pb ages and Hf isotopes of detrital zircons 5275 5276 1988; Stock and Montgomery, 1996; Ruhl and 5310 from arenaceous formations of the Saraburi

Hodges, 2005). The nonmetric MDS is not affected by the considerable disparity in the number of analyses between the considered samples, the MDS is only sensitive of the empirical cumulative distribution functions. The goal of nonmetric MDS is not to approximate the dissimilarities themselves, but rather their relative ranks (Vermeesch, 2013). Hence, it is possible to infer that the outcome of the MDS would probably not change with additional data. Therefore, the KS dissimilarity matrix (Table 2) and MDS visual comparison (Figure 9) do indicate that all the samples within the KKFTB share significant similarities only with terranes NE of the Permian-Triassic south-western margin of Indochina, particularly from the Khorat Plateau, South China, Truong Son and NE Vietnam regions (Figure 10).

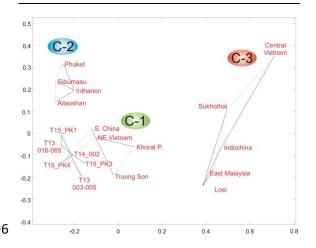
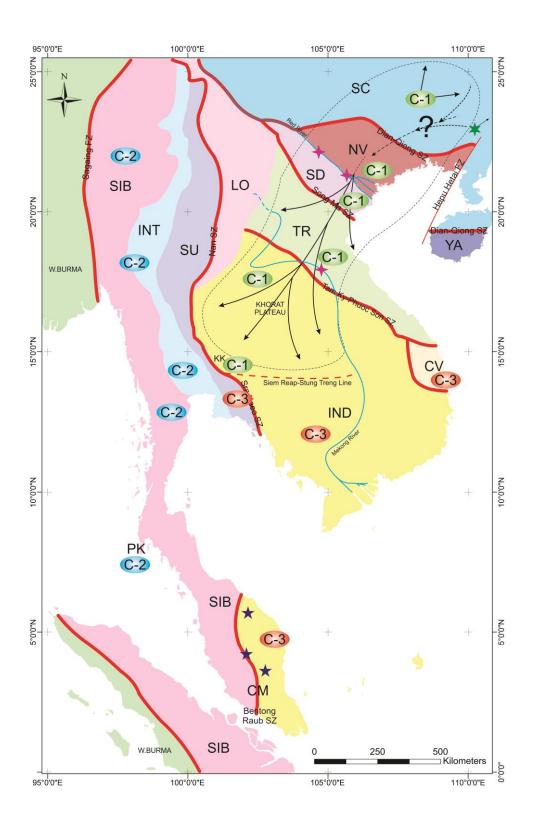


Figure 9. Metric MDS plot of the Asian database (Carter and Bristow, 2003; Li et al., 2012; Hara et al., 2013; Burrett et al., 2014) using the KS effect size as a dissimilarity measure. Solid lines mark the closest neighbours and dashed lines the second closest neighbours (see Vermeesch 2013). The samples with the lowest dissimilarity values are plotted close to each other forming three different clusters C1,2,3. These clusters are only the visual representation of the samples with the lowest dissimilarity values.

6. Conclusions



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Figure 10. Schematic tectonic map of SE Asia (modified from Metcalfe, 2013; Burrett et al., 2014) representing a tentative reconstruction of the statistically most probable provenance sources and sedimentary pathways (black arrows) during Permian-Triassic ages. C-1,2,3 represent the provenance clusters obtained with MDS analysis. The C1,2,3 logs are placed in the map on the locations where the analysed samples were collected. Five-pointed stars: data from Sevastjanova et al., (2011); four-pointed stars: data from Bodet and Shärer (2000); six-pointed stars: data from Li et al., (2012). CM: Central Malaysia, CV: Central Vietnam, IND: Indochina, INT: Inthanon, LO: Loei, NV: Northeast Vietnam, SIB: Sibumasu, SC: South S18 China, SD: Song Da, SU: Sukhothai, TR: Truong Son; SZ: Suture Zone, FZ: Fault Zone. 5319 Group deposited during latest Palaeozoic- 5362 5320 Early Mesozoic on the south-western margin 5363 5321 of the Indochina Terrane. Although only 5364 5322 maximum possible ages are indicated by the 5365 5323 important detrital zircons thev have 5366 implications for the stratigraphy of the 5324 5367 5325 Saraburi Group. 5368

- 5326 1- A substantial revision to the 5369 5327 stratigraphy of the Saraburi Group is 5370 5328 indicated, with the Pang Asok 5371 5329 Formation changed from the Permian 5372 5330 to the Early Triassic. Instead of the 5373 5331 Nong Pong and Khao Kwang 5374 5332 formations exclusively occupying the 5375 northern half of the area a new Upper 5333 5376 Triassic marine formation is identified, 5334 informally referred to as the Clastic 4 5377 5335 5378 unit. 5336 5379
- 5337 2- The Triassic basins are re-interpreted 5380 5338 as syn-tectonic foredeep or piggyback 5381 basins. It is suggested that the Pang 5339 5382 Asok Formation records between ca. 5340 5383 250 Ma and 240 Ma a change from 5341 5384 deposition in a foredeep basin to 5342 5385 being folded, thrusted, and intruded 5343 5386 by a ca. 240 Ma granodiorite. 5344 5387 propagated Deformation slowly 5345 northward with time, or experienced 5388 5346 5389 a hiatus. Deposition of the Clastic 4 5347 5390 unit during 230-209 Ma (Norian) 5348 5391 Ma 5349 implies a possible gap >15 5392 between the end of known thrusting 5350 5393 in the southern half of the area, and 5351 5394 deformation in the northern area. The 5352 5395 different ages probably reflect Early 5353 Triassic Sukhothai Terrane-Indochina 5396 5354 collision, followed in the Late Triassic 5397 5355 Sukhothai 5398 5356 by the amalgamated Terrane/Indochina block- Sibumasu 5399 5357 5358 collision. 5400
- 53593-U-Pb detrital zircon ages revealed that54015360deposition within the south-western54025361margin of the Indochina terrane5403

lasted until at least 205 ± 6 Ma. It is uncertain whether deposition was in a marine or lacustrine basin.

- 4- The age distributions yield dominant Ordovician to Devonian (~450-350 Ma) peaks with Neoproterozoic and Mesoproterozoic (~950, ~1200, ~1400 Ma) age groups, and individual zircons dating back to the Palaeoarchean. Hfisotope data identify different magma sources before and during the subduction of the palaeo-Tethys ocean.
- 5- Multidimensional scaling analysis on detrital zircon ages from throughout SE Asia collected in the last decades is interpreted to indicate a NE source of sediment feeding the western margin of the Indochina terrane during the Permian and the Triassic.
- 6- Further, the KS statistical analysis highlights the mismatch within Indochina, between the sediments from the Khorat Plateau in the north, and Cambodia in the south: strengthening the idea already advocated by Lepvrier et al., (2004), and Morley et al., (2013) of a more complicated geometry of the Indochina block. It is possible to speculate about the presence of a possible minor intra-continent ocean that acted as provenance separation (Siem Reap-Stung Treng Line).
- 7- Upper Triassic detritus from the KKFTB also preserved middle Mesoproterozoic and Triassic detritus that is interpreted as sourced from the newly accreted Sibumasu Terrane.
- 8- The data indicate that the stratigraphy of the Saraburi Group needs more intensive study,

5404 understand the 5444 particularly to distribution of Triassic versus Permian 5445 Geosciences, 1(1), 11-22. 5405 5406 sedimentary rocks.

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Chapter VI Arboit, F., Collins, A. S., Morley, C., King, R., Amrouch, K. (2016). Geochronological and geochemical study of mafic dykes from the Khao Khwang Fold-Thrust Belt: Implications for petrogenesis and tectonic evolution. Gondwana Research.

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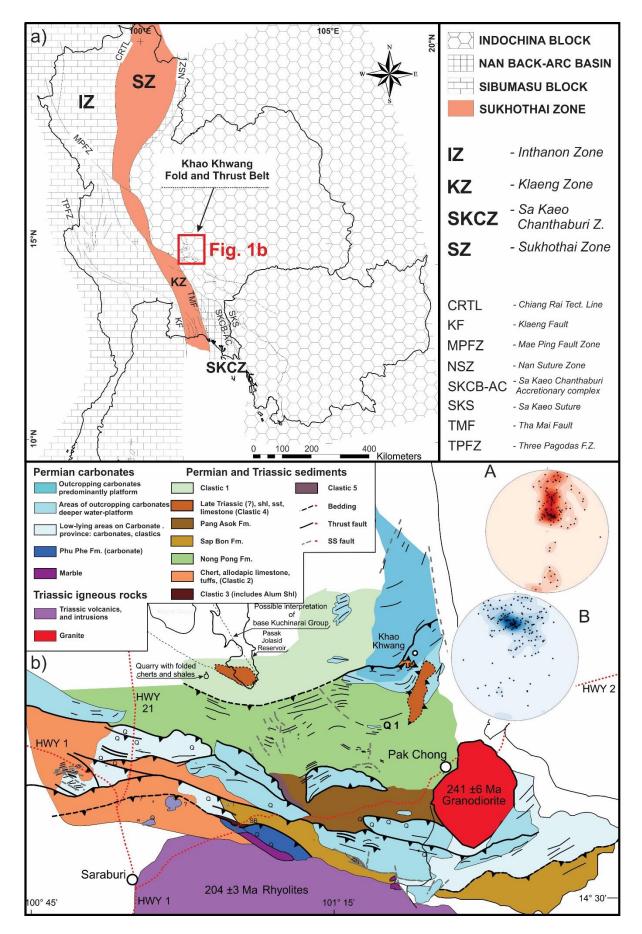
5904 ABSTRACT

Zircon U–Pb, mica ⁴⁰Ar/³⁹Ar ages and geochemistry of the Permo-Triassic mafic to intermediate dyke 5905 swarms at the south-western margin of the Indochina Block, central Thailand, are reported here and 5906 5907 used to decipher the timing of the Sukhothai-Indochina & Sibumasu-Indochina collisions during the 5908 Permo-Triassic stages of the Indosinian Orogeny. The mafic dyke swarms in the folded layers of the 5909 Khao Khwang Fold-Thrust Belt (KKFTB) were emplaced between the Late Permian and the Late 5910 Triassic. The volcanic rocks ranges from slightly tholeiitic to mostly calc-alkalic, but can be subdivided 5911 into three different volcanic groups on the basis of trace and incompatible element abundances such as Ni, Cr, P, Co, and Th. However, all the groups present similar chemical footprints and are enriched 5912 5913 in large ion lithophile elements (LILE) (Rb, Ba, Sr, Pb) and light rare earth elements (LREE), and 5914 depleted in HFSE such as Nb, and Ti highlighting the volcanic arc nature of the system. Isotopically, 5915 the three groups are characterized by subtle differences in $\epsilon Nd(t)$ values (from +3.2 to +5.2) and initial ⁸⁷Sr/⁸⁶Sr ratios (from 0.7056 to 0.7067). The KKFTB mafic dykes share a few geochemical 5916 characteristics of the mafic dykes from the Chiang Khong volcanic suite in the Sukhothai terrane, and 5917 5918 from the Loei volcanic belt in northern Indochina. These geochemical features suggest that the 5919 KKFTB mafic dykes, and the volcanic rocks in central-northern Thailand, were likely crystallized in a 5920 similar orogenic setting. The rocks of Group III are interpreted to have intruded from the Early 5921 Triassic (255 \pm 6 Ma) to the Late Triassic (207 \pm 2 Ma), and were probably sourced from a more 5922 crustally contaminated magma.

5923 1. Introduction

5945 The 'Indosinian Orogeny' broadly includes all 5924 5946 5925 the Late Palaeozoic to Early Mesozoic tectonic 5947 5926 events related to closure of the eastern Paleo-5948 Tethys Ocean (Cho et al., 2008). These events 5949 5927 5928 comprise collision of a succession of 5950 Gondwana-derived continental fragments, 5951 5929 and volcanic arcs (Sone and Metcalfe, 2008; 5952 5930 Metcalfe 2013). In Thailand, the orogeny 5953 5931 mainly developed during the Triassic and 5932 5954 earliest Jurassic (Sone and Metcalfe, 2008; 5933 5955 Metcalfe, 2011) and is the result of the 5934 5956 collision between the Sibumasu, Sukhothai 5935 5957 and Indochina Terranes (Figure 1a, b). Models 5936 5958 for the tectonic evolution of Thailand from 5959 5937 the Indosinian Orogeny to the present have 5960 5938 5939 been defined using biostratigraphical, 5940 petrological, structural and geochronological 5961 The igneous rocks studied are intruded within 5941 data (Metcalfe and Sone, 2008; Sone and 5962 the Khao Khwang fold-thrust belt (KKFTB) and 5942 Metcalfe, 2008; Ridd and Morley, 2011; 5963 form a large igneous trend south of the 5943 Morley et al., 2013; Arboit et al., 2014; 5964 KKFTB. This fold-thrust belt occupies an

5944 Hansberry et al., 2014). However, a consensus on the location of the terrane boundaries, and nature and position of the relative suture zones has not been reached (Barr and Macdonald, 1991; Charusiri et al., 1994, 1997; Metcalfe, 2000). Volcanic rocks are an important tool able to provide fundamental information on the tectonic history of an area. Unfortunately, most of the volcanic and igneous rocks emplaced within central Thailand lack detailed petrochemical data and precise ages. This paper attempts to interrogate the volcanic rocks and mafic dykes in the Saraburi area of central Thailand in order to understand the nature of the magma sources and the tectonic setting of their emplacement.



5966 Figure 1. a) Subdivision of Thailand into main tectonic terranes, that amalgamated during the Indosinian Orogeny (modified 5967 from Ueno and Charoentitirat, 2011), B) geological map of the Khao Khwang Fold and Thrust Belt. It has been modified 5968 from Warren et al., (2014) to show possible interpretations of the stratigraphy as a consequence of this study (A: poles to 5969 bedding within the KKFTB; B: poles to major thrusts and strike-slip faults in the southern portion of the KKFTB).

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5970 important position on the edge of the Nan-Sa 6009 representing the site of the Palaeo-Tethys 5971 Kaeo suture zone between Indochina and the 6010 5972 Sukhothai volcanic arc, and are thought to 6011 5973 correlate to the well documented volcanic 6012 5974 bodies along the margin of these two terranes 6013 (Nakchaiya et al., 2008; Boongsoong et al., 6014 5975 5976 2011) and in northern Thailand (Barr and 6015 5977 Macdonald, 2000, 2006). 6016

6017 In this paper, we report new petrological data, 5978 6018 40 Ar/ 39 Ar mica and U–Pb zircon ages, along 6019 5979 with both whole rock elemental and Sr-Nd 5980 6020 isotopic data for the most representative 5981 6021 dykes in the KKFTB with the aims to (1) 5982 6022 establish the average crystallization age for 5983 6023 5984 the dykes, (2) unravel the origin and 6024 5985 petrogenesis of the dykes, and, (3) 6025 5986 constraining the compressional events 6026 affecting the Sukhothai and 5987 Indochina 6027 terranes and shed light on the tectonic 5988 6028 evolution of the Triassic Indosinian Orogeny in 5989 6029 5990 central Thailand. 6030

5991 2. Regional setting

5992 Ueno (1999) and Ueno et al., (2002) proposed 6033 four geotectonic units for northern Thailand 5993 6034 (from west to east): the Sibumasu, Inthanon, 5994 6035 Sukhothai, and Indochina terranes, separated 5995 by the Changning–Menglian–Inthanon, and 6036 5996 sutures 6037 Nan and Sra Kaeo 5997 Jinghong, respectively (Figure 1a). However, the nature 6038 5998 6039 and the precise position of some the suture 5999 zones running through Thailand have been ⁶⁰⁴⁰ 6000 of ⁶⁰⁴¹ historically hampered by the lack 6001 information from areas such as the western 6042 6002 6043 margin of the Indochina Terrane (Figure 1a). 6003 In Thailand, the Nan (or Nan–Uttaradit) suture ⁶⁰⁴⁴ 6004 has been regarded by many workers as a 6045 6005 major boundary between the Gondwanan ⁶⁰⁴⁶ 6006 Sibumasu terrane to the west and the ⁶⁰⁴⁷ 6007 hence ⁶⁰⁴⁸ terrane to the east, 6008 Indochina

Ocean during the Late Palaeozoic-Triassic (Hutchison 1975; Bunopas 1981; Barr & Macdonald 1987; Yang et al. 1994; Okamura et al. 1997). However, the Nan suture has more recently been correlated with each of the Jinshajiang-Ailaoshan suture, the Lancangjiang suture, and the Changning-Menglian suture in Yunnan (Barr et al., 2006, see review in Gardiner et al., 2015). Most authors (Ricou, 1994; Ueno et al., 1999, 2001; Sone and Metcalfe, 2008; Metcalfe, 2013; Gardiner et al., 2015) prefer an alternative site for the true Palaeo-Tethys subduction zone in the N-S trending Inthanon Zone-Chiang Rai line to the west where pelagic cherts of Devonian-Triassic ages and Permo-Triassic seamount carbonates are distributed. This zone lies is roughly parallel to the Loei Volcanic belt. Sone and Metcalfe (2008) regarded the Nan and Sra Kaeo sutures as a back-arc suture zone between the Sukothai volcanic arc and the Indochina Terrane (Figure 6032 1a).

> The KKFTB is located in the southern portion Loei–Phetchabun–Nakhon Nayok of the Volcanic Belt. This belt is composed of acidic to basic lavas, and compositionally-related. In the Loei area, these volcanic rocks may be further separated into eastern, central, and western sub-belts. The volcanic rocks of the eastern sub-belt are mainly rhyolitic, whereas those of western sub-belt are largely andesitic (Jungyusuk & Khositanont 1992; Della-Pasqua & Khin 2002, Boonsoong et al., 2011). Both have been interpreted to be the products of Permo-Triassic arc volcanism (e.g. Bunopas & Vella 1983). The arc-related rhyolitic samples of the eastern sub-belt, however, yielded U-Pb zircon ages of 425 \pm 7 and 433 \pm 4 Ma

6049 (Early Silurian-beginning of Palaeo-Tethys 6050 subduction) (Khositanont et al., 2008). The 6051 central sub-belt is composed mainly of pillow 6052 lava, hyaloclastite, and pillow breccia, 6053 (Boonsoong et al., 2011) interpreted as 6054 forming in a mid-oceanic ridge environment 6055 (Intasopa & Dunn 1994). Additionally, 6056 Panjasawatwong et al. (2006) reported that 6057 the mid-ocean ridge basalt (MORB) exists 6058 along with oceanic island-arc mafic lava in the 6059 central sub-belt. The arc lavas were probably 6060 built on oceanic basement in a major ocean 6061 basin or in a mature back-arc basin. The 6062 volcanic rocks of the western sub-belt in the 6063 Phetchabun area have a mica ⁴⁰Ar/³⁹Ar 6064 plateau age of 238 ± 4 Ma (Middle Triassic) 6065 and geochemistry indicated formation along 6066 an active continental margin (Kamvong et al. 6067 2006; Marhotorn et al. 2008; 6068 Tangwattananukul et al. 2008). The volcanic 6069 rocks within the KKFTB have not been so 6070 thoroughly investigated. The geological map 6071 proposed by Morley et al. (2013) highlights a 6072 Triassic andesitic-rhyolitic volcanic body south 6073 of the KKFTB and a Permian granodioritic 6074 intrusion east of the KKFTB. Most of the 6075 exposed intrusions of the KKFTB lie within the 6076 carbonates of the Khao Khad Formation. 6077 Dykes and sills are common features in the 6078 KKFTB, in most cases they cross-cut folds and 6079 cross-cut or follow thrusts, indicating they 6080 were intruded after the main Indosinian 6081 deformation. However, in some cases dykes 6082 are offset by thrusts or are folded. Hence 6083 magmatic activity began before or during 6084 deformation, but continued and increased in ⁶⁰⁹¹ activity after deformation ceased (Figure 2). 6092 6085 6086 Therefore, these dykes have the potential to 6093 provide new insights in the understanding of 6094 6087 6095 6088 the Sukhothai-Indochina collision that 6096 developed during the early stages of the 6097 6089 6090 Indosinian orogeny. 6098



Figure 2. a) photographs of dykes intruding the folded carbonate of the Khao Khad Formation after the main deformation; b) dyke folded within the Alum Shale clastic unit (Morley et al., 2013); c) undeformed dyke within the Khao Khad Formation showing some clear offsetting by flexural slip of bedding; d) stereogram with the poles of the dyke planes throughout the southern KKFTB showing a clear E-W trend.

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3. Analytical methods

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6145 6102 We undertook a range of geochemical and 6146 6103 geochronological techniques to unravel the 6147 age and origin of the basaltic-andesite dyke 6104 6148 complex and investigate the relative tectonic 6105 6149 setting. These methods are detailed below. 6106 6150

U/Pb laser-ablation inductively $^{\rm 6151}$

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plasma

spectrometry (LA-ICPMS)

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3.1.

6110 Zircons grains were separated using standard 6154 6111 separation techniques such as specific-gravity 6155 liquid ($\rho \ge 3.2$) and a Frantz magnetic 6156 6112 separator. Hand-picked zircons were then 6157 6113 mounted on a 2.5 cm-diameter circular epoxy 6158 6114 mounts and then polished to expose a section 6159 6115 at their inner core. Prior to their analysis the 6160 6116 Gatan 6161 6117 grains were imaged using а cathodoluminescence analyser attached to a 6162 6118 Phillips XL20 scanning electron microscope. 6163 6119 Zircon U/Pb isotope analysis was performed 6164 6120 using LA-ICP-MS at The University of Adelaide 6165 6121 following the method of Payne et al. (2010). 6166 6122 Zircons were ablated with a New Wave 6167 6123 Research UP-213 laser using a spot-size of 30 6168 6124 $\mu m,$ a frequency of 5 Hz and intensity at $_{6169}$ 6125 100%. Isotopic data were acquired with the $_{6170}$ 6126 Agilent 7500 series Inductively Coupled 6171 6127 Plasma Mass Spectrometer on eight masses: 6172 6128 ²⁰⁶Pb/²³⁸U; ²⁰⁷Pb/²³⁵U; ²⁰⁷Pb/²⁰⁶Pb; ²⁰⁸Pb/²³²U. 6173 6129 Mass discrimination of the mass spectrometer 6174 6130 and elemental fractionation during laser 6175 6131 ablation were corrected by calibration against 6176 6132 the GEMOC GJ-1 zircon with thermal ion mass 6177 6133 spectrometry (TIMS) normalising ages of 6134 6178 $^{207}\text{Pb}/^{206}\text{Pb}$ = 607.7 ± 4.3 Ma, $^{206}\text{Pb}/^{238}\text{U}$ = 6135 6179 600.7 ± 1.1 Ma and 207 Pb/ 235 U = $602.0 \pm 1.0 \frac{6180}{6180}$ 6136 Ma (Jackson et al. 2004). The Plešovice zircon 61816137 internal standard (ID TIMS $^{206}Pb/^{238}U$ age = $_{6182}$ 6138 337.13 ± 0.37 Ma, Sláma et al., 2008), was 6183 6139 6140

used to assess accuracy before and during the $_{6184}$ analysis of the unknowns. Over the course of 6185 6141 the laser session, a total of 110 Plešovice 6186 6142 6143 internal standards analyses were carried out, 6187

6144 and gave a weighted average 207 Pb/ 206 Pb = 334 ± 29 Ma (MSWD = 0.53), and a weighted average 206 Pb/ 238 U age = 366 ± 4.4 Ma (MSWD = 0.95). Data were collected, corrected and filtered in the GLITTER version 3.0 (Van Achterbergh et al., 2001) software package. Concordia diagrams and weighted averages were calculated using ISOPLOT 4.11 for Excel mass 6152 (Ludwig, 2009).

3.2. Major and trace elements analyses

Thirty-nine samples were prepared for wholerock analysis by splitting into conveniently sized fragments, and then crushing into small chips, using а Rocklabs hydraulic crusher/breaker. The crushed fragments were cleaned with an air hose; 30-50 g aliquots of the rock chips displaying no sign of weathered surfaces, or veins were pulverised for 2-3 min in a tungsten-carbide Rocklabs ring mill. All the procedures described above were carried out in the Department of Earth Science at the University of Adelaide. Major oxides were determined on 34 samples by wavelengthdispersive X-ray fluorescence spectrometry (XRF) using a Axios featuring a 4.0 kilowatt Rh SST-mAX⁵⁰ X-ray tube from Panalytical. The spectrometer is controlled by Super-Q software at the Geology, Geophysics and Geochemistry laboratories in the University of Tasmania. XRF analyses were performed with a Sc-Mo 3kW side window X-ray using standard techniques (Robinson 2003). Corrections for mass absorption are calculated using Philips X40 software with De Jongh's calibration model and Philips (or CSIRO) alpha coefficients. Calibrations are on pure element oxide mixes in pure silica. The trace elements were determined for 39 samples at AcmeLabs (presently Bureau Veritas Minerals) in Vancouver, Canada. The solutions were analysed using a Spectro Ciros Vision emission spectrometer ICP-ES/MS (AQ200 detection level) and a Perkin Elmer

Elan 6000/9000 inductively coupled plasma 6230 6188 mass spectrometer (ICP-MS) for 45 elements 6231 6189 6190 (Ba, Be, Co, Cs, Ga, Hf, Nb, Rb, Sn, Sr, Ta, Th, 6232 U, V, Cr, W, Zr, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, 6233 6191 Tb, Dy, Ho, Er, Tm, Yb, Lu, Mo, Cu, Pb, Zn, Ni, 6234 6192 As, Cd, Sb, Bi, Ag, Au, Hg, Tl, and Se). 6193 6235

6236 Whole-rock Sr, and Nd isotopes 6194 3.3. 6237 6195 analyses 6238

Samples of 0.5 g of rock powder from three $^{\rm 6239}$ 6196 significative samples were dissolved together ⁶²⁴⁰ 6197 with $(^{147}$ Sm and 150 Nd) mixed spike, in a 6241 6198 solution of 2mL 7M HNO_3 and 4mL 48%HF and $\,^{6242}$ 6199 left overnight at 140°C, then evaporated to ⁶²⁴³ 6200 dryness. The procedure was repeated in the ⁶²⁴⁴ 6201 same solution, and then evaporated to ⁶²⁴⁵ 6202 dryness after a digestion of 48 hours. The ⁶²⁴⁶ 6203 dissolution procedure also involves digestion ⁶²⁴⁷ 6204 of the solution in 6mL 6M HCl for conversion 6248 6205 to chlorides. The solutions were separated for 6249 6206 Sr, Nd and Sm by ion chromatography. Two ml 6250 6207 of the solution were passed twice through ⁶²⁵¹ 6208 AGW X8 200-400 mesh resin in Polyprep 6252 6209 columns and then 1 ml of the final solution $^{\rm 6253}$ 6210 was passed once through eichrom Ln resin 6254 6211 SPS for the isotopes separation. The analyses ⁶²⁵⁵ 6212 were carried out in the University of Adelaide 6256 6213 using a Finnigan MAT262 thermal ionization ⁶²⁵⁷ 6214 mass spectrometer (TIMS), in double collector ⁶²⁵⁸ 6215 dynamic measurement mode. Measurements 6259 6216 were done with at least 10 blocks of 10 scans ⁶²⁶⁰ 6217 (8 second each) for a minimum of 100 6261 6218 measurements, the results for strontium were ⁶²⁶² 6219 then normalized to a fixed 88 Sr/ 86 Sr = 6263 6220 8.375209, and for neodymium to a fixed 6264 6221 146 Nd/ 144 Nd = 0.721903. Both the isotopes 6265 6222 concentrations have been corrected using the ⁶²⁶⁶ 6223 outcome of 200 pg blank solution. For an 6267 6224 optimal result the Sm concentrations were ⁶²⁶⁸ 6225 6269 corrected for 150 pg of blank solution. 6226 6270

6227

3.4.

Mica ⁴⁰Ar/³⁹Ar geochronology

6271

6272 We selected two andesitic dykes with an 6228 6273 average of 59.6% in SiO₂ from Group III for 6229 6274

⁴⁰Ar/³⁹Ar dating and extracted several unaltered biotite and muscovite crystals of 315-500 µm in diameter. These minerals were carefully handpicked under a binocular microscope after magnetic separation from the crushed materials and washed in an ultrasonic bath using ultrapure water. Samples were loaded into a small well of one 1.9 cm diameter and 0.3 cm depth aluminium disc. This well was bracketed by small wells that included Fish Canyon sanidine (FCs) used as a neutron fluence monitor for which an age of 28.294 \pm 0.036 Ma (1 σ error) was adopted (Renne et al., 2011) and an excellent grain-tograin reproducibility was demonstrated (Jourdan and Renne, 2007). The discs were Cd-shielded (to minimize undesirable nuclear interference reactions) and irradiated for 40 h in the Oregon TRIGA research reactor in a central position. The mean J-value computed from standard grains within the small pits is 0.0000635, 0.01058900 ± which is determined as the average and standard deviation of J-values of the small wells. Mass discrimination was monitored using an automated air pipette and provided a mean value of 1.005014 (±0.06%) per dalton (atomic mass unit) relative to an air ratio of 298.56 ± 0.31 (Lee et al., 2006). The correction factors for interfering isotopes were (³⁹Ar/³⁷Ar)Ca = 7.60×10^{-4} (±1.2%), (³⁶Ar/³⁷Ar)Ca = 2.70 × 10⁻⁴ $(\pm 0.74\%)$ and $({}^{40}\text{Ar}/{}^{39}\text{Ar})\text{K} = 7.30 \times 10^{-4}$ (±12.4%). The ⁴⁰Ar/³⁹Ar analyses were performed at the Western Australian Argon Isotope Facility at Curtin University. The crystals were step-heated using a 110 W Spectron Laser Systems, with a continuous Nd-YAG (IR; 1064 nm) laser rastered over the sample during 1 min to ensure that all the gas has been extracted from the sample. The gas was purified in a stainless steel extraction line using two SAES AP10 getters and a GP50 getter. Ar isotopes were measured in static mode using aMAP 215-50 mass spectrometer (resolution of ~450; sensitivity of 4 \times 10⁻¹⁴

mol/V) with a Balzers SEV 217 electron 6319 6275 6276 multiplier using 9 to 10 cycles of peak- 6320 6277 hopping. The data acquisition was performed 6321 6278 with the Argus program written by M.O. 6322 6279 McWilliams and was run under a LabView 6323 environment. The raw data were processed 6324 6280 using the ArArCALC software (Koppers, 2002) 6325 6281 6282 and the ages were calculated using the decay 6326 6283 constants recommended by Renne et al. 6327 6284 (2011). Blanks were monitored every 3 to 4 6328 steps and typical 40 Ar blanks range from 1 × 6329 6285 10^{-16} to 2 × 10^{-16} mol. 6286 6330

6331

6332

6287 4. Sample description and petrography

The dykes occur within the E-W to NW-SE $^{\rm 6333}$ 6288 trending hills of the KKFTB (Supplementary 6334 6289 Data-1). For this study, the freshest samples ⁶³³⁵ 6290 6291 were selected for both geochemical and 6336 no 6337 are There 6292 petrographical analyses. previous studies on the igneous rocks that $^{\rm 6338}$ 6293 onlv 6339 the 6294 the KKFTB, and intruded geochronological constraints for this area ⁶³⁴⁰ 6295 were reported on the Late Permian early 6341 6296 Triassic granodiorite east to the KKFTB in 6342 6297 Morley et al. (2013). However, the ages of the 6343 6298 igneous rocks have here been assumed on the 6344 6299 basis of geometrical relationships with the 6345 6300 associated sedimentary rocks, and from ⁶³⁴⁶ 6301 provenance criteria. Most of the outcrops $^{\rm 6347}$ 6302 examined during this study consist of green to 6348 6303 dark grey basaltic and andesitic dykes and sills ⁶³⁴⁹ 6304 with rare flows or welded tuffs. The mafic 6350 6305 dykes in the KKFTB have mostly basaltic and 6351 6306 and esitic compositions (Table 1 – Appendix C) 6352 6307 and intrude carbonates of the Khao Khad $^{\rm 6353}$ 6308 Formation and the Alum Shale unit in the 6354 6309 southern portion of the Siam Cement quarry 6355 6310 (Figure 1). These two compositions of dykes ⁶³⁵⁶ 6311 do not present any type of cross-cutting 6357 6312 relationship making it impossible to define a 6358 6313 relative age. However, an andesitic dyke ⁶³⁵⁹ 6314 cross-cuts the gabbroic intrusion southeast of 6360 6315 the KKFTB, revealing their relative late timing 6361 6316 of emplacement. There is field evidence for 6362 6317 both the basaltic and andesitic dykes to have $\,^{6363}$ 6318

intruded the KKFTB before and after the main folding event (Figure 2a, b, c). Evidence for pre-deformation emplacement is relatively infrequent and includes folding of intrusions, and offsetting of intrusions by flexural slip of bedding and thrusts. The majority of the dykes cross-cut folds, exhibit an E-W strike and steep dips (Figure 2d). The strike direction is sub-parallel to the orientation of the major fold hinges in the area (Arboit et al., 2014), which also suggests post-tectonic emplacement. Dykes are tensile fractures, which develop in orientations parallel to the maximum horizontal stress, hence emplacement sub-parallel to fold hinges is incompatible with the stress orientation required for fold development. The dykes are commonly free of noticeable metamorphism; although, the presence of rare crypto-crystals of cummingtonite, actinolite, and chlorite in coexistence with crystals of hornblende low-grade highlights possible regional metamorphism. The average thickness of the dykes ranges from 1 m up to 10-15 m. In this study, the representative fresh basaltic and andesitic dykes from quarries were sampled. The basaltic andesite and andesite intrusions are fine grained, dark to green in colour, with porphyritic to aphanitic texture and mainly containing plagioclase crystals set in an interlocking matrix of quartz and alkali feldspar. The plagioclase crystals are usually affected by intense sericitic alteration that has obliterated the primary structure; or they are pseudomorphed by chlorite and calcite. Pyroxenes are mostly euhedral and sometimes are altered to amphiboles (20-35%), clinopyroxene shows disequilibrium features such as rounded/corroded edges. The plagioclase and alkali feldspar are both euhedral. The groundmass presents a scattered presence (40-60%) of biotite and muscovite (2-5%) and accessory cryptocrysts of olivine and magnetite. Most samples lack olivine, others have minor amounts and only a 6364 few have quantifiable The 6407 amounts. 6365 gabbro/gabbroic basalt samples have 6408 aphanitic to ophitic textures. Microgabbro 6409 6366 samples show porphyritic textures with 6410 6367 6368 clinopyroxene and orthopyroxene 6411 6369 characterized by inequigranular distributions. 6412 The pyroxenes are partially pseudomorphed 6413 6370 6371 by epidote, actinolite and calcite 6414 6372 microphenocrysts, with subordinate 6415 plagioclase, hornblende, and rare accessory 6416 6373 magnetite partially altered to hematite. These 6417 6374 evidences of greenshist facies conditions 6418 6375 might be related to events of high fluid 6419 6376 circulations that led to the formation of 6420 6377 marbles in the southern portion of the KKFTB 6421 6378 (Warren et al., 2014). The metamorphic 6422 which is interpreted as the age 6379 6380 imprinting represents possible very-low to low 6423 crystallisation (Figure 3).

6381 grade regional 6382 consistent metamorphism, 6383 with the maximum 6384 temperatures of 160-210 °C 6385 reported in the eastern KKFTB by Arboit et al. (2015). 6386 6387 The basaltic dykes are 6388 extremely fine grained and 6389 contain only sporadic 6390 euhedral lath-shaped 6391 plagioclase phenocrysts (1-6392 5%) (Table 1 – Appendix C). 6393 Matrix minerals are mainly 6394 plagioclase and crypto-6395 crystals of olivine. The 6396 presence of olivine might be 6397 a sign of incomplete reaction 6398 on account of rapid rise and

6424 quick cooling of the magma. Trace amount of 6399 6425 6400 magnetite, hematite, hornblende and 6426 6401 brownish biotite make up the accessory 6427 6402 minerals.

6403 5. Results

6404 5.1. U/Pb dating 6430

6405 Rhyolitic sample T14 004 was selected for U/Pb dating. The sample consists of scattered 6406

plagioclase and feldspar phenocrysts and rare felsic and mafic clasts in a fine-grained quartzo-feldspathic groundmass. Sample T14_004 yielded zircons, which vary from fineto coarse-grained, water-clear, colourless to pale pink or pale yellow, stubby euhedral grains. A few grains are large shardlike fragments, short or equant prisms with slightly irregular crystal faces. Thirty zircon spots were analysed, of which 10 analyses yielded values within 5% of concordance (Supplementary data-2). Of these, three were inherited, one showed evidences of lead loss, and six analyses yielded a weighted ²⁰⁶Pb/²³⁸U mean age of 207.1 ± 2.4 Ma (MSWD = 0.18), of

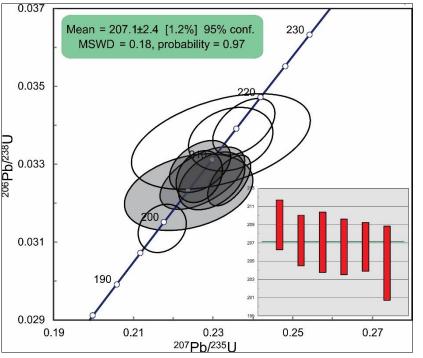
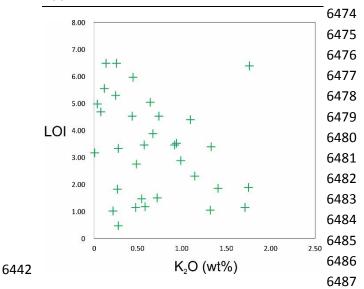


Figure 3. Concordia plot for zircon U-Pb isotopic rats of the Khao Yai rhyolite south to the KKFTB. Black shaded ellipses show the six ages within the 5% of concordance that were used to calculate the weighted mean age.

6428 5.2. Major oxides and trace elements

Major and trace elements were selected for 6429 whole-rock chemical analysis from rocks that intruded the KKFTB before, during and after 6431 6432 the Indosinian orogeny. Volcanic rocks are

susceptible to alteration, and accordingly their 6465 of the major elements, such as FeO_T , Al_2O_3 , 6433 6434 chemical compositions are unlikely to be 6466 6435 primary. To avoid this we only selected 6467 6436 samples with minor traces of alteration. 6468 6437 Petrographic evidences, as well as elevated 6469 6438 LOI (loss on ignition) values (Figure 4) show 6470 that samples in the area have been subjected 6471 6439 6440 to very low- to low metamorphism (Table 2 - 64726441 Appendix C). 6473



6443 Figure 4. K2O (in wt%) versus the Loss Of Ignition (LOI) 6488 6444 showing the level of alteration of the igneous and 6489 6445 volcanic suite of the KKFTB. 6490

These secondary processes may have led to 6446 6447 alteration of the mobile elements, accordingly 6448 only relatively immobile elements have been 6449 used herein. Elements such as Cr, Ni, Ti, Nb, 6450 Hf, Zr, P, V, and REE (Pearce and Cann, 1976; 6451 Pearce, 1996), and the relatively immobile 6452 FeO_T/MgO ratio and Mg number (Mg#) 6453 (Miyashiro et al., 1975) are taken in consideration. The data are plotted in several 6454 6455 diagrams in order to provide their 6491 compositional array and help comparison with 6492 6456 data from the Chon Daen-Wang Pong area in 6493 6457 6458 the western Loei volcanic sub-belt, and from 6494 6459 the Pak Chom area within the central Loei 6495 2011; 6460 volcanic belt (Boonsoong et al., Panjasawatwong et al., 2006). The majority of 6496 6461 the samples analysed are basaltic to andesitic, 6497 6462 and with a SiO $_2$ content between 40 % and 62 $_{6498}$ immobile elements and their ratio; the 6463 6464 % (average 47%) (Table 2 – Appendix C). Most

 P_2O_5 , present a linear trend with increasing abundances of both SiO₂ and Zr/TiO₂ (Figure 5), while as expected from the observed alteration, the more mobile elements such as the alkali group have a more scattered behaviour. Because of the possible alteration/weathering effects on the samples, it is useful to have immobile element proxy diagrams to replace conventional diagrams for 6475 rock classification. At present, the Zr/TiO_2 vs Nb/Y plot (Figure 6) is an efficient replacement for the total alkali-silica (TAS) plot (Winchester and Floyd, 1977). The samples tend to plot in the subalkalic field, with a narrow Nb/Y ratio (0.05 - 0.50) and to have a slightly tholeiitic to calc-alkalic affinity based on the Co/Th ratio (Hastie et al., 2007). They straddle the border between basalts and andesites on the basis of the Zr/Ti ratio (0.05 - 0.76). The entire set of rocks do not show any particular variation of TiO_2 and FeO_T as the fractionation parameter increases; although bivariate plots show an increase of Cr, and Ni contents with increasing Mg# and FeO_T/MgO ratio (Figure 7).

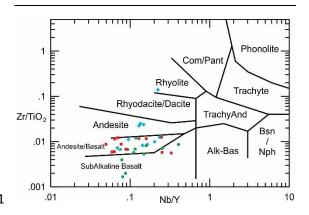
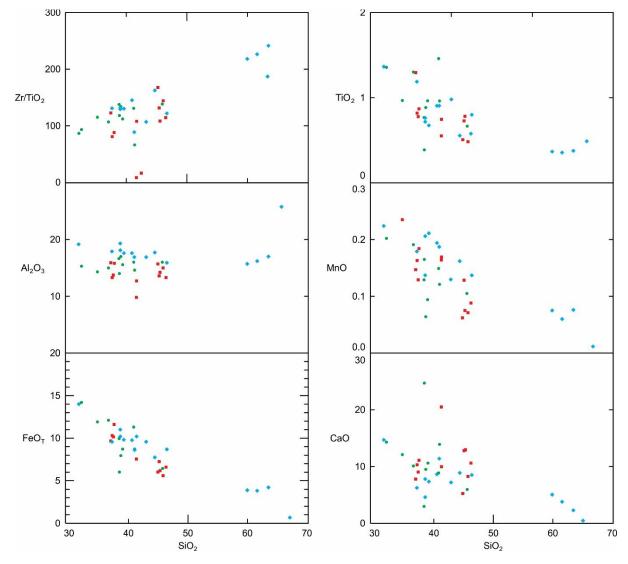


Figure 6. Plot of Nb/Y vs Zr/TiO₂ discimination diagram (Winchester and Floyd, 1977) for the KKFTB igneous and volcanic rocks. For symbology refer to Figure 4.

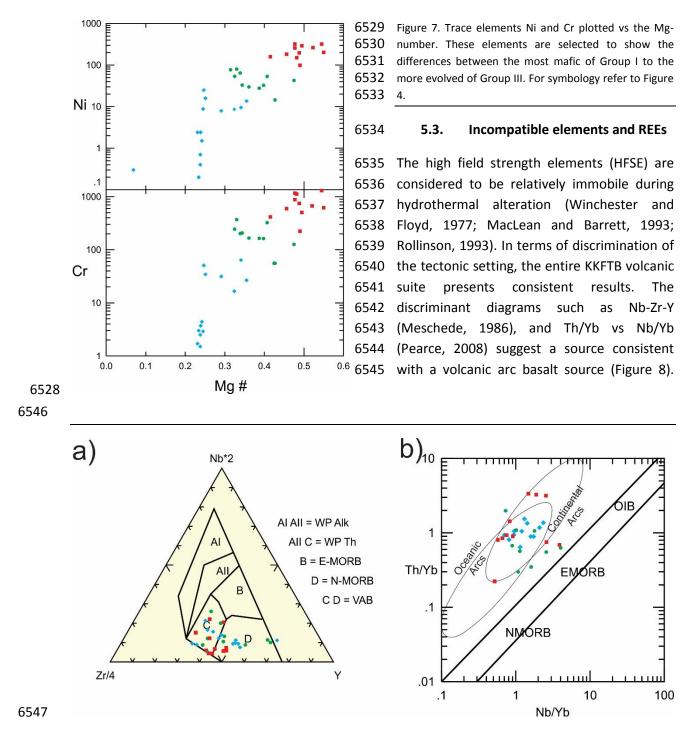
Therefore, considering wide this compositional range in terms of relatively 6499 volcanic rocks separated into three different 6512 the bivariate plots) appears to be formed of volcanic groups on the basis of immobile and 6513 6500 6501 incompatible elements. Group I (GI, red 6514 6502 squares in the bivariate plots) is mostly 6515 6503 represented by basalts, these rocks have the 6516 highest average Zr/Nb ratio (50.07), with the 6517 6504 6505 lowest FeO_T/MgO (average 0.86) ratio along 6518 6506 with the highest Cr (average 688 ppm), and Ni 6519 6507 (average 222 ppm). Group II (GII, green circles 6520 in the bivariate plots) presents intermediate 6521 6508 average values of Cr, Ni, and variable values of 6522 6509 6510 SiO₂ (38.9-62.2%), with a wide modal 6523 6511 distribution. Group III (GIII, cyan diamonds in 6524

calc-alkaline basalts and andesites. Group III presents a narrow range of SiO₂ values (41.9-51.7%) and the lowest value for the Zr/Nb ratio (average 29.83) along with Zr/V (0.3647), and also the highest P₂O₅ abundances and the lowest Cr and Ni at similar values of Mg#. Group III shows very low Ni (average 5.5 ppm) and Cr (average 33.7 ppm) abundances. All the rocks of Group III have a fairly consistent average FeO_T/MgO ratio of 2.58, and a very consistent high value of P2O5 (average 0.45 %).





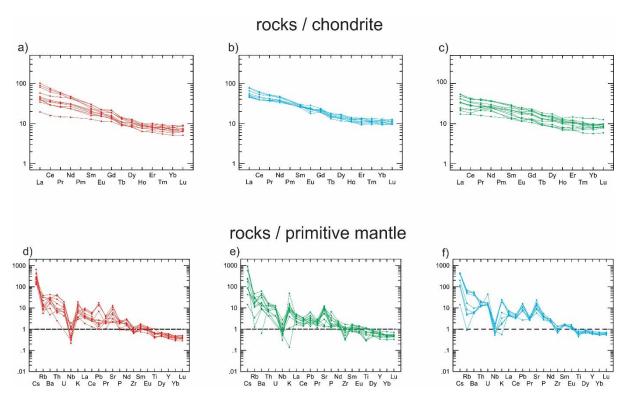
6526 Figure 5. Major elements plotted as function of SiO₂ (all in wt%) for the KKFTB sills, tuffs and dykes. Symbols representing 6527 the different groups, Group I= red squares, Group II= green circles, Group III= blue diamonds



6548 Figure 8. Plots discriminating the tectonic setting of the KKFTB; a) Zr/4-Nb*2-Y (Meschede, 1986); b) Nb/Yb vs Th/Yb 6549 (Pearce, 2008). Symbols are as in Figure 4.

Looking to the Zr/(Zr/Y) ratio it is possible to 6558 normalised REE plots (Figure 9a, b, c) each of 6550 further discriminate the tectonic setting, 6559 6551 6552 which might have developed along an active 6560 6553 continental margin, with the involvement of 6561 6554 continental crust. The rare earth element 6562 such as Ce/La and Cr/Ni show fairly consistent 6555 (REE) data from all the samples show a similar 6563 trends, with the Ce/La ratio being almost chemical imprinting for the entire KKFTB 6564 constant for all the groups (mean: 2.13, σ: 6556 volcanic suite. As shown by chondrite 6565 0.2). This is a little less than the primordial 6557 6566

the volcanic group are characterised by a relatively similar flat pattern of the HREE. The ratios between incompatible trace elements

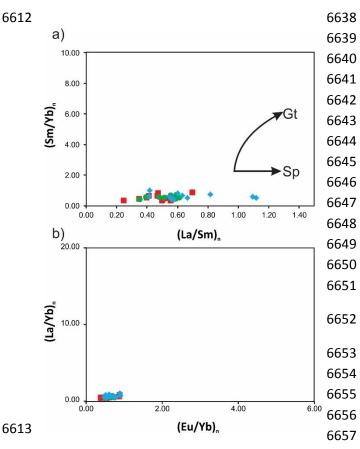


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Figure 9. a-b-c) Chondrite normalized REE data from the KKFTB volcanic and igneous suite. 6569 6570 Chondrite-normalizing values are from Sun & McDonough (1989). d-e-f) Multi-element variation 6571 diagram, with data from the KKFTB volcanic belts normalized to normal mid-ocean ridge basalt (N-MORB) from Sun & McDonough (1989). A-d) Group I; b-e) Group II; c-f) Group III. 6572

mantle value of 2.6, suggested by Wood 6593 the groups excludes the presence of garnet in 6573 (1979), and the chondrite value of 2.64, 6594 6574 reported by Nakamura (1974). The Cr/Ni ratio 6595 6575 in the three volcanic groups is almost the 6596 6576 6577 same in the three groups, with values ranging 6597 6578 from 0.33 up to 14.99 (mean = 3.5, σ = 0.5). 6598 6579 Therefore, the differences between the 6599 6580 groups might have originated through several 6600 processes, and considering the similar values 6601 6581 among each group, was probably due to 6602 6582 6583 either crystal fractionation, crustal 6603 6584 contamination or to the magma arising from 6604 6585 slightly different sources and depth of 6605 melting, or a combination of both. The trend 6606 6586 6587 of the trace element patterns is best 6607 represented by the MREE/HREE fractionation 6608 6588 system (Figure 10). The MREE/HREE ratio (e.g. 6609 6589 6590 $(Sm Yb)_n$ of all the groups presents 6610 systematically similar values (Figure 10a), the 6611 6591 low and linear trend of the Sm/Yb ratio of all 6592

their source which would fractionate the MREE/HREE ratio and rather suggest the melting of a shallow spinel-bearing source. Little distinctions also occur between the LREE/HREE ratio in the volcanic groups of the KKFTB (Figure 10b) showing similar melting conditions. The N-MORB normalized trace elements distributions are analogous to the surrounding volcanic belts (Barr et al., 2000, 2006; Panjasawatwon et al., 2006; Boonsoong et al., 2011), with trace elements patterns strongly depleted in HFSE. Groups II and III have minimal Eu anomalies probably corresponding to the andesites and metamorphic hornblende-bearing microgabbros, whereas basalts of Group I do not show any particular anomaly. The N-MORB multi-element variation diagrams



6614Figure 10. a) (Sm/Yb)n vs (La/Sm)n and (La/Yb)n vs 66586615(Eu/Yb)n for the KKFTB. Values are chondrite-normalized6616after Boynton (1984). Black curves: estimation of the
melting curves of garnet-bearing Iherzolite mantle
sources.6618sources.6621

(Figure 9d, e, f) for each of the volcanic groups 6663 6619 6620 reveal the enrichment of LREE and depletion 6664 6621 in HFSE compared to the MORB composition. 6665 In detail, samples with higher levels of Cr, Ni 6666 6622 (Groups I and II), and Mg are slightly lower in 6667 6623 6624 their incompatible element abundances in 6668 6625 comparison to dykes of Group III. Further, 6669 6626 Group III shows a stronger depletion in HREE 6670 6627 (higher La_N/Yb_N average ratio). The variation 6671 6628 diagrams show a distinct anomaly in Nd 6672 6629 relative to highly incompatible large ion 6673 6630 lithophile elements (LILE) as well as light rare 6674 6631 earth elements such as Th, K, Ce, La. This 6675 trend is probably intrinsic to the mantle 6676 6632 6633 source composition, as discriminated by using 6677 6634 the HFSE (Kelemen et al., 1993; Pearce, 1996) 6678 6635 (Figure 8). However, the anomaly in Nd might 6679 be evidence for a partial imprinting of crustal 6680 6636 contamination. The Ce/Pb ratio is relatively 6681 6637

low in the more intermediate andesites of Group III (<15), this ratio compared to the high and uniform in MORB (25 ± 5; Hofmann et al., 1986) strengthens the involvement of partial crustal contamination. Further, most of the samples show similarities with data from the Chiang Khong volcanic suite within the Sukhothai volcanic arc (Barr et al., 2006), with a very distinctive positive anomaly of Sr and Pb probably related to crustal contamination. However, only few of the rocks in GII show slightly higher abundances of Ti and lower degrees of enrichment of middle rare earth elements such as Eu and Dy relatively to Ti.

2 5.4. Sr and Nd isotopic data

Major elements data can be ambiguous when trying to discriminate between source compositions and crustal contamination as causes of chemical diversification. Three samples, from each of the three different volcanic groups were analysed for initial Sr-Nd isotopic composition, which are commonly used as tracers for magma sources (e.g. Jourdan et al., 2007). The samples have similar chemical imprinting; however they represent three different tectonic stages as follows: 1) Sample T13_027 (Group I) crosscuts without any evident deformation one of the best exposed fault-bend folds in the Khao Yai hill, and demonstrate post -tectonic emplacement. 2) Sample T13_062 (Group II) has been cut off and displaced several hundred meters by a major thrust supporting the timing of emplacement before or during the main tectonic event, and 3) Sample T13_070 (Group III) is represented by a tuff layer syn-depositional to the Khao Khad Formation. These field relationships in addition to the new ⁴⁰Ar/³⁹Ar and U-Pb analytical results, and to the U-Pb ages from the granodiorite intrusion east of the KKFTB (287 ± 7 Ma) (by S. Meffre Pers. comm.), were used in relation to the general tectonic architecture of the KKFTB in order to estimate

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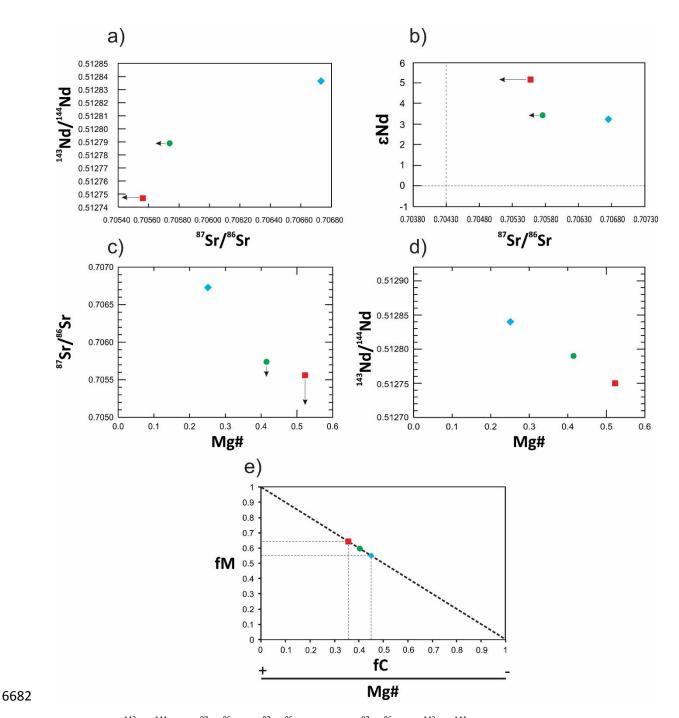


Figure 11. a) ¹⁴³Nd/¹⁴⁴Nd vs ⁸⁷Sr/⁸⁶Sr; b) ⁸⁷Sr/⁸⁶Sr vs εNd; c) ⁸⁷Sr/⁸⁶Sr; d) ¹⁴³Nd/¹⁴⁴Nd initial isotopic composition vs Mg-6683 6684 number; and e) plot showing the balancing of the isotopes masses and the relative trend with respect to the Mg-number. Black arrows in plots a, b, c point out the possibly lower values of ⁸⁷Sr/⁸⁶Sr in samples from group I and II, related to the 6685 6686 level of alteration (high Loss Of Ignition

6687 ages for each samples. All of them have a 6694 slightly higher and the model ages are 6688 narrow range of $\varepsilon Nd(t)$ values ranging from 6695 younger than those reported for the less +5.16 (Sample T13_070, ±280 Ma) to +3.22 6696 juvenile basaltic dyke within the Khao Yai Hill 6689 (Sample T13_027, ±230 Ma), with relative 6697 (Table 3 – Appendix C). All the samples have a 6690 6691 calculated mantle ages are in the range of c. 6698 relatively narrow range in Sr isotopic ratios 700-900 Ma. The ε Nd(t) values of the dykes 6699 (87 Sr/ 86 Sr(t) = 0.705560– 0.706729), with the 6692 6693 that predate the main tectonic event are 6700 lowest values pairing with the highest $\varepsilon Nd(t)$

in Group I while Group III stands out for the 6744 6701 6702 highest 87 Sr/ 86 Sr(t) and both the lowest Mg# 6745 and $\varepsilon Nd(t)$. The trend of the $\varepsilon Nd(t)$ and of the 6746 6703 6704 ⁸⁷Sr/⁸⁶Sr(t) in the dykes of the KKFTB might 6747 suggest that some of the magmas were either 6748 6705

affected by crustal contamination or reflect a 6706 heterogeneous mantle source(s). Looking at 6707 6708 the LOI of the rock samples it is possible to imply that the 87 Sr/ 86 Sr(t) might have been 6709 modified by alteration, resulting in values 6710 higher than its original isotopic composition 6711 (Figure 11a, b, c). One of the key differences 6712 between the volcanic groups is their quite 6713 constant and overlapping REE trends (Figure 6714 10), these ratios seem to indicate similar 6715 6716 depths of melting for the volcanic groups of the KKFTB. Both 87 Sr/ 86 Sr(*t*) and 143 Nd/ 144 Nd(*t*) 6717 correlate with Mg-number which rather 6718 suggest that these variations are related to 6719 crustal contamination processes. Balancing 6720 6721 the isotopes masses (Faure, 2013) at 220 and 6722 250 Ma we calculated that a slight increase of 6723 crustal contamination of only 10%, from about (65% fM - ±35% fC) to (55% fM - ±45% 6724 6725 fC), is necessary to lower the ratio of $\varepsilon Nd(t)$ 6726 from +5.16 to +3.22 (Figure 11e). Similar values of crustal component were calculated 6749 6727 in the parental magma of the rocks of the 6750 6728 Main Range in the Malay Peninsula (Ng et al., 6751 6729 6730 2015a).

muscovite are shown in Figure 12. In this 6754

study, an age plateau is defined as a sequence 6755

corresponding to at least 70% of the total ³⁹Ar ⁶⁷⁵⁷

reproducible at the 95% confidence level (2 σ). ⁶⁷⁵⁹

The two samples, both of Group III, yielded 6760

well-defined plateau ages at 255 \pm 6 Ma 6761

yield

(MSWD 2.0, P=0.05), and 224 ± 1.9

(MSWD 1.0, P=0.43), (Figure 11).

6743 characteristics of the age spectra suggest that ⁶⁷⁶⁴

more consecutive

apparent

⁴⁰Ar/³⁹Ar geochronology 6731 5.5.

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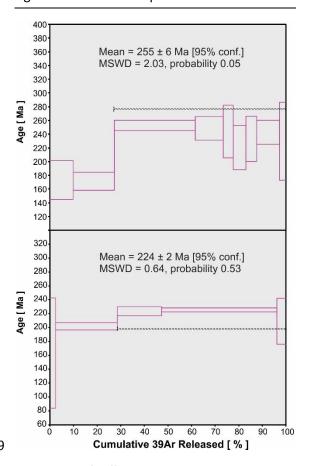
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⁴⁰Ar/³⁹Ar analytical results for biotite and

of three or

that

argon loss occurred in the samples from subsequent thermal event, but this event affected only the low-temperature extraction steps and allowed us to derive a crystallization age for those two samples.



⁴⁰Ar/³⁹Ar weighted mean plateau ages Figure 12. calculated for two andesites of Group III.

6. Discussions

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6.1. SE Asia tectonic context

Perhaps the most outstanding feature of the Indosinian Orogeny in Thailand and Malaysia is the extensive, highly voluminous, nature of 'l' and 'S'-type granites (Beckinsale, 1979) and Cobbing et al., 1986). With the Sibumasu granites west of the Raub-Bentong suture being predominantly 'S-type', while those east of the suture (Sukhothai-Indochina block) being predominantly 'I-type'. Traditionally this division, following Chappell and White (1974), has been used to infer an Andean-type setting for the 'I-type' granites and continent

6766 collision, associated with considerable crustal 6810 et al., 2012, Ng et al., 2015b). The extensive 6767 thickening and melting of a sedimentary 6811 6768 protolith, for the 'S-type' granites. This 6812 6769 association would make the Sibumasu- 6813 6770 Sukhothai/Indochina collision in Thailand and 6814 6771 Malaysia appear to be more like a major 6815 continent-continent collision, and less like an 6816 6772 6773 accretionary orogen. 6817

6818 6774 Accretionary orogens are characterized by a 6819 succession of collisional events, that if long-6775 6820 6776 lived enough can involve seamount/plateau 6821 6777 accretion, ridge-trench interaction, formation 6822 of supra-subduction ridges and back-arc 6823 6778 6779 basins, arc-arc, and arc-continent collision, 6824 oroclinal bending, and collision of island arcs 6780 6825 and continental fragments. An example of an 6781 6826 6782 extremely long-lived accretionary orogeny is 6827 the Altaids of Central Asia that developed 6783 6828 from 600 Ma to 250 Ma (see review in 6784 6829 Wilhem et al., 2012). The accretion of narrow, 6830 6785 ribbon-shaped terranes enables subduction to 6786 6831 initiate or continue on the outboard side of 6832 6787 the ribbon, thus permitting the accretionary 6833 6788 6789 orogen to continue growing. Whereas in a major continent-continent collision zone such 6834 6790 6791 as the Alps or the Himalayas subduction 6835 6792 continues and ultimately terminates at the 6836 6793 site of collision. Consequently a considerably 6837 greater degree of continental crust thickening, 6838 6794 6795 and subduction occurs in major continent- 6839 6796 continent collision zones compared with 6840 6797 accretionary orogens. 6841

Indosinian orogeny is virtually a 6842 6798 The 6799 continuation of processes seen earlier in the 6843 6800 Altides to the north, and Sibumasu is a ribbon 6844 6801 continental terrane, not a major continental 6845 block. Hence, the tin belt association with a 6846 6802 6803 major continental collision has not been an 6847 6804 easy one to reconcile. Recently interpretation 6848 6805 of the origin of the granites has become more 6849 nuanced because geochemically the two 6850 6806 6807 provinces in Malaysia actually only show slight 6851 6808 differences in lithology, geochemistry and 6852 6809 isotope values (e.g. Ghani et al., 2013, Searle 6853 viscous flow of lower crust) are considered to

occurrence of tin-bearing granites (~220-195 Ma) within the Sibumasu Terrane is interpreted to be consequence of а widespread crustal thickening (e.g. Cobbing et al., 1992; Cobbing, 2011). However, Ng et al. (2015b) note that although up to 40% crustal sources were incorporated into melts due to anatexis of metasedimentary basement, fluids driven off a subduction zone on the west side of Sibumasu remained an important factor in triggering partial melting of thickened Sibumasu crust. Granites in the eastern belt span ages around 290-220 Ma (Ng et al., 2015a). They are metaluminous to weakly peraluminous, with an enriched high field strength element (HFSE) signature, and are interpreted formed to have in а suprasubduction zone setting (Ng et al., 2015b). Around 20% crustal source contribution has been determined, with little difference in crustal signature between eastern and western Malaysia (Ng et al., 2015b).

The interpretation of Ng et al. (2015b), which minimizes the contribution of crustal thickening to the development of the tinbearing granites in Malaysia (and by association, Thailand) and invokes subduction on the western side of Sibumasu, emphasizes the accretionary nature of the Indosinian orogen into the Early Jurassic.

The crustal thickness in Thailand ranges from 31 to 38 km (Noisagool et al., 2014). However, this measure provides no evidence for crustal thicknesses attained during the Indosinian orogeny, since it is well known that other ancient orogenic belts, particularly the Scandinavian Caledonides, have normalized their thicknesses post-collision (Blundell, 1984, 2002). In the case of the Caledonides a range of processes (erosion, plate divergence, gravity-driven collapse of the orogenic wedge,

be responsible (Fossen et al., 2014). While 6898 6854 6855 normalization has probably occurred in 6899 6856 Thailand the preservation of low-grade 6900 metamorphism fold and thrust belts, and the 6901 6857 widespread absence of exhumed high-grade 6902 6858 6859 terranes indicates that uplift and erosion 6903 during the orogeny was limited. One exposed 6904 6860 6861 region of high grade Indosinian 6905 6862 metamorphism is Doi Inthanon, where P-T 6906 6863 analysis indicates high temperatures (700-6907 6864 750°C) but moderate pressures (6-7 kbar), i.e. 6908 6865 depths of 20-23 km, at peak metamorphism 6909 (Macdonald et al. 2010). These observations 6910 6866 6867 support the interpretation that the crust 6911 never became very thick (<50km?). The high 6912 6868 6869 grade (amphibolite-granulite) gneissic 6913 6870 terranes that are exposed in Thailand, in most 6914 6871 cases, were exhumed as a consequence of 6915 Late Cretaceous-Cenozoic tectonics, 6872 not 6916 6873 processes 6917 Indosinian orogeny-related 6874 (Macdonald et al., 2010; see review in Morley 6918 et al., 2012). This tectonic complexity is well 6875 reflected within the KKFTB. The compositional 6919 6876 variations amongst the three groups identified 6920 6877 in the preceding sections most likely reflect 6921 6878 complicated magmatic processes and/or the 6922 6879 nature of the source(s). These characteristics 6923 6880 can generally be attributed to: (1) various 6924 6881 assimilation/fractional 6925 6882 amounts of crystallization of mantle-derived magma and 6926 6883 crustal contamination en route to the surface; 6927 6884 (2) various degrees of partial melting of a 6928 6885 homogeneous source at different pressures 6929 6886 and temperatures; and (3) mantle source 6930 6887 variability, e.g. metasomatised lithospheric 6931 6888 ^{and} 6932 6889 mantle or hybridized source (Bell 6890 Simonetti, 1996). 6933

6891 6.2. Effect of alterations

The mafic dykes in the region have commonly 6936 1993; Zhang et al., 1994, 1995; Kato et al., 6893 been altered to various degrees after 6937 1997) and lower crustal intermediate 6894 intrusion, which can be determined from 6938 granulites (Gao et al., 1998) in the deep crust 6895 petrographic observations and exemplified by 6939 would produce high-Si liquids (Rapp et al., 6896 the relatively high loss on ignition in most of 6940 2003). However, the dykes probably do not 6897 the sample with andesitic samples over 6941 represent primary melts, as judged from their

basaltic samples having a LOI between 2 and 7 wt% (Figure 4). Some incompatible elements, such as Rb, Ba and K, are known to be mobile during weathering (Deniel, 1998), as demonstrated by the considerable scatter in the N-MORB multi-element variation diagrams. However, the consistency demonstrated by the data set (except for the most mobile elements) in primitive-mantlenormalized patterns (Figure 9d, e, f), suggests that absolute abundances and ratios of incompatible elements, such as LREE and HREE are the least sensitive to weathering. This is supported by a large number of studies (Jochum et al., 1991; Deniel, 1998; Kerrich et al., 1999; Xu et al., 2001). Accordingly, the following discussions focus mostly on the most immobile elements as well as the Mg#, $\varepsilon Nd(t)$ values, although we will tentatively use the 87 Sr/ 86 Sr(t) ratio for supporting our hypothesis.

6.3. Magma sources

The Mg# is a differentiation proxy which monitors the chemical evolution of the magma (Lindh et al., 2001). The Ni, Cr and P contents show quite consistent correlation with the Mg#. The low SiO₂ contents (average 46.6 wt. %) suggests that the dykes of the KKFTB were possibly derived from a ultramafic mantle source (by opposition to anatectic melts derived from the crust). This is also supported by high concentrations of Ni (average 222 ppm) and Cr (average 688 ppm), in the most mafic dykes of the KKFTB. Crustal rocks might be ruled out as possible sources because experimental evidence shows that partial melting of any of the older, exposed crustal rocks (Hirajima et al., 1990; Yang et al., 1993; Zhang et al., 1994, 1995; Kato et al., 1997) and lower crustal intermediate granulites (Gao et al., 1998) in the deep crust would produce high-Si liquids (Rapp et al., 2003). However, the dykes probably do not

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MgO (average <6.1%), Mg# (0.29–0.99) and Ni 6986 6942 contents (1.5-320 ppm). The Mg# negative 6987 6943 trend showed by the rock groups of the 6988 6944 KKFTB, from Group I to Group III, suggests 6989 6945 6946 that the most evolved rocks might have 6990 undergone to crustal contamination as also 6991 6947 indicated by the co-variation in 87 Sr/ 86 Sr(t), 6992 6948 6949 and in $\epsilon Nd(t)$ (Figure 11c, d). The differences 6993 6950 between rocks of Group I and III might be also 6994 related to a degree of fractional crystallization 6995 6951 prior to emplacement. Looking at the major 6996 6952 6953 and trace elements, Group III and partially 6997 6954 Group II rocks may have experienced 6998 fractionation of olivine and clinopyroxene 6999 6955 6956 from the parental magmas, supported by the 7000 6957 positive correlation between Mg# and Cr and 7001 6958 Ni (Figure 7). The slight increase of CaO/Al₂O₃ 7002 with higher abundances of Mg# (not shown) 7003 6959 indicates possible clinopyroxene fractionation. 7004 6960 In primitive mantle normalized diagrams 7005 6961 (Figure 9) all the rocks reveal very distinctive 7006 6962 negative anomalies for Nb, Ta and Ti, and 7007 6963 positive anomalies for Sr and Pb. HFSE- 7008 6964 6965 depletion indicates the involvement of 7009 6966 components from the Tethyan/back-arc oceanic or ancient continental crust (Zhang et $\ensuremath{^{7010}}$ 6967 6968 al., 2005a). Accordingly, the above 7011 continental 7012 6969 observations suggest that materials were involved in the development $_{7013}$ 6970 of these mantle-derived magmas (Pearce, 7014 6971 1996; Jahn et al., 1999). 6972 7015

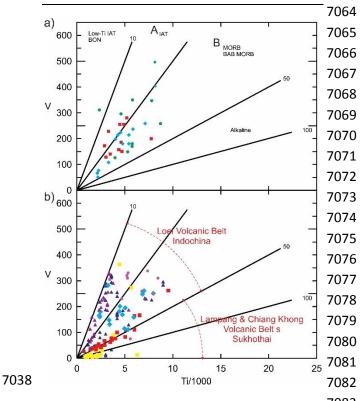
7016 The Nd and Sr isotopic records help 6973 7017 constraining the nature of the mafic parental 6974 7018 magma. The slightly positive ENd values are 6975 7019 similar to those in the 240 Ma rhyolitic tuff 6976 7020 from the Phetchabun fold-thrust belt area 6977 7021 (Figure 11b) (+4.8 to +5.8, Barr et al., 2000, 6978 7022 2006). However, a more complicated scenario 6979 7023 appears when looking at the data from 6980 7024 Intasopa (1993) and Intasopa and Dunn 6981 7025 (1994), who reported ɛNd values from +0.39 6982 7026 to -1.35 for rhyolites in the Loei area. These 6983 7027 rocks are Devonian-Carboniferous in age and 6984 are interpreted by Intasopa (1993) and ⁷⁰²⁸ 6985

Intasopa and Dunn (1994) to have been derived from crust on the edge of the Indochina Terrane. Hence, these are not directly comparable to those from the KKFTB. These geochemical and isotopic data suggest that the parental magma of the dykes is unlikely to be have derived from different depths of melting as indicated by the MREE/HREE (Figure 10), and probably arose from the lithospheric wedge after the metasomatism of the subducted back-arc basin between Sukhothai and Indochina. The younger and more evolved samples might have undergone to higher degrees of crustal contamination (Figure 11b) and this process possibly occurred during the late Permian to Late Triassic evolution of the Indosinian orogeny after the Sukhothai-Indochina collision and the relative slab break-off. Other similarities appear with volcanic belts within the Sukhothai terrane, in fact the $\varepsilon Nd(t)$ values yield Neoproterozoic T_{DM} ages (ca. 600-900 Ma) similar to those from the Chiang Khong volcanic suite (Barr et al,. 2006).

6.4. Tectonic setting

As outlined above, geochemical features of the studied dykes suggest a LILE and LREE enriched mantle source, possibly modified through metasomatism of a lithospheric mantle component in a subduction-related environment (Pearce, 1982, 1996). The Th/Yb vs Nb/Yb (Pearce, 2008) plot indicates that the KKFTB volcanic suite is chemically affine to a continental volcanic arc tectonic setting. Figure 13a shows a spreading of the data from the IAT affine to MORB enriched rocks, and the drift in some calc-alkaline samples of Group III (Figure 13a), with the lowest values of Ti and V, seems to represents magnetite fractionation (Shervais, 1982). Therefore, the overall trend might not be compatible with an oversimplified tectonic framework, and any proposed geodynamic model must explain the

following characteristics of the KKFTB mafic 7055 Sukhothai might have caused break-up of the 7029 dykes: (1) high VAB geochemical affinity; (2) 7056 subducted back-arc slab in the Early Triassic. 7030 7031 small volume; (3) isotopic evidences of crustal 7057 7032 contamination in the late stages of the 7058 tectonic event, (5) signs of shallow spinel-7059 7033 7034 bearing source for the dykes of the KKFTB, 7060 and (4) the temporal coincidence with a 7061 7035 7036 sequence of geologic events in central 7062 7037 Thailand 7063



7039Figure 13. a) Binary plot of Ti/1000 vs V for the igneous70837040and volcanic rocks of the KKFTB (Shervais, 1982); b)70847041Binary plot of Ti/1000 vs V for the igneous and volcanic70857042rocks of the Loei volcanic belt (see text for references)70867043(Shervais, 1982).7087

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70446.4.1.Regional tectonic model

The previously discussed data might be 7090 7045 representative of a tectonic setting within the 7091 7046 KKFTB, where the arc-affinity rocks of the 7092 7047 KKFTB represent the stage of the subduction 7093 7048 of the slab (proximal BAB) between Sukhothai 7094 7049 and Indochina. The post-collisional setting 7095 7050 after the Sukhothai-Indochina collision, and 7096 7051 the possible beginning of the collision 7097 7052 7053 between the westward Sibumasu terrane and 7054 the already amalgamated Indochina-

and the intrusion of a more MORB-like magma with higher levels of Ti depletion (Figure 9d,e,f; Figure 13a). This tectonic framework appears to be quite consistent throughout the entire Loei volcanic belt and the southwestern margin of Indochina (Figure 13b) (Panjasawatwong et al., 2006; Boonsoong et al., 2011; Salam et al., 2013; Vivatpinyo et al., 2014). However, on a more regional scale, the volcanic rocks in northern Thailand within the Sukhothai terrane (Lampang volcanic belt; Barr et al., 2000, 2006) seem to describe а more heterogeneous tectonic framework with a more MORB-like to alkaline affinity, probably describing the early stages of rifting between Sukhothai and Indochina during the Early Permian (Figure 13b). All these geochemical, isotopic and geochronological evidences make possible to constraint the evolution of the Indosinian tectonic on the southwestern margin of the Indochina block from the Mid-Permian with the emplacement of the dykes of Group I during the subduction of the backarc basin between Sukhothai and Indochina. The 40 Ar/ 39 Ar ages on mica from the andesites of Group III move the early stages of the postcollisional setting to the Early Triassic (245 ± 6 Ma) and possibly the latest post-collisional stages to the Late Triassic (224± 1.9 Ma), as also constrained by 40 Ar/ 39 Ar ages of 238 ± 4 and 237 ± 12 Ma from andesitic samples near the northern Phetchabun fold-thrust and Loei volcanic belt (Intasopa, 1993). Increased basal heat flow due to mantle upwelling may have maintained relatively high temperatures during the latest stages of the post-tectonic exhumation. This might have driven to crustal partial melting and the consequent eruption of the Khao Yai rhyolite in the latest Triassic (207.1 ± 2.4 Ma) (Figure 14).

7098This model fits the available chronological 71407099data, but the lack of ages of highly mafic rocks 71417100from Group I means that this model is not 71427101unique. A second possible model would be 71437102that the different geochemical groups 71447103represent repeated injections of magma with 71457104increased crustal-component throughout the 71467105Permian and Triassic.7147

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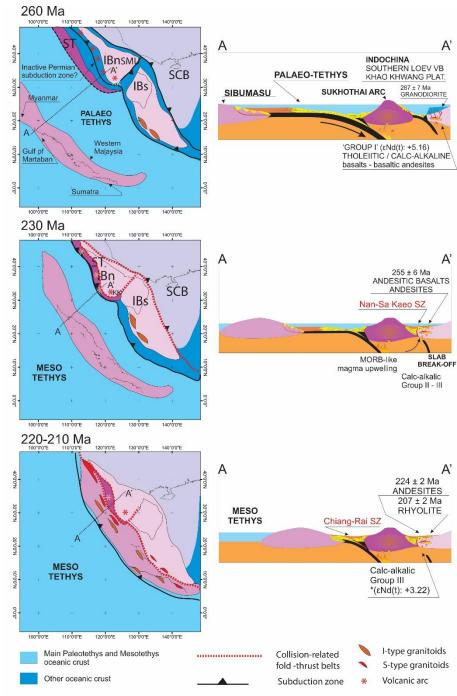
7106 **7. Conclusions**

Our new geochemical, geochronological, and 7150 7107 7151 isotopic data reported in this study together 7108 7109 with the geometrical relationship between 7152 igneous rocks hosting 7110 the and the 7153 7111 stratigraphy; provide information on the 7154 petrogenesis and mantle source origins of the 7155 7112 rocks that intruded the KKFTB within the 7113 7156 southwestern margin of the Indochina block: 7114 7157

Chemically the volcanic suite can be 7158 7115 7159 divided in three sub-groups. They 7116 7160 share the distributions of elements 7117 7161 such as HFSE (Nb, Ti, P), Th, Hf, Ta, Zr, 7118 7162 and Y indicating high affinity with a 7119 continental volcanic arc tectonic 7163 7120 7164 setting. The KKFTB volcanic suite is 7121 7165 associated with a range of stages in 7122 7166 the development of the Indosinian 7123 Orogeny from the early tectonic 7167 7124 7168 stages in the Mid-Permian to the post 7125 collisional stages in the Late Triassic 7169 7126 7170 (Figure 14). These ages are in 7127 7171 agreement with the end of Triassic 7128 7172 deposition in the Mae Sariang and 7129 Fang formations on the eastern 7173 7130 Block 7174 margin of the Sibumasu 7131 7175 (Kamata et al., 2002; Srinak et al., 7132 7176 2007, Hara et al., 2013), and with the 7133 7177 U-Pb zircon ages of 211-203 Ma for 7134 the Doi Inthanon orthogneisses and 7135 7178 the granite (Dunning et al., 1995; 7136 7179 Macdonald et al., 1993, 2010). 7137 7180 The MREE/HREE ratios are explained 7181 7138 7182 spinel-bearing 7139 similar bv а 7183 composition of the source for the whole KKFTB igneous suite that rose to the base of the lithosphere underneath the southwestern Indochina margin from the Mid Permian to Early Triassic. The isotopic variations show that the KKFTB igneous suite possibly underwent to degrees of crustal contamination, whereas the LREE/HFSE fractionation strengthens the dominance of a volcanic arc tectonic setting.

In this slab break-off model, the detachment of a lithospheric slab allows the asthenosphere underlying the downgoing plate to flow up into the broken slab window above the sinking slab. The heat supply from the uprising asthenosphere can affect overlying thickened lithosphere, yielding characteristic isotopic trend. Asthenosphere upwelling induced partial melting of the overlying mantle lithospheric previously metasomatized during subduction. Thermal flux lowered the density of the remnant lithosphere of limited extent, with the possible consequent crustal melting. Heated crust facilitates the involvement of crustal components within mantle-derived assimilationmelts through fractionation-crystallization processes (von Blanckenburg and Davies, 1995). This geodynamic model might explain the extensive andesitic dyke swarm within the KKFTB, as well as the Khao Yai rhyolite south of the KKFTB.

 40 Ar/ 39 Ar ages from andesitic dykes of Group III (255 ± 6 Ma, 224 ± 1.9 Ma) and U-Pb crystallization age from rhyolite of Group III (206 Pb/ 238 U zircon mean age of 207.1 ± 2.4 Ma) constrained the timing for the andesitic magmatism to the Late Triassic. These ages



coupled with that of the dacite south of the KKFTB (213 ± 10 Ma) (By S. Meffre Pers. comm.) are interpreted to indicate that the break-up of the Sukhothai backarc slab started during the Early Triassic following the complete subduction Sukhothaiand Indochina collision.

Figure 14. Palaeogeographic schematic reconstructions of SE Asia based on the GPlate software reconstruction file (rotation in Supplementary data-3). The cross-sections show the tectonic development of the Indochina, Sukothai and Sibumasu blocks during the Early Permian to the Late Triassic; resulting in the emplacement of the Late Permian VAB to MORB-like theTriassic andesites ad rhyolites within the southern portion of the Loei volcanic belt

SCB: South China Block; SMU: Sibumasu; IBn: Indochina Block north; Ibs: Indochina Block south ST: Sukhothai arc; KK: Khao Khwang Fold-Thrust Belt

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Chapter VII

t	Arboit, F., Amrouch, K., Morley, C., Collins, A. S., & King, R. (2016). The effect of active margin tectonic on palaeostress magnitudes: Results after calcite twin analysis in central Thailand.				
Tectonophysics.					

The effect of active margin tectonic on palaeostress magnitudes: Results after 7804 calcite twin analysis in central Thailand 7805

ABSTRACT 7806

7807 Using the Khao Khwang fold-thrust belt in central Thailand as case study, we handled data from 7808 calcite twinning analysis in order to propose the quantification of the effective principal 7809 palaeostresses magnitudes since the onset of the early stages of the Indosinian orogeny. We also 7810 combined the differential stress estimates from mechanically-induced calcite twins with 7811 geochronological data in order to constrain the timing of the palaeoburial depth and subsequent uplift by folding within the Khao Khwang fold-thrust belt. The proposed mechanical scenario is 7812 7813 based on the time-constrained kinematic sequence of fracturing, faulting, and folding in the strata of the carbonate formations of the Saraburi Group. Cross-checking the data on the palaeostress 7814 7815 orientations, regimes, and differential stress magnitudes with rock mechanics analysis; we provided data on the principal stress magnitudes for each tectonic stage that developed during the Indosinian 7816 orogeny. Further, ⁴⁰Ar/³⁹Ar and U-Pb geochronological data allowed to place reliable constraints on 7817 the amount and rate of vertical uplift of the carbonate formations of the Saraburi-Group. 7818

7819 1. Introduction

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7820 The state of stress in rocks is generally 7848 anisotropic and is represented by the 7849 7821 magnitudes of the principal axes of the stress 7850 7822 ellipsoid. In positive compression, the longest 7851 7823 axis is the ellipsoid's major stress (σ_1), the $_{7852}$ 7824 intermediate axis is the intermediate stress 7853 7825 (σ_2), and the shortest axis is the minimum 7854 7826 stress (σ_3) (Jaeger and Cook, 1969, Sibson, 7855 7827 1977; Price and Cosgrove, 1990). The 7856 7828 distribution of the modern-day stress-field 7857 7829 states (e.g. Zoback, 1992; Sandiford et al., 7858 7830 2004), as well as the palaeostress orientation 7859 7831 and differential stress values (Lacombe et al., 7860 7832 1992; Lacombe and Laurent, 1996; Lacombe, 7861 7833 2001; Lacombe et al., 2007; Lacombe, 2007; 7862 7834 Amrouch et al., 2010a), have been deeply 7863 7835 investigated in the last decades. However, 7864 7836 effective 7865 7837 quantitative estimates of palaeostress magnitudes through geological 7866 7838 time are difficult to make and have been well 7867 7839 studied only in the last years (Lacombe et al., 7868 7840 2009; Amrouch et al., 2011). Never-the-less 7869 7841 estimates of the palaeostress states from 7870 7842 rocks affected by tectonic events are of 7871 7843 addressing 7872 7844 fundamental importance for unsettled problems such as the mechanical 7873 (Etchecopar, 1984) to provide estimates of 7845

7846 behaviour of geological materials and deciphering various tectonic mechanisms, from those related to plate motions at a large scale to those causing jointing and faulting or even microstructures at a smaller scale (Lacombe, 2007; Amrouch et al., 2010a, 2010b). For these purposes, several analytical methodologies were developed in the last decades (Etchecopar et al., 1981; Angelier et al., 1982; Armijo et al., 1982; Gephart and Forsyth, 1984; Michael, 1984; Carey-Gailhardis and Mercier, 1987; Reches, 1987; Angelier, 1990; Gephart, 1990; Marrett and Almandinger, 1990; Will and Powell, 1991; Yin and Ranalli, 1993). Dynamically recrystallized grain size, along with well-calibrated relationship between the stress state and the re-arrangement of crystal lattices, are parameters associated with dislocation creep of crystalline solids. This is especially important as a stress indicator via piezometer calibrations, where quantification of palaeostresses can be numerically expressed using calcite twinning (Lacombe, 2001; Amrouch et al., 2011). Here, following the analysis in Arboit et al. (2015), we use calcite twinning analysis using Etchecopar Method

maximum differential stress (Lacombe, 2007; 7917 7874 Amrouch et al., 2010a). This contribution is 7918 7875 aimed at presenting the effect of the 7919 7876 7877 differential stress, and constraining the 7920 effective principal stress magnitudes during 7921 7878 the Indosinian orogeny, in order to better 7922 7879 understand the complicate geodynamic 7923 7880 7881 evolution of the Khao Khwang fold-thrust belt 7924 7882 since the Mid Permian in central Thailand. 7925

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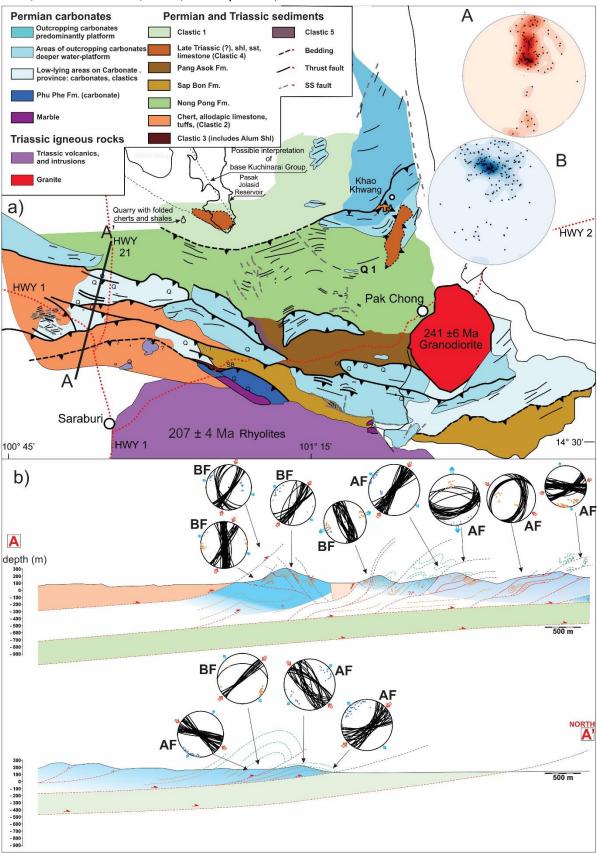
7883 2. Tectonic framework

7928 The Khao Khwang fold-thrust belt (KKFTB) 7884 7929 (Figure 1) lies in the Saraburi Province in 7885 7930 central Thailand, and it is tectonically located 7886 7931 on the SW margin of the Indochina Block 7887 7932 7888 (Bunopas, 1982; Metcalfe, 2011; Morley et al., 7933 2013). It is bounded to the north and to the 7889 7890 east by the Khorat Plateau, which trends NW- 7934 7935 SE, and to the south by the Cenozoic Mae Ping 7891 7936 strike-slip fault (Morley, 2007; Morley et al., 7892 7937 2013). This region has undergone a complex 7893 7938 geological history, which mainly developed 7894 7939 during the Indosinian tectonic event, this is 7895 7940 characterised by two different subduction and 7896 7941 collision episodes that covered the period 7897 7942 from ca. 260 to 200 Ma (Late Permian to Late 7898 7943 Triassic) (Sone and Metcalfe, 2008; Morley, 7899 7944 2007; Morley et al., 2013, Arboit et al., 2015). 7900 7945 The resulting tectonic belts and suture zones 7901 7946 in Thailand have a dominant N-S trend. The 7902 7947 Indosinian orogeny in Thailand has been 7903 7948 7904 considered to involve two stages of collision 7949 7905 during the Triassic-Early Jurassic between the 7950 7906 three main terranes, which, from east to west. 7951 are: Indochina, Sukhothai and Sibumasu 7907 7952 2008: (Figure 1a) (Sone and Metcalfe, 7908 7953 beyond 7909 Additionally, Metcalfe, 2013). 7954 Thailand, to the NE, coeval Triassic collision 7910 7955 the both 7911 also occurred between 7956 Indochina/South China Blocks (Cai and Zhang, 7912 7957 2009) and the South/North China Cratons 7913 7958 7914 (Dong et al., 2015). 7959

7915 The Sukhothai Terrane is believed to have 7960 2013; Singsoupho et al. 2014) to the northern 7916 been a volcanic arc that rifted away from the 7961 side of the fault, the boundary does not

south-western margin of Indochina in the Early Permian, as consequence of rollback above the subducting Paleo-Tethys, and opening of the back-arc basin between the volcanic arc (Sukhothai) and the Indochina Terrane (Sone and Metcalfe, 2008). However, the geodynamic evolution on the southwestern margin of the Indochina terrane has been poorly understood. The first tectonic event on the Indochina margin has been recently constrained as resulting from the latest Permian (255~4 Ma; Arboit et al., 2016) collision as the Sukhothai Terrane reamalgamated with Indochina, with the related closure of the Permian back-arc basin (Metcalfe, 2005; Sone and Metcalfe, 2008; Metcalfe, 2013). Subsequently, in the Late Triassic, during the late stages of the Indosinian collision, the Sibumasu Terrane is thought to have collided with the now combined Indochina/Sukhothai Terrane, causing the complete closure of the Paleo-Tethys in this region. The Indosinian orogeny has usually been thought as resulting from the collisions between these two strongly linear terranes and Indochina. However, despite the common N-S trend of the suture zones (Nan-Sra Kaeo and Changning-Menglian S.Z.) (Figure 1a) between the blocks involved in the collision, in some areas the tectonic trend diverges from simply N-S to NW-SE and E-W trends. The most prominent of these regions is the Saraburi region (Morley et al., 2013; Arboit et al., 2014). One explanation for the different trend is that the belt was rotated from a N-S direction to a more E-W orientation by motion along the NW-SE trending Cenozoic Mae Ping Fault Zone; Tapponier et al. (1986) proposed sinistral displacement of about 150 km on this fault. However, even after restoring this offset, and applying a relative clockwise rotation of about 25°-30° (Charusiri, 2006; Cung and Geissman, 2013; Singsoupho et al. 2014) to the northern

- 7962 restore to a N-S orientation (Anchuelas et al., 7964 2013).
- 7963 2012; Mochales et al., 2012; Morley et al.,



7965

7966 Figure 1. Geological map of the Khao Khwang Fold and Thrust Belt. It has been modified from Warren et al., (2014) to show 7967 possible interpretations of the stratigraphy as a consequence of this study. (A) Stereonet of poles to bedding for the region, 7968 (B) Stereonet of poles to main thrusts along Highway 21. b) N-S oriented regional cross-section A-A' through the southern 7969 portion of the Saraburi Region, the Khao Khwang Fold-and-Thrust Belt (see Figure 1a for location). BF: before folding; AF: 7970 after folding.

7972 the original orientation of the continental 8012 fracture set-2 developed during the main LPS margins, or possibly due to a poorly 8013 7973 7974 documented intra-Indochina suture, that 8014 7975 strikes east-west, and lies close to the 8015 7976 southern margin of the Khorat Plateau 8016 (Hutchinson, 1975; Morley et al. 2013). The 8017 7977 7978 sequence of deformation includes a layer- 8018 7979 parallel shortening event (LPS) that is 8019 7980 addressed to be the result of the Sukhothai- 8020 Indochina collision (Arboit et al., 2015). This 8021 7981 7982 sequence of fracturing has been recently 8022 constrained (Arboit et al., 2015), with the 8023 7983 7984 oldest system of conjugated fractures striking 8024 035° to 055° at high angle to the bedding. The 7985 7986 second set of conjugate fractures is the more 8025widespread throughout the Saraburi region; it 8026 7987 took place during the Indosinian stress build- 8027 7988 up (LPS event) and was probably coeval to the $\frac{8028}{2}$ 7989 Sukhothai-Indochina collision (Arboit et al., 8029 7990 2015). This set of fracture in the southern $_{\rm 8030}$ 7991 portion of the KKFTB seems to have formed 8031 7992 under the same stress tensor that is 8032 7993 responsible for the formation of conjugate $_{8033}$ 7994 sets of newly formed reverse faults that strike 80347995 parallel to the major anticlines in the area. 8035 7996 The majority of the folds in the southern 8036 7997 portion of the KKFTB developed in response 8037 7998 to thrusting as fault bend, detachment, and $_{8038}$ 7999 fault propagation folds (Morley et al., 2013; 8039 8000 Arboit et al., 2014); hence, thrusting is 8040 8001 interpreted as coeval with the growth of the $_{8041}$ 8002 8003 major anticlines. The third stage of fractures 8004 developed during the Indosinian event with a 8042 general low angle and striking 200° to 240° 8043 8005 appear to be almost synchronous or to have 8044 8006 formed just after the main LPS event (Figure 8045 8007 1b). The subsequent stress tensor is 8046 8008 associated with a stage of fold-tightening 8047 8009 8010 (Warren et al., 2015; Arboit et al,. 2015). This 8048 successive vein sets that developed since the

7971 Alternatively, the deflection may be due to 8011 stage is characterised by the reactivation of event, and by the newly formed fractures striking 070° to 090° mainly detected on the hinge zones and probably developed in response to the fold-tightening parallel to the fold axis. The fifth stage of fracturing is the latest brittle event that seems to have affected the southern portion of the KKFTB, it is marked by strike-slip faults, tail-cracks associated with shear veins and the reactivation of reverse faults previously emplaced during the main LPS event (Figure 1).

3. Methodologies

The palaeostresses that affected central Thailand since the Mid Permian were correlated to the stress that builded up mainly during the Indosinian event (Morley et al., 2013; Arboit et al., 2015). The orientations and the regimes were determined from fractures, faults, and calcite twinning analysis using the Calcite Stress Inversion Technique (CSIT) (Etchecopar, 1984; Lacombe and Laurent. 1992, 1996; Lacombe, 2001: Amrouch et al., 2010a; Amrouch et al., 2010c). This methodology computes the mean stress tensor with both the principal stress orientations and the associated differential stress magnitudes from mechanically developed sets of calcite twin data.

The sequence of tectonic events detected with the calcite twins has been constrained with respect to the fracturing/faulting development by the comparison of the reduced stress tensors T' recorded both within the matrix of the rock and in the 8049 Mid Permian (Arboit et al., 2015). Knowing 8091 2011). The values of the differential stresses 8050 the reduced stress tensors T', we quantified 8092 (Table 1 – Appendix D) were estimate from 8051 the deviatoric stress tensors T_D as (Lacombe, 8093 calcite twin analyses (Arboit et al., 2015). For 8052 2001) (1): 8094 a specific tectonic event, the quantification of

8053
$$T_D =$$

$$= T - \left[\frac{\sigma_1 + \sigma_2 + \sigma_3}{3}\right] I$$
(1)

8097 8054 The quantification of the deviatoric stress 8098 tensors T_D , depends upon: the complete 80998055 stress tensor (T), the three principal stresses $_{8100}$ 8056 (σ_1 , σ_2 , σ_3), the unit matrix (I), and the 81018057 8058 determination of a fifth parameter of the $_{8102}$ 8059 complete stress tensor that is the scalar peak 8103 8060 differential stress (σ_1 – σ_3). This determination 8061 relies on the existence of a constant Critical 8104 Resolved Shear Stress (CRSS) for twinning τ_a 8105 8062 8063 (smallest resolved shear stress; for more 8106 8064 details see Etchecopar, 1984), and on the 8107 8065 accurate estimate of τ_a ' that correspond to 8108 8066 the normalized value of the CRSS for the 8109 reduced stress tensor used for calculation 8110 8067 8068 (Lacombe, 2001; Amrouch et al., 2010a).

8069 However, the reduced stress tensor concept is 8070 based on the shape factor of the stress 8071 ellipsoid (Angelier, 1994), and it is of 8072 independent the absolute stress magnitudes, since it considers only the 8073 8074 relative ratios of principal stress magnitudes. 8075 Therefore, it is independent of the pore-water 8076 pressure ($\sigma_{\rm p}$) under hydrostatic conditions (i.e. pore-water pressure is smaller than the 8077 8078 minimum principal stress magnitudes $\sigma_p < \sigma_3$), 8079 if we adhere to those conditions, the 8080 thickness of the sedimentary column and the relative overburden is the only effective 8081 8082 influence. The T_D lacks in the isotropic module 8083 in order to define the complete stress tensor 8084 (e.g. Lacombe, 2001); hence, the palaeostress 8085 orientations and regimes were here combined 8086 with rock mechanics data; these data were successively plotted as a Mohr circle in order 8111 8087 to extrapolate the effective principal stress 8112 8088 magnitudes (Lacombe and Laurent, 1996; 8113 8089 Lacombe et al., 2007, 2009; Amrouch et al., 8114 8090 8115

8091 2011). The values of the differential stresses 8092 (Table 1 – Appendix D) were estimate from 8093 calcite twin analyses (Arboit et al., 2015). For 8094 a specific tectonic event, the quantification of 8095 the complete stress tensor consists of 8096 determining the effective values of the 8097 vertical effective stress (σ_{veff}), σ_{e1} , σ_{e2} , and σ_{e3} , 8098 these values must be compatible with newly 8099 formed (Mohr-Coulomb criterion) and 8100 reactivated pre-existing planes (Byerlee's 8101 friction law; Byerlee, 1978) (Lacombe and 8102 Laurent, 1992; Lacombe, 2001; Amrouch et 8103 al., 2011).

The internal mechanical properties of the limestones outcropping in the southern and eastern portion of the KKFTB (Khao Khad formations and Saraburi marble) were here used to describe the intrinsic failure envelope of the Khao Khad Formation (Figure 2a) (Tepnarong, 2001).

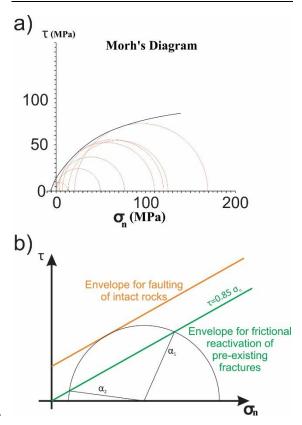


Figure 2. a) crack development curve (CDC) (red circles) from rock mechanic tests. b) Mohr circle representation of the orientations of planes that would reactivate in a given state of stress according to equations 3 and 4

8116 given in the text. The angular range $2\alpha 2 - 2\alpha 1$, shown at 8159 $\tau = 50$ MPa + 0.6 σ_n) rock type does not 8117 the intersection with the green line, defines the 8160 influence friction coefficient values in the 8118 orientational spectrum of the reactivable planes. 8161 failure criteria for reactivation of pre-existing

The objective of the triaxial compressive ⁸¹⁶² 8119 the 8163 8120 strength test was to determine compressive strengths of Saraburi limestones 8164 8121 under various confining pressures. The sample 8165 8122 preparation and test procedure followed the 8166 8123 applicable ASTM (ASTM D2664-86) and ISRM 8124 8125 suggested method (Brown, 1981). A total of 5 8167 8126 specimens have been tested under various 8168 confining pressures. The Length/Diameter of 8169 8127 8128 the specimen equals 2.0. The samples 8170 8129 underwent to tension and compression under 8171 8130 confining pressures of 1.7, 3.4, 6.9, 13.8 and 8172 8131 20.7 MPa, the deviatoric stress necessary to 8173 8132 obtain failure within the samples were 8174 8133 calculated at each step (Table 2 - Appendix C). 8175 8134 The relationship between the applied stresses 8176 and the crack development is the physical 8177 8135 8136 expression of the equation (Hoek, 1990): $\tau = 8178$ 8137 $c_i + \sigma_n \tan \Phi$, where c_i is the cohesive 8179 8138 internal strength calculated from the tangent 8180 8139 to the envelope, and Φ is the Mohr-Coulomb 8181 8140 friction angle. The data from Tepnarong (2001) were then used to calculate the Mohr 8182 8141 8142 circles corresponding to the crack and shear development at different confining pressures 8183 8143 following the methodology of Lacombe(2001) 8144 and Amrouch et al. (2011). 8145 8184

8146 4. Palaeostress conditions

8147 Bergerat (1987), and Angelier 8148 proposed that palaeostress could be 8187 estimated based on determining the most 8188 8149 easily derivable stress value, which is the 8189 8150 vertical stress (σ_v). This value is controlled by 8151 8190 the thickness of the overburden, the average 8152 density of the rock column (ρ = 2500 kg/m³) ⁸¹⁹¹ 8153 under hydrostatic fluid pressure conditions, ⁸¹⁹² 8154 and the gravity acceleration (g= 9.82 ms^{-2}). 8193 8155 Jaeger and Cook (1969); Byerlee (1970, 1978) ⁸¹⁹⁴ 8156 and Sibson (1994) demonstrated that at 8195 8157 intermediate pressures (5< σ_n <200 MPa; and 8158

 τ = 50 MPa + 0.6 σ_n) rock type does not influence friction coefficient values in the failure criteria for reactivation of pre-existing shear surfaces. Additionally the initial surface roughness has little effect on friction values and the failure criteria for pre-existing shear surfaces can be approximated by equation (2):

$$\tau = [\mu_w | 0.85 |] \sigma_n$$
 (2)

where τ , μ_{ω} and σ_n are respectively the shear stress, the coefficient of sliding friction and the normal stress. Palaeostress analysis of reactivated faults is based on the kinematic theory of reactivation for a given state of stress. This theory predicts: (I) the favourable orientations of the fault planes for reactivation, and (II) the direction along which slip is likely to occur on a given fault surface (Wallace, 1951; Bott, 1959). The angular range, α_1 , α_2 , defines the spectrum of the plane orientations that gualify for reactivation in a given stress state and can be predicted by equations 3 and 4 as follows (Jaeger and Cook, 1969) (Figure 2b):

$$\alpha_{1} = \frac{1}{2\pi} - \cos^{-1} \left\{ \frac{\frac{\mu_{W}}{(\mu_{W}^{2}+1)^{1}}}{2} \right\} + \frac{1}{2} \cos^{-1} \left\{ \frac{\frac{\mu_{W}\sigma_{m}}{\tau_{m}(\mu_{W}^{2}+1)^{1}}}{2} \right\}$$
(3)
$$\alpha_{2} = \frac{1}{2\pi} - \cos^{-1} \left\{ \frac{\frac{\mu_{W}}{(\mu_{W}^{2}+1)^{1}}}{2} \right\} - \frac{1}{2} \cos^{-1} \left\{ \frac{\frac{\mu_{W}\sigma_{m}}{\tau_{m}(\mu_{W}^{2}+1)^{1}}}{2} \right\}$$
(4)

(1989) 8186 Where β_1 or β_2 are the angles between the d be 8187 point, where the vector perpendicular to the most 8188 normal stress axe intersect the plane is the 8189 { $\tau = [\mu_w|0.85|]\sigma_n$ }, with $\sigma_m = (\frac{\sigma_1 + \sigma_3}{2})$, and lled by verage 8190 $\tau_m = (\frac{\sigma_1 - \sigma_3}{2})$. These equations, which are kg/m³) 8191 independent of the degree of heterogeneity ditions, 8192 and rock type, help predict the orientations of ms⁻²). 8193 faults that should reactivate in a given state of 1978) 8194 stress.

4.1.Stage 1

8196 The samples yielding the effective principal 8239 8197 stress tensor related to the first tectonic stage 8240 8198 of the Indosinian orogeny represent an 8241 extensional event, and is well constrained by 8242 8199 newly formed mode II veins. After unfolding 8243 8200 8201 calculations (Arboit et al., 2015) the veins are 8244 almost normal to the bedding with a θ angle 8245 8202 8203 of about 20°. The geometrical representation 8246 8204 of the maximum differential stress (σ_{e1} - σ_{e3}) is 8247 8205 tangent to the crack development curve with 8248 8206 a magnitude of about 43 MPa (Table 2 - 8249 8207 Appendix C). σ_{e1} is the vertical effective 8250 8208 principal stress (σ_{veff}) during Stage I, with a 8251 magnitude of ~38 MPa and σ_{e3} ~ –5 MPa. The 8252 8209 negative σ_{e3} corresponds to the opening of 8253 8210 8211 fractures that occurred with the shearing 8254 caused by moderate fluid overpressure. The 8255 8212 8213 value of the stress ratio " Φ " drives σ_2 towards 8256 8214 values of ~ 8 MPa. The calculated σ_{e1} principal 8257 stress axis lies within the two sets of 8258 8215 8216 conjugate fractures Set-AI (65°/150°) and Set-8259 All (65°/175°), at an angle β of ~20° to σ_1 8217 8218 (Figure 3a). 8260

8219 4.2. Stage 2

8261 8262

The second tectonic stage is interpreted to be 8263 8220 8221 the main compressive tectonic event in SE 8264 Asia during the Early Triassic in SE Asia and 8265 8222 8223 corresponds to the formation of a new set of 8266 8224 faults (pure compressive stress regime) and to 8267 8225 two new fracture sets (strike-slip stress 8268 regime): Set-AIII (80°/050°) and Set-AIV 8269 8226 (90°/080°) (Arboit et al., 2015). The stress 8270 8227 tensors detected with calcite twin analysis 8271 8228 describe both the deformations observed in 8272 8229 8230 the field, both with a horizontal σ_1 axis 8273 8231 oriented NE-SW that trends perpendicular to 8274 mean fold hinge orientation. The 8275 8232 the 8233 emplacement during the Early Triassic 8276 8234 throughout the KKFTB of newly formed 8277 8235 conjugate set of strike-slip veins and of 8278 8236 reverse faults containing the σ_2 axis and at an 8279 angle θ of 20° to 28° to the σ_1 axis (when 8280 σ_{e1} = ~78 MPa, (σ_{veff}) σ_{e2} = ~12 MPa, and σ_{e3} 8237 unfolded) requires the Mohr circle to be 8281 =~46 MPa. 8238

tangent to the CDC (Figure 3). Differential stress in compressive conditions reaches the value of ~59 MPa with the effective principal stress values σ_{e1} = 54 MPa and (σ_{veff}) σ_{e3} = -5 (Figure 3a), and σ_{e2} = 27 MPa. Differential stress in strike-slip regime is calculated to be ~44 MPa, with the vertical effective stress $(\sigma_{veff}) \sigma_{e2} = ~30$ MPa, and the other effective principal stress values being σ_{e1} = 39 MPa and σ_{e3} = -5 (Figure 3b). The values of the σ_2 - σ_3 differential stress obtained after CSIT calculation are the same for both the stress tensors (~34 MPa) with only the maximum horizontal stress (σ_{e1}) being higher in the pure compressive tensor. In both the geometrical construction the Mohr circles corresponding to the two differential stresses present a negative minimum principal stress, indicating the increase of fluid overpressure from Stage 1 to Stage 2

4.3. Stage 3

The third stress event caused the left lateral shear reactivation of the pre-existing set of fractures formed during the extensional phase (stage 1), and the LPS (stage 2) under strikeslip regime, these reactivated veins are often associated with wing cracks and Riedel arrays (R and R') when reactivated under a strike-slip regime. The only pure compressive stress tensor yields a quite low stress ratio (Φ = 0.2) that might permit σ_2 - σ_3 stress permutation. The reactivated strike-slip fractures sets are vertical and contain the principal stress σ_2 . The Mohr circle representing the stress tensors in Stage 3 is secant to the reactivation friction curve ($\tau = 0.85\sigma_n$) at two points, with the lower α angle (~20°) representing the reactivated strike-slip fractures. The differential stress has same value in all the stress tensors (~66 MPa) and the absolute values of the effective principal stresses are:

8282 4.4. Stage 4

8283 The fourth stress event is characterized by 8327 two compressive and one strike-slip stress 8328 8284 tensors, the latter of which have a similar 8329 8285 attitude to the strike-slip tensors of stage 3. 8330 8286 The differential stress value of this stress 8331 8287 tensor (~38 MPa) was high enough to allow 8332 8288 right lateral shear reactivation of the pre- 8333 8289 existing set of strike-slip fractures formed 8334 8290 during Stage 1 and Stage 2. The two 8335 8291 compressive stress tensors yield relatively low 8336 8292 stress ratios (Φ = 0.1, 0.35), and values of high $_{8337}$ 8293 differential stress (~65 MPa) that reactivated 8338 8294 some of the major north-verging reverse 8339 8295 faults that created the most significant fault- 8340 8296 related folds within the KKFTB during the LPS. $_{8341}$ 8297 The Mohr circle representing the compressive 8342 8298 regime is secant to the reactivation friction $_{8343}$ 8299 curve ($au=0.85\sigma_n$) at two points, with the $_{8344}$ 8300 8301 higher α angle (~45°) representing reactivated 8302 thrusts throughout the KKFTB. The principal 8345 effective stresses are: σ_{e1} = ~77 MPa, σ_{e2} = ~18 8303 MPa, and (σ_{veff}) σ_{e3} =~12 MPa. The strike-slip ⁸³⁴⁶ 8304 stress tensor is associated with reactivation of 83478305 fractures with an average θ angle of ~20°. $_{8348}$ 8306 8307 Consistently, the Mohr circle representing the 8349 reactivation of these fractures is tangent to ${\scriptstyle 8350}$ 8308 the friction curve at an angle α of the same $_{8351}$ 8309 amount and present effective stress values of 8352 8310 $\sigma_{\text{e1}}\text{=}$ ~49 MPa, σe_3 =~11 MPa, and (σ_{veff}) $\sigma_{\text{e2}}\text{=}$ $_{8353}$ 8311 8312 ~43 MPa (Figure 3d). 8354

8313 4.5. Stage 5

8314 This stage is associated with the peak 8357 8315 differential stress (σ_{e1} - σ_{e3}) recorded by the 8358 8316 calcite twins during the tectonic stage that 8359 8317 has been interpreted as the only one not 8360 8318 related to the Indosinian event. Both fractures 8361 and calcite twins recorded a consistent post- 8362 8319 8320 folding relationship. This stage is represented 8363 8321 by two strike -slip and two compressive stress 8364 8322 tensors. The stress ratios of the latter is lower 8365 8323 (average Φ = 0.36) than those of the strike-slip 8366 8324 tensors (average Φ = 0.66). Arboit et al. (2015) 8367 induced by using a proxy CDC from the

pointed out that several fractures and faults underwent a post-tilting reactivation with a high angle between the reactivated planes and the maximum horizontal stress σ_1 (Figure 3e). For the sake of semplicity we consider that all the strike-slip fractures were reactivated during Stage 5 with an angle α = ~25°, while the angle of the reactivated reverse faults is around ~47° (Figure 3e). The Mohr circle representing the pure compressive regime is secant to the reactivation friction curve at two points, with the pure compressive regime having higher differential stress (~61 MPa), whereas the strike-slip regime show a lower differential stress, quite similar to the values of the previous strike-slip stress tensors (~47 MPa). The effective principal stress values ranges from ~75 to ~60 MPa (σ_{e1}), with quite similar σ_{e3} = ~12 MPa (Figure 3e).

5. Discussion

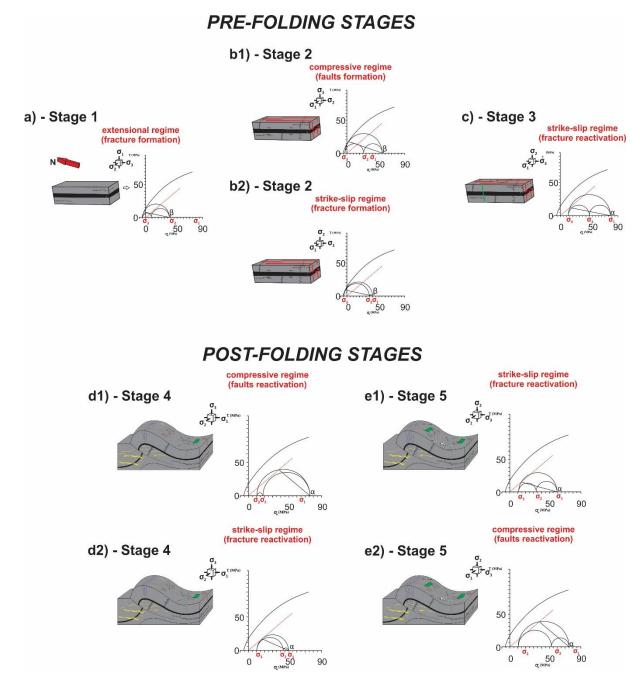
8325 8326

8355

8356

5.1. Uncertainties

Before discussing the quantification of the stress magnitude, we will first review few underlying factors that are necessary to define a complete stress tensors. There are several criteria and inaccuracies that have to be taken in account for the final palaeostress quantification. For instance: 1) the values of differential stress detected with calcite twin analysis suffer of a level of uncertainties of ~20% (Lacombe et al., 2001). However, the accuracy of the quantification of the differential stress values might have increased after the statistical calibration between the critical resolved shear stress, twinning strain and grain size (Lacombe et al., 2009; Amrouch, 2010b). 2) It was not possible to construct the CDC directly from the samples that were used to extrapolate the stress tensors responsible for the deformation of the KKFTB. Therefore, uncertainties might be



8369

8370

Figure 3. Mohr circles construction corresponding to each tectonic stage within the KKFTB since the 8371 8372 Mid-Permian. For details on these kinematic and mechanical scenarios, see Tables 1 and 2

literature (Tepnarong, 2001) to constraint the 8381 representative only if the fractures were 8373 8374 position of the Mohr circles. 3) One principal 8382 coeval, either if newly formed or the results of 8375 stress is considered to be close to the vertical 8383 8376 position. If one principal stress was not coaxial 8384 with gravity, this will result in an increase of 8377 vertical effective stress toward $\sigma_{\mbox{\tiny e1}}$ 4) The 8385 8378 Mohr circles, representing the fractures sets 8386 8379 8387 at each tectonic stage, are assumed to be 8380

reactivation of pre-existing discontinuities (Andrè et al., 2001).

As consequence of these considerations, the values obtained should be considered in the order of magnitudes rather than absolute

values (Lacombe, 2001; Lacombe et al., 2009; 8429 8388 Amrouch et al., 2011). However, these are the 8430 8389 8390 only available record for the uppermost 8431 8391 crustal palaeostresses in central Thailand from 8432 8392 the onset of the Indosinian deformation. 8433 Further, the validity of the methodology has 8393 8434 already been proved by Lacombe (2001), 8394 8435 8395 Amrouch et al. (2010a, 2011).

5.2. Consistency of the of palaeostress $^{\rm 8436}$ 8396 8437 with 8397 results from calcite twins 8438 8398 **Thailand regional tectonics** 8439

Each stress state revealed by the twinning 8440 8399 8400 analysis has been correlated to a specific 8441 8401 tectonic event (Arboit et al., 2015). However, 8442 8402 we need to take in consideration that the 8443 8403 samples used for calculating the differential 8444 8404 stress were collected within a fold-thrust belt, 8445 8405 and might correspond to a local value (e.g. 8446 8406 concentrations related to 8447 high stress 8407 asperities along major thrust in the area); and 8448 8408 consequently might not be indicative of the 8449 8409 far field stress conditions. However, the tight 8450 8410 stress-strain relationships observed in Arboit 8451 et al. (2015) indicate that the palaeostress 8452 8411 8412 tensors can be related to regional tectonic 8453 8413 events. 8454

8455 All the calculated maximum differential stress 8456 8414 values (Table 2) fit reasonably with a bracket 8415 8457 of values between 30 MPa and 65 Mpa. These 8416 8458 values are higher than the average values in a $_{
m 8459}$ 8417 common intraplate setting (Lacombe et al., 8460 8418 1996; Rocher et al., 2004) and possibly 8461 8419 8420 adequate for an active collisional setting. The 8462 8421 $(\sigma_1 - \sigma_3)$ values for each tectonic event are: 8463

STAGE 1: (pre-folding setting) About $^{\rm 8464}$ 8422 8423 45 MPa for the N-S extension; 8465 8466 STAGE 2: (pre-folding setting) About 8424 8467 60 MPa for the N-S compression, and 8425 8468 8426 about 40 MPa for S2 NS strike-slip; 8469 8427 8428 66 MPa for the E-W strike-slip;

- STAGE 4: (post-folding setting) About 59 MPa for the N-S compression and ~40 MPa strike-slip regime;
- STAGE 5: (post-folding setting) About 62 MPa for the ENE-SWS pure compressive state and ~48 MPa strike-slip regime.

Samples with insufficient untwinned planes can give overestimated differential stress values (Rocher et al., 2004). In the few samples with insufficient untwinned planes (values between square brackets, Table 2), the calculated differential stress values appears to be overestimated; hence, these samples are not taken in consideration. The formation of pre-folding extensional veins can be related to the overburden stress associated with burial, predating, or coeval with, formation of few bedding-parallel stylolites. All these fractures and beddingparallel stylolites have a more restricted occurrence than the sets of fractures that developed during later stages. The relatively narrow strike of the fracture sets that took place during Stage 1 implies a uniform distribution of minimum stress σ_3 and a constant position through time of the vertical stress σ_1 . We proposed that the sets of vein developed during the Permian extensional phase on the southwestern margin of the Indochina terrane, within the KKFTB before the main LPS event, and possibly in response to the N-S oriented flexure of the foreland in front of the advancing thrust sheets, contemporary with burial and possibly under high fluid pressures (Arboit et al., 2015).

The second tectonic stage is connected to a N-S major oriented collision, this compressional stage is consistent with the direction of tectonic transport within the KKFTB (Morley et al., 2013; Arboit et al., STAGE 3: (pre-folding setting) About 8470 2014), supporting the regional significance of 8471 the stress tensors. This tectonic stage is well

8472 represented by strike-slip and compressive 8516 the earlier Indosinian I event (Booth and 8473 stress tensors. These tensors link to the 8517 8474 formation of both strike-slip fractures, and 8518 major reverse faults. The strike-slip tensors 8519 8475 8476 were mostly detected within the N-E striking 8520 8477 veins and present lower differential stress 8521 8478 values than the compression stress tensors 8522 8479 that were recorded in the N-S striking veins. 8523 8480 All the Mohr circles representing the stress 8524 tensors of Stage 2 have a negative σ_3 value; 8525 8481 8482 and these values are reflected by the high 8526 8483 number of horizontal veins that opened 8527 8484 during the LPS on Stage 2 (Arboit et al., 2015). 8528

8529 Stage 3 is represented by three strike-slip and 8530 8485 one compressive stress tensors. The strike-slip 8531 8486 stress tensors calculated on the calcite veins 8532 8487 present distinctive differential stress values 8533 8488 that resemble the magnitude of the average 8534 8489 These 8535 8490 compressive stages (~65 MPa). 8491 anomalously high strike-slip differential stress 8492 values allow to advance the hypothesis where 8536 Price and Cosgrove (1990) demonstrated that 8493 Stage 3 might corresponds to a compressional 8537 tectonic stage; however, the high stress ratio 8538 8494 8495 does not justify this idea (Table 2). Also, it 8539 must be taken in consideration that the high 8496 8497 fracturing and faulting activity in Stage 2 8498 released huge amounts of fluid pressure. This 8499 drop in fluid pressure massively shifted the 8500 Mohr circle corresponding to Stage 3 towards 8540 higher effective stress values (Figure 3c), and 8541 8501 this might be the reason of such high 8542 8502 8543 8503 differential stress.

The macro deformation associated with Stage 8545 8504 4 is responsible for the reactivation of E-W 8546 8505 striking thrusts, the tightening of pre-existing 8547 8506 fault-propagation folds and reactivation of the 8548 8507 fractures developed during the earlier events. 8549 8508 During the latest Triassic, the half-graben 8550 8509 8510 basins in the Khorat Plateau (NE Thailand) 8551 Kuchinarai Group (Late 8552 8511 containing the Triassic) ceased to subside and some were 8553 8512 structurally inverted, and the degree of 8554 8513 deformation associated with this event is very 8555 8514 8515 much less than the one that took place during

Sattayarak, 2011). However the differential stress that was necessary to reactivate the fractures in the post-folding stress states was in the order of 50-60 MPa. This might be caused also by the complex polyphase prefolding deformation that induced high levels of strain hardening in the crystal lattices, and this had a remarkable effect on the yield stress value of the post-folding events (Stage 4; Stage 5). These post-folding differential stresses range in the order of few MPa (Table 2), and this might be a consequence of the more homogeneous tectonic framework in central Thailand after the collision of Sibumasu with the amalgamated Sukhothai-Indochina terrane during the Late Triassic ~220 Ma (Sone and Metcalfe, 2008; Morley et al., 2013; Metcalfe, 2013; Arboit et al., 2015; Ng et al., 2015; Arboit et al., 2015).

from equation (5) with a coefficient k= 4.0, that corresponds to a coefficient of friction (μ) of 0.75:

$$(\sigma_1 - \sigma_3) = (k-1) \left[(a)\sigma_2 \text{ or } (b)\frac{\sigma_1}{k} \text{ or } (c)\frac{\sigma_2}{k} \right] (5)$$

At a given depth, the ratios of differential stress required for reaching shear conditions are higher for (a) compressive conditions, (b) intermediate for strike-slip and lower for (c) extensional systems. This partially agrees with the differential stress values calculated within the KKFTB, except for the anomalous differential stress values in Stage 3. Indeed, the average differential stress values of the pure compressive tectonic stages have higher magnitude (average ~65 MPa) than those of strike-slip regimes (average ~50 MPa). Sibson (1977) assumed that if the angle (θ) between the plane of the fault and the principal stress (σ_1) increase, the magnitude of the stress tensor necessary to reactivate a fault plane

has to be higher. This principle is reflected on 8600 as maximum values (Lacombe, 2007; Lacombe 8556 the differential stresses that acted on the 8601 et al., 2009, Amrouch et al., 2011). 8557 KKFTB, where the magnitudes increased from 8558 8602 Stage 2 to Stage 5 (Table 2) because of the 8559 8603 growth of the general bedding, and the 8560 8604 consequent tilting of the faults, after the main 8561 8605 folding event (Arboit et al., 2015). 8562 8606

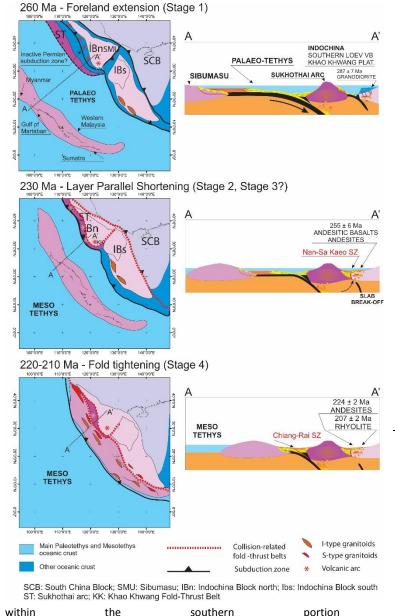
8563 5.3. Relationship between palaeostress, 8607 8564 tectonic framework and palaeoburial 8608 in central Thailand from the Mid- 8609 8565 8566 Permian 8610 8611

The obtained values of differential stress are 8567 8612 independent of the fluid pressure (Rowe and 8568 8613 Rutter, 1990), and we can use this evidence in 8614 8569 8570 order to prove that the calculated values are the maximal values reached during the 8615 8571 8572 deformational cycles undergone by the calcite 8616 8573 grains during the same tectonic event. 8617 8574 Lacombe (2001, 2007), Lacombe et al. (2009) 8618 proved the relationship between palaeo- 8619 8575 8576 differential stress data and depth, deriving 8620 8577 increasing values of differential stresses with 8621 8578 depth. Since it is feasible to imply that the LPS 8622 was coeval with the onset of folding, the 8623 8579 8580 related stress tensors were probably recorded 8624 8581 by twinning at the time of the maximum 8625 8582 burial. After CSIT calculation we obtained 8626 differential stress for Stage 1 of ~45 MPa, with 8627 8583 effective stress as σ_{e3} =~-5 MPa and σ_{e1} =~40 8628 8584 8585 MPa (Figure 3a). These values imply a 8629 8586 maximum burial depth of about 1.9 Km, the 8630 stratigraphic thickness at which the LPS 8631 8587 occurred in the KKFTB is not well established; 8632 8588 8589 nonetheless, Ueno and Charoentitirat (2011) 8633 suggested similar burial depths for the Khao 8590 Khad Formation during the Early Triassic ⁸⁶³⁴ 8591 (1800 m). Stock et al. (1985) and Morris and $^{\rm 8635}$ 8592 Ferril (1996) modelled that within an ⁸⁶³⁶ 8593 8637 extensional setting σ_2 is 50-70% of σ_1 and σ_3 is 8594 8638 20-30% of σ_1 , in such case the effective 8595 stresses would be $\sigma_{e3}\text{=}$ ~10 MPa, $\sigma_{e2}\text{=}$ ~30 8639 8596 MPa, and $\sigma_{e1}\text{=}$ ~55 MPa. Consequently the 8640 8597 8641 depth of burial would be ~2 km~, and we 8598 might consider these palaeoburial estimates $^{\ensuremath{\text{8642}}}$ 8599

The active folding within the KKFTB started when the flexure of the foreland basin shut off and the collision between Sukhothai and Indochina began. The basin on the edge of the southwestern margin of the Indochina terrane that was then filled by Late Permian foredeep and Triassic foreland deposits. The Mid Permian structural regime was, therefore, likely dominated by foreland flexure (Sone and Metcalfe, 2008; Morley et al., 2013), so that burial stylolites and the extensional veins in the foreland probably developed during the Early to Mid Permian.

Thrusting/folding in the KKFTB began during the Early Triassic, with maximum shortening probably at the time of the Sukhothai-Indochina collision. After Morley et al. (2013), and Arboit et al. (2014) it is possible to link the formation of the main anticlines to the first major folding episode, with possibly a later reactivation coeval with a phase of fold tightening that occurred during the Late Triassic after the Sibumasu-Indochina collision. Depending on the structural evolution during the Triassic, the maximum burial might have been reached at different times through the Triassic, depending on the position within the fold-thrust belt, however it is feasible to imply the LPS to have occurred while the KKFTB reached its maximum burial depth.

The ages of the syntectonic sedimentation of the foredeep $(^{206}Pb/^{238}U$ age= 251 ± 3 Ma) and foreland $(^{206}Pb/^{238}U$ age= 205 ± 6 Ma) deposit on top of the Khao Khwang carbonate platform (Arboit et al., 2016); the 208 ± 4 Ma ⁴⁰Ar/³⁹Ar ages on the orogenic illite collected on a reactivated thrust plane of the KKFTB (Hansberry et al., 2015); and the 255 ± 6 Ma, 224 \pm 2 Ma ⁴⁰Ar/³⁹Ar crystallization ages on biotite and muscovite from andesitic dykes



that intruded the core of a faultpropagation fold and propagated passively on a thrust of the KKFTB (Arboit et al., 2016) (Figure 4) provide a relatively good constraint on the timing of the several palaeostress states that deformed the KKFTB. As a result, the limestones of the KKFTB were buried in the Early Triassic at a depth that might range from ~1.9 ~2 to km (Ueno up and Charoentitirat, 2011) and on basis of this data it is possible to derive a mean rate of exhumation of the sedimentary Permian and Triassic cover of the KKFTB in the range 0.05-0.07 mm/yr.

Figure 4. Modified from Arboit et al. (in press). Palaeo-geographic schematic reconstructions of SE Asia based on the GPlate software reconstruction (contour and rotation file in Supplementary data). The cross-sections show the tectonic development of the Indochina, Sukothai and Sibumasu blocks during the Early Permian to the Late Triassic; resulting in the LPS and fold-tightening deformations, of the KKFTB.

8672

8673 6. Conclusions

8687 Quantitative estimates of crustal stresses and 8674 strength are central to many problems of rock 8688 8675 8676 mechanics. This paper presents a first attempt at comparing and combining palaeostress ⁸⁶⁸⁹ 8677 magnitude data together with geomechanical $^{\ensuremath{8690}}$ 8678 data in order to constraint the effective 8691 8679 magnitude values of the principal axes that 8680 affected the sedimentary layers of the KKFTB 8692 8681 in central Thailand mainly during the Triassic 8693 8682 8683 Indosinian orogeny, and feasible estimates of 8694 8684 average denudation rates. Hence, this 8695 8685 combination of stress data brings useful 8696

8686 information on the strength and mechanical8687 behaviour of the upper continental crust in

central Thailand since the Mid Permian, and might be considered for future modelling.

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Tethyan Realm) and #628 (The Gondwana 8736 Angelier, J., Tarantola, A., Valette, B., & 8697 Map) and we gratefully acknowledge all the 8737 8698 8699 funding organizations. This publication forms 8738 8700 TRaX Record #xxx. 8739

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Conclusions and Perspective

9053

9054 This study was set out to explore the geodynamic evolution of the southwestern margin of the 9055 Indochina terrane during the early stages of the Indosinian orogeny, using the KKFTB as case study. 9056 The revision of the rocks within the Saraburi region has sought to shed some light on their 9057 depositional history and the deformation they underwent, in order to fit them into a coherent 9058 pattern – a tectono-stratigraphic model. However, several analyses have shown that a clear-cut 9059 distinction on the type and driving mechanism of this FTB is still far to be achieved. Notwithstanding, 9060 it seems reasonable to assume that the KKFTB can be correlated to the development of the 9061 Sukhothai-Indochina collisional zone, and therefore to a far-field stress driven systems. The study 9062 has also sought to identify the various tectonic events that characterised the whole Indosinian event 9063 and to use the stratigraphic record as much as the igneous suite within the KKFTB to constrain their 9064 timing. Hence, we used the geological record of the KKFTB in order to answer few questions on the 9065 tectonic geodynamic evolution of the southwestern margin of Indochina, such as: 1. What driving 9066 mechanism deformed the Khao Khwang carbonate platform? 2 Is the KKFTB the final product of 9067 tectonic mechanisms that deformed the edge of the Indochina terrane or the Sukhothai volcanic 9068 arc? Is it possible to fit the E-W trend of the structures within the KKFTB with the contrasting N-S 9069 general present day setting of the Indosinian terranes in SE Asia?

9070 The Palaeozoic and Mesozoic evolution of central Thailand and the adjacent regions of SE Asia 9071 involved the rifting and separation of three collages of continental terranes (probably as elongate 9072 micro-continents) from eastern Gondwana and the successive opening and closure of two oceans, 9073 the back-arc between Sukhothai and Indochina, and the Palaeotethys. The development of the 9074 KKFTB centres on the closure and subduction of the back-arc basin from the Middle Permian to the 9075 Early Triassic, where the slab under-ridded the accretionary complex on the southwestern margin of 9076 the Indochina terrane. Finally, once Sukhothai had collided, it started a phase of crustal shortening 9077 involving further thrusting until the Late Triassic. The subduction and consequent metasomatism of 9078 the subducted back-arc basin reflected in the emplacement of a large igneous province, the Loei-9079 Petchabun volcanic belt on the edge of the Indochina terrane.

9080 This province comprises several regions made of diverse igneous rock types and ages, which extends 9081 from Loei in the north to Khao Yai (or Saraburi) and Sa Kaeo in the south. The igneous rocks that 9082 intruded the KKFTB sedimentary sequence form part of the south portion of the Loei volcanic belt. Few ⁴⁰Ar/³⁹Ar mica and U–Pb zircon ages, along with both whole rock elemental and Sr–Nd isotopic 9083 data shed some light on the average crystallization age for the dykes that intruded the KKFTB. The 9084 9085 most evolved igneous rocks constrained the age of the possible Sukhothai-Indochina collision in the 9086 Late Permian Early Triassic (255 ± 6 Ma), and possibly the latest post-collisional stages to the Late 9087 Triassic (224 ± 1.9 Ma). The latest stages of the Indosinian orogeny correspond to the Sibumasu-9088 Sukhothai collision, and this compressive stress seems to have propagated towards the western 9089 margin of the Indochina margin triggering the effusion of the Khao Yai rhyolite. This volcanic body 9090 presents similar geochemical, geochronological, and isotopic characteristics to the Malaysian 9091 granitoids of the western Southeast Asian tin belt, which present a high degree of involvement of a 9092 predominantly sedimentary-sourced melt. Therefore, the effusive rhyolite body in the southern 9093 KKFTB seems to be linked to an increased basal heat flow due to mantle upwelling, which might have 9094 driven to crustal partial melting and the consequent eruption in the latest Triassic (207.1 ± 2.4 Ma).

9095 The deformation that affected the KKFTB during the Sukhothai-Indochina collisional event – and 9096 especially the brittle dislocations that occurred within the crystal lattices of the carbonate rocks of 9097 the Saraburi Group – unravelled the stress-strain relationship of each Indosinian tectonic phase in 9098 space and time before and after the main folding event in central Thailand.

9099 Within the western edge of the KKFTB, the comparison of major structures, such as large anticlines, 9100 with fracture patterns, and the palaeostress tensors from calcite twins (describing all the tectonic 9101 events developed during the Indosinian orogeny) revealed a consistent record of the tectonic 9102 stresses at the scale of the entire KKFTB. In central Thailand the closure of the back-arc basin has 9103 been studied by many researchers; however the characteristics of the paleostress evolution have 9104 never been investigated before. This analysis unravelled the polyphase tectonic history of the 9105 southwestern margin of Indochina, which revealed that the KKFTB underwent to a complex 9106 deformation and allowed the interpretation of a FTB developed on the southwestern margin of one 9107 of the Indochina continental fragments during the onset of the Indosinian orogeny.

9108 The tectonic implications opened by the palaeostress history necessitated of further constraints to 9109 strengthen the possibility where the Indochina terrane was not a unique block with strongly linear 9110 boundary, as suggested in the previous models. Conversely, it might have consisted in a series of 9111 continental blocks, separated by Permian rifting that during the early stages of collision (particularly 9112 collision of the South China-Cathaysian Terrane with the Vietnam portion of Indochina) in the Early 9113 Triassic became amalgamated by closure along the older rifts.

9114 Hence, we tried to constrain the provenance of the sedimentary sources in order to obtain a better idea of the palaeogeographic and tectonic setting of central Thailand during Permian and Triassic 9115 9116 ages. This investigation involved the analysis of zircon U-Pb ages and Hf isotopes from detrital 9117 zircons of the arenaceous formations of the Saraburi Group, which were deposited during latest 9118 Palaeozoic-Early Mesozoic on the southwestern margin of the Indochina Terrane. Structural 9119 investigations on the KKFTB previously highlighted the northward direction of tectonic transport, 9120 and this structural architecture was imitated by the depositional setting that was active until the 9121 Late Permian in the southern KKFTB and until the Late Triassic in the northern KKFTB.

9122 The U-Pb age peaks in the arenaceous lithologies of the KKFTB reflected the depositional influx after 9123 the Early Triassic Sukhothai-Indochina collision. However, the siliciclastic formations lying in the 9124 northern portion of the KKFTB recorded an unexpected Late Triassic, Early Jurassic sedimentary 9125 inflow, which is probably to be attributed to the Sibumasu/Sukhothai+Indochina amalgamation. 9126 Hence, the maximum depositional ages in the northern KKFTB opened to a tectono-sedimentary 9127 scenario in central Thailand that was active until at least 205 ± 6 Ma.

9128 Moreover, the Hf-isotope data identified that different magma sources were feeding the 9129 depositional system before and during the subduction of the back-arc basin, and statistical analysis 9130 on SE Asian sedimentary record highlighted the mismatch of the sediments within Indochina. The 9131 sediments from the Khorat Plateau in the north are noticeably different from the Cambodian 9132 sediments in the southern portion of the Indochina terrane. The different sedimentary sources 9133 within Indochina strengthen the hypothesis suggested by the palaeostress analysis of a more 9134 complicated geometry within the Indochina terrane. Therefore, it is possible to speculate about the 9135 presence of a minor intra-continent ocean (Siem Reap-Stung Treng Line) that acted as provenance 9136 separation. The stress propagated into the carbonate rocks of the KKFTB from the welding of this9137 suture, and might have caused the anomalous strike of the major structures within the KKFTB.

9138 All these new data from the KKFTB emphasizes the accretionary nature of the Indosinian orogen 9139 from the Mid Permian early stages, to the Early Jurassic. Undeniably, we can assert that SE Asia was 9140 characterized by a succession of collisional events, that involved seamount/plateau accretion, ridge-9141 trench interaction, formation of supra-subduction ridges and back-arc basins, and collision of island 9142 arcs with continental fragments. This tectonic complexity is well reflected within the KKFTB; the 9143 compositional variations of the igneous rocks, the polyphase palaeostress history and the complex 9144 pattern of the sedimentary sources are a fundamental data that helped - to some extent - in 9145 constraining the geodynamic evolution of the Indosinian orogeny. 9146

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9160	Supplementary Data	
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9187	Appendix A
9187 9188	Appendix A
	Appendix A
9188	Appendix A
9188 9189	Appendix A
9188 9189 9190	Appendix A
9188 9189 9190 9191	Appendix A
9188 9189 9190 9191 9192	Appendix A
9188 9189 9190 9191 9192 9193	Appendix A
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9188 9189 9190 9191 9192 9193 9194 9195 9196	Appendix A

9200	Etchecopar's calcite stress inversion technique (CSIT)
9201	Stress Tensors extensional - Phase N*1
9202	***** ECHANTILLON 20 ***********************************
9203	***************************************
9204	POURCENTAGE: 50
9205	NOMBRE DE MACLES 200.
9206	NOMBRE DE NON MACLES 73.
9207	MACLES INCORPOREES 100
9208	POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 37. %
9209	******
9210	SIGMA 1 DIRECTION 312. PENDAGE 542.178
9211	SIGMA 2 DIRECTION 108. PENDAGE 341.372
9212	SIGMA 3 DIRECTION 206. PENDAGE 112.686
9213	f= .49 RAPPORT R= 0.7 .675
9214	
9215	421 501 226 504 520 401 408 521 102 416 309 10 414 506
9216	113 201 402 625 310 329 412 105 420 116 327 324 718 228
9217	323 204 508 427 315 106 104 107 526 509 119 13 29 123
9218	110 15-705 511 505 519 510 209 101-722 517 128 121 211
9219	316 516 523 108 715 314-804 313 26-707 230 502 616 130
9220	210 220 114 9 23 20 206-612 124 328 14 103 525 406
9221	6 308 127 126 131 529-713 317 407 207 21 115 528 216
9222	223 217 202 27 28 24 430 205
9223	******
9224	SIGMA 1 DIRECTION 321. PENDAGE 582.086
9225	SIGMA 2 DIRECTION 115. PENDAGE 291.366
9226	SIGMA 3 DIRECTION 211. PENDAGE 122.594
9227	f= .37 RAPPORT R= 0.6 .629
9228	
9229	520 226 504 521 421 408 309 501 113 102 201 625 416 327
9230	401 310 508 324 412 228 10 506 329 402 315 105 414 104
9231	323 526 106 116 29 427 13 204 316 509 119 420 110 523
9232	107 314 718-804 517 123 519 128 313 505 26 23 516 511
9233	230 211 9 308 209 101-722 328 502 15 317 616 14 121
9234	108 223-612 510 207 528-705 124 126 24 529 28 103 715
9235	525 21 407 27 20 114 130 6 210 406 25 326-824-818
9236	430-801 507 405-707 206 131 220 322 127
9237	
9238	SEUIL INTERNE = 0.1184
9239	TAILLE DES CRISTAUX = 100 MICRONS
9240	SEUIL CALCULE = 11.5 MPa
9241	SIGMA1-SIGMA3 = 97.1
9242	SIGMA2-SIGMA3 = 61.1
9243	SIGMA1d = 44.4

9289	5 430 521 303 248 505-501 421 261 205 201 445 557 441
9290	514 413 232 433 423 229 320 560 12 431 506 449 323 829
9291	-863-608 811-862 615 318 415 868 121 13 315 848 212-804
9292	-704 707 247 28 244-715 270-834 224 129-812 262 438 841
9293	**********
9294	SEUIL INTERNE = 0.1314
9295	TAILLE DES CRISTAUX = 100 MICRONS
9296	SEUIL CALCULE = 11.5 MPa
9297	SIGMA1-SIGMA3 = 87.5
9298	SIGMA2-SIGMA3 = 25.7
9299	SIGMA1d = 49.8
9300	
9301	***** ECHANTILLON 18 ***********************************
9302	***************************************
9303	POURCENTAGE: 28
9304	NOMBRE DE MACLES 186.
9305	NOMBRE DE NON MACLES 81.
9306	MACLES INCORPOREES 52
9307	POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 44. %
9308	************
9309	SIGMA 1 DIRECTION 293. PENDAGE 542.158
9310	SIGMA 2 DIRECTION 142. PENDAGE 321.816
9311	SIGMA 3 DIRECTION 43. PENDAGE 142.392
9312	f= .69 RAPPORT R= 0.4 .366
9313	
9314	271 116 603 534 267 167 270 622-608 422 624-629 564 225
9315	513 129 309 30-611 202 141 256 214 553-605 536 563 2
9316	121 402 233 101 142 164 439 327 152 223 6 232 823 133
9317	263 626 318 512-627 532 149 554 413 411-621 404 212-616
9318	-854 406 803-623 463
9319	**********
9320	SIGMA 1 DIRECTION 288. PENDAGE 572.098
9321	SIGMA 2 DIRECTION 139. PENDAGE 291.820
9322	SIGMA 3 DIRECTION 41. PENDAGE 142.429
9323	f= .52 RAPPORT R= 0.3 .336
9324	
9325	271 116 534 603 422 622 167 267 624 225 270-608 30 513
9326	-629 141 309 129-605 564 553 536 2 214-611 142 256 121
9327	202 327 402 563 101 6 164 152 133 823 439 232 223 413
9328	626 404 233 263 149 803 406 105 463 411 532-855 512 318
9329	844
9330	***************************************
9331	SEUIL INTERNE = 0.2743
9332	TAILLE DES CRISTAUX = 100 MICRONS
9333	SEUIL CALCULE = 11.5 MPa

9334	SIGMA1-SIGMA3 = 41.9
9335	SIGMA2-SIGMA3 = 14.1
9336	SIGMA1d = 23.3
9337	
9338	Etchecopar's calcite stress inversion technique (CSIT)
9339	Stress Tensors compressional / strike-slip - Phase N*2
9340	***** ECHANTILLON 29 *****************
9341	**********************
9342	POURCENTAGE: 38
9343	NOMBRE DE MACLES 183.
9344	NOMBRE DE NON MACLES 106.
9345	MACLES INCORPOREES 69
9346	POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 58. %
9347	************
9348	SIGMA 1 DIRECTION 27. PENDAGE 112.255
9349	SIGMA 2 DIRECTION 296. PENDAGE 92.895
9350	SIGMA 3 DIRECTION 167. PENDAGE 76222
9351	f= 2.16 RAPPORT R= 0.6 .604
9352	
9353	414 407 325 132-851 404-842-844 412 406 138-629 144 246
9354	436-743-713 708 619-831 455 30 456-737 235 408 710-865
9355	-754 233-731 444-736 732 833 101 143 702 309 701 104 106
9356	-852 623 8 326 16 149 706 231 255 622 854-729 307 242
9357	222 411 110 566 410 426 330 450 454 266 440-739 420 317
9358	314 327 102 439-705 116-628 860 402 254-730 451 271-850
9359	17 114-805-723 716-822 409
9360	***************************************
9361	SIGMA 1 DIRECTION 23. PENDAGE 162.237
9362	SIGMA 2 DIRECTION 290. PENDAGE 132.778
9363	SIGMA 3 DIRECTION 163. PENDAGE 69291
9364 0265	f= 1.80 RAPPORT R= 0.5 .515
9365 0266	414 942 122 225 407 404 246 144 951 426 944 405 409 955
9366 9367	414-842 132 325 407 404 246 144-851 436-844 406 408-865 412 455 8 138-629 410-713 456 307 235-852 30-831 420
9367	412 455 8 138-629 410-713 456 307 235-852 30-831 420 706 622 143 326 101 17 16-850 833 732-729 619-743-736
9369 9369	-628 708 439 450 255 411 327 426 566 701 710-822 437 860
9309 9370	-028 708 439 430 233 411 327 428 388 701 710-822 437 880 116-737 402 623 106 233 454 314 857-705 105 271-731 113
9371	266-730 267-805-869 856 231 110 451-840 447 309-754 317
9372	242 311-855 854 444 149 131 716 702
9373	***************************************
9374	SEUIL INTERNE = 0.1961
9375	SEUIL CALCULE = 11.5 MPa
9376	SIGMA1-SIGMA3 = 58.6
9377	SIGMA2-SIGMA3 = 30.2

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9378
         SIGMA1d =
                     29.0
      ***** ECHANTILLON 08 *********************
9379
      9380
9381
      POURCENTAGE: 30
9382
      NOMBRE DE MACLES
                         166.
9383
      NOMBRE DE NON MACLES
                           87.
9384
      MACLES INCORPOREES
                          49
9385
      POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES = 52. %
          *****
9386
        SIGMA 1 DIRECTION 287. PENDAGE 39.
9387
                                        -.905
        SIGMA 2 DIRECTION 44. PENDAGE 30.
9388
                                        -2.216
        SIGMA 3 DIRECTION 159. PENDAGE 37.
9389
                                         -.361
9390
         f= .42 RAPPORT R= 0.8
                             .813
9391
       7 120 8-717-645 610 614 612 2 642 41 611 1 309
9392
      603 305 234 244 403-707 532 601 37 631 24 547 341 629
9393
9394
      314 501 30 313 527-704 630 5 418 534 201 608 40-604
9395
      544 342 516-621 618 104 235 426-606 617 9 607 18 6
          *****
9396
9397
        SIGMA 1 DIRECTION 272. PENDAGE 33.
                                        - 693
9398
        SIGMA 2 DIRECTION 37. PENDAGE 41. -2.118
9399
        SIGMA 3 DIRECTION 159. PENDAGE 31.
                                        -.367
         f= .30 RAPPORT R= 0.9
9400
                             .914
9401
      234 244 642 7 601 8 501 547 120 37 610 527 314 341
9402
      532-717 614 30 24 41 2 603 608 403-645-707 607 305
9403
9404
      232 1 309 612 611 302 516 238 544 104 407 537 201 5
9405
      247-606 631-704 534 618 303-621 9 629 237 42 235 426
          ******
9406
9407
         SEUIL INTERNE = 0.3058
9408
         SEUIL CALCULE = 11.5 MPa
9409
         SIGMA1-SIGMA3 = 37.6
9410
         SIGMA2-SIGMA3 = 34.4
9411
         SIGMA1d =
                     13.6
9412
      9413
      9414
9415
      POURCENTAGE: 34
9416
      NOMBRE DE MACLES
                         152.
9417
      NOMBRE DE NON MACLES 68.
9418
      MACLES INCORPOREES
                          51
9419
      POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 45. %
          ******
9420
9421
        SIGMA 1 DIRECTION 237. PENDAGE 28.
                                         -.550
9422
        SIGMA 2 DIRECTION 8. PENDAGE 50.
                                        -2.010
```

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9423
         SIGMA 3 DIRECTION 133. PENDAGE 25.
                                             -.824
9424
          f= .98 RAPPORT R= 0.8
                                .816
9425
9426
       316 315 14 113 732 730 325 121 124 115 122-610 117-719
9427
       525-628-601 7 723-721 709 422 736 28 107 321 626-717
9428
       412 135 25 120 724 726 712 130 126 132 326 429 301 311
9429
       305 424 430 225-615-735 625 133 307 403 114 701-720 528
9430
       123 520 119 136
           ******
9431
9432
         SIGMA 1 DIRECTION 244. PENDAGE 27.
                                           -.552
9433
         SIGMA 2 DIRECTION 6. PENDAGE 47. -2.121
9434
         SIGMA 3 DIRECTION 136. PENDAGE 32.
                                             -.766
9435
          f= .67 RAPPORT R= 0.8
                                .769
9436
9437
       14 316 730 325 315 709 124 107 122 121 525 321 429 732
9438
       113 626 7-628 723-717 117 736 726 132 422-601-719-610
9439
       115 712-735 520 114 412-721 701 305 28 135-720 130-615
       306 625 120 123 301 724-616 802 136 126 25 225-733 133
9440
9441
       326 521 311 516 320 307 424
           ******
9442
9443
          SEUIL INTERNE = 0.2603
          SEUIL CALCULE = 11.5 MPa
9444
9445
          SIGMA1-SIGMA3 = 44.2
          SIGMA2-SIGMA3 = 34.0
9446
9447
          SIGMA1d =
                       18.1
9448
       Etchecopar's calcite stress inversion technique (CSIT)
9449
9450
       Stress Tensors compressional / strike-slip - Phase N*3
9451
       9452
       *****
9453
9454
       POURCENTAGE: 38
9455
       NOMBRE DE MACLES
                           249
9456
       NOMBRE DE NON MACLES 86.
9457
       MACLES INCORPOREES
                            94
9458
       POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 35. %
          ******
9459
9460
         SIGMA 1 DIRECTION 109. PENDAGE 38.
                                             -.890
9461
         SIGMA 2 DIRECTION 352. PENDAGE 30.
                                             -.924
9462
         SIGMA 3 DIRECTION 236. PENDAGE 37.
                                            -2.161
9463
          f= 1.17 RAPPORT R= 0.5
                                 .482
9464
9465
       529 226 305 808 29 125 121 324 212 717 7 18 427 25
        6 23-739 404 506 105 204 3 9 450 118 307 507 423
9466
```

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9467
       207 325 518-810 106 16 227 154 416 115 405 509 210 217
       215 142 102 103 516 801 114 144 510 219 511 513 13 214
9468
9469
       414 514-823-605 141-625 303 110 609 512 224 206 27 320
9470
       441 222 425 221-825 418-805-804 229 419 508 143 119 402
9471
       504 703 149 429 526 439 454-701-816 520 426-601-741 124
       607-616 123-807-732 442 108 503 445-757-455 705-746 421
9472
          ******
9473
9474
         SIGMA 1 DIRECTION 110. PENDAGE 33.
                                              -.749
9475
         SIGMA 2 DIRECTION 353. PENDAGE 36.
                                              -.916
9476
         SIGMA 3 DIRECTION 230. PENDAGE 38.
                                             -2.270
           f= .65 RAPPORT R= 0.5
9477
                                 .515
9478
9479
       529 226 305 29 808 125 717 25 18 121 324 427 212 23
9480
        6 7-739 506 404 3 507 307 207 423 518 204 115 210
       105 450 217 9 118 142 405 106 514 325 16 416 13 154
9481
9482
       441 510-810 27 509 103 504 801 215 221 703 425 511 119
9483
       114 206 609 144 418 227 513 102-625 110 516 219-605 214
       -741-757 454 141 402-823 12 705 508 224 520 222 124 607
9484
9485
       143 512 229 414-825 442 419 526 421 149 720-732 439 228
9486
       -816 429-621 156 320-805 116 123 303 502
9487
           9488
           SEUIL INTERNE = 0.1522
9489
           SEUIL CALCULE = 11.5 MPa
9490
           SIGMA1-SIGMA3 = 75.5
9491
           SIGMA2-SIGMA3 = 38.9
9492
           SIGMA1d =
                        37.4
9493
       9494
       *****
9495
9496
       POURCENTAGE: 32
9497
       NOMBRE DE MACLES
                            273.
9498
       NOMBRE DE NON MACLES 81.
       MACLES INCORPOREES
9499
                             87
9500
       POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 30. %; FAIBLE !
9501
       POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 30. %
           ******
9502
9503
         SIGMA 1 DIRECTION 137. PENDAGE 59.
                                            -1.447
9504
         SIGMA 2 DIRECTION 36. PENDAGE 6.
                                            -1.042
         SIGMA 3 DIRECTION 303. PENDAGE 30.
9505
                                              -1.000
9506
           f= 1.22 RAPPORT R= 0.4
                                 .399
9507
9508
       868 451 428 407 409 440 427 465 448 454 435 865 857 166
       -829 866 405 408 5 162 835 442 449 11 417 126 1-804
9509
9510
       410 313 870 10 467-811 24-826 441-730 426 18 834 117
9511
        15 125 244 9 464 27 401-853 462 502 452 304 13 455
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9512
       466 533 421 312 416 832 801 319 429-613 224 106 824 29
       -623-833 264 823 571 717-612-725-710 762 766-716 138 604
9513
9514
        21 310 2 565 867 263 303 254 524 17-308 128 864 110
9515
       567-722 265 4
           ******
9516
9517
         SIGMA 1 DIRECTION 133. PENDAGE 49.
                                              -1.459
9518
         SIGMA 2 DIRECTION 37. PENDAGE 5.
                                              -.861
9519
         SIGMA 3 DIRECTION 303. PENDAGE 41.
                                              -.995
9520
           f= .96 RAPPORT R= 0.4
                                 .392
9521
       427 435 409 166 428 440-829 407 866 857 868 451 835 162
9522
       448 426 465 13 454 405 442 417 5 865 410 304 801-804
9523
       441 455 834 18 452 421 126 224 571 125 425 502 467 10
9524
       106 313 17 24-826 408 565 151 11 832 416 870 449 1
9525
        27-722 867-716-853-748 856 836 9 265 319 429 464 268
9526
9527
       -613 401 503 533 257-730 323-725 139 29 22 717 604 244
9528
       -739 466-811 203 329 302 762 138 8 567 556 12 568 303
9529
       003
           ******
9530
9531
           SEUIL INTERNE = 0.1614
9532
           TAILLE DES CRISTAUX = 100 MICRONS
           SEUIL CALCULE = 11.5 MPa
9533
9534
           SIGMA1-SIGMA3 = 71.2
9535
           SIGMA2-SIGMA3 = 27.9
9536
           SIGMA1d =
                        38.2
9537
       ***** ECHANTILLON 18 **********************
9538
       **************
9539
9540
       POURCENTAGE: 32
9541
       NOMBRE DE MACLES
                            223.
9542
       NOMBRE DE NON MACLES 68.
       MACLES INCORPOREES
                             71
9543
9544
       POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 30. %
           ******
9545
9546
         SIGMA 1 DIRECTION 109. PENDAGE 38.
                                               -.890
9547
         SIGMA 2 DIRECTION 352. PENDAGE 30.
                                              -.924
9548
         SIGMA 3 DIRECTION 236. PENDAGE 37. -2.161
9549
           f= 1.05 RAPPORT R= 0.5
                                  482
9550
       323 304 319-809 227 302 322 330 303 22 406 101 13 116
9551
       728 125 606 27 530 210 103 215 18 20 706 329 8-727
9552
9553
       -806 519 12 618 431 131 411 105 515-714 5 3-630 522
       110 423 230 17 619-737 21 108 620 436 204 501 432 109
9554
9555
       -734 224 415 104 413 512 214-612 829-613 23 830-823-602
9556
       127-816 729 416 10 112 229 207 19-623 404 128 318-627
```

9557	433
9558	***********
9559	SIGMA 1 DIRECTION 112. PENDAGE 33925
9560	SIGMA 2 DIRECTION 4. PENDAGE 24757
9561	SIGMA 3 DIRECTION 246. PENDAGE 471.994
9562	f= .91 RAPPORT R= 0.5 .478
9563	
9564	323 304 227 13 116 728 530-809 322 302 22 406-727 125
9565	330 131 319 103 522 101 411 606 17 519 303 706 501 431
9566	512 215 210 8 620-737 329-734 12 104-823-714 619 27
9567	18 230 20 3 5 110-630 214 127 423 437 729-613 105
9568	204 23 502 830 222 416 618 207 432 415-806 109 10 515
9569	-612 224 413 527 111-617 19 436 218 108 112 128
9570	************
9571	SEUIL INTERNE = 0.1478
9572	TAILLE DES CRISTAUX = 100 MICRONS
9573	SEUIL CALCULE = 11.5 MPa
9574	SIGMA1-SIGMA3 = 77.8
9575	SIGMA2-SIGMA3 = 37.2
9576	SIGMA1d = 39.5
9577	
9578	***** ECHANTILLON 11 **********************************

9579	••••••
9579 9580	POURCENTAGE: 40
9580 9581 9582	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86.
9580 9581	POURCENTAGE: 40 NOMBRE DE MACLES 259.
9580 9581 9582	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86.
9580 9581 9582 9583 9584	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. %
9580 9581 9582 9583 9584 9585	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. %
9580 9581 9582 9583 9584 9585 9586	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. % ************************************
9580 9581 9582 9583 9584 9585 9586 9586	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. % ************************************
9580 9581 9582 9583 9584 9585 9586 9587 9588	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. % ************************************
9580 9581 9582 9583 9584 9585 9586 9586 9587 9588 9589	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. % ************************************
9580 9581 9582 9583 9584 9585 9586 9587 9588 9589 9590	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. % ************************************
9580 9581 9582 9583 9584 9585 9586 9586 9587 9588 9589 9590 9590	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33.% ***********************************
9580 9581 9582 9583 9584 9585 9586 9587 9588 9589 9590 9590 9591 9592	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. % ************************************
9580 9581 9582 9583 9584 9585 9586 9587 9588 9589 9590 9590 9591 9592 9593	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33.% ************************************
9580 9581 9582 9583 9584 9585 9586 9587 9588 9589 9590 9590 9591 9592 9593 9594	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33.% ************************************
9580 9581 9582 9583 9584 9585 9586 9587 9588 9589 9590 9591 9592 9593 9594 9595	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33.% ************************************
9580 9581 9582 9583 9584 9585 9586 9587 9588 9589 9590 9590 9591 9592 9593 9594 9595 9596	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33.% ************************************
9580 9581 9582 9583 9584 9585 9586 9587 9588 9589 9590 9591 9592 9593 9594 9593 9594 9595 9596 9597	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. % ************************************
9580 9581 9582 9583 9584 9585 9586 9587 9588 9589 9590 9591 9592 9593 9594 9595 9596 9597 9598	POURCENTAGE: 40 NOMBRE DE MACLES 259. NOMBRE DE NON MACLES 86. MACLES INCORPOREES 103 POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 33. % ************************************

9602	SIGMA 2 DIRECTION 355. PENDAGE 29837
9603	SIGMA 3 DIRECTION 234. PENDAGE 422.195
9604	f= .85 RAPPORT R= 0.5 .491
9605	
9606	529 305 29 226 808 717 18 324 212 125 23 427 6 121
9607	25 7 307 404-739 207 506 9 3 450 204 115 518 507
9608	217 423 16 210 106 142 105 514 215 118 405 13 516 214
9609	509-810 114 227 801 511 102 416 325 103 513 510 425 124
9610	154-625 402 441 221 414 144 12 222 206-741 27-757 609
9611	224-605-823 512 110 10 520 119 504 703 418 143 320 219
9612	442-746-816-805-732-701 508 229 141 454 526 720 705 419
9613	156 150 421 502 426 303 429-825 21 108 702 607-722 149
9614	603 439 228 123 515
9615	***********
9616	SEUIL INTERNE = 0.1393
9617	TAILLE DES CRISTAUX = 100 MICRONS
9618	SEUIL CALCULE = 11.5 MPa
9619	SIGMA1-SIGMA3 = 82.6
9620	SIGMA2-SIGMA3 = 40.5
9621	SIGMA1d = 41.5
9622	
9623	Etchecopar's calcite stress inversion technique (CSIT)
9624	Stress Tensors compressional - Phase N*4
9624 9625	Stress Tensors compressional - Phase N*4
	Stress Tensors compressional - Phase N*4 ***** ECHANTILLON 08 ***********************************
9625	·
9625 9626	***** ECHANTILLON 08 ***********************************
9625 9626 9627	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631 9632	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631 9632 9633	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631 9632 9633 9634	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631 9632 9633 9634 9635	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631 9632 9633 9634 9635 9636	<pre>***** ECHANTILLON 08 ***********************************</pre>
9625 9627 9628 9629 9630 9631 9632 9633 9633 9634 9635 9636	<pre>***** ECHANTILLON 08 ***********************************</pre>
9625 9626 9627 9628 9629 9630 9631 9632 9633 9634 9635 9636 9637 9638	<pre>***** ECHANTILLON 08 ***********************************</pre>
9625 9627 9628 9629 9630 9631 9632 9633 9634 9635 9636 9637 9638 9639	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631 9632 9633 9634 9635 9636 9637 9638 9639 9640	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631 9632 9633 9634 9635 9636 9637 9638 9639 9639 9640 9641	***** ECHANTILLON 08 ***********************************
9625 9626 9627 9628 9629 9630 9631 9632 9633 9634 9635 9636 9637 9638 9639 9640 9641 9642	<pre>***** ECHANTILLON 08 ***********************************</pre>

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9825
         SIGMA 1 DIRECTION 126. PENDAGE 9.
                                             -.162
9826
         SIGMA 2 DIRECTION 351. PENDAGE 77.
                                             -1.413
9827
         SIGMA 3 DIRECTION 217. PENDAGE 9.
                                            -2.495
9828
           f= .47 RAPPORT R= 0.3
                                 .315
9829
       291 276 382 557 275 574 248 388 62 348 273 260 368 282
9830
9831
        56 438 139 563 372 266-365 384 570-887 90 558 86 729
9832
       256 153 364 279 59 277 87 579 143 582 571 581-595 154
9833
       349 140 142-744 70 573 251 448 75 89 136 151 378 566
9834
       361 254 133 553 431 128 569 374 357-888 734 369 663 377
       351 286 743 650 293-863 589 564 135 267 678 447 149 385
9835
9836
       263 562-683 592 590
           ******
9837
9838
           SEUIL INTERNE = 0.2164
9839
           SEUIL CALCULE = 11.5 MPa
9840
           SIGMA1-SIGMA3 = 53.1
9841
           SIGMA2-SIGMA3 = 16.7
           SIGMA1d =
9842
                        29.9
       9843
       *****
9844
9845
       POURCENTAGE: 40
9846
       NOMBRE DE MACLES
                            276.
9847
       NOMBRE DE NON MACLES 87.
9848
       MACLES INCORPOREES
                            110
9849
       POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES = 32. %
           ******
9850
9851
         SIGMA 1 DIRECTION 155. PENDAGE 19.
                                              -.592
9852
         SIGMA 2 DIRECTION 54. PENDAGE 29.
                                             - 615
9853
         SIGMA 3 DIRECTION 274. PENDAGE 55.
                                             -1.510
9854
           f= 1.34 RAPPORT R= 0.6
                                 .594
9855
9856
       101 802 323 102 333 332 119 410 424 114 320 412 126 526
       208 508 116 427 539-836 343 105 718 833 422 123 223 17
9857
9858
       408 413 125 306-518 107 106 226 316-823 511 506 515 110
9859
       428 217 335 19 206 311-728-616 536 338 404 219 3 402
9860
       411 121 25 35 33 29 31 321 122 225 127 521 22-623
9861
       103 405 239 328 425 117 340 414 15 419 204 326 415 16
9862
       211-818 331 38 32-619 108 236 329 720 519 312 39 837
       541-622 421-821-805 45 345-503 520-640 222 514 609 416
9863
9864
       -643 113 529 710 317-835 218 809 504 842 613-701 605 210
           ******
9865
9866
         SIGMA 1 DIRECTION 160. PENDAGE 15.
                                            -.645
         SIGMA 2 DIRECTION 64. PENDAGE 20.
9867
                                             -.448
9868
         SIGMA 3 DIRECTION 284. PENDAGE 64. -1.330
           f= .95 RAPPORT R= 0.6
9869
                                 .580
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9870	
9871	323 802 114 101 102 410 119 427 424 320 422 17 105 333
9872	413 332 126 123 412 506 306 208 428 116 408 343 311 125
9873	107 526 404 19 508 539 106-616 718 121 328 25 321 425
9874	226-818 411 405-518 16 331 206 833-836 15 415 108-823
9875	22 316-619 515 329 402 312 217 3 103 536 33 511 345
9876	223 419 39 609 421-622 326 29 31-503-728 110 710 613
9877	414 122 605-623 210 842-835 35-716 335 512 243 340 118
9878	510 541 218 245-701 706 225 514-639 720 317 117 28 416
9879	-643 127 45 32 529-636 38 43 239 521 219 339 338 625
9880	*****************
9881	SEUIL INTERNE = 0.1908
9882	TAILLE DES CRISTAUX = 100 MICRONS
9883	SEUIL CALCULE = 11.5 MPa
9884	SIGMA1-SIGMA3 = 60.3
9885	SIGMA2-SIGMA3 = 35.0
9886	SIGMA1d = 28.5
9887	***** ECHANTILLON 08 **********************
9888	*************************
9889	POURCENTAGE: 38
9890	NOMBRE DE MACLES 303.
9891	NOMBRE DE NON MACLES 84.
9892	MACLES INCORPOREES 115
9893	POURCENTAGE DU NOMBRE DE NON MACLES SUR MACLES= 28. %; FAIBLE !
9894	*****************
9895	SIGMA 1 DIRECTION 149. PENDAGE 321.159
9896	SIGMA 2 DIRECTION 50. PENDAGE 13616
9897	SIGMA 3 DIRECTION 301. PENDAGE 551.037
9898	f= 1.28 RAPPORT R= 0.7 .692
9899	
9900	323 126 802 431 120 127 702 515 217 333 422 417 706 343
9901	206 406 710 320-836 130 136 128 316-518 332 208 722 112
9902	103 33 124 123 108 19 16 22 226 17 102 508 25 223
9903	-818 536 326 39 335 111-436 809 202 32 328 339 711 125
9904	29 539 204 31 338 15-823 526 721 210 219 833 306 716
9905	311 35 134 245 506 517 322 214 331-806 427 514 215 122
9906	107 723 106 109-717 209 412 329 131 224 116 239-845 3
9907	321 43 511 28 842 502 426 317 45 129 312-616 225-821
9908	212 345 211-805 613 425 402 705-826 409-623-640 728 38
9909	26 222-619-810 11
9910	*************
9911	SIGMA 1 DIRECTION 154. PENDAGE 261.096
9912	SIGMA 2 DIRECTION 57. PENDAGE 13509
9913	SIGMA 3 DIRECTION 303. PENDAGE 61993
9914	f= 1.14 RAPPORT R= 0.7 .694

9915	
9916	323 126 802 120 422 702 406 431 127 130 710 320 417 333
9917	515 343 217 112 206 108 128 17 19 103 124 16 706 22
9918	25 332-518 208-818 316 111 123-836 136 508 328 39 33
9919	125 226 722 306 15 326 311-436 506 134 536 721 210 102
9920	107 711 339 245 331 526 223 202 321 29 31 809 716 116
9921	329 539 723 322 32-616 514 209 43 833 312-823-806 335
9922	3 345 28-717 106 212 842 214 613 413 426-619-845 35
9923	45 317 338 26 122 609 219 412 23 109 239 511 728 224
9924	204 409 724 121 605 427 517 225 425-503 243 541 12 131
9925	***********
9926	SEUIL INTERNE = 0.1424
9927	TAILLE DES CRISTAUX = 100 MICRONS
9928	SEUIL CALCULE = 11.5 MPa
9929	SIGMA1-SIGMA3 = 80.8
9930	SIGMA2-SIGMA3 = 56.1
9931	SIGMA1d = 35.2
9932	
9933	
9934	
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9973	Appendix B
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9984	

						LA	A-ICP-MS	U/Pb d	etrital zir	con da	ita						
Analysis	²⁰⁷ Pb/ ²⁰⁶ Pb	$\pm 2\sigma$	²⁰⁶ Pb/ ²³⁸ U	$\pm 2\sigma$	²⁰⁷ Pb/ ²³⁵ U	$\pm 2\sigma$	²⁰⁸ Pb/ ²³² Th	$\pm 2\sigma$	²⁰⁷ Pb/ ²⁰⁶ Pb	$\pm 2\sigma$	²⁰⁶ Pb/ ²³⁸ U	$\pm 2\sigma$	²⁰⁷ Pb/ ²³⁵ U	$\pm 2\sigma$	²⁰⁸ Pb/ ²³² Th	$\pm 2\sigma$	Concordancy
Sample	Т15_РК1 -	Volcani	ic Sandst	ones – (Clastic Un	it 4		•					•				
PK1 - 1	0.10838	0.00171	0.3193	0.00421	4.77212	0.08037	0.0793	0.00449	1772.4	28.52	1786.3	20.56	1780	14.14	1542.4	84.16	101
PK1 - 2	0.05422	0.00087	0.05994	0.00079	0.44813	0.00763	0.01022	0.00035	380.1	35.6	375.3	4.83	376	5.35	205.6	7.08	99
PK1 - 3	0.05591	0.00121	0.07258	0.00105	0.5595	0.01236	0.01059	0.00044	448.6	47.19	451.7	6.31	451.2	8.05	212.9	8.9	101
PK1 - 4	0.05545	0.00101	0.06759	0.00092	0.51674	0.00981	0.0114	0.00042	430.2	39.64	421.6	5.55	423	6.57	229.1	8.46	98
PK1 - 5	0.05999	0.00249	0.09213	0.00187	0.76055	0.0297	0.0045	0.00036	603.2	87.38	568.1	11.03	574.3	17.13	90.7	7.23	94
PK1 - 6	0.05985	0.00465	0.09223	0.00314	0.75624	0.05433	0.00137	0.00015	598.2	159.79	568.7	18.53	571.8	31.41	27.7	3.03	95
PK1 - 7	0.13124	0.00223	0.38813	0.00531	7.02501	0.12703	0.09655	0.00649	2114.6	29.45	2114.2	24.67	2114.6	16.07	1862.9	119.64	100
PK1 - 8	0.1473	0.01203	0.43392	0.01503	8.80681	0.68605	0.14055	0.05827	2314.8	133.74	2323.4	67.59	2318.2	71.03	2658.1	1032.64	100
PK1 - 9	0.10989	0.00203	0.32189	0.00463	4.87645	0.09646	0.0661	0.00453	1797.5	33.32	1798.9	22.57	1798.2	16.67	1293.6	85.89	100
PK1 - 10	0.10364	0.00446	0.29916	0.00608	4.27705	0.17848	0.07329	0.01277	1690.2	77.31	1687.1	30.17	1689	34.34	1429.6	240.51	100
PK1 - 11	0.08845	0.00164	0.24058	0.00336	2.93436	0.05739	0.0636	0.00498	1392.2	34.98	1389.7	17.47	1390.8	14.81	1246.2	94.59	100
PK1 - 12	0.16286	0.00534	0.47052	0.00817	10.567	0.33663	0.1254	0.0184	2485.6	54.25	2485.8	35.8	2485.8	29.55	2387.8	330.48	100
PK1 - 13	0.09146	0.00872	0.25338	0.00924	3.18882	0.29196	0.0379	0.01021	1456	171.35	1455.9	47.5	1454.5	70.77	751.8	198.82	100
PK1 - 14	0.19009	0.00444	0.53059	0.00809	13.90687	0.33781	0.11844	0.01198	2742.9	37.93	2743.9	34.07	2743.4	23.01	2262.4	216.57	100
PK1 - 15	0.05494	0.00279	0.06473	0.00143	0.48957	0.02397	0.0036	0.00031	409.8	109.6	404.3	8.68	404.6	16.34	72.6	6.22	99
PK1 - 16	0.08665	0.00115	0.23374	0.00315	2.79257	0.04204	0.04371	0.00142	1352.8	25.35	1354.1	16.45	1353.5	11.26	864.8	27.42	100
PK1 - 17	0.05195	0.0015	0.04382	0.0007	0.31397	0.00899	0.00549	0.00022	283.1	64.67	276.5	4.33	277.3	6.94	110.6	4.44	98
PK1 - 18	0.05508	0.00136	0.06748	0.001	0.51243	0.01289	0.01942	0.001	415.5	53.64	421	6.06	420.1	8.66	388.8	19.87	101
PK1 - 19	0.05118	0.00246	0.03952	0.00082	0.27906	0.01286	0.00349	0.00023	249.1	106.83	249.8	5.09	249.9	10.21	70.4	4.56	100
PK1 - 20	0.0534	0.00206	0.05582	0.00095	0.41063	0.01557	0.01581	0.00115	345.6	84.74	350.2	5.8	349.3	11.21	317.1	22.87	101
PK1 - 21	0.16531	0.00262	0.47619	0.00684	10.85748	0.19247	0.10772	0.00619	2510.7	26.45	2510.7	29.87	2511	16.48	2067.7	113.04	100
PK1 - 22	0.06444	0.00466	0.12291	0.00462	1.09285	0.07124	0.0026	0.00027	756.2	145.64	747.3	26.54	749.9	34.56	52.4	5.36	99
PK1 - 23	0.05295	0.00485	0.05143	0.00142	0.3752	0.03333	0.01641	0.00189	326.6	195.32	323.3	8.73	323.5	24.61	328.9	37.62	99
PK1 - 24	0.15676	0.00229	0.45585	0.00644	9.85379	0.16388	0.08267	0.00376	2421	24.54	2421.2	28.52	2421.2	15.33	1605.4	70.13	100
PK1 - 25	0.07861	0.00227	0.19681	0.00321	2.13135	0.0615	0.05496	0.00509	1162.3	56.28	1158.2	17.28	1159	19.94	1081.4	97.54	100
PK1 - 26	0.0726	0.00139	0.16764	0.0025	1.67849	0.03417	0.02789	0.00135	1002.8	38.43	999.1	13.79	1000.4	12.95	555.9	26.51	100

PK1 - 27	0.06876	0.00322	0.051	0.00099	0.48332	0.02209	0.01656	0.00133	891.5	93.8	320.7	6.06	400.3	15.12	332	26.43	36
PK1 - 28	0.08763	0.00201	0.23767	0.00374	2.87132	0.06891	0.06763	0.00595	1374.5	43.44	1374.6	19.48	1374.4	18.07	1322.6	112.73	100
PK1 - 29	0.05653	0.00483	0.07654	0.00242	0.59504	0.04903	0.02156	0.00512	472.5	179.43	475.5	14.49	474.1	31.21	431.2	101.25	101
PK1 - 30	0.0539	0.00341	0.05793	0.00128	0.43054	0.02658	0.01538	0.00137	366.6	136.15	363	7.82	363.6	18.87	308.5	27.35	99
PK1 - 31	0.06208	0.00208	0.11071	0.00198	0.94711	0.0306	0.0159	0.00072	677	69.88	676.8	11.51	676.6	15.96	318.8	14.3	100
PK1 - 32	0.05488	0.00108	0.06504	0.00095	0.49232	0.01022	0.01318	0.00054	407.1	42.97	406.2	5.77	406.5	6.95	264.7	10.83	100
PK1 - 33	0.10375	0.00158	0.30052	0.0042	4.29938	0.07303	0.07554	0.00381	1692.3	27.78	1693.9	20.8	1693.2	13.99	1472	71.66	100
PK1 - 34	0.06703	0.00234	0.13743	0.00261	1.2689	0.04191	0.00831	0.00047	838.6	71.06	830.1	14.77	831.9	18.76	167.3	9.45	99
PK1 - 35	0.05413	0.00434	0.06135	0.00186	0.45823	0.035	0.00944	0.00126	376.4	171.07	383.8	11.27	383	24.37	190	25.26	102
PK1 - 36	0.09055	0.00223	0.24961	0.00405	3.1165	0.07694	0.03197	0.00155	1437.2	46.28	1436.5	20.88	1436.8	18.98	636.1	30.39	100
PK1 - 37	0.10228	0.00248	0.29485	0.00443	4.15512	0.10049	0.07316	0.00629	1665.9	44.14	1665.7	22.06	1665.2	19.79	1427.2	118.45	100
PK1 - 38	0.05517	0.00123	0.06736	0.001	0.51249	0.01179	0.01385	0.00071	418.8	48.55	420.2	6.01	420.1	7.91	278.1	14.13	100
PK1 - 39	0.07331	0.00194	0.17131	0.00279	1.72963	0.04411	0.01176	0.00052	1022.5	52.53	1019.3	15.35	1019.6	16.41	236.3	10.45	100
РК1 - 40	0.05561	0.00233	0.07095	0.00132	0.54442	0.02225	0.01788	0.00164	436.6	90.59	441.9	7.95	441.3	14.63	358.2	32.57	101
PK1 - 41	0.05852	0.00103	0.08908	0.00124	0.71866	0.01327	0.01282	0.00055	549.3	37.99	550.1	7.37	549.9	7.84	257.4	11	100
PK1 - 42	0.05787	0.00221	0.08305	0.00159	0.66139	0.02395	0.00474	0.00027	524.6	82.04	514.3	9.45	515.5	14.64	95.7	5.36	98
PK1 - 43	0.15216	0.00288	0.44452	0.00649	9.32226	0.18096	0.04526	0.00212	2370.4	31.88	2370.8	28.97	2370.2	17.8	894.8	40.93	100
PK1 - 44	0.07026	0.00128	0.15611	0.00218	1.51164	0.02846	0.02156	0.00097	935.9	36.86	935.1	12.14	935.1	11.51	431.1	19.11	100
PK1 - 45	0.08917	0.00245	0.24341	0.00398	2.98752	0.07927	0.01572	0.00085	1407.7	51.74	1404.4	20.65	1404.4	20.19	315.3	16.9	100
РК1 - 46	0.11363	0.00208	0.05541	0.00079	0.86802	0.01628	0.01569	0.00052	1858.3	32.77	347.7	4.8	634.5	8.85	314.7	10.32	19
РК1 - 47	0.07006	0.00124	0.04884	0.00067	0.47175	0.00863	0.00816	0.00023	930.1	35.84	307.4	4.09	392.4	5.95	164.2	4.68	33
РК1 - 48	0.05389	0.00297	0.05796	0.00153	0.43089	0.02167	0.00141	0.00008	366.4	119	363.2	9.33	363.8	15.38	28.4	1.71	99
РК1 - 49	0.09249	0.00137	0.25781	0.00342	3.28787	0.05291	0.04214	0.00149	1477.4	27.99	1478.6	17.54	1478.2	12.53	834.3	28.99	100
РК1 - 50	0.06925	0.00148	0.15083	0.00222	1.4405	0.03065	0.015	0.00059	906.3	43.5	905.6	12.44	905.9	12.75	301	11.82	100
PK1 - 51	0.06543	0.00212	0.13308	0.00254	1.20028	0.03508	0.00268	0.00017	788.2	66.71	805.4	14.45	800.7	16.19	54.1	3.48	102
PK1 - 52	0.08448	0.00179	0.22434	0.0033	2.61472	0.05495	0.01705	0.00069	1303.5	40.66	1304.8	17.39	1304.8	15.44	341.7	13.66	100
PK1 - 53	0.05523	0.00102	0.06815	0.00094	0.5194	0.00991	0.00843	0.00032	421.4	40.08	425	5.66	424.8	6.62	169.7	6.32	101
PK1 - 54	0.05568	0.00162	0.07122	0.00115	0.5475	0.0154	0.00495	0.00024	439.2	63.44	443.5	6.94	443.4	10.11	99.9	4.85	101
PK1 - 55	0.05557	0.00111	0.07077	0.00098	0.54265	0.01105	0.00882	0.00034	435	43.54	440.8	5.93	440.2	7.27	177.6	6.78	101

PK1 - 56	0.09101	0.0017	0.25178	0.00348	3.16116	0.06013	0.03494	0.00138	1446.7	35.07	1447.7	17.92	1447.7	14.67	694.1	27.03	100
PK1 - 57	0.05772	0.00117	0.08465	0.00116	0.67412	0.01384	0.0135	0.00061	519	43.99	523.8	6.88	523.2	8.4	271.1	12.1	101
PK1 - 58	0.07157	0.00208	0.16351	0.0027	1.61616	0.0444	0.00828	0.00045	973.7	58.05	976.3	14.96	976.5	17.23	166.7	8.93	100
PK1 - 59	0.12261	0.00268	0.36345	0.0053	6.15772	0.13281	0.0195	0.00095	1994.5	38.39	1998.5	25.07	1998.5	18.84	390.3	18.9	100
PK1 - 60	0.08854	0.00164	0.24201	0.00331	2.95896	0.05602	0.02973	0.00138	1394.2	35.07	1397.1	17.19	1397.1	14.37	592.2	27.18	100
PK1 - 61	0.05973	0.0014	0.097	0.00148	0.79897	0.01808	0.00389	0.00013	593.9	49.95	596.8	8.71	596.2	10.2	78.5	2.7	100
PK1 - 62	0.07721	0.00159	0.19078	0.00273	2.03061	0.04273	0.03438	0.00122	1126.6	40.41	1125.6	14.79	1125.8	14.32	683.2	23.91	100
PK1 - 63	0.05525	0.00129	0.06743	0.00099	0.51353	0.01201	0.00756	0.00025	422.1	50.57	420.7	5.98	420.8	8.06	152.2	4.94	100
PK1 - 64	0.15674	0.00506	0.45622	0.00775	9.8595	0.30844	0.11562	0.01478	2420.8	53.81	2422.9	34.33	2421.7	28.84	2211.5	267.83	100
PK1 - 65	0.05832	0.00261	0.08796	0.00199	0.70764	0.02917	0.00227	0.00014	541.1	95.71	543.5	11.77	543.3	17.34	45.9	2.8	100
PK1 - 66	0.06977	0.00111	0.15386	0.00206	1.47965	0.02531	0.03177	0.00133	921.6	32.4	922.6	11.5	922.1	10.36	632.1	25.99	100
PK1 - 67	0.05743	0.00345	0.07934	0.00248	0.62784	0.03364	0.00152	0.00012	507.5	127.51	492.2	14.81	494.8	20.99	30.7	2.37	97
PK1 - 68	0.06496	0.00369	0.12786	0.00349	1.14536	0.06009	0.00568	0.00042	773.1	115.17	775.6	19.97	775	28.44	114.5	8.51	100
PK1 - 69	0.05071	0.00154	0.03543	0.0006	0.24772	0.00719	0.0023	0.00011	227.8	68.89	224.4	3.72	224.7	5.85	46.5	2.22	99
PK1 - 70	0.13771	0.00237	0.40618	0.00562	7.70842	0.14187	0.107	0.00723	2198.7	29.56	2197.4	25.76	2197.6	16.54	2054.7	132.02	100
PK1 - 71	0.05624	0.00257	0.07238	0.00157	0.56125	0.02409	0.00301	0.00018	461.2	98.9	450.5	9.42	452.3	15.67	60.8	3.72	98
PK1 - 72	0.05645	0.00122	0.07464	0.00106	0.58071	0.01297	0.02097	0.00154	469.5	47.73	464.1	6.39	464.9	8.33	419.4	30.39	99
PK1 - 73	0.07845	0.00182	0.19627	0.003	2.1216	0.04913	0.01951	0.0009	1158.3	45.3	1155.3	16.16	1155.9	15.98	390.5	17.79	100
PK1 - 74	0.05436	0.00168	0.06157	0.00095	0.46123	0.01418	0.0192	0.00152	385.8	67.67	385.2	5.75	385.1	9.85	384.4	30.24	100
PK1 - 75	0.0558	0.00209	0.07142	0.00126	0.54927	0.02021	0.02302	0.003	444.2	81.27	444.7	7.58	444.5	13.24	459.9	59.24	100
PK1 - 76	0.0757	0.00261	0.18404	0.00368	1.91821	0.06003	0.00582	0.00026	1087.2	67.56	1089	20.05	1087.4	20.89	117.3	5.23	106
PK1 - 77	0.11454	0.00127	0.33799	0.00402	5.33518	0.06498	0.05556	0.0014	1872.6	19.88	1877	19.36	1874.5	10.41	1093	26.77	105
PK1 - 78	0.05535	0.00075	0.06823	0.00084	0.52059	0.00752	0.00914	0.00024	426.1	29.97	425.5	5.06	425.5	5.02	183.8	4.87	102
PK1 - 79	0.10019	0.00242	0.28735	0.00417	3.96872	0.09482	0.06729	0.0051	1627.7	44.19	1628.3	20.86	1627.8	19.38	1316.3	96.67	102
PK1 - 80	0.08134	0.00156	0.21013	0.00287	2.35682	0.04497	0.02237	0.00067	1229.6	37.18	1229.5	15.27	1229.6	13.6	447.1	13.29	102
PK1 - 81	0.05472	0.0027	0.06363	0.00149	0.47978	0.02177	0.00167	0.00009	401	106.44	397.7	9.05	397.9	14.94	33.7	1.74	100
PK1 - 82	0.10237	0.0018	0.29542	0.00394	4.17018	0.07293	0.02289	0.00081	1667.6	32.13	1668.6	19.59	1668.2	14.32	457.4	15.98	100
PK1 - 83	0.07855	0.00221	0.19806	0.00328	2.14449	0.0562	0.00482	0.00022	1160.9	54.73	1164.9	17.67	1163.3	18.15	97.2	4.49	100
PK1 - 84	0.08878	0.00216	0.23853	0.00319	2.89764	0.06806	0.07048	0.00709	1399.3	45.85	1379.1	16.61	1381.3	17.73	1376.6	133.8	100

PK1 - 85	0.057	0.00124	0.07736	0.00104	0.60778	0.01318	0.02076	0.00129	490.9	47.12	480.3	6.21	482.2	8.33	415.2	25.64	100
PK1 - 86	0.05564	0.00108	0.07196	0.00091	0.55134	0.01071	0.02207	0.00128	437.7	42.25	447.9	5.47	445.9	7.01	441.3	25.31	100
PK1 - 87	0.056	0.00169	0.07198	0.00113	0.55577	0.01611	0.00851	0.00042	452	65.61	448.1	6.78	448.8	10.52	171.2	8.37	100
PK1 - 88	0.09139	0.00227	0.25365	0.00385	3.19597	0.07626	0.0184	0.00085	1454.6	46.67	1457.3	19.79	1456.2	18.45	368.5	16.9	100
PK1 - 89	0.05637	0.00158	0.0752	0.00115	0.58431	0.01574	0.00596	0.00029	466	61.35	467.4	6.9	467.2	10.09	120.1	5.84	100
PK1 - 90	0.09979	0.00197	0.2856	0.00388	3.92956	0.07704	0.02974	0.00132	1620.3	36.34	1619.5	19.43	1619.8	15.87	592.4	25.95	100
PK1 - 91	0.07138	0.00145	0.16137	0.00223	1.58851	0.03117	0.01079	0.00037	968.4	40.83	964.4	12.36	965.7	12.23	216.9	7.49	100
PK1 - 92	0.05881	0.00271	0.09089	0.00206	0.73781	0.03115	0.00309	0.00018	560.1	97.52	560.8	12.17	561.1	18.2	62.3	3.55	100
PK1 - 93	0.05521	0.0009	0.06713	0.00085	0.51088	0.00852	0.00998	0.00031	420.4	35.65	418.8	5.11	419	5.73	200.7	6.11	100
PK1 - 94	0.05546	0.00086	0.07046	0.00087	0.53877	0.00867	0.01195	0.00032	430.7	33.67	438.9	5.25	437.6	5.72	240.1	6.35	100
PK1 - 95	0.06145	0.00319	0.10932	0.00287	0.92963	0.0432	0.00263	0.00016	655	107.48	668.8	16.69	667.4	22.73	53.2	3.25	100
PK1 - 96	0.05261	0.00172	0.04983	0.00085	0.36163	0.01082	0.002	0.00009	312	72.47	313.5	5.22	313.4	8.07	40.4	1.82	100
PK1 - 97	0.05273	0.00376	0.05313	0.00128	0.38623	0.02655	0.0137	0.0016	317.3	153.94	333.7	7.86	331.6	19.45	275	31.93	100
PK1 - 98	0.09932	0.0017	0.28385	0.00365	3.8869	0.06666	0.0261	0.00091	1611.5	31.47	1610.7	18.31	1611	13.85	520.8	17.99	100
PK1 - 99	0.0678	0.00153	0.14254	0.00198	1.33227	0.02907	0.01035	0.00039	862.5	46.12	859	11.2	859.9	12.66	208.2	7.9	100
PK1 - 100	0.074	0.00196	0.17501	0.00266	1.78547	0.04445	0.00848	0.00036	1041.6	52.43	1039.6	14.57	1040.2	16.2	170.7	7.27	100
PK1 - 101	0.07399	0.00219	0.12133	0.00187	1.23767	0.03585	0.03083	0.00257	1041.2	58.72	738.2	10.77	817.8	16.27	613.7	50.35	100
PK1 - 102	0.06066	0.00183	0.1014	0.00161	0.84787	0.02376	0.00456	0.00022	627.1	63.72	622.6	9.45	623.5	13.06	92	4.49	100
PK1 - 103	0.05814	0.00201	0.08627	0.00148	0.6914	0.02207	0.01195	0.00066	534.4	74.3	533.4	8.76	533.6	13.25	240.2	13.19	100
PK1 - 104	0.06569	0.0033	0.13126	0.00313	1.18904	0.05433	0.00779	0.00055	796.4	101.8	795.1	17.85	795.5	25.2	156.8	11.11	100
PK1 - 105	0.05548	0.00445	0.06353	0.00235	0.48726	0.03232	0.00089	0.0001	431.2	169.61	397	14.25	403	22.07	17.9	2.08	100
PK1 - 106	0.06599	0.00346	0.14224	0.00397	1.29333	0.06148	0.00386	0.00027	806.2	106.2	857.3	22.41	842.8	27.22	77.9	5.39	100
PK1 - 107	0.09721	0.00123	0.27582	0.00332	3.69606	0.05086	0.0578	0.00187	1571.3	23.54	1570.3	16.77	1570.5	11	1135.8	35.65	100
PK1 - 108	0.0779	0.00128	0.19416	0.0024	2.08483	0.03519	0.05237	0.00277	1144.3	32.34	1143.8	12.94	1143.8	11.58	1031.7	53.29	100
PK1 - 109	0.05495	0.00129	0.06585	0.00087	0.49877	0.01167	0.01935	0.00096	410.1	50.87	411.1	5.25	410.9	7.91	387.3	18.95	100
PK1 - 110	0.15076	0.00196	0.44094	0.00538	9.16309	0.12756	0.06051	0.00172	2354.5	22.03	2354.8	24.07	2354.4	12.74	1187.5	32.76	100
PK1 - 111	0.19542	0.00356	0.54172	0.00742	14.59914	0.26322	0.03075	0.0011	2788.3	29.5	2790.7	31.04	2789.5	17.13	612.2	21.51	100
PK1 - 112	0.11334	0.00232	0.33293	0.00469	5.20604	0.10397	0.01589	0.0006	1853.6	36.57	1852.6	22.69	1853.6	17.01	318.7	11.99	100
PK1 - 113	0.10035	0.0014	0.28779	0.00353	3.98085	0.0586	0.04287	0.00137	1630.6	25.67	1630.5	17.68	1630.3	11.95	848.5	26.56	100

PK1 - 114	0.06853	0.00165	0.05438	0.00074	0.5137	0.01221	0.0139	0.00082	884.7	48.92	341.4	4.5	420.9	8.19	279.1	16.25	100
PK1 - 115	0.05921	0.0044	0.07807	0.00205	0.63583	0.04523	0.01513	0.00278	574.7	154.01	484.6	12.27	499.7	28.07	303.4	55.42	100
PK1 - 116	0.06343	0.00103	0.11885	0.00151	1.03936	0.01739	0.01435	0.00053	722.7	33.95	724	8.69	723.6	8.66	288	10.58	100
PK1 - 117	0.06954	0.00112	0.15243	0.0019	1.46114	0.02432	0.02846	0.00113	914.8	32.76	914.6	10.64	914.5	10.04	567.2	22.13	100
PK1 - 118	0.06719	0.00151	0.1404	0.00196	1.30086	0.02897	0.01467	0.0006	843.8	45.97	846.9	11.09	846.1	12.78	294.3	11.97	100
PK1 - 119	0.07512	0.0012	0.18061	0.00225	1.87006	0.03101	0.03161	0.00135	1071.7	31.84	1070.3	12.26	1070.6	10.97	629	26.52	100
PK1 - 120	0.09002	0.00155	0.24774	0.00321	3.0747	0.05441	0.03075	0.00125	1425.9	32.53	1426.8	16.57	1426.4	13.56	612.1	24.61	100
PK1 - 121	0.10749	0.0017	0.31293	0.00404	4.63598	0.07325	0.03921	0.00109	1757.2	28.65	1755.1	19.85	1755.8	13.2	777.3	21.24	100
PK1 - 122	0.05637	0.00091	0.07499	0.00094	0.58271	0.00972	0.01055	0.00034	466.1	35.82	466.2	5.64	466.2	6.23	212.1	6.75	100
PK1 - 123	0.09644	0.00124	0.27284	0.0033	3.6269	0.04976	0.03916	0.001	1556.3	23.9	1555.2	16.72	1555.5	10.92	776.5	19.39	100
PK1 - 124	0.09983	0.0013	0.28601	0.00344	3.93589	0.05479	0.04848	0.00138	1620.9	24.1	1621.6	17.24	1621.1	11.27	956.8	26.54	100
PK1 - 125	0.10659	0.00138	0.31017	0.00373	4.55749	0.06271	0.03934	0.00106	1742	23.5	1741.5	18.35	1741.5	11.46	779.9	20.68	100
PK1 - 126	0.07339	0.0011	0.17217	0.00213	1.74161	0.02704	0.02202	0.00062	1024.7	29.77	1024	11.7	1024.1	10.01	440.3	12.19	100
PK1 - 127	0.06	0.00087	0.09809	0.00118	0.81143	0.01234	0.02055	0.00074	603.7	31.09	603.2	6.92	603.3	6.92	411.2	14.61	99
PK1 - 128	0.11061	0.00152	0.3239	0.00389	4.93881	0.07147	0.05692	0.00196	1809.4	24.78	1808.7	18.94	1808.9	12.22	1119	37.5	99
PK1 - 129	0.08892	0.00124	0.24283	0.00291	2.97662	0.04349	0.0407	0.00139	1402.5	26.47	1401.4	15.1	1401.7	11.1	806.4	26.92	99
PK1 - 130	0.12978	0.00222	0.38383	0.00497	6.86613	0.11735	0.03426	0.00124	2095	29.72	2094.1	23.17	2094.3	15.15	680.9	24.16	99
PK1 - 131	0.08899	0.0013	0.24317	0.00292	2.9835	0.04541	0.0537	0.0024	1403.9	27.62	1403.1	15.13	1403.4	11.58	1057.2	45.99	98
PK1 - 132	0.06664	0.00121	0.13695	0.00175	1.258	0.02272	0.02202	0.00094	826.7	37.47	827.4	9.92	827	10.22	440.2	18.68	92
PK1 - 133	0.12709	0.00229	0.37582	0.00482	6.58295	0.11758	0.03443	0.00135	2058.1	31.51	2056.7	22.57	2057.1	15.74	684.3	26.37	84
PK1 - 134	0.16474	0.00258	0.47476	0.00579	10.7839	0.17375	0.11889	0.00681	2504.9	26.08	2504.4	25.3	2504.7	14.97	2270.6	123.01	71
PK1 - 135	0.07622	0.00167	0.1859	0.00247	1.95445	0.04234	0.04642	0.00343	1100.8	43.2	1099.1	13.43	1100	14.55	917.2	66.26	39
Sample	Т15_РКЗ -	- Immatu	ure Volca	nic San	dstones –	Clastic	Unit 5										
PK3 - 01	0.11629	0.00338	0.36135	0.00564	5.80425	0.16078	0.06232	0.00427	1899.9	51.36	1988.6	26.69	1947	23.99	1221.9	81.23	105
РКЗ - 02	0.0873	0.001	0.2288	0.00247	2.75484	0.03249	0.04726	0.00105	1367.2	21.91	1328.2	12.94	1343.4	8.79	933.3	20.17	97
PK3 - 03	0.08792	0.00133	0.23695	0.00272	2.87716	0.04313	0.02194	0.0007	1380.8	28.84	1370.8	14.17	1375.9	11.29	438.7	13.93	99
PK3 - 04	0.12091	0.00482	0.36143	0.00697	6.07499	0.22882	0.01698	0.00133	1969.7	69.42	1988.9	33	1986.7	32.84	340.4	26.38	101
PK3 - 05	0.12698	0.00146	0.35008	0.00379	6.13013	0.07225	0.05834	0.00126	2056.6	20.1	1935	18.12	1994.5	10.29	1146	23.97	94
PK3 - 06	0.07254	0.00111	0.04498	0.00051	0.44981	0.0069	0.01412	0.00045	1001.2	30.88	283.6	3.17	377.1	4.83	283.4	8.96	28
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РКЗ - 07	0.06688	0.00112	0.04608	0.00054	0.42488	0.00708	0.01294	0.00049	833.9	34.41	290.4	3.32	359.5	5.04	260	9.7	35
PK3 - 08	0.05795	0.00091	0.04284	0.00049	0.34217	0.00538	0.0119	0.00042	527.4	34.31	270.4	3.02	298.8	4.07	239	8.46	51
РКЗ - 09	0.0893	0.00206	0.23908	0.00317	2.94401	0.06646	0.06358	0.00472	1410.5	43.4	1381.9	16.47	1393.3	17.11	1245.9	89.68	98
РКЗ - 10	0.0953	0.00176	0.25613	0.00316	3.36722	0.06067	0.01914	0.00066	1534	34.37	1470	16.22	1496.8	14.11	383.2	13.18	96
PK3 - 11	0.07011	0.00231	0.15094	0.00234	1.46027	0.04691	0.03931	0.00442	931.5	66.28	906.2	13.09	914.1	19.36	779.4	85.95	97
РКЗ - 12	0.07328	0.00252	0.17313	0.00295	1.74993	0.05808	0.00944	0.00066	1021.8	68.21	1029.3	16.2	1027.1	21.45	189.8	13.21	101
РКЗ - 13	0.08971	0.00132	0.22548	0.0026	2.78851	0.04169	0.05626	0.0022	1419.4	27.78	1310.8	13.67	1352.5	11.17	1106.4	42.19	92
PK3 - 14	0.08623	0.00149	0.23206	0.00282	2.75873	0.04771	0.04111	0.00164	1343.2	33	1345.3	14.75	1344.4	12.89	814.3	31.81	100
РКЗ - 15	0.05499	0.00133	0.06555	0.00087	0.497	0.01176	0.00716	0.00031	411.7	52.47	409.3	5.29	409.7	7.98	144.3	6.25	99
РКЗ - 16	0.0561	0.00112	0.07328	0.00089	0.56678	0.01119	0.01989	0.00068	456.1	43.69	455.9	5.36	455.9	7.25	398	13.52	100
PK3 - 17	0.05331	0.00583	0.05029	0.00176	0.36964	0.03864	0.01631	0.00216	341.9	230.31	316.3	10.81	319.4	28.64	327	43.05	93
PK3 - 18	0.08469	0.00126	0.22528	0.00264	2.6308	0.03921	0.03045	0.00088	1308.2	28.66	1309.7	13.88	1309.3	10.96	606.3	17.27	100
PK3 - 19	0.09618	0.00227	0.27339	0.00381	3.62663	0.08139	0.01835	0.00079	1551.3	43.77	1558	19.28	1555.4	17.86	367.6	15.67	100
PK3 - 20	0.06347	0.00265	0.11969	0.00241	1.0464	0.04013	0.00273	0.00016	723.9	86.22	728.8	13.89	727.1	19.91	55.2	3.17	101
PK3 - 21	0.05556	0.00082	0.07006	0.0008	0.53672	0.008	0.01288	0.00034	434.5	32.2	436.5	4.81	436.3	5.29	258.7	6.81	100
РКЗ - 22	0.11011	0.00417	0.3218	0.00567	4.87986	0.17428	0.08464	0.0097	1801.1	67.31	1798.5	27.64	1798.8	30.1	1642.2	180.74	100
РКЗ - 23	0.05448	0.00096	0.06209	0.00073	0.46641	0.00816	0.01341	0.00044	390.8	38.86	388.3	4.44	388.7	5.65	269.3	8.71	99
РКЗ - 24	0.06993	0.00112	0.15616	0.00182	1.50574	0.02399	0.02899	0.00088	926.2	32.62	935.4	10.14	932.7	9.72	577.6	17.31	101
PK3 - 25	0.07332	0.00105	0.17118	0.00194	1.73055	0.02499	0.03668	0.00123	1022.7	28.73	1018.6	10.67	1020	9.29	728.2	23.99	100
РКЗ - 26	0.05336	0.00206	0.05579	0.00089	0.41015	0.01522	0.01309	0.00096	344.2	85.03	350	5.44	349	10.96	262.9	19.21	102
PK3 - 27	0.0558	0.00196	0.06458	0.00097	0.49672	0.0168	0.00918	0.00035	444	76.42	403.4	5.86	409.5	11.4	184.7	6.97	91
PK3 - 28	0.0558	0.00095	0.07176	0.00083	0.55216	0.00929	0.01567	0.00058	444.2	36.98	446.7	5.02	446.4	6.08	314.3	11.59	101
PK3 - 29	0.05449	0.00138	0.06317	0.00081	0.47466	0.01172	0.01699	0.00083	391.2	55.75	394.9	4.93	394.4	8.07	340.5	16.54	101
PK3 - 30	0.06158	0.00212	0.10855	0.00174	0.92162	0.02997	0.0088	0.00039	659.7	72.15	664.3	10.09	663.2	15.84	177	7.78	101
PK3 - 31	0.05869	0.00169	0.08791	0.0013	0.70977	0.01936	0.00684	0.00026	555.8	61.53	543.1	7.7	544.6	11.5	137.9	5.2	98
PK3 - 32	0.07461	0.00161	0.17712	0.00227	1.82146	0.0382	0.04483	0.00186	1057.7	43.11	1051.2	12.41	1053.2	13.75	886.5	35.99	99
РКЗ - 33	0.05373	0.00116	0.05679	0.00071	0.42043	0.00888	0.00979	0.00034	359.6	48.07	356.1	4.36	356.4	6.35	197	6.79	99
PK3 - 34	0.05891	0.00105	0.09177	0.0011	0.74504	0.01321	0.0252	0.00108	563.7	38.37	566	6.48	565.3	7.69	503	21.22	100
РКЗ - 35	0.05624	0.00117	0.07442	0.00091	0.57686	0.01176	0.01865	0.00065	461	45.67	462.8	5.48	462.4	7.57	373.5	12.91	100

PK3 - 36	0.05568	0.00145	0.06985	0.00092	0.53612	0.01352	0.01991	0.00101	439.4	56.53	435.3	5.55	435.9	8.93	398.4	19.92	99
PK3 - 37	0.05525	0.00107	0.06788	0.00082	0.51698	0.00989	0.01844	0.00087	422.2	42.16	423.4	4.93	423.1	6.62	369.3	17.17	100
PK3 - 38	0.05	0.00376	0.03228	0.00099	0.22237	0.01563	0.0024	0.0003	195.2	165.85	204.8	6.19	203.9	12.99	48.5	6.1	105
PK3 - 39	0.05282	0.00119	0.05067	0.00064	0.36897	0.00816	0.01266	0.00053	321.2	50.34	318.7	3.92	318.9	6.05	254.2	10.62	99
PK3 - 40	0.05437	0.00115	0.06188	0.00077	0.46374	0.00961	0.01089	0.00038	386.2	46.59	387.1	4.68	386.9	6.67	218.9	7.56	100
PK3 - 41	0.09614	0.00172	0.27165	0.00334	3.6	0.06361	0.04283	0.00182	1550.6	33.21	1549.1	16.91	1549.5	14.04	847.7	35.36	100
PK3 - 42	0.05369	0.00119	0.05691	0.00072	0.42126	0.00913	0.01029	0.00042	358.1	49.3	356.8	4.39	357	6.52	206.9	8.31	100
PK3 - 43	0.08883	0.00143	0.24259	0.00285	2.97044	0.04788	0.05991	0.00278	1400.4	30.49	1400.2	14.8	1400.1	12.24	1176.1	53.06	100
PK3 - 44	0.06833	0.0029	0.05425	0.00097	0.51106	0.02067	0.01464	0.00111	878.7	85.4	340.5	5.91	419.2	13.89	293.8	22.17	39
PK3 - 45	0.08793	0.00438	0.23951	0.00492	2.90234	0.13718	0.0645	0.01093	1380.9	92.66	1384.1	25.61	1382.5	35.69	1263.3	207.56	100
PK3 - 46	0.08687	0.00337	0.23264	0.00428	2.78488	0.10225	0.04346	0.00348	1357.7	72.95	1348.3	22.38	1351.5	27.43	859.9	67.46	99
PK3 - 47	0.08172	0.0033	0.18524	0.00339	2.08876	0.08033	0.02213	0.00195	1238.9	77.11	1095.5	18.43	1145.1	26.41	442.4	38.52	88
PK3 - 48	0.08871	0.00121	0.24256	0.00279	2.9662	0.04145	0.04854	0.00146	1397.8	25.8	1400	14.45	1399	10.61	958.1	28.16	100
PK3 - 49	0.09127	0.00141	0.21457	0.00255	2.69974	0.04227	0.0538	0.00195	1452.1	29.11	1253.1	13.56	1328.4	11.6	1059.1	37.45	86
PK3 - 50	0.087	0.00164	0.23461	0.00299	2.81375	0.05216	0.03602	0.00128	1360.4	35.79	1358.6	15.59	1359.2	13.89	715.2	24.92	100
PK3 - 51	0.05632	0.00168	0.04711	0.00066	0.36578	0.01057	0.00849	0.00034	464.2	65.12	296.7	4.08	316.5	7.85	170.9	6.88	64
PK3 - 52	0.0508	0.00142	0.03538	0.00051	0.2479	0.00666	0.00249	0.00012	231.7	63.23	224.2	3.18	224.9	5.42	50.4	2.51	97
PK3 - 53	0.05347	0.00184	0.0547	0.00081	0.4032	0.01341	0.0161	0.00099	348.5	75.69	343.3	4.94	344	9.7	322.8	19.69	99
PK3 - 54	0.05343	0.00115	0.05342	0.00067	0.39352	0.00838	0.01186	0.00049	346.9	48.08	335.5	4.11	336.9	6.11	238.3	9.72	97
PK3 - 55	0.05519	0.00264	0.06622	0.00122	0.50386	0.02313	0.02179	0.00322	419.9	103.46	413.3	7.4	414.3	15.62	435.7	63.76	98
PK3 - 56	0.14253	0.00603	0.41998	0.00928	8.33149	0.33852	0.0092	0.00083	2258.1	71.22	2260.4	42.12	2267.8	36.84	185.1	16.7	100
PK3 - 57	0.05528	0.00097	0.06802	0.0008	0.51838	0.00907	0.01309	0.00041	423.2	38.12	424.2	4.85	424.1	6.06	262.9	8.13	104
PK3 - 58	0.0552	0.00122	0.06685	0.00086	0.50906	0.01115	0.01884	0.00114	420.3	48	417.2	5.19	417.8	7.5	377.2	22.68	103
PK3 - 59	0.08175	0.00448	0.14505	0.00381	1.65981	0.08117	0.00338	0.00031	1239.6	103.88	873.2	21.46	993.3	30.99	68.2	6.29	103
PK3 - 60	0.07091	0.00163	0.16019	0.00209	1.56679	0.03463	0.01465	0.00071	954.7	46.42	957.8	11.62	957.2	13.7	294	14.13	103
PK3 - 61	0.08962	0.00324	0.23891	0.00427	2.9656	0.09676	0.00561	0.00035	1417.4	67.47	1381	22.22	1398.8	24.78	113	7.03	102
PK3 - 62	0.05235	0.00141	0.04731	0.00065	0.34154	0.00881	0.00549	0.00029	300.6	60.26	298	3.98	298.3	6.67	110.6	5.91	102
PK3 - 63	0.06631	0.00156	0.13495	0.00179	1.23407	0.02818	0.01635	0.00075	816.1	48.41	816.1	10.18	816.2	12.81	327.8	14.87	102
PK3 - 64	0.08436	0.00173	0.2235	0.0029	2.59969	0.05239	0.03024	0.00136	1300.7	39.36	1300.3	15.28	1300.6	14.78	602.2	26.6	101

РКЗ - 65	0.07328	0.00193	0.17171	0.00235	1.73434	0.0433	0.01346	0.0007	1021.7	52.38	1021.5	12.94	1021.4	16.08	270.3	13.99	101
РКЗ - 66	0.05708	0.00163	0.07994	0.00113	0.62887	0.01707	0.00763	0.00043	493.9	62.32	495.8	6.76	495.4	10.64	153.6	8.66	101
PK3 - 67	0.05509	0.00103	0.06669	0.00081	0.50656	0.00951	0.01576	0.00073	415.8	40.99	416.2	4.88	416.1	6.41	316	14.61	101
РКЗ - 68	0.05308	0.00277	0.05221	0.00086	0.38211	0.01956	0.01645	0.00122	332.3	113.97	328.1	5.26	328.6	14.37	329.9	24.28	101
РКЗ - 69	0.08542	0.00196	0.22815	0.0031	2.68709	0.06061	0.03291	0.00176	1324.9	43.84	1324.8	16.28	1324.9	16.69	654.4	34.41	101
РКЗ - 70	0.06366	0.00116	0.07647	0.00093	0.67117	0.01229	0.01657	0.00078	730.5	38.11	475	5.57	521.4	7.47	332.2	15.5	101
РКЗ - 71	0.05199	0.00226	0.04134	0.00075	0.29624	0.01257	0.01345	0.00197	284.8	96.13	261.1	4.66	263.5	9.84	270	39.37	100
РКЗ - 72	0.05551	0.00144	0.06901	0.00096	0.52851	0.01322	0.00571	0.0002	432.7	56.42	430.2	5.77	430.8	8.78	115.1	4.02	100
РКЗ - 73	0.07864	0.00168	0.19778	0.00268	2.14681	0.04439	0.01412	0.00045	1163	41.84	1163.4	14.45	1164	14.32	283.3	9.02	100
РКЗ - 74	0.0762	0.00166	0.18649	0.00254	1.96127	0.0411	0.01351	0.00047	1100.4	42.99	1102.3	13.83	1102.3	14.09	271.1	9.4	100
РКЗ - 75	0.07476	0.00123	0.17842	0.00219	1.83865	0.03086	0.04738	0.00202	1062.1	32.63	1058.3	11.97	1059.4	11.04	935.6	39.07	100
РКЗ - 76	0.07298	0.00146	0.17049	0.00224	1.71724	0.03336	0.00924	0.0003	1013.3	40.06	1014.8	12.34	1015	12.47	185.9	6.05	100
РКЗ - 77	0.06682	0.00165	0.06826	0.00094	0.62843	0.01523	0.02072	0.0014	832	50.58	425.7	5.67	495.1	9.5	414.6	27.8	100
РКЗ - 78	0.05795	0.00333	0.08411	0.00167	0.67182	0.03732	0.02663	0.00204	527.6	121.71	520.6	9.93	521.8	22.67	531.2	40.14	100
РКЗ - 79	0.09601	0.0017	0.27142	0.00349	3.59701	0.06275	0.016	0.0005	1547.9	32.85	1548	17.69	1548.9	13.86	320.8	10.04	100
РКЗ - 80	0.07763	0.00153	0.19348	0.00256	2.07236	0.04031	0.00656	0.00024	1137.5	38.7	1140.2	13.85	1139.7	13.32	132.1	4.74	100
PK3 - 81	0.11922	0.0032	0.34952	0.00523	5.74297	0.14877	0.09804	0.00894	1944.5	47.27	1932.3	25	1937.9	22.4	1890.5	164.49	100
PK3 - 82	0.08437	0.00246	0.22326	0.0037	2.59899	0.07235	0.01239	0.00052	1300.9	55.73	1299.1	19.5	1300.4	20.41	248.8	10.48	100
PK3 - 83	0.05022	0.00225	0.03346	0.00082	0.23194	0.00994	0.00105	0.00007	205.3	100.91	212.2	5.08	211.8	8.19	21.1	1.35	100
РКЗ - 84	0.10908	0.00171	0.31128	0.00377	4.68063	0.07575	0.0783	0.00439	1784	28.4	1747	18.54	1763.8	13.54	1523.7	82.27	100
PK3 - 85	0.05667	0.00115	0.07763	0.00099	0.60666	0.01214	0.00871	0.00027	477.9	44.56	481.9	5.95	481.5	7.67	175.3	5.33	100
PK3 - 86	0.05273	0.00166	0.04856	0.00077	0.35301	0.01069	0.0031	0.00012	317	69.81	305.7	4.71	307	8.02	62.5	2.47	100
PK3 - 87	0.10456	0.00148	0.30322	0.00369	4.37205	0.06351	0.03693	0.00097	1706.6	25.9	1707.3	18.24	1707.1	12	732.9	18.83	100
PK3 - 88	0.13359	0.00206	0.39517	0.00503	7.28074	0.11259	0.03441	0.00106	2145.7	26.75	2146.8	23.24	2146.5	13.81	683.7	20.76	100
PK3 - 89	0.06261	0.00304	0.11348	0.00289	0.98041	0.04279	0.00324	0.0002	695.1	100.11	692.9	16.73	693.8	21.94	65.3	4.06	100
PK3 - 90	0.05127	0.00089	0.04083	0.0005	0.28867	0.00501	0.00568	0.00017	252.9	39.27	257.9	3.09	257.5	3.95	114.6	3.42	100
PK3 - 91	0.05173	0.00123	0.04321	0.00059	0.30838	0.00709	0.00372	0.00013	273.4	53.48	272.7	3.65	272.9	5.5	75.1	2.69	100
PK3 - 92	0.05195	0.00165	0.04458	0.00061	0.31933	0.01	0.00991	0.00044	283.1	71.1	281.2	3.74	281.4	7.7	199.3	8.76	100
РКЗ - 93	0.07101	0.00101	0.16011	0.00188	1.56805	0.02289	0.02843	0.00103	957.6	28.8	957.4	10.47	957.7	9.05	566.7	20.22	100
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PK3 - 94	0.0567	0.00415	0.07761	0.00214	0.60735	0.04215	0.00329	0.00026	479	154.84	481.8	12.83	481.9	26.63	66.3	5.23	100
РКЗ - 95	0.05515	0.00116	0.06726	0.00084	0.51141	0.01063	0.02014	0.00119	418.2	45.49	419.6	5.05	419.4	7.14	403	23.55	100
РКЗ - 96	0.15271	0.0029	0.44578	0.00594	9.39625	0.17433	0.03466	0.00136	2376.5	31.98	2376.5	26.5	2377.5	17.03	688.8	26.5	100
РКЗ - 97	0.05306	0.00336	0.0522	0.00109	0.38175	0.02332	0.01558	0.00189	331.3	136.83	328	6.68	328.3	17.14	312.5	37.7	100
РКЗ - 98	0.0868	0.00135	0.23402	0.00279	2.80139	0.04413	0.03789	0.00155	1356	29.68	1355.5	14.55	1355.9	11.79	751.6	30.17	100
РКЗ - 99	0.05185	0.00316	0.04457	0.00097	0.31823	0.01856	0.01425	0.00262	278.7	133.84	281.1	5.97	280.5	14.29	286	52.25	100
PK3 - 100	0.08902	0.01176	0.24122	0.01245	2.95935	0.37194	0.06388	0.01463	1404.4	233.91	1393.1	64.67	1397.2	95.38	1251.6	277.95	100
PK3 - 101	0.07376	0.00195	0.17437	0.00253	1.77493	0.04524	0.01729	0.00095	1035	52.47	1036.1	13.9	1036.3	16.55	346.5	18.95	100
PK3 - 102	0.09098	0.00183	0.25134	0.00329	3.15213	0.06331	0.07351	0.0047	1446.2	37.81	1445.4	16.96	1445.5	15.48	1433.8	88.54	100
PK3 - 103	0.05491	0.00416	0.06614	0.00225	0.5009	0.03461	0.00214	0.00018	408.5	161.12	412.9	13.62	412.3	23.41	43.3	3.54	100
PK3 - 104	0.05863	0.00478	0.08795	0.00366	0.70637	0.05097	0.00151	0.00013	553.4	168.57	543.4	21.66	542.6	30.33	30.5	2.6	100
PK3 - 105	0.10521	0.00237	0.05654	0.00077	0.82024	0.01784	0.01178	0.0004	1718	40.81	354.6	4.68	608.2	9.95	236.8	8.07	100
PK3 - 106	0.0933	0.00221	0.26038	0.00372	3.35003	0.07591	0.02294	0.00101	1493.9	44.16	1491.8	19.04	1492.8	17.72	458.5	20.05	100
PK3 - 107	0.06289	0.00104	0.11541	0.00141	1.0007	0.01675	0.01962	0.00072	704.4	34.73	704.1	8.13	704.2	8.5	392.7	14.36	100
PK3 - 108	0.05607	0.00126	0.07395	0.00094	0.57165	0.01273	0.02214	0.00111	454.8	48.88	459.9	5.62	459.1	8.22	442.7	22.02	100
PK3 - 109	0.05437	0.00127	0.05976	0.00076	0.44795	0.01034	0.01796	0.00103	386.4	51.37	374.1	4.63	375.8	7.25	359.9	20.38	100
PK3 - 110	0.10741	0.00185	0.31324	0.00394	4.63872	0.08039	0.04631	0.00207	1756	31.09	1756.6	19.35	1756.3	14.48	915	39.98	100
PK3 - 111	0.06786	0.00158	0.14392	0.00197	1.34639	0.03028	0.01596	0.00082	864.4	47.62	866.8	11.08	866	13.1	320	16.31	100
PK3 - 112	0.09209	0.00261	0.25544	0.00397	3.24278	0.08739	0.02525	0.0015	1469	52.93	1466.5	20.4	1467.5	20.91	504.1	29.63	100
PK3 - 113	0.08825	0.00177	0.23989	0.00311	2.91837	0.05901	0.05756	0.0042	1388	38.01	1386.1	16.19	1386.7	15.29	1131.2	80.29	100
PK3 - 114	0.15889	0.00329	0.46108	0.0061	10.09936	0.20624	0.05542	0.00311	2443.9	34.61	2444.3	26.92	2443.9	18.87	1090.3	59.47	100
PK3 - 115	0.06813	0.00216	0.1447	0.00231	1.35857	0.04022	0.00943	0.00059	872.5	64.2	871.2	12.99	871.3	17.31	189.7	11.88	100
PK3 - 116	0.08014	0.00161	0.20449	0.00258	2.25929	0.04516	0.06037	0.00447	1200.5	39.13	1199.4	13.79	1199.7	14.07	1184.7	85.2	100
РКЗ - 117	0.16218	0.00205	0.46854	0.00546	10.47572	0.13933	0.0832	0.00241	2478.5	21.12	2477.1	23.98	2477.8	12.33	1615.3	44.97	100
РКЗ - 118	0.09455	0.00125	0.26573	0.00312	3.46352	0.04814	0.04454	0.00137	1519	24.81	1519.1	15.91	1519	10.95	880.8	26.51	100
РКЗ - 119	0.07243	0.00205	0.16737	0.00255	1.67172	0.04378	0.0041	0.00021	998.2	56.14	997.6	14.09	997.8	16.64	82.7	4.21	100
РКЗ - 120	0.08228	0.00157	0.21461	0.00279	2.43482	0.04589	0.0252	0.00101	1252.2	36.76	1253.3	14.78	1252.9	13.56	503	19.86	100
РКЗ - 121	0.05467	0.00123	0.06344	0.00084	0.47826	0.01044	0.0062	0.00025	398.8	49.16	396.5	5.12	396.9	7.17	124.9	5	100
PK3 - 122	0.07123	0.00146	0.16078	0.00211	1.57899	0.03183	0.01624	0.00067	964	41.41	961.1	11.74	962	12.53	325.7	13.39	99

РКЗ - 123	0.05276	0.00167	0.0496	0.00077	0.36078	0.0107	0.00335	0.00018	318.3	70.51	312	4.76	312.8	7.98	67.5	3.67	99
РКЗ - 124	0.05183	0.00095	0.04387	0.00054	0.31342	0.00579	0.00799	0.0003	277.7	41.59	276.8	3.31	276.8	4.48	160.9	6.01	99
PK3 - 125	0.13483	0.00293	0.39858	0.00533	7.40927	0.15664	0.03277	0.00171	2161.8	37.48	2162.5	24.56	2162.1	18.91	651.8	33.5	99
PK3 - 126	0.0536	0.003	0.05615	0.00143	0.41438	0.02107	0.00215	0.00017	354.2	121.06	352.1	8.71	352	15.12	43.3	3.36	99
PK3 - 127	0.05459	0.00166	0.06362	0.00096	0.47886	0.01403	0.00625	0.00034	395.5	66.22	397.6	5.79	397.3	9.63	126	6.89	99
PK3 - 128	0.05633	0.00095	0.07521	0.0009	0.58403	0.00999	0.01558	0.00069	464.5	37.37	467.4	5.4	467	6.4	312.4	13.69	99
PK3 - 129	0.05152	0.00201	0.04289	0.00067	0.30467	0.0116	0.00717	0.00041	264.3	87.24	270.7	4.12	270	9.03	144.5	8.14	99
PK3 - 130	0.05239	0.00221	0.04889	0.00087	0.35315	0.01412	0.00384	0.00025	302.5	93.2	307.7	5.35	307.1	10.59	77.4	5.11	99
PK3 - 131	0.0835	0.00157	0.21975	0.00278	2.52974	0.04737	0.0346	0.00166	1280.8	36.28	1280.5	14.69	1280.6	13.63	687.4	32.52	99
PK3 - 132	0.05533	0.00153	0.06837	0.00097	0.5217	0.01395	0.00663	0.00024	425.2	60.09	426.3	5.84	426.3	9.31	133.6	4.92	99
РКЗ - 133	0.10797	0.00467	0.31399	0.00668	4.66848	0.19236	0.09421	0.01118	1765.4	76.95	1760.3	32.75	1761.6	34.46	1819.8	206.58	99
PK3 - 134	0.0548	0.00574	0.067	0.00219	0.50592	0.05106	0.01759	0.00238	404	219.03	418	13.26	415.7	34.43	352.4	47.3	98
PK3 - 135	0.07473	0.00306	0.17925	0.00343	1.84679	0.07165	0.01299	0.00051	1061.3	80.14	1062.9	18.73	1062.3	25.56	260.8	10.12	98
PK3 - 136	0.07114	0.0018	0.16064	0.00225	1.57425	0.03766	0.00704	0.00031	961.5	50.71	960.3	12.5	960.1	14.85	141.8	6.14	98
PK3 - 137	0.08679	0.00167	0.23419	0.00297	2.80153	0.05267	0.01803	0.00071	1355.8	36.63	1356.4	15.52	1355.9	14.07	361.2	14.12	98
PK3 - 138	0.08714	0.0012	0.24693	0.00288	2.96631	0.04233	0.04307	0.0014	1363.6	26.3	1422.6	14.91	1399	10.84	852.4	27.19	97
PK3 - 139	0.07514	0.00309	0.17694	0.00377	1.82438	0.06895	0.00343	0.00024	1072.1	80.53	1050.3	20.64	1054.3	24.79	69.1	4.86	97
РКЗ - 140	0.05339	0.00376	0.05676	0.00125	0.41766	0.02856	0.01793	0.00154	345.2	151.62	355.9	7.6	354.4	20.46	359.1	30.63	96
PK3 - 141	0.08875	0.00133	0.24204	0.00289	2.96128	0.04571	0.05344	0.00225	1398.6	28.36	1397.3	14.99	1397.7	11.72	1052.3	43.25	96
РКЗ - 142	0.15461	0.00259	0.45026	0.00563	9.59503	0.16366	0.06397	0.00286	2397.5	28.26	2396.4	25.03	2396.7	15.68	1253.2	54.31	96
РКЗ - 143	0.05568	0.00433	0.06738	0.00179	0.51705	0.03856	0.02019	0.00366	439.3	164.66	420.3	10.83	423.2	25.81	404	72.54	92
РКЗ - 144	0.05551	0.00295	0.06688	0.00174	0.50903	0.02521	0.00121	0.0001	432.5	114.48	417.3	10.52	417.8	16.97	24.5	2.04	70
PK3 - 145	0.05565	0.00168	0.06973	0.00103	0.53479	0.01579	0.01762	0.00147	438.1	65.51	434.5	6.23	435	10.45	353.1	29.22	65
PK3 - 146	0.08037	0.00174	0.20557	0.00274	2.27651	0.04891	0.01954	0.00103	1206.1	42.16	1205.2	14.66	1205	15.16	391	20.38	51
PK3 - 147	0.05597	0.00236	0.07221	0.00123	0.55723	0.02257	0.02664	0.00359	451	90.6	449.5	7.37	449.7	14.71	531.5	70.68	21
Sample	Т15_РК4 -	-Volcani	c Sandsto	ones – C	lastic Uni	t 4						_11					
PK4 - 01	0.05568	0.00249	0.06966	0.00141	0.53503	0.02346	0.01506	0.00103	439.4	96.46	434.1	8.5	435.1	15.52	302.2	20.46	105
РК4 - 02	0.08113	0.00104	0.20875	0.00303	2.3347	0.03731	0.03712	0.0009	1224.7	25.03	1222.2	16.16	1222.9	11.36	736.8	17.5	102
	0.07622	0.00207	0.18855	0.00326	1.98121	0.05512	0.05218	0.00259	1100.9	53.51	1113.5	17.66	1109.1	18.77	1028	49.7	102

Pr4-5 Const2 Const2 <thconst2< th=""> Const2 <thconst2< th=""> <thconst2< th=""></thconst2<></thconst2<></thconst2<>																		
Pri-10 DEMON OMDEL OMDEL <t< td=""><td>РК4 - 04</td><td>0.14124</td><td>0.00246</td><td>0.41465</td><td>0.00653</td><td>8.06964</td><td>0.14858</td><td>0.03099</td><td>0.00095</td><td>2242.4</td><td>29.77</td><td>2236.2</td><td>29.74</td><td>2238.9</td><td>16.63</td><td>616.9</td><td>18.67</td><td>101</td></t<>	РК4 - 04	0.14124	0.00246	0.41465	0.00653	8.06964	0.14858	0.03099	0.00095	2242.4	29.77	2236.2	29.74	2238.9	16.63	616.9	18.67	101
PR4-17 0.1844 0.017 0.0975 0.0025 0.52572 0.0105 0.52572 0.0105 0.52572 0.0105 0.52572 0.0105 0.52572 0.0105 0.52572 0.0105 0.52572 0.0105 0.52572 0.0105 0.52572 0.0105 0.52572 0.0105 0.00264 0.0007 41.2 1.714 <td>PK4 - 05</td> <td>0.05822</td> <td>0.00084</td> <td>0.08621</td> <td>0.00128</td> <td>0.69193</td> <td>0.01128</td> <td>0.00743</td> <td>0.00016</td> <td>537.4</td> <td>31.79</td> <td>533.1</td> <td>7.62</td> <td>534</td> <td>6.77</td> <td>149.6</td> <td>3.15</td> <td>101</td>	PK4 - 05	0.05822	0.00084	0.08621	0.00128	0.69193	0.01128	0.00743	0.00016	537.4	31.79	533.1	7.62	534	6.77	149.6	3.15	101
PH4-08 0.00107 0.01107 0.00107 0.00107 0.01107 0.01107 0.00107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.01107 0.00107 0.00017 0.00117 0.0117 0.0116 0.0017 0.00117 0.00117 0.0116 0.0017 0.00117 0.00117 0.0018 0.0017 0.00117 0.00118 0.0018 0.00117 0.00118 0.00117 0.00117 0.00118 0.00117 0.00117 0.00118 0.00117 0.00117 0.00118 0.00117 0.00117 0.00117 0.00117 0.00118 0.00118 0.00118 0.00117 0.00117 0.00117 0.00117	РК4 - 06	0.05692	0.00073	0.08012	0.00117	0.62868	0.01015	0.02285	0.00057	487.8	28.27	496.9	6.99	495.3	6.33	456.6	11.19	101
PR4-09 ONESP ONESP <t< td=""><td>РК4 - 07</td><td>0.10616</td><td>0.00121</td><td>0.30903</td><td>0.00455</td><td>4.52277</td><td>0.06805</td><td>0.05435</td><td>0.00108</td><td>1734.5</td><td>20.76</td><td>1735.9</td><td>22.4</td><td>1735.2</td><td>12.51</td><td>1069.7</td><td>20.75</td><td>101</td></t<>	РК4 - 07	0.10616	0.00121	0.30903	0.00455	4.52277	0.06805	0.05435	0.00108	1734.5	20.76	1735.9	22.4	1735.2	12.51	1069.7	20.75	101
PR4.10 OD5476 OD557 OD577 OD5777 OD577 OD577	РК4 - 08	0.05577	0.00102	0.06839	0.00105	0.52572	0.01079	0.01944	0.00072	442.9	39.61	426.4	6.35	429	7.18	389.1	14.23	101
PH-1 0.002911 0.00252 0.24772 0.04056 0.00495 0.00495 1.44 4.82 1.124.1 2.10 1.427.1 2.03 1.124.2 88.6 1.144.1 PM-12 0.06837 0.00245 0.14458 0.0024 1.8648 0.0027 0.00317 0.0038 879.8 72.51 870.5 15.79 873.4 196.6 1.41.3 7.61 11 PM-13 0.00764 0.0078 0.1751 0.0026 1.5788 0.0017 0.00178 0.1578 9.80 1.52 99.8 15.55 99.8 15.65 233.2 9.48 10 PM-14 0.00746 0.0078 0.00228 0.51616 0.0044 0.0002 413.6 142.4 1.78 422.7 3.66 233.2 9.48 10 PM-15 0.0529 0.0578 0.0024 0.6416 0.0124 0.0002 411.4 1.60 423.8 107 4.08.4 101.9 10 10 10 10	РК4 - 09	0.06039	0.00371	0.06299	0.00169	0.52346	0.0301	0.00346	0.00037	617.4	127.41	393.8	10.25	427.5	20.06	69.8	7.4	101
PH-12 OOBSH7 OOBSH7 OOBSH7 OOBSH7 OOBSH7 OOBSH7 OODSH7 OODSH7 </td <td>РК4 - 10</td> <td>0.05476</td> <td>0.00156</td> <td>0.0624</td> <td>0.00107</td> <td>0.47075</td> <td>0.01289</td> <td>0.00265</td> <td>0.0001</td> <td>402.5</td> <td>61.67</td> <td>390.2</td> <td>6.51</td> <td>391.7</td> <td>8.9</td> <td>53.6</td> <td>1.96</td> <td>101</td>	РК4 - 10	0.05476	0.00156	0.0624	0.00107	0.47075	0.01289	0.00265	0.0001	402.5	61.67	390.2	6.51	391.7	8.9	53.6	1.96	101
PH4-13 0.00764 0.00764 0.00764 0.00764 0.00764 0.00764 0.00764 0.0017 0.0025 1.000.1 34.32 1008.2 10.33 0.0016 0.0017 PH4-14 0.07746 0.00178 0.10776 0.0022 0.5656 0.0013 0.0017 998.8 49.2 993.3 13.25 99.4 55.6 233.2 4.8 10.33 <t< td=""><td>РК4 - 11</td><td>0.09041</td><td>0.00232</td><td>0.24722</td><td>0.00426</td><td>3.08004</td><td>0.08173</td><td>0.06086</td><td>0.00465</td><td>1434</td><td>48.25</td><td>1424.1</td><td>21.99</td><td>1427.7</td><td>20.34</td><td>1194.2</td><td>88.6</td><td>101</td></t<>	РК4 - 11	0.09041	0.00232	0.24722	0.00426	3.08004	0.08173	0.06086	0.00465	1434	48.25	1424.1	21.99	1427.7	20.34	1194.2	88.6	101
PH4-14 0.00724 0.0078 0.0076 1.6768 0.041 0.016 0.998.8 4.92 999.3 1.55 99.8 1.66 233.2 243.8 1.92.4 4.25 1.57 99.8 1.66 233.2 0.83.3 1.17 PH4-15 0.05529 0.00589 0.0778 0.0022 0.5184 0.0124 0.0241 0.4231 0.4231 0.4231 0.4231 0.4231 0.4231 0.4231 0.4231 0.4231 0.4231 0.4231 0.4231 0.433 0.424 0.0124 0.4231 0.0224 0.433 0.0271 0.0271 0.433	РК4 - 12	0.06837	0.00245	0.14458	0.0028	1.36348	0.04575	0.00712	0.00038	879.8	72.51	870.5	15.79	873.4	19.66	143.3	7.61	101
PK4-15 0.0578 0.0028 0.06778 0.0028 0.01572 0.0612 423.6 192.4 422.8 13.78 422.7 30.46 37.48 103.33 11 PK4-16 0.0579 0.0029 0.0793 0.0024 0.6246 0.01243 0.0244 0.0028 443.3 38.05 492.1 7.38 492.4 7.77 408.1 16.64 11 PK4-16 0.0551 0.0068 0.0767 0.0011 0.5939 0.00224 0.0028 471.1 26.69 473.8 6.97 473.3 6.02 258.9 41.0 11 PK4-18 0.05514 0.0074 0.0578 0.0029 0.0279 0.0274 0.0028 473.4 114.2 428.5 18.17 446.6 41.19 11 PK4-19 0.08192 0.00144 0.06975 0.00144 0.0278 0.0028 433.7 83.7 430.6 6.65 585.5 8.83 331.2 116 55.9 131	РК4 - 13	0.07604	0.00096	0.1751	0.00261	1.83533	0.0299	0.04505	0.00137	1096.2	25.13	1040.1	14.32	1058.2	10.71	890.6	26.44	101
PK4-16 0.0579 0.00099 0.07933 0.0014 0.0244 0.00264 444.3 38.05 492.1 7.38 442.4 7.77 408.1 16.64 18.65 PK4-17 0.0555 0.00029 0.07933 0.0014 0.5389 0.0024 0.0023 471.1 26.69 473.8 6.02 28.9 4.57 13.6 PK4-18 0.0514 0.0029 0.06781 0.0015 0.52588 0.02234 0.0008 457.4 114.28 423 9.36 425.5 18.17 446.6 41.19 14.9 PK4-19 0.08122 0.00144 0.0698 0.0011 0.70099 0.1548 0.0076 0.0002 876.3 38.76 873.3 13.13 873.8 11.94 28.98 7.31 11.9 PK4-20 0.06825 0.00124 0.06975 0.0177 0.00576 0.0022 433.7 83.73 43.13 8.77 45.1 270.8 6.77 37.7 1.35 11.9 9	РК4 - 14	0.07246	0.00178	0.16768	0.00276	1.67681	0.0413	0.0116	0.00047	998.8	49.2	999.3	15.25	999.8	15.66	233.2	9.48	101
PR4-17 Oxede Oxede <t< td=""><td>РК4 - 15</td><td>0.05529</td><td>0.00508</td><td>0.06778</td><td>0.00228</td><td>0.51636</td><td>0.04549</td><td>0.01872</td><td>0.00521</td><td>423.6</td><td>192.94</td><td>422.8</td><td>13.78</td><td>422.7</td><td>30.46</td><td>374.8</td><td>103.33</td><td>101</td></t<>	РК4 - 15	0.05529	0.00508	0.06778	0.00228	0.51636	0.04549	0.01872	0.00521	423.6	192.94	422.8	13.78	422.7	30.46	374.8	103.33	101
Price Pric Price Price	РК4 - 16	0.05709	0.00099	0.07933	0.00124	0.62416	0.01243	0.0204	0.00084	494.3	38.05	492.1	7.38	492.4	7.77	408.1	16.64	101
Lease Lease <th< td=""><td>РК4 - 17</td><td>0.0565</td><td>0.00068</td><td>0.07627</td><td>0.00116</td><td>0.59389</td><td>0.00945</td><td>0.01289</td><td>0.00023</td><td>471.1</td><td>26.69</td><td>473.8</td><td>6.97</td><td>473.3</td><td>6.02</td><td>258.9</td><td>4.57</td><td>101</td></th<>	РК4 - 17	0.0565	0.00068	0.07627	0.00116	0.59389	0.00945	0.01289	0.00023	471.1	26.69	473.8	6.97	473.3	6.02	258.9	4.57	101
PK4 O	РК4 - 18	0.05614	0.00299	0.06781	0.00155	0.52508	0.02729	0.02234	0.00208	457.4	114.28	423	9.36	428.5	18.17	446.6	41.19	100
Matrix Matrix<	РК4 - 19	0.08192	0.00144	0.06908	0.0011	0.78009	0.01548	0.01765	0.00036	1243.7	33.79	430.6	6.65	585.5	8.83	353.5	7.06	100
Number of the state o	РК4 - 20	0.06825	0.00129	0.14508	0.00233	1.36445	0.0278	0.01444	0.00037	876.3	38.76	873.3	13.13	873.8	11.94	289.8	7.31	100
Image: Normal and the state of the	РК4 - 21	0.05554	0.00214	0.06875	0.00134	0.52615	0.01972	0.00576	0.00028	433.7	83.73	428.6	8.07	429.3	13.12	116	5.59	100
Image: Normal and the state of the	РК4 - 22	0.05191	0.00154	0.0427	0.00073	0.30566	0.00871	0.00187	0.00007	281.5	66.27	269.5	4.51	270.8	6.77	37.7	1.35	100
Image: Normal and the state of the	PK4 - 23	0.05416	0.00085	0.05997	0.00094	0.4478	0.00841	0.01138	0.00025	377.7	35.11	375.5	5.73	375.7	5.9	228.7	4.98	100
R4 - 26 0.00136 0.0136 0.14439 0.00237 1.35633 0.02909 0.0141 0.00053 873.7 40.77 869.5 1.3.66 870.4 1.2.54 2.89.3 1.0.6 1.0	РК4 - 24	0.13697	0.0025	0.40433	0.00615	7.63576	0.14181	0.01677	0.00054	2189.2	31.45	2188.9	28.25	2189.1	16.67	336.2	10.71	100
L L <thl< th=""> <thl< th=""> <thl< th=""> <thl< th=""></thl<></thl<></thl<></thl<>	PK4 - 25	0.05305	0.00315	0.05292	0.00144	0.38742	0.02094	0.00183	0.00013	331	128.55	332.4	8.83	332.5	15.32	37	2.57	100
Image: Normal and the state of the	PK4 - 26	0.06817	0.00136	0.14439	0.00237	1.35653	0.02909	0.01441	0.00053	873.7	40.77	869.5	13.36	870.4	12.54	289.3	10.6	100
PK4 - 29 0.005518 0.00076 0.0646 0.00103 0.48762 0.00963 0.0012 0.0012 267.1 70.16 259.2 4.6 260 7.09 54.5 2.45 1.0	PK4 - 27	0.05255	0.0014	0.04936	0.00084	0.35759	0.00953	0.00328	0.00012	309.2	59.32	310.6	5.17	310.4	7.13	66.2	2.4	100
PK4 - 31 0.05159 0.00161 0.04103 0.029182 0.00903 0.0027 0.0012 267.1 70.16 259.2 4.6 260 7.09 54.5 2.45 2.45 2.45	PK4 - 28	0.06385	0.00107	0.12102	0.002	1.06506	0.02159	0.02411	0.001	736.6	34.95	736.4	11.53	736.3	10.62	481.5	19.64	100
PK4 - 31 0.05159 0.00161 0.04103 0.00074 0.29182 0.0093 0.0027 0.0012 267.1 70.16 259.2 4.6 260 7.09 54.5 2.45 10	PK4 - 29	0.05518	0.00085	0.06758	0.00108	0.51403	0.00968	0.01407	0.00038	419.2	33.66	421.6	6.53	421.2	6.49	282.4	7.51	100
	PK4 - 30	0.05475	0.00076	0.0646	0.00103	0.48762	0.00866	0.01196	0.00032	401.9	30.38	403.6	6.26	403.3	5.91	240.3	6.46	100
PK4-32 0.07383 0.00092 0.17425 0.0026 1.77349 0.02818 0.03015 0.00072 1.036.8 24.91 1.035.5 14.29 1.035.8 10.32 600.4 14.17 1.0	PK4 - 31	0.05159	0.00161	0.04103	0.00074	0.29182	0.00903	0.0027	0.00012	267.1	70.16	259.2	4.6	260	7.09	54.5	2.45	100
	РК4 - 32	0.07383	0.00092	0.17425	0.0026	1.77349	0.02818	0.03015	0.00072	1036.8	24.91	1035.5	14.29	1035.8	10.32	600.4	14.17	100

РК4 - 33	0.05486	0.00077	0.06554	0.00105	0.49566	0.00894	0.0141	0.00042	406.4	30.75	409.2	6.36	408.8	6.07	283.1	8.32	100
PK4 - 34	0.12308	0.00148	0.36388	0.00542	6.17446	0.09522	0.05567	0.00122	2001.4	21.16	2000.5	25.61	2000.8	13.48	1095.1	23.39	100
PK4 - 35	0.05025	0.00177	0.03428	0.00065	0.23697	0.0076	0.00082	0.00004	206.5	79.57	217.3	4.03	215.9	6.24	16.6	0.8	100
РК4 - 36	0.08056	0.00151	0.20573	0.00323	2.28394	0.04479	0.01456	0.00047	1210.7	36.38	1206	17.25	1207.3	13.85	292.2	9.41	100
РК4 - 37	0.06683	0.00119	0.13844	0.00214	1.27603	0.02413	0.01166	0.0003	832.5	36.69	835.9	12.14	835.1	10.76	234.2	5.91	100
РК4 - 38	0.11495	0.0013	0.33803	0.00494	5.35744	0.08138	0.09317	0.0022	1879.1	20.18	1877.2	23.79	1878.1	13	1800.5	40.63	100
РК4 - 39	0.05646	0.00214	0.0751	0.00142	0.58479	0.02198	0.02	0.00122	469.9	82.4	466.8	8.53	467.5	14.08	400.3	24.2	100
РК4 - 40	0.08585	0.00133	0.23028	0.00342	2.72731	0.04403	0.01255	0.00028	1334.8	29.71	1335.9	17.92	1335.9	11.99	252	5.67	100
РК4 - 41	0.05647	0.00184	0.07611	0.00137	0.59288	0.01793	0.0023	0.00008	470.2	70.76	472.9	8.21	472.7	11.43	46.5	1.7	100
РК4 - 42	0.05912	0.00066	0.09329	0.00135	0.76055	0.01111	0.01526	0.00027	571.3	23.58	575	7.97	574.3	6.41	306.1	5.47	100
РК4 - 43	0.06394	0.00203	0.12215	0.00223	1.07726	0.03207	0.00707	0.00028	739.8	65.88	742.9	12.8	742.3	15.68	142.4	5.66	100
РК4 - 44	0.08003	0.001	0.20496	0.00302	2.26304	0.03464	0.0315	0.00059	1197.8	24.4	1201.9	16.17	1200.9	10.78	626.9	11.61	100
РК4 - 45	0.05745	0.00141	0.08226	0.00133	0.65214	0.01553	0.00418	0.00012	508.5	53.44	509.6	7.91	509.8	9.55	84.3	2.39	100
РК4 - 46	0.05683	0.0008	0.0777	0.00115	0.60907	0.01038	0.01852	0.00042	484.4	31.16	482.4	6.88	483	6.55	370.9	8.38	100
РК4 - 47	0.05482	0.0013	0.06529	0.00104	0.49403	0.01149	0.00377	0.0001	405	51.87	407.7	6.29	407.7	7.81	76.1	2.11	100
РК4 - 48	0.06845	0.0017	0.14641	0.00238	1.3832	0.03236	0.00626	0.00019	882.3	50.5	880.8	13.39	881.8	13.79	126	3.86	100
РК4 - 49	0.05574	0.00089	0.0705	0.00105	0.5423	0.00959	0.00762	0.00017	441.6	34.66	439.2	6.34	439.9	6.31	153.5	3.32	100
РК4 - 50	0.05488	0.00075	0.06615	0.00097	0.50105	0.00808	0.00823	0.00017	407.3	30	412.9	5.88	412.4	5.46	165.6	3.5	100
РК4 - 51	0.05451	0.00138	0.06287	0.00102	0.47324	0.01163	0.00338	0.0001	392.1	55.4	393.1	6.16	393.4	8.02	68.1	2.03	100
РК4 - 52	0.07219	0.00139	0.16604	0.00258	1.65482	0.03231	0.01087	0.00023	991.4	38.55	990.3	14.24	991.4	12.36	218.5	4.69	100
РК4 - 53	0.0708	0.00132	0.15893	0.00237	1.55383	0.02841	0.00607	0.00014	951.6	37.61	950.8	13.19	952	11.3	122.3	2.86	100
РК4 - 54	0.05764	0.00164	0.08121	0.00133	0.64575	0.0168	0.00359	0.00013	515.7	61.49	503.4	7.95	505.9	10.37	72.4	2.53	100
РК4 - 55	0.05568	0.00076	0.07067	0.00105	0.54254	0.00919	0.02172	0.0006	439.5	29.62	440.2	6.32	440.1	6.05	434.3	11.81	100
РК4 - 56	0.05589	0.0007	0.07098	0.00105	0.54707	0.00881	0.01728	0.00038	447.7	27.16	442.1	6.34	443.1	5.78	346.2	7.51	100
РК4 - 57	0.06917	0.00145	0.15099	0.00221	1.44159	0.02811	0.00526	0.00017	903.9	42.52	906.5	12.4	906.4	11.69	106	3.43	100
РК4 - 58	0.0912	0.00106	0.25284	0.00372	3.17998	0.04809	0.04388	0.00083	1450.7	22.02	1453.1	19.15	1452.3	11.68	868	16.08	100
РК4 - 59	0.05838	0.00266	0.0704	0.0016	0.56667	0.02333	0.00252	0.00013	544.2	96.46	438.6	9.61	455.9	15.12	51	2.72	100
РК4 - 60	0.11135	0.00139	0.32663	0.00485	5.01653	0.07614	0.03336	0.00073	1821.6	22.42	1822	23.57	1822.1	12.85	663.2	14.36	100
РК4 - 61	0.10635	0.00134	0.30955	0.00463	4.54031	0.07061	0.03428	0.0008	1737.8	23.01	1738.5	22.81	1738.4	12.94	681.2	15.58	100

PK4 - 62	0.08832	0.00119	0.24102	0.00363	2.9354	0.04748	0.02489	0.00061	1389.4	25.64	1392	18.87	1391.1	12.25	496.9	11.94	100
РК4 - 63	0.1123	0.00149	0.33011	0.00499	5.11176	0.08234	0.03996	0.00098	1837	23.82	1838.9	24.19	1838.1	13.68	791.9	18.98	100
PK4 - 64	0.09029	0.00123	0.24847	0.00374	3.09319	0.05011	0.02695	0.00067	1431.5	25.83	1430.6	19.33	1431	12.43	537.5	13.11	100
РК4 - 65	0.06845	0.00168	0.1461	0.00236	1.37964	0.03241	0.00765	0.00027	882.3	49.95	879	13.27	880.3	13.83	154	5.47	100
РК4 - 66	0.05908	0.00087	0.09276	0.0014	0.75558	0.01318	0.01607	0.0004	570.2	31.61	571.8	8.27	571.5	7.62	322.3	8.04	100
РК4 - 67	0.06651	0.00123	0.13568	0.00208	1.24454	0.02392	0.01014	0.00025	822.3	38	820.2	11.83	820.9	10.82	203.9	5.03	100
РК4 - 68	0.08482	0.00125	0.22566	0.00336	2.63922	0.04302	0.01801	0.00042	1311.4	28.42	1311.7	17.7	1311.6	12	360.9	8.28	100
РК4 - 69	0.09354	0.00138	0.2619	0.00394	3.37731	0.05592	0.02334	0.00052	1498.9	27.59	1499.6	20.15	1499.1	12.97	466.3	10.35	100
РК4 - 70	0.07818	0.00248	0.15521	0.00289	1.67322	0.05249	0.01663	0.00094	1151.5	61.62	930.1	16.11	998.4	19.94	333.4	18.68	100
РК4 - 71	0.17213	0.00215	0.44833	0.00669	10.63547	0.16545	0.05567	0.00126	2578.4	20.68	2387.8	29.79	2491.8	14.44	1094.9	24.05	100
РК4 - 72	0.05416	0.00157	0.06139	0.00103	0.45945	0.01261	0.00175	0.00006	377.5	63.82	384	6.26	383.9	8.78	35.4	1.28	100
РК4 - 73	0.0553	0.00446	0.06662	0.00197	0.50752	0.03931	0.01703	0.00224	424.2	170.49	415.7	11.92	416.8	26.48	341.2	44.43	100
PK4 - 74	0.05796	0.00122	0.06615	0.00101	0.52863	0.01188	0.01918	0.00093	527.9	45.74	412.9	6.12	430.9	7.89	383.9	18.4	100
РК4 - 75	0.05517	0.00146	0.0664	0.0011	0.505	0.01299	0.00309	0.00011	419.1	57.36	414.4	6.65	415.1	8.77	62.4	2.17	100
РК4 - 76	0.05594	0.00088	0.07235	0.00109	0.55784	0.00995	0.00821	0.0002	449.6	34.28	450.3	6.56	450.1	6.48	165.4	4.08	100
PK4 - 77	0.05524	0.00089	0.06827	0.00104	0.51989	0.00939	0.00706	0.0002	422	35.4	425.7	6.25	425.1	6.27	142.1	4	100
PK4 - 78	0.07468	0.00253	0.1714	0.0033	1.75988	0.05599	0.006	0.00029	1059.8	66.72	1019.8	18.17	1030.8	20.6	121	5.78	100
РК4 - 79	0.15337	0.00185	0.3585	0.00525	7.58031	0.11723	0.0586	0.00138	2383.8	20.38	1975.1	24.9	2182.5	13.87	1151	26.32	100
РК4 - 80	0.07268	0.00103	0.16905	0.00254	1.69369	0.02885	0.02621	0.00074	1005	28.58	1006.9	14	1006.2	10.87	522.9	14.48	100
РК4 - 81	0.07445	0.00115	0.1774	0.00269	1.82065	0.03251	0.02449	0.00073	1053.5	31.26	1052.7	14.73	1052.9	11.7	488.9	14.31	100
РК4 - 82	0.0625	0.0008	0.11303	0.00169	0.97404	0.01568	0.0195	0.00038	691.3	27.18	690.3	9.77	690.5	8.06	390.3	7.61	100
РК4 - 83	0.07276	0.00143	0.16922	0.00273	1.69812	0.0348	0.01331	0.00033	1007.2	39.4	1007.8	15.03	1007.8	13.1	267.2	6.5	100
РК4 - 84	0.07072	0.0009	0.15866	0.00236	1.54707	0.02474	0.02722	0.0005	949.3	25.74	949.3	13.11	949.3	9.86	542.8	9.85	100
РК4 - 85	0.05385	0.00088	0.05885	0.0009	0.43701	0.00802	0.00613	0.00013	364.7	36.71	368.6	5.5	368.1	5.67	123.5	2.52	100
РК4 - 86	0.09139	0.00122	0.25353	0.00384	3.19545	0.05061	0.02265	0.00047	1454.7	25.15	1456.7	19.76	1456.1	12.25	452.8	9.23	100
РК4 - 87	0.05634	0.00109	0.07453	0.00118	0.57905	0.01208	0.00926	0.00024	465	42.46	463.4	7.06	463.8	7.77	186.4	4.8	100
РК4 - 88	0.05839	0.0013	0.07412	0.00116	0.59667	0.01407	0.0208	0.00091	544.6	48.38	460.9	6.95	475.1	8.95	416.1	18.03	99
PK4 - 89	0.08047	0.00135	0.20666	0.00323	2.293	0.04103	0.00743	0.00021	1208.5	32.73	1211	17.25	1210.1	12.65	149.7	4.19	99
РК4 - 90	0.05563	0.00106	0.07097	0.00113	0.54448	0.01095	0.00484	0.00012	437.4	41.44	442	6.78	441.4	7.2	97.6	2.36	99
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PK4 - 91	0.08484	0.00128	0.22529	0.00347	2.63536	0.04366	0.01143	0.00032	1311.9	29.03	1309.8	18.23	1310.6	12.19	229.8	6.49	99
PK4 - 92	0.07145	0.0009	0.16203	0.00242	1.59635	0.02519	0.02254	0.00047	970.3	25.44	968.1	13.44	968.8	9.85	450.5	9.28	99
РК4 - 93	0.09003	0.00117	0.24739	0.0037	3.07107	0.05065	0.0671	0.00211	1426.1	24.56	1425	19.15	1425.5	12.63	1312.7	39.89	99
РК4 - 94	0.05803	0.00107	0.08608	0.00137	0.68882	0.01343	0.00573	0.00017	530.3	40.13	532.3	8.13	532.1	8.07	115.4	3.4	99
РК4 - 95	0.05533	0.00091	0.06922	0.00108	0.5281	0.00972	0.007	0.00018	425.3	35.66	431.5	6.48	430.5	6.46	141	3.54	99
PK4 - 96	0.06388	0.00105	0.12142	0.00189	1.06959	0.01979	0.01412	0.00036	737.7	34.35	738.8	10.89	738.5	9.71	283.5	7.2	99
PK4 - 97	0.05606	0.00066	0.07271	0.00107	0.56213	0.00856	0.01285	0.00021	454.5	25.51	452.5	6.44	452.9	5.56	258.1	4.18	99
PK4 - 98	0.10479	0.00112	0.30404	0.00449	4.39366	0.06373	0.04088	0.00068	1710.6	19.54	1711.3	22.2	1711.1	12	809.8	13.13	99
РК4 - 99	0.08973	0.00106	0.24657	0.00368	3.05158	0.04604	0.0315	0.00056	1419.8	22.37	1420.8	19.03	1420.6	11.54	626.9	11.07	99
РК4 - 100	0.0549	0.00081	0.0653	0.00099	0.49441	0.00862	0.00921	0.00018	407.9	32.6	407.8	5.99	407.9	5.86	185.3	3.56	98
PK4 - 101	0.0589	0.00141	0.0915	0.00144	0.74272	0.01669	0.00379	0.00013	563.5	51.17	564.4	8.5	564	9.72	76.5	2.66	98
PK4 - 102	0.05553	0.00139	0.06942	0.00114	0.53143	0.01388	0.02087	0.00101	433.4	54.29	432.6	6.85	432.8	9.2	417.4	20.08	98
РК4 - 103	0.06022	0.00089	0.09203	0.00138	0.76419	0.01359	0.02593	0.00073	611.6	31.54	567.5	8.16	576.4	7.82	517.4	14.39	97
PK4 - 104	0.10766	0.00122	0.31383	0.0046	4.65912	0.06998	0.05462	0.0011	1760.2	20.56	1759.5	22.57	1759.9	12.56	1074.9	21.14	97
PK4 - 105	0.063	0.00159	0.1146	0.00179	0.99615	0.02284	0.00202	0.00008	708.1	52.76	699.4	10.33	701.9	11.62	40.7	1.53	96
PK4 - 106	0.06251	0.00267	0.11344	0.00243	0.97842	0.03834	0.003	0.00016	691.5	88.63	692.7	14.09	692.8	19.68	60.6	3.27	96
РК4 - 107	0.05779	0.00217	0.08371	0.00161	0.66791	0.02288	0.00178	0.00008	521.6	80.6	518.2	9.6	519.4	13.93	35.9	1.66	96
PK4 - 108	0.0588	0.00084	0.09101	0.00136	0.7379	0.01259	0.01395	0.00032	559.6	31	561.5	8.06	561.2	7.35	280.1	6.39	96
PK4 - 109	0.05468	0.00298	0.06148	0.0014	0.46356	0.02452	0.01662	0.00165	399	117.29	384.6	8.48	386.7	17.01	333.2	32.86	95
РК4 - 110	0.08017	0.00158	0.20482	0.00314	2.26515	0.0447	0.01412	0.00045	1201.2	38.43	1201.2	16.81	1201.5	13.9	283.5	9.06	93
PK4 - 111	0.06545	0.00189	0.13025	0.0022	1.17566	0.0317	0.00619	0.00026	788.9	59.62	789.3	12.56	789.3	14.8	124.8	5.15	93
PK4 - 112	0.05588	0.00319	0.07224	0.00168	0.55627	0.03082	0.0222	0.00169	447.2	122.4	449.7	10.12	449.1	20.11	443.9	33.32	92
РК4 - 113	0.0666	0.00212	0.13583	0.00247	1.24727	0.03784	0.00709	0.00021	825.2	65.17	821.1	14.04	822.2	17.1	142.7	4.22	85
РК4 - 114	0.06117	0.00084	0.10684	0.00161	0.90101	0.01545	0.02795	0.00064	645.4	29.15	654.4	9.38	652.3	8.25	557.1	12.63	83
РК4 - 115	0.08029	0.00124	0.20535	0.00309	2.27382	0.0391	0.01501	0.00039	1204.2	30.09	1204	16.55	1204.2	12.13	301.1	7.67	81
PK4 - 116	0.05645	0.00073	0.07364	0.00109	0.57303	0.0093	0.01411	0.00027	469.2	28.58	458	6.57	460	6	283.1	5.39	81
РК4 - 117	0.05605	0.00309	0.0727	0.00162	0.56184	0.02994	0.02587	0.00219	453.9	118.22	452.4	9.75	452.7	19.46	516.3	43.13	78
PK4 - 118	0.06096	0.0012	0.07531	0.00118	0.63285	0.01377	0.02394	0.00078	637.7	41.87	468.1	7.09	497.9	8.56	478.3	15.5	73
PK4 - 119	0.11254	0.00247	0.33084	0.00517	5.13309	0.10703	0.01162	0.00045	1840.9	39.27	1842.4	25.04	1841.6	17.72	233.6	9.04	64

РК4 - 120	0.06505	0.0014	0.12818	0.00196	1.14997	0.02422	0.00496	0.00017	776.1	44.67	777.5	11.2	777.2	11.44	100	3.42	35
Pang As	ok Format	ion												•			
Sample	T13_003 -	Slaty Sa	ndstones	5													
T13_003 - 1	0.05366	0.00168	0.05749	0.00092	0.42529	0.01321	0.01718	0.00077	356.6	68.92	360.4	5.62	359.8	9.41	344.2	15.24	120
T13_003 - 2	0.09243	0.00125	0.25005	0.00332	3.18625	0.04908	0.07685	0.00212	1476	25.55	1438.7	17.11	1453.8	11.91	1496.6	39.76	114
T13_003 - 3	0.05645	0.00171	0.04263	0.00066	0.33178	0.00997	0.01477	0.00056	469.5	65.93	269.1	4.09	290.9	7.6	296.3	11.18	108
T13_003 - 4	0.05608	0.00073	0.05599	0.00072	0.43282	0.00646	0.01851	0.00048	455	28.35	351.2	4.41	365.2	4.58	370.6	9.43	106
T13_003 - 5	0.05729	0.00091	0.07538	0.00098	0.59543	0.01016	0.02347	0.00077	502.4	34.38	468.5	5.9	474.3	6.47	468.9	15.22	105
T13_003 - 6	0.05371	0.00084	0.06086	0.0008	0.45066	0.00769	0.01986	0.00063	358.9	34.97	380.8	4.89	377.7	5.38	397.4	12.41	104
T13_003 - 7	0.05356	0.00238	0.04337	0.00079	0.32004	0.01376	0.01474	0.00093	352.6	97	273.7	4.9	281.9	10.59	295.8	18.53	103
T13_003 - 8	0.05377	0.0011	0.0525	0.0007	0.38919	0.00814	0.01719	0.00049	361.3	45.68	329.8	4.27	333.8	5.95	344.5	9.66	103
T13_003 - 9	0.10242	0.00117	0.15138	0.00191	2.13711	0.02891	0.04312	0.00102	1668.4	21.06	908.7	10.69	1160.9	9.36	853.3	19.74	103
T13_003 - 10	0.12053	0.00138	0.18815	0.00234	3.12616	0.04171	0.07683	0.00184	1964.1	20.25	1111.4	12.69	1439.2	10.26	1496.2	34.51	101
T13_003 - 11	0.07852	0.00145	0.09262	0.00134	1.0019	0.01981	0.06044	0.00355	1160.1	36.18	571	7.88	704.8	10.05	1186.1	67.7	101
T13_003 - 12	0.05856	0.002	0.0609	0.00101	0.49155	0.0166	0.02105	0.00099	550.7	72.97	381.1	6.17	406	11.3	421.1	19.64	101
T13_003 - 13	0.06963	0.00112	0.06251	0.00086	0.60014	0.01055	0.01987	0.00081	917.5	32.62	390.9	5.2	477.3	6.69	397.7	16.12	101
T13_003 - 14	0.06786	0.00091	0.06491	0.00084	0.60725	0.00922	0.02681	0.00095	864.2	27.57	405.4	5.08	481.8	5.82	534.7	18.64	101
T13_003 - 15	0.09047	0.00109	0.23618	0.00288	2.94553	0.0399	0.06561	0.00189	1435.3	22.78	1366.8	14.99	1393.7	10.27	1284.5	35.76	101
T13_003 - 16	0.05614	0.00086	0.07106	0.00096	0.54998	0.00933	0.02246	0.00059	457.4	33.32	442.6	5.76	445	6.11	449	11.65	101
T13_003 - 17	0.08979	0.00105	0.24981	0.00321	3.09202	0.0429	0.07238	0.00178	1420.9	22.1	1437.5	16.53	1430.7	10.64	1412.5	33.5	100
T13_003 - 18	0.05064	0.00084	0.04284	0.00058	0.29909	0.00539	0.01327	0.00043	224.7	37.75	270.4	3.59	265.7	4.21	266.4	8.56	100
T13_003 - 19	0.05534	0.00087	0.05599	0.00074	0.42717	0.0073	0.01776	0.00059	425.9	34	351.2	4.54	361.2	5.19	355.8	11.7	100
T13_003 - 20	0.09006	0.00106	0.23179	0.0029	2.87781	0.0392	0.07234	0.00173	1426.8	22.23	1343.9	15.18	1376.1	10.26	1411.7	32.53	100
T13_003 - 21	0.1144	0.00283	0.04605	0.00075	0.72613	0.01782	0.01996	0.00089	1870.5	44.01	290.2	4.62	554.3	10.48	399.5	17.55	100
T13_003 - 22	0.06826	0.00091	0.0874	0.00114	0.82251	0.01246	0.02315	0.00072	876.6	27.24	540.1	6.75	609.4	6.94	462.6	14.32	100
T13_003 - 23	0.0945	0.00146	0.24117	0.00339	3.14186	0.05489	0.05349	0.00236	1518.2	28.9	1392.8	17.61	1443	13.46	1053.2	45.34	100
713_003 - 24	0.09054	0.00106	0.24138	0.00306	3.01257	0.04155	0.09124	0.00262	1436.9	22.17	1393.9	15.89	1410.8	10.51	1764.7	48.5	100
713_003 - 25	0.06038	0.00095	0.09481	0.0013	0.78937	0.01376	0.02853	0.00093	617.4	33.44	583.9	7.68	590.8	7.81	568.5	18.24	100
25 T13_003 - 26	0.05134	0.00116	0.04276	0.0006	0.30268	0.00698	0.01399	0.00048	256.3	50.9	269.9	3.73	268.5	5.44	280.7	9.5	100

T13_003 - 27	0.05587	0.00093	0.07033	0.00093	0.54172	0.00968	0.02249	0.00092	447	36.37	438.2	5.62	439.6	6.38	449.5	18.17	100
T13_003 - 28	0.1067	0.00136	0.30471	0.00396	4.48249	0.06585	0.08495	0.00249	1743.8	23.1	1714.6	19.58	1727.7	12.2	1648	46.3	100
T13_003 - 29	0.18418	0.00228	0.51322	0.00671	13.03219	0.18936	0.14223	0.0044	2690.9	20.3	2670.4	28.57	2682	13.7	2687.8	77.89	99
T13_003 - 30	0.0566	0.00097	0.05992	0.00084	0.46766	0.00873	0.02151	0.00095	475.3	37.69	375.1	5.08	389.6	6.04	430.2	18.88	99
T13_003 - 31	0.10006	0.0014	0.29787	0.00381	4.10868	0.06292	0.1034	0.0037	1625.1	25.81	1680.8	18.94	1656	12.51	1988.8	67.84	99
T13_003 - 32	0.09431	0.00119	0.233	0.00316	3.02922	0.04565	0.07706	0.00188	1514.4	23.7	1350.2	16.52	1415	11.5	1500.4	35.27	99
T13_003 - 33	0.08436	0.00116	0.16818	0.00231	1.95561	0.0312	0.07552	0.00211	1300.7	26.59	1002.1	12.76	1100.4	10.72	1471.5	39.6	99
T13_003 - 34	0.05307	0.00097	0.0533	0.00073	0.38986	0.00758	0.01684	0.0004	331.6	40.73	334.7	4.49	334.3	5.54	337.5	7.86	98
T13_003 - 35	0.11297	0.00127	0.33317	0.00431	5.1889	0.07088	0.0963	0.0021	1847.8	20.18	1853.7	20.84	1850.8	11.63	1858.3	38.67	98
T13_003 - 36	0.05571	0.00076	0.06744	0.0009	0.51799	0.00816	0.0211	0.00053	440.7	29.78	420.7	5.44	423.8	5.46	422.1	10.51	98
T13_003 - 37	0.0563	0.00074	0.06902	0.00092	0.53573	0.00818	0.02141	0.00054	463.5	28.86	430.3	5.55	435.6	5.41	428.2	10.76	98
T13_003 - 38	0.09043	0.00106	0.24932	0.00324	3.10804	0.04363	0.07516	0.00182	1434.5	22.22	1435	16.7	1434.7	10.78	1464.8	34.16	97
T13_003 - 39	0.09045	0.00115	0.24067	0.00314	3.00089	0.0441	0.07457	0.00213	1434.9	23.97	1390.2	16.33	1407.8	11.19	1453.6	40.01	97
T13_003 - 40	0.05646	0.00074	0.07173	0.00094	0.55832	0.00839	0.02174	0.00064	469.8	28.87	446.6	5.64	450.4	5.47	434.8	12.59	97
T13_003 - 41	0.05189	0.00097	0.0431	0.00058	0.30831	0.00606	0.01358	0.00035	280.4	42.32	272	3.58	272.9	4.7	272.7	7.05	97
T13_003 - 42	0.08002	0.00099	0.03825	0.0005	0.42194	0.00614	0.01722	0.00048	1197.6	24.26	242	3.1	357.4	4.38	345.1	9.52	97
T13_003 - 43	0.05218	0.00099	0.04483	0.00061	0.32251	0.00645	0.01389	0.00041	293.2	42.89	282.7	3.77	283.8	4.95	278.9	8.12	97
T13_003 - 44	0.1701	0.00269	0.49309	0.00684	11.55986	0.20063	0.13037	0.00636	2558.7	26.26	2584	29.53	2569.4	16.22	2477	113.69	97
T13_003 - 45	0.05694	0.00094	0.07928	0.00101	0.62243	0.01079	0.02317	0.00099	488.7	36.45	491.8	6.05	491.4	6.75	463	19.63	97
T13_003 - 46	0.05194	0.00145	0.04183	0.00064	0.29935	0.00838	0.01355	0.00055	282.8	62.49	264.2	3.98	265.9	6.55	272	10.96	96
T13_003 - 47	0.05332	0.00072	0.0589	0.00075	0.43309	0.00655	0.0187	0.00041	342.6	30.35	369	4.55	365.4	4.64	374.5	8.16	96
T13_003 - 48	0.10308	0.00131	0.29609	0.00388	4.2071	0.06208	0.08998	0.00268	1680.3	23.31	1671.9	19.28	1675.4	12.1	1741.5	49.72	95
T13_003 - 49	0.10893	0.00133	0.28773	0.00348	4.32303	0.05851	0.08948	0.00264	1781.6	22.09	1630.2	17.43	1697.8	11.16	1732.2	48.97	95
T13_003 - 50	0.06744	0.00094	0.03872	0.00051	0.35986	0.00562	0.01432	0.00046	851.5	28.68	244.9	3.15	312.1	4.2	287.4	9.1	95
T13_003 - 51	0.06344	0.00128	0.07329	0.00103	0.64091	0.01341	0.02363	0.0009	722.9	42.37	455.9	6.18	502.9	8.3	472.1	17.81	95
T13_003 - 52	0.09104	0.00133	0.17605	0.00209	2.20974	0.03335	0.04145	0.0018	1447.4	27.59	1045.3	11.44	1184.1	10.55	821	34.92	95
T13_003 - 53	0.05632	0.00109	0.07091	0.00097	0.55062	0.01104	0.02092	0.00105	464.4	42.48	441.7	5.86	445.4	7.23	418.4	20.75	94
T13_003 - 54	0.05106	0.00106	0.0397	0.0005	0.27962	0.00578	0.0131	0.00049	243.5	47.05	251	3.11	250.4	4.59	263	9.84	94
T13_003 - 55	0.05472	0.00111	0.05827	0.00079	0.43941	0.00913	0.01873	0.00068	400.1	45.06	365.1	4.79	369.8	6.44	375	13.56	93

T13_003 - 56	0.0788	0.00131	0.19457	0.00242	2.11551	0.03586	0.06286	0.0026	1167	32.62	1146.1	13.07	1153.9	11.69	1232.1	49.51	93
T13_003 - 57	0.05895	0.00086	0.07935	0.00098	0.64497	0.00997	0.02384	0.00079	565.1	31.39	492.3	5.85	505.4	6.15	476.3	15.59	93
T13_003 - 58	0.18902	0.00259	0.5061	0.00628	13.18884	0.19298	0.13913	0.00508	2733.7	22.4	2640	26.9	2693.3	13.81	2633	90.2	92
T13_003 - 59	0.11659	0.00148	0.33367	0.00404	5.36441	0.07418	0.09816	0.00325	1904.6	22.58	1856.2	19.51	1879.2	11.84	1892.6	59.88	92
T13_003 - 60	0.11289	0.0017	0.32512	0.00419	5.05662	0.08123	0.09164	0.00395	1846.4	27.05	1814.7	20.36	1828.9	13.62	1772.2	73.13	92
T13_003 - 61	0.05693	0.00099	0.07601	0.00103	0.59641	0.01112	0.02275	0.00061	488.3	38.29	472.3	6.19	475	7.07	454.6	12.14	92
T13_003 - 62	0.09345	0.00128	0.26198	0.00331	3.3756	0.05059	0.07862	0.00196	1497.1	25.74	1500	16.92	1498.7	11.74	1529.8	36.74	91
T13_003 - 63	0.07043	0.00081	0.1584	0.00196	1.53827	0.0207	0.04854	0.00105	940.8	23.5	947.9	10.92	945.8	8.28	958	20.21	91
53 T13_003 - 64	0.05918	0.00155	0.07777	0.00119	0.63354	0.01675	0.01701	0.00106	573.8	55.85	482.8	7.1	498.3	10.41	340.9	21.04	90
T13_003 - 65	0.05651	0.00101	0.07304	0.00091	0.56934	0.01042	0.02326	0.00073	471.7	39.48	454.5	5.49	457.6	6.74	464.7	14.5	89
T13_003 - 66	0.09099	0.00105	0.25112	0.00309	3.15074	0.04198	0.0746	0.00167	1446.2	21.72	1444.3	15.94	1445.2	10.27	1454.2	31.45	89
T13_003 - 67	0.05925	0.00111	0.09351	0.00124	0.76459	0.01487	0.02993	0.00143	576.3	40.23	576.3	7.28	576.7	8.56	596.1	27.98	87
T13_003 - 68	0.05475	0.00115	0.05877	0.00079	0.44364	0.00947	0.01932	0.00061	402.2	45.85	368.1	4.8	372.8	6.66	386.7	12	86
T13_003 - 69	0.09047	0.00114	0.21824	0.00282	2.72222	0.03976	0.06808	0.00212	1435.3	23.76	1272.6	14.91	1334.5	10.85	1331.3	40.1	84
T13_003 - 70	0.05755	0.00116	0.07583	0.00112	0.60193	0.01302	0.03337	0.00319	512.4	44.09	471.2	6.68	478.5	8.25	663.4	62.38	82
T13_003 - 71	0.1174	0.00162	0.34618	0.00443	5.60314	0.08524	0.10387	0.00337	1917	24.58	1916.3	21.19	1916.6	13.11	1997.4	61.71	79
T13_003 - 72	0.06357	0.00096	0.11973	0.00153	1.04937	0.0171	0.03794	0.00117	727.3	31.63	729	8.81	728.6	8.47	752.6	22.82	78
T13_003 - 73	0.05568	0.0009	0.06975	0.00089	0.53552	0.0092	0.02167	0.00067	439.4	35.27	434.7	5.34	435.5	6.08	433.4	13.32	77
T13_003 - 74	0.07186	0.00096	0.16419	0.0021	1.6268	0.02451	0.05054	0.00163	982	26.97	980	11.62	980.6	9.47	996.6	31.41	77
T13_003 - 75	0.05774	0.00145	0.07137	0.00109	0.56812	0.0146	0.02211	0.00099	519.7	54.46	444.4	6.56	456.8	9.45	442	19.52	76
T13_003 - 76	0.09181	0.00109	0.2635	0.00327	3.33552	0.04541	0.07794	0.00181	1463.3	22.42	1507.7	16.66	1489.4	10.63	1517	33.94	72
T13_003 - 77	0.10208	0.0013	0.29399	0.00373	4.13753	0.05969	0.08653	0.00239	1662.3	23.32	1661.4	18.58	1661.7	11.8	1677.3	44.55	69
T13_003 - 78	0.07682	0.00108	0.04125	0.00051	0.43688	0.00655	0.01815	0.00055	1116.4	27.83	260.6	3.13	368	4.63	363.5	10.99	63
T13_003 - 79	0.05755	0.00114	0.06238	0.00087	0.49499	0.01022	0.02086	0.00079	512.3	43.23	390.1	5.27	408.3	6.94	417.3	15.73	62
T13_003 - 80	0.06462	0.00101	0.12554	0.00163	1.1185	0.0188	0.04057	0.0012	762.1	32.62	762.4	9.34	762.3	9.01	803.8	23.39	57
T13_003 - 81	0.06369	0.00125	0.03854	0.00053	0.3384	0.00685	0.01754	0.00097	731.4	41.04	243.7	3.27	296	5.2	351.5	19.29	57
T13_003 - 82	0.07054	0.00098	0.1401	0.00181	1.36242	0.02115	0.04364	0.00136	944.1	28.21	845.2	10.25	872.9	9.09	863.4	26.27	54
T13_003 - 83	0.08178	0.00145	0.21024	0.00292	2.37066	0.04461	0.06185	0.00237	1240.3	34.18	1230.1	15.56	1233.8	13.44	1212.9	45.13	49
T13_003 - 84	0.05733	0.00101	0.08075	0.00115	0.6382	0.01229	0.02496	0.00112	503.8	37.99	500.6	6.87	501.2	7.62	498.4	22.11	47
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T13_003 - 85	0.14093	0.00169	0.41409	0.00529	8.04474	0.11305	0.11794	0.00341	2238.6	20.62	2233.6	24.13	2236.1	12.69	2253.3	61.57	43
T13_003 - 86	0.08832	0.00201	0.25109	0.00341	3.05757	0.06916	0.06735	0.00524	1389.5	42.92	1444.1	17.54	1422.1	17.31	1317.4	99.3	33
T13_003 - 87	0.05642	0.00103	0.07605	0.00101	0.59153	0.01127	0.02357	0.00086	468.2	40.13	472.5	6.07	471.8	7.19	470.9	17.01	29
T13_003 - 88	0.05487	0.00084	0.07432	0.00098	0.56224	0.00947	0.02204	0.00074	407.1	33.64	462.2	5.9	453	6.15	440.6	14.65	23
T13_003 - 89	0.05942	0.00116	0.08884	0.00117	0.72768	0.01445	0.02806	0.00117	582.7	41.71	548.7	6.91	555.2	8.49	559.4	22.98	20
T13_003 - 90	0.07329	0.00098	0.17018	0.00223	1.71948	0.02627	0.05202	0.00183	1022.1	26.82	1013.1	12.26	1015.8	9.81	1025	35.14	16
Sample	T13_005 -	Slaty Sai	ndstones														
T13_005 - 1	0.10234	0.00116	0.30517	0.0041	4.30551	0.06102	0.09206	0.00197	1666.9	20.85	1716.9	20.27	1694.4	11.68	1780	36.47	84
T13_005 - 2	0.1348	0.00289	0.27573	0.0044	5.11948	0.11482	0.03201	0.00173	2161.4	36.96	1569.8	22.22	1839.3	19.05	636.8	33.94	40
T13_005 - 3	0.09097	0.00109	0.25177	0.00337	3.15768	0.04583	0.07279	0.00183	1445.9	22.6	1447.6	17.37	1446.9	11.19	1420.1	34.55	97
T13_005 - 4	0.07457	0.00105	0.04463	0.00063	0.45878	0.00754	0.01722	0.00041	1056.6	28.51	281.5	3.87	383.4	5.25	345.1	8.06	95
T13_005 - 5	0.14595	0.0017	0.42842	0.00584	8.62008	0.12541	0.11922	0.00314	2299	19.87	2298.6	26.34	2298.7	13.24	2276.5	56.68	56
T13_005 - 6	0.05213	0.00081	0.0439	0.00063	0.31551	0.00563	0.01335	0.00043	291.3	35.12	277	3.88	278.4	4.35	268.1	8.59	97
T13_005 - 7	0.12	0.00175	0.22021	0.00308	3.64283	0.06027	0.04352	0.00153	1956.2	25.75	1283	16.26	1558.9	13.18	861.1	29.56	84
T13_005 - 8	0.0701	0.00085	0.0907	0.00122	0.87653	0.01289	0.0269	0.00071	931.3	24.7	559.7	7.19	639.1	6.97	536.6	13.88	68
T13_005 - 9	0.10629	0.0016	0.18772	0.00256	2.75069	0.04591	0.02711	0.00103	1736.7	27.36	1109	13.91	1342.3	12.43	540.6	20.19	104
T13_005 - 10	0.07102	0.00091	0.12833	0.00177	1.25646	0.01956	0.04039	0.00134	957.9	26.09	778.4	10.14	826.3	8.8	800.2	25.94	102
T13_005 - 11	0.09156	0.00153	0.2533	0.00374	3.19719	0.06038	0.07098	0.00383	1458.2	31.53	1455.5	19.26	1456.5	14.61	1386.1	72.25	97
T13_005 - 12	0.06912	0.00104	0.11684	0.00164	1.11348	0.01906	0.02111	0.00075	902.4	30.6	712.4	9.44	759.8	9.16	422.2	14.8	84
T13_005 - 13	0.09101	0.00112	0.25049	0.00343	3.14301	0.04743	0.07208	0.00232	1446.7	23.27	1441	17.68	1443.3	11.62	1406.8	43.7	98
T13_005 - 14	0.07885	0.00102	0.18408	0.00256	2.00107	0.03124	0.04725	0.00151	1168.5	25.29	1089.2	13.96	1115.9	10.57	933.2	29.14	90
T13_005 - 15	0.08617	0.00164	0.06196	0.00094	0.73596	0.01531	0.01911	0.00118	1342.1	36.41	387.5	5.69	560	8.95	382.7	23.39	89
T13_005 - 16	0.05369	0.00116	0.04184	0.00062	0.30967	0.00702	0.01416	0.00047	357.8	48.08	264.2	3.81	273.9	5.44	284.2	9.34	100
T13_005 - 17	0.09017	0.00139	0.24846	0.00348	3.08914	0.05369	0.07464	0.00338	1429	29.14	1430.5	17.96	1430	13.33	1454.9	63.56	95
T13_005 - 18	0.05672	0.00085	0.07666	0.00107	0.59946	0.01025	0.02319	0.00067	479.8	33.16	476.2	6.39	476.9	6.51	463.4	13.3	98
T13_005 - 19	0.12703	0.00191	0.37628	0.00557	6.59028	0.11669	0.08916	0.00366	2057.3	26.23	2058.9	26.08	2058	15.61	1726.2	68	108
T13_005 - 20	0.05894	0.00108	0.0729	0.00104	0.59248	0.01171	0.02307	0.0012	564.9	39.53	453.6	6.24	472.5	7.46	460.9	23.72	85
T13_005 - 21	0.08847	0.00272	0.2386	0.00427	2.90181	0.09013	0.06373	0.00664	1392.7	57.77	1379.4	22.22	1382.4	23.46	1248.7	126.15	87
T13_005 - 22	0.05443	0.00139	0.04293	0.00066	0.32218	0.00848	0.01262	0.00043	389	56.14	271	4.05	283.6	6.52	253.4	8.61	103

T13 005 -	0.09213	0.00137	0.23526	0.00344	2.98821	0.05231	0.05295	0.00203	1470	28.16	1362	17.95	1404.6	13.32	1042.8	39.05	84
23																	
T13_005 - 24	0.05138	0.00101	0.04228	0.00062	0.2995	0.00633	0.01356	0.00049	257.8	44.53	267	3.81	266	4.94	272.2	9.68	137
T13_005 - 25	0.19532	0.00738	0.53911	0.01074	14.51129	0.54392	0.18489	0.02804	2787.5	60.54	2779.7	44.98	2783.7	35.61	3429	478.33	102
T13_005 - 26	0.05643	0.00081	0.07424	0.00105	0.57765	0.00976	0.02277	0.00084	468.6	31.74	461.7	6.31	462.9	6.28	455	16.55	108
T13_005 - 27	0.08954	0.00116	0.25813	0.00366	3.18679	0.05071	0.06618	0.00218	1415.7	24.63	1480.3	18.75	1454	12.3	1295.3	41.27	102
T13_005 - 28	0.05652	0.00185	0.07301	0.00122	0.56904	0.01852	0.02197	0.00203	472	71.49	454.3	7.34	457.4	11.99	439.3	40.19	96
T13_005 - 29	0.10816	0.00217	0.31248	0.00465	4.66046	0.09979	0.08987	0.00641	1768.5	36.33	1752.9	22.84	1760.2	17.9	1739.4	118.86	64
T13_005 - 30	0.14726	0.00523	0.43181	0.00824	8.76621	0.30823	0.12128	0.01678	2314.3	59.69	2313.9	37.11	2314	32.05	2313.6	302.42	92
T13_005 - 31	0.0805	0.00098	0.1876	0.0026	2.08182	0.03152	0.05525	0.00156	1209.3	23.72	1108.3	14.13	1142.8	10.39	1087	29.82	85
T13_005 - 32	0.05555	0.00086	0.07007	0.00101	0.53661	0.00961	0.02143	0.00062	434.3	33.64	436.6	6.09	436.2	6.35	428.5	12.18	77
T13_005 - 33	0.08914	0.00112	0.23453	0.00327	2.88194	0.0446	0.07646	0.00223	1407.1	23.92	1358.2	17.08	1377.2	11.67	1489.3	41.82	106
T13_005 - 34	0.05742	0.00082	0.07852	0.00113	0.62144	0.01053	0.02093	0.0007	507.3	30.82	487.3	6.73	490.8	6.59	418.7	13.78	97
T13_005 - 35	0.09407	0.00143	0.24926	0.00355	3.23227	0.05613	0.06479	0.00256	1509.5	28.52	1434.6	18.31	1464.9	13.47	1268.9	48.59	101
T13_005 - 36	0.10982	0.00137	0.31666	0.00446	4.79399	0.07423	0.09473	0.00286	1796.4	22.52	1773.4	21.84	1783.8	13.01	1829.3	52.87	92
T13_005 - 37	0.07998	0.00144	0.19454	0.00298	2.14481	0.04309	0.0498	0.00206	1196.5	35.19	1145.9	16.07	1163.4	13.91	982.3	39.74	89
T13_005 - 38	0.06227	0.00089	0.04167	0.00061	0.35767	0.00613	0.02132	0.00082	683.5	30.28	263.1	3.75	310.5	4.58	426.4	16.14	77
T13_005 - 39	0.05551	0.00077	0.06886	0.00097	0.52695	0.00872	0.02199	0.00072	432.7	30.22	429.3	5.87	429.8	5.8	439.7	14.29	98
T13_005 - 40	0.10528	0.00174	0.23608	0.00348	3.42609	0.06372	0.08372	0.00412	1719.2	30.15	1366.3	18.13	1510.4	14.62	1625.1	76.89	94
T13_005 - 41	0.05637	0.00094	0.07168	0.00101	0.55701	0.01028	0.02288	0.00089	466.1	36.68	446.3	6.1	449.6	6.7	457.3	17.65	97
T13_005 - 42	0.07188	0.00145	0.15119	0.00235	1.49692	0.03279	0.04506	0.00312	982.6	40.65	907.6	13.16	929.1	13.33	890.8	60.33	96
T13_005 - 43	0.14916	0.00607	0.43378	0.00882	8.91624	0.36682	0.07691	0.01198	2336.3	68.07	2322.7	39.64	2329.5	37.56	1497.6	224.76	104
T13_005 - 44	0.05217	0.00465	0.04213	0.00128	0.30292	0.02588	0.01232	0.00183	292.8	191.14	266	7.93	268.7	20.17	247.6	36.44	91
T13_005 - 45	0.07806	0.00168	0.05822	0.00087	0.6262	0.01404	0.01604	0.00122	1148.4	42.1	364.8	5.31	493.7	8.77	321.7	24.29	102
T13_005 - 46	0.11193	0.00188	0.27474	0.00411	4.24022	0.08073	0.06059	0.00331	1831	30.17	1564.8	20.8	1681.8	15.64	1189	63.03	102
T13_005 - 47	0.06672	0.00133	0.06164	0.00094	0.56707	0.01219	0.01759	0.00054	829.1	40.91	385.6	5.73	456.1	7.9	352.4	10.77	101
T13_005 - 48	0.06029	0.00087	0.1003	0.00143	0.83374	0.01413	0.03158	0.001	614	30.89	616.2	8.37	615.7	7.82	628.5	19.66	54
T13_005 - 49	0.08992	0.00371	0.2553	0.00516	3.17085	0.12726	0.03858	0.00447	1423.8	77.01	1465.7	26.51	1450.1	30.98	765.2	87.04	103
T13_005 - 50	0.09962	0.00118	0.24686	0.00334	3.39099	0.04963	0.07268	0.00207	1616.9	21.97	1422.3	17.28	1502.3	11.48	1418.1	39.03	101
T13_005 - 51	0.10755	0.00133	0.28355	0.00398	4.20432	0.06471	0.0641	0.00198	1758.2	22.37	1609.2	20.01	1674.9	12.62	1255.7	37.6	85
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T13 005 -	0.05977	0.00254	0.05985	0.00117	0.49347	0.02053	0.01734	0.00144	595	90.12	374.7	7.1	407.3	13.96	347.6	28.57	107
52	0.03577	0.00234	0.05505	0.00117	0.45547	0.02033	0.01754	0.00144	555	50.12	574.7	7.1	407.5	15.50	547.0	20.57	107
T13_005 - 53	0.11032	0.00139	0.25109	0.0035	3.81967	0.05892	0.06304	0.00215	1804.7	22.67	1444.1	18.02	1596.9	12.41	1235.6	40.88	74
T13_005 - 54	0.0515	0.00173	0.04153	0.00069	0.29491	0.0098	0.01386	0.00088	263.2	75.29	262.3	4.25	262.4	7.68	278.1	17.45	104
T13_005 - 55	0.25411	0.00352	0.64436	0.00904	22.57718	0.36766	0.16731	0.00695	3210.5	21.72	3206.1	35.45	3208.9	15.83	3126.9	120.26	89
T13_005 - 56	0.05692	0.00084	0.07742	0.00107	0.60781	0.01023	0.02451	0.00097	487.8	32.72	480.7	6.41	482.2	6.46	489.4	19.14	102
T13_005 - 57	0.10145	0.00153	0.28739	0.00416	4.01952	0.07016	0.07712	0.00322	1650.8	27.65	1628.5	20.82	1638.2	14.19	1501.5	60.37	99
T13_005 - 58	0.11031	0.00177	0.32287	0.00467	4.91118	0.08929	0.08254	0.0044	1804.5	28.93	1803.7	22.78	1804.2	15.34	1603	82.06	104
T13_005 - 59	0.11189	0.00153	0.32897	0.00461	5.07539	0.08221	0.07269	0.0029	1830.4	24.64	1833.4	22.35	1832	13.74	1418.2	54.59	83
T13_005 - 60	0.17173	0.00237	0.49138	0.00677	11.63883	0.1863	0.13265	0.00554	2574.5	22.85	2576.6	29.28	2575.8	14.97	2517.7	98.88	106
T13_005 - 61	0.09811	0.00142	0.28573	0.00427	3.86489	0.06703	0.07777	0.00231	1588.5	26.88	1620.1	21.4	1606.4	13.99	1513.7	43.33	101
T13_005 - 62	0.11276	0.00144	0.33191	0.00456	5.15923	0.07902	0.09278	0.00299	1844.4	22.9	1847.6	22.07	1845.9	13.03	1793.4	55.32	119
T13_005 - 63	0.05656	0.00162	0.07641	0.00126	0.59555	0.01725	0.02278	0.00196	473.7	62.13	474.7	7.53	474.4	10.98	455.3	38.69	129
T13_005 - 64	0.05179	0.00087	0.04451	0.00067	0.31781	0.00611	0.01456	0.00056	276.1	38.01	280.7	4.11	280.2	4.71	292.2	11.25	168
T13_005 - 65	0.05607	0.00095	0.07309	0.00098	0.56503	0.01021	0.02058	0.00089	454.8	36.77	454.7	5.9	454.8	6.63	411.8	17.59	118
T13_005 - 66	0.10729	0.00144	0.32249	0.00456	4.77034	0.07647	0.09391	0.00315	1753.9	24.29	1801.9	22.25	1779.7	13.46	1814.2	58.17	128
T13_005 - 67	0.05198	0.00108	0.04442	0.00064	0.31829	0.00692	0.01323	0.00067	284.5	46.94	280.2	3.95	280.6	5.33	265.6	13.33	138
T13_005 - 68	0.05331	0.00085	0.05444	0.00079	0.40007	0.00733	0.01698	0.0006	341.8	35.6	341.7	4.85	341.7	5.31	340.4	11.83	103
T13_005 - 69	0.05718	0.00125	0.0804	0.0013	0.63378	0.01495	0.02206	0.00128	497.9	48.1	498.5	7.75	498.4	9.29	441.1	25.34	100
T13_005 - 70	0.05505	0.00081	0.05944	0.00084	0.45111	0.00768	0.01756	0.00068	414	32.21	372.2	5.11	378.1	5.37	351.9	13.46	104
T13_005 - 71	0.08763	0.00125	0.23804	0.00339	2.87594	0.04802	0.07529	0.00303	1374.4	27.06	1376.5	17.66	1375.6	12.58	1467.2	57.03	103
T13_005 - 72	0.11161	0.00141	0.36963	0.00523	5.68745	0.08882	0.09525	0.00336	1825.7	22.69	2027.7	24.64	1929.5	13.49	1839	61.92	97
T13_005 - 73	0.08096	0.00127	0.21172	0.00319	2.36363	0.04344	0.0644	0.00297	1220.6	30.45	1238	16.98	1231.7	13.11	1261.5	56.37	103
T13_005 - 74	0.06394	0.00124	0.11758	0.00174	1.03649	0.02163	0.03709	0.00212	739.5	40.59	716.6	10.05	722.2	10.79	736.2	41.37	101
T13_005 - 75	0.05361	0.00105	0.04254	0.00066	0.31443	0.00682	0.01399	0.00077	354.5	43.86	268.6	4.1	277.6	5.27	280.7	15.32	102
T13_005 - 76	0.16508	0.00195	0.36798	0.00525	8.37409	0.12845	0.06252	0.00165	2508.4	19.71	2019.9	24.72	2272.4	13.91	1225.7	31.37	106
T13_005 - 77	0.05657	0.00093	0.07186	0.00101	0.56042	0.01026	0.02332	0.00081	474	36.19	447.3	6.09	451.8	6.68	466	16.03	97
T13_005 - 78	0.05623	0.00092	0.0744	0.00108	0.57674	0.01076	0.02343	0.0008	460.9	36.01	462.6	6.5	462.4	6.93	468	15.8	99
T13_005 - 79	0.14376	0.00189	0.40996	0.00606	8.12305	0.13461	0.09927	0.00315	2273	22.45	2214.7	27.71	2244.8	14.98	1913	57.88	109
T13_005 - 80	0.09043	0.00222	0.25051	0.00378	3.12392	0.07764	0.07888	0.00749	1434.5	46.1	1441.1	19.46	1438.6	19.12	1534.6	140.29	97

T13_005 - 81	0.05953	0.00141	0.06697	0.00109	0.54949	0.01379	0.01636	0.00118	586.5	50.47	417.9	6.61	444.7	9.04	328	23.53	98
T13_005 - 82	0.09277	0.00137	0.25822	0.00384	3.3017	0.05883	0.07917	0.00324	1483.1	27.76	1480.7	19.68	1481.5	13.89	1540	60.75	106
T13_005 - 83	0.19399	0.00263	0.43703	0.00643	11.6857	0.19664	0.12067	0.00425	2776.3	22.02	2337.3	28.86	2579.6	15.74	2302.7	76.58	101
T13_005 - 84	0.05948	0.00134	0.06292	0.001	0.51585	0.01248	0.02157	0.00097	584.6	48.3	393.4	6.06	422.4	8.36	431.3	19.26	107
T13_005 - 85	0.08018	0.00123	0.2036	0.00297	2.25041	0.04031	0.06034	0.00255	1201.4	29.88	1194.7	15.89	1196.9	12.59	1184.2	48.59	98
T13_005 - 86	0.07985	0.00118	0.19624	0.00282	2.15999	0.03777	0.06223	0.00266	1193.2	28.97	1155.1	15.21	1168.3	12.14	1220.2	50.67	100
T13_005 - 87	0.05934	0.00423	0.05658	0.00156	0.4629	0.03158	0.01604	0.00289	579.8	147.82	354.8	9.51	386.3	21.92	321.5	57.55	103
T13_005 - 88	0.05634	0.0011	0.05949	0.00088	0.46205	0.00982	0.0205	0.00095	465.1	43.05	372.5	5.36	385.7	6.82	410.1	18.82	107
T13_005 - 89	0.05437	0.00087	0.04418	0.00064	0.33109	0.0061	0.01427	0.00059	386.2	35.24	278.7	3.96	290.4	4.65	286.3	11.73	101
T13_005 - 90	0.05532	0.00131	0.04278	0.00068	0.32628	0.00821	0.01323	0.00063	425.1	51.56	270.1	4.18	286.7	6.28	265.7	12.63	96
	ment Quar	ry lithol	ogical un	it													
Sample	T13_016 -	Silty San	dstones														
T13_016 - 1	0.05751	0.00076	0.07883	0.00115	0.62498	0.01026	0.02395	0.00056	510.6	28.59	489.1	6.88	493	6.41	478.5	11.06	106
T13_016 - 2	0.05818	0.00078	0.07714	0.00106	0.61859	0.00981	0.02558	0.00055	535.8	29.72	479	6.35	489	6.16	510.5	10.84	79
T13_016 - 3	0.05738	0.00073	0.07806	0.0011	0.61741	0.00973	0.0248	0.00063	505.6	27.87	484.5	6.6	488.2	6.11	495.1	12.44	93
T13_016 - 4	0.07292	0.00094	0.16517	0.00229	1.66005	0.02576	0.05325	0.00122	1011.6	25.84	985.4	12.68	993.4	9.83	1048.7	23.34	98
T13_016 - 5	0.0561	0.00094	0.06922	0.00101	0.53516	0.01015	0.02176	0.00078	455.8	36.66	431.5	6.11	435.2	6.71	435.1	15.4	99
T13_016 - 6	0.18086	0.00191	0.50866	0.00691	12.6871	0.17285	0.12472	0.0025	2660.8	17.36	2650.9	29.54	2656.7	12.82	2375.6	44.94	76
T13_016 - 7	0.07226	0.00083	0.1668	0.00227	1.66128	0.024	0.04872	0.00119	993.3	23.2	994.4	12.54	993.9	9.16	961.6	22.9	95
T13_016 - 8	0.06996	0.0014	0.1541	0.00216	1.48603	0.03085	0.0499	0.00283	927.1	40.65	923.9	12.07	924.7	12.6	984.3	54.49	108
T13_016 - 9	0.08428	0.00097	0.22343	0.00329	2.59968	0.03883	0.05235	0.00123	1299	22.14	1299.9	17.34	1300.5	10.95	1031.3	23.6	94
T13_016 - 10	0.05824	0.00099	0.04246	0.00062	0.34057	0.0065	0.01378	0.00055	538.1	37.47	268	3.81	297.6	4.92	276.7	10.94	103
T13_016 - 11	0.07515	0.00089	0.18372	0.00254	1.90298	0.02837	0.05406	0.00158	1072.4	23.68	1087.3	13.82	1082.1	9.92	1064.2	30.32	97
T13_016 - 12	0.07924	0.00093	0.19777	0.00281	2.16047	0.03266	0.05904	0.00157	1178	22.95	1163.3	15.11	1168.4	10.49	1159.5	29.99	81
T13_016 - 13	0.0708	0.00091	0.15137	0.00224	1.47749	0.02431	0.0351	0.00117	951.5	26.17	908.7	12.55	921.2	9.96	697.3	22.9	103
T13_016 - 14	0.05702	0.00087	0.07031	0.00106	0.55277	0.01006	0.02132	0.00076	491.9	33.46	438	6.39	446.8	6.58	426.3	15.04	98
T13_016 - 15	0.12074	0.00316	0.35719	0.00589	5.94228	0.16339	0.11058	0.01131	1967.2	45.99	1968.9	28	1967.4	23.9	2119.9	205.89	95
T13_016 - 16	0.06973	0.00082	0.15556	0.00225	1.49541	0.02298	0.04423	0.00123	920.4	23.88	932	12.57	928.5	9.35	874.8	23.76	92
		0.00074	0.09987	0.00146	0.81316	0.013	0.03123	0.00082	569.1	26.88	613.7	8.59	604.2	7.28	621.6	16.08	97

T13_016 -	0.06074	0.00108	0.06986	0.00111	0.58518	0.01194	0.02266	0.00084	629.9	37.82	435.3	6.67	467.8	7.65	452.9	16.55	100
18 T13 016 -	0.05688	0.001	0.08082	0.00126	0.63373	0.0128	0.02019	0.00079	486.3	38.78	501	7.52	498.4	7.96	404.1	15.58	95
19																	
T13_016 - 20	0.05275	0.00079	0.04593	0.00066	0.33404	0.00582	0.015	0.0006	318.2	33.74	289.5	4.04	292.6	4.43	300.9	12	101
T13_016 - 21	0.05459	0.00077	0.07184	0.00109	0.54075	0.00946	0.02145	0.00063	395.5	31.11	447.2	6.56	438.9	6.23	428.9	12.56	87
T13_016 - 22	0.06644	0.00088	0.13484	0.002	1.23509	0.02056	0.03916	0.00116	820.2	27.5	815.4	11.36	816.7	9.34	776.4	22.56	94
T13_016 - 23	0.05759	0.00088	0.08053	0.00123	0.63934	0.01179	0.02676	0.00107	513.7	33.68	499.3	7.35	501.9	7.3	533.8	21.02	87
T13_016 - 24	0.1748	0.00199	0.49458	0.00719	11.92039	0.18111	0.11297	0.00335	2604.2	18.84	2590.5	31	2598.2	14.23	2163.4	60.9	100
T13_016 - 25	0.19895	0.00226	0.47884	0.007	13.13643	0.19949	0.11568	0.00313	2817.6	18.47	2522.2	30.51	2689.5	14.33	2212.5	56.71	105
T13_016 - 26	0.09363	0.00139	0.24318	0.00359	3.13905	0.05491	0.0712	0.0027	1500.7	27.72	1403.2	18.63	1442.3	13.47	1390.2	50.98	101
T13_016 - 27	0.07518	0.00093	0.18422	0.00267	1.90944	0.03021	0.05603	0.00211	1073.4	24.54	1090	14.54	1084.4	10.54	1101.8	40.39	92
T13_016 - 28	0.07682	0.001	0.18197	0.00277	1.92826	0.03222	0.04477	0.00151	1116.6	25.68	1077.7	15.13	1090.9	11.17	885.2	29.26	89
T13_016 - 29	0.08084	0.00125	0.21667	0.00331	2.41474	0.04436	0.06568	0.0028	1217.5	30.02	1264.2	17.52	1247	13.19	1285.7	53.02	100
T13_016 - 30	0.05351	0.0008	0.05317	0.00079	0.39227	0.00699	0.01545	0.00062	350.5	33.28	334	4.81	336	5.1	309.9	12.27	89
T13_016 - 31	0.05763	0.00099	0.08515	0.00134	0.67662	0.01358	0.02563	0.00106	515.4	37.6	526.8	7.97	524.7	8.22	511.4	20.86	88
T13_016 - 32	0.05593	0.0009	0.07511	0.00115	0.57916	0.011	0.02316	0.00075	449.4	35.05	466.9	6.89	463.9	7.08	462.7	14.89	94
T13_016 - 33	0.05732	0.00075	0.0793	0.00117	0.6266	0.01041	0.02338	0.00071	503.6	28.7	491.9	7.01	494	6.5	467.1	14.02	88
T13_016 - 34	0.05633	0.0008	0.07414	0.00109	0.57566	0.00987	0.02344	0.00085	464.6	31.29	461.1	6.51	461.7	6.36	468.3	16.86	86
T13_016 - 35	0.0598	0.00079	0.08872	0.0013	0.73143	0.01205	0.02429	0.00137	596.5	28.33	548	7.68	557.4	7.07	485.1	27.02	70
T13_016 - 36	0.11337	0.00135	0.33319	0.00486	5.20751	0.08144	0.09003	0.00304	1854.2	21.39	1853.8	23.52	1853.8	13.32	1742.4	56.36	92
T13_016 - 37	0.10336	0.00173	0.3051	0.00492	4.3476	0.08619	0.07559	0.00406	1685.3	30.59	1716.6	24.28	1702.4	16.36	1472.9	76.26	87
T13_016 - 38	0.07975	0.00121	0.20142	0.00294	2.2142	0.03905	0.06032	0.00272	1190.9	29.57	1182.9	15.76	1185.5	12.34	1183.8	51.84	83
T13_016 - 39	0.05268	0.00102	0.05196	0.00081	0.37733	0.00811	0.01699	0.0008	314.9	43.33	326.5	4.96	325.1	5.98	340.6	15.84	89
T13_016 - 40	0.0706	0.001	0.16191	0.00246	1.57596	0.02754	0.04904	0.00205	945.8	28.75	967.4	13.62	960.8	10.86	967.6	39.51	94
T13_016 - 41	0.05281	0.00111	0.05701	0.00092	0.4151	0.00957	0.01615	0.00065	320.4	46.87	357.4	5.58	352.5	6.87	323.8	12.86	88
T13_016 - 42	0.05613	0.00078	0.07223	0.00107	0.55905	0.00954	0.02004	0.00079	457.3	30.24	449.6	6.44	450.9	6.22	401	15.65	95
T13_016 - 43	0.05815	0.00088	0.07828	0.00115	0.62756	0.0112	0.02483	0.0012	534.8	33.31	485.9	6.9	494.6	6.99	495.8	23.6	93
T13_016 - 44	0.06031	0.00088	0.10456	0.00158	0.86947	0.01546	0.02823	0.00115	614.8	31.28	641.1	9.24	635.3	8.39	562.7	22.7	79
T13_016 - 45	0.09449	0.00174	0.26536	0.00443	3.45869	0.07271	0.06288	0.00322	1518	34.32	1517.2	22.54	1517.9	16.56	1232.5	61.28	95
T13_016 - 46	0.15724	0.00319	0.42173	0.00657	9.14336	0.20263	0.10705	0.00872	2426.2	34.05	2268.3	29.81	2352.5	20.28	2055.5	159.17	98

47 13.016 0.0012 0.0012 0.0021 0.0022 0.0011 0.0022 0.0011 0.0022 0.0012 0.0021 0.0086 0.0122 0.0011 0.0022 0.0011 0.0022 0.0012 0.0086 0.0012 0.0086 0.0012 0.0022 0.0011 0.0022 0.0011 0.0086 0.0122 0.0012 0.0010 0.0086 0.0012 0.0086 0.0012 0.0018 0.0012 0.0021 0.0086 0.0012 0.0022 0.0011 0.0024 0.0011 0.0086 0.0012 0.0086 0.0012 0.0026 0.0022 0.0011 0.0026 0.0022 0.0011 0.0026 0.0026 0.0026 0.0026 0.0026 0.0026 </th <th>98</th> <th>83.55</th> <th>2226.4</th> <th>15.73</th> <th>2460.6</th> <th>30.97</th> <th>2443.4</th> <th>22.37</th> <th>2474.8</th> <th>0.00461</th> <th>0.11644</th> <th>0.17485</th> <th>10.28363</th> <th>0.00702</th> <th>0.46087</th> <th>0.00216</th> <th>0.16182</th> <th>T13_016 -</th>	98	83.55	2226.4	15.73	2460.6	30.97	2443.4	22.37	2474.8	0.00461	0.11644	0.17485	10.28363	0.00702	0.46087	0.00216	0.16182	T13_016 -
Th3 016- 0.08774 0.00011 0.08887 0.00136 0.70754 0.01282 0.00101 519.6 34.61 546.3 6.77 543.3 7.9 475.8 70 T13_016- 0.00577 0.00254 0.00688 0.0011 0.5155 0.0188 0.00181 0.0011 778 856.3 6.79 442 113.7 366.8 27.55 5 T13_016- 0.00574 0.0004 0.007874 0.0012 0.60394 0.0178 0.00124 0.0018 433.9 36.77 488.6 7.5 475.2 7.46 470.3 23.44 5 T13_016- 0.07586 0.00117 0.188 0.00212 0.00226 0.0117 586.6 39.27 471.2 7.05 487.5 7.99 442.6 0.012 5 4.55 4.689 489.7 7.33 489.1 9.09 442.6 0.012 5 1.015 5 1.015 1.015 1.015 1.015 1.015 1.015 1.016	101	42.78	913.1	11.88	946.3	13.41	939	33.64	963.3	0.00221	0.04621	0.02971	1.53941	0.00241	0.1568	0.00119	0.0712	T13_016 -
T13 0161- 0.06577 0.00254 0.05681 0.00111 0.51525 0.0138 0.0141 799 78.8 336.3 6.79 422 13.27 366.8 27.95 T13<016-	104	20	475.8	7.9	543.3	8.07	548.9	34.61	519.6	0.00101	0.02382	0.01329	0.70754	0.00136	0.08887	0.00091	0.05774	T13_016 -
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	123	27.95	366.8	13.27	422	6.79	356.3	78.8	799	0.00141	0.01831	0.0198	0.51525	0.00111	0.05683	0.00254	0.06577	T13_016 -
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	163	23.24	470.3	7.46	479.2	7.16	488.6	36.77	433.9	0.00118	0.02354	0.01178	0.60304	0.0012	0.07874	0.00094	0.05554	T13_016 -
T13_016- 0.05893 0.0018 0.07384 0.0018 0.01619 0.0127 0.0229 0.0017 5646 39.27 4712 7.05 487.5 7.99 457.7 23.08 T13_016- 0.05866 0.00122 0.07893 0.00126 0.61887 0.0102 485.6 46.89 489.7 7.53 449.1 9.09 432.6 20.12 T13_016- 0.05118 0.0008 0.0449 0.0068 0.31394 0.0058 0.01182 0.0052 248.8 35.62 280.6 4.22 277.2 4.53 223.75 10.45 T13_016- 0.07918 0.00233 0.2022 0.00426 2.213 0.00898 0.00420 0.0394 117.66 78.65 1187.1 22.84 118.43 28.17 832.5 76.44 T13_016- 0.06997 0.00145 0.24739 0.038 0.06721 0.00397 1424.8 30.38 1425 19.64 1424.9 1452 131.47 73.72 T13_016- 0.06997 0.0014 0.0491 0.0415 0.0415 0.00357	98	44.7	956.6	12.69	1086.2	16.1	1110.5	31.7	1037.6	0.00232	0.04846	0.03641	1.91453	0.00297	0.188	0.00117	0.07386	T13_016 -
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	99	23.08	457.7	7.99	487.5	7.05	471.2	39.27	564.6	0.00117	0.0229	0.01272	0.61619	0.00118	0.07584	0.00108	0.05893	T13_016 -
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	91	20.12	432.6	9.09	489.1	7.53	489.7	46.89	485.6	0.00102	0.02163	0.01449	0.61887	0.00126	0.07893	0.00122	0.05686	T13_016 -
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	95	10.45	237.5	4.53	277.2	4.22	280.6	35.62	248.8	0.00052	0.01182	0.00586	0.31394	0.00068	0.04449	0.0008	0.05118	T13_016 -
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	93	76.44	832.5	28.17	1184.3	22.84	1187.1	78.65	1176.6	0.00394	0.04205	0.08908	2.2103	0.00426	0.2022	0.00323	0.07918	T13_016 -
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	91	73.72	1314.7	14.52	1424.9	19.64	1425	30.38	1424.8	0.00389	0.06721	0.05818	3.0686	0.0038	0.24739	0.00145	0.08997	T13_016 -
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	102	20.28	307.9	7.07	353	4.74	290.5	45.04	787.2	0.00102	0.01535	0.00985	0.41575	0.00077	0.0461	0.00142	0.0654	T13_016 -
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	100	67.11	1475.6	15.17	1785	24.09	1781.5	26.63	1789.1	0.00357	0.07574	0.08669	4.80036	0.00493	0.31832	0.00161	0.10938	T13_016 -
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	101	46	860.7	11.63	963	13.82	979.3	32.07	926.2	0.00237	0.0435	0.02958	1.58162	0.0025	0.16406	0.0011	0.06993	T13_016 -
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	104	58.06	1711.5	14.07	1818.5	24.19	1843.4	23.18	1790.3	0.00313	0.08836	0.0831	4.99518	0.005	0.33103	0.0014	0.10946	T13_016 -
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	104	16.46	395.3	7.73	446.9	7.07	452.2	40.39	420.5	0.00083	0.01975	0.01183	0.55293	0.00118	0.07266	0.00103	0.05521	T13_016 -
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	98	10.64	268.3	4.86	281.4	4.23	282	38.58	276.6	0.00053	0.01336	0.00631	0.31934	0.00069	0.04472	0.00088	0.0518	T13_016 -
T13_016 - 65 0.0601 0.0011 0.0054 0.0087 0.44743 0.0097 0.01481 0.006 667.3 40.69 339 5.34 337.5 6.81 297.2 12.03 T13_016 - 65 0.05343 0.0099 0.06054 0.0092 0.44596 0.00872 0.0173 0.00071 347.1 37.72 378.9 5.57 374.4 6.12 355.3 14.17 66 0.06582 0.00203 0.1142 0.00208 1.03632 0.03277 0.06863 0.00764 800.5 63.27 667.1 12.05 722.1 16.34 1341.6 144.51 713_016 - 67 0.06582 0.00203 0.1142 0.00208 0.03277 0.06863 0.00764 800.5 63.27 667.1 12.05 722.1 16.34 1341.6 144.51	103	67.59	2013.5	14.52	2166	26.61	2085.1	21.35	2243.7	0.00369	0.10475	0.1207	7.44136	0.0057	0.38188	0.00176	0.14134	T13_016 -
T13_016 - 66 0.05343 0.0009 0.06054 0.0092 0.44596 0.00872 0.0173 0.0071 347.1 37.2 378.9 5.57 374.4 6.12 355.3 14.17 T13_016 - 67 0.06582 0.00203 0.1142 0.00208 1.03632 0.03277 0.06863 0.00764 800.5 63.27 697.1 12.05 722.1 16.34 1341.6 144.51	105	12.03	297.2	6.81	375.5	5.34	339	40.69	607.3	0.0006	0.01481	0.0097	0.44743	0.00087	0.054	0.00115	0.0601	T13_016 -
T13_016 - 67 0.06582 0.00203 0.1142 0.00208 1.03632 0.03277 0.06863 0.00764 800.5 63.27 697.1 12.05 722.1 16.34 1341.6 144.51	99	14.17	355.3	6.12	374.4	5.57	378.9	37.72	347.1	0.00071	0.01773	0.00872	0.44596	0.00092	0.06054	0.0009	0.05343	T13_016 -
	103	144.51	1341.6	16.34	722.1	12.05	697.1	63.27	800.5	0.00764	0.06863	0.03277	1.03632	0.00208	0.1142	0.00203	0.06582	T13_016 -
T13_016 - 0.05613 0.00083 0.0717 0.00109 0.55482 0.01002 0.02047 0.00083 457 32.19 446.4 6.55 448.1 6.54 409.6 16.4 68 68 68 655 68 655	97	16.4	409.6	6.54	448.1	6.55	446.4	32.19	457	0.00083	0.02047	0.01002	0.55482	0.00109	0.0717	0.00083	0.05613	T13_016 -
T13_016 - 69 0.08146 0.00107 0.13376 0.00202 1.50213 0.02543 0.03811 0.00162 1232.5 25.68 809.3 11.5 931.3 10.32 756 31.58	102	31.58	756	10.32	931.3	11.5	809.3	25.68	1232.5	0.00162	0.03811	0.02543	1.50213	0.00202	0.13376	0.00107	0.08146	T13_016 -
Ti3_016 - 70 0.0726 0.0013 0.16812 0.00275 1.68227 0.03526 0.0467 0.00267 1002.7 35.9 1001.8 15.18 1001.8 13.35 922.6 51.49	99	51.49	922.6	13.35	1001.8	15.18	1001.8	35.9	1002.7	0.00267	0.0467	0.03526	1.68227	0.00275	0.16812	0.0013	0.0726	T13_016 -
T13_016 - 71 0.05545 0.00091 0.07072 0.0011 0.54062 0.0152 0.02173 0.00112 430 35.71 440.5 6.63 438.8 6.93 434.5 22.2	108	22.2	434.5	6.93	438.8	6.63	440.5	35.71	430	0.00112	0.02173	0.01052	0.54062	0.0011	0.07072	0.00091	0.05545	T13_016 -
T13_016 - 72 0.05313 0.00148 0.04855 0.00085 0.35551 0.0103 0.01581 0.00138 334.4 61.78 305.6 5.21 308.9 7.72 317 27.53	98	27.53	317	7.72	308.9	5.21	305.6	61.78	334.4	0.00138	0.01581	0.0103	0.35551	0.00085	0.04855	0.00148	0.05313	T13_016 -
T13_016 - 73 0.05329 0.00138 0.05478 0.00092 0.40252 0.01102 0.01693 0.001 341.3 57.57 343.8 5.6 343.5 7.98 339.3 19.85	95	19.85	339.3	7.98	343.5	5.6	343.8	57.57	341.3	0.001	0.01693	0.01102	0.40252	0.00092	0.05478	0.00138	0.05329	T13_016 -
T13_016 - 74 0.05684 0.00108 0.07571 0.00118 0.59329 0.01266 0.02331 0.00129 484.8 41.73 470.4 7.07 473 8.07 465.6 25.56	112	25.56	465.6	8.07	473	7.07	470.4	41.73	484.8	0.00129	0.02331	0.01266	0.59329	0.00118	0.07571	0.00108	0.05684	
T13_016 - 75 0.07943 0.00123 0.20719 0.00324 2.26888 0.04273 0.06028 0.00325 1182.8 30.4 1213.9 17.28 1202.7 13.27 1183 61.97	99	61.97	1183	13.27	1202.7	17.28	1213.9	30.4	1182.8	0.00325	0.06028	0.04273	2.26888	0.00324	0.20719	0.00123	0.07943	

Somela	T12 06		Condot														
T13_065 -	e T13_065	0.00124	0.26304	0.00335	4.11822	0.05483	0.07704	0.00152	1857.2	19.67	1505.4	17.09	1657.9	10.88	1500.1	28.49	97
1 T13_065 -	0.12169	0.00134	0.36014	0.00459	6.04194	0.08068	0.10879	0.00235	1981.2	19.51	1982.8	21.75	1981.9	11.63	2087.2	42.93	101
2 T13_065 -	0.0619	0.00089	0.09104	0.00119	0.77691	0.0124	0.02986	0.00064	670.7	30.41	561.7	7.05	583.7	7.09	594.7	12.6	99
3 T13_065 -	0.0721	0.00081	0.05769	0.00074	0.57347	0.00777	0.06825	0.00151	988.8	22.72	361.6	4.48	460.3	5.01	1334.4	28.6	96
4	0.13156	0.00001		0.00074	6.49479	0.08786		0.0025	2119	19.53	1973.1	21.71	2045.2	11.9	2106.8	45.52	75
T13_065 - 5			0.35808				0.10986										
T13_065 - 6	0.16361	0.00192	0.44216	0.00571	9.97335	0.13845	0.13502	0.00323	2493.3	19.6	2360.3	25.52	2432.3	12.81	2559.8	57.44	84
T13_065 - 7	0.05791	0.00074	0.07702	0.001	0.61487	0.00908	0.02496	0.00062	525.9	28.15	478.3	5.96	486.6	5.71	498.4	12.22	74
T13_065 - 8	0.10551	0.00128	0.08162	0.00105	1.18732	0.01686	0.05071	0.00131	1723.3	22.12	505.8	6.28	794.7	7.82	999.8	25.29	91
T13_065 - 9	0.06966	0.00098	0.12779	0.00168	1.22722	0.01933	0.03913	0.00104	918.4	28.68	775.2	9.59	813.1	8.81	775.8	20.27	71
T13_065 - 10	0.05789	0.00076	0.06777	0.00088	0.54089	0.00813	0.02215	0.00062	525.5	28.84	422.7	5.3	439	5.36	442.8	12.21	82
T13_065 - 11	0.06913	0.00103	0.13958	0.00185	1.33015	0.02182	0.04146	0.00122	902.5	30.36	842.3	10.46	858.9	9.51	821	23.77	44
T13_065 - 12	0.07014	0.00096	0.13829	0.00181	1.33727	0.02062	0.04858	0.00146	932.5	27.74	835	10.24	862	8.96	958.8	28.13	102
T13_065 - 13	0.16375	0.00201	0.46351	0.006	10.4637	0.1503	0.13621	0.00413	2494.7	20.54	2455	26.42	2476.7	13.31	2581	73.52	96
T13_065 - 14	0.06056	0.00079	0.0609	0.00079	0.50849	0.00761	0.02037	0.00064	623.7	27.89	381.1	4.8	417.4	5.12	407.6	12.63	82
T13_065 - 15	0.05563	0.00144	0.05369	0.00079	0.41177	0.0107	0.01739	0.00063	437.1	56.21	337.2	4.85	350.2	7.7	348.5	12.55	103
T13_065 - 16	0.05962	0.0007	0.05793	0.00074	0.47616	0.00667	0.01892	0.00042	589.7	25.37	363	4.53	395.4	4.59	378.9	8.23	68
T13_065 - 17	0.09996	0.00116	0.27443	0.00352	3.78207	0.05227	0.07921	0.00181	1623.4	21.41	1563.2	17.82	1588.9	11.1	1540.7	33.84	40
T13_065 - 18	0.06154	0.00076	0.09209	0.00118	0.78136	0.01121	0.02875	0.0007	658.2	26.14	567.9	6.99	586.3	6.39	572.9	13.75	55
T13_065 - 19	0.09984	0.00116	0.28531	0.00365	3.92706	0.0541	0.08441	0.00195	1621.1	21.39	1618.1	18.3	1619.3	11.15	1637.9	36.39	97
T13_065 - 20	0.15909	0.00182	0.3954	0.00504	8.67189	0.11823	0.10974	0.0026	2446	19.18	2147.8	23.29	2304.1	12.41	2104.6	47.32	97
T13_065 - 21	0.11047	0.00133	0.30889	0.00397	4.70423	0.06638	0.07646	0.00191	1807.1	21.79	1735.3	19.55	1768	11.82	1489.2	35.78	63
T13_065 - 22	0.05668	0.0009	0.07726	0.00102	0.60369	0.01038	0.02392	0.00063	478.3	35.08	479.8	6.1	479.6	6.57	477.8	12.48	93
T13_065 - 23	0.09934	0.00121	0.28683	0.00368	3.92828	0.05567	0.08035	0.00208	1611.8	22.55	1625.7	18.41	1619.5	11.47	1562.1	38.88	98
T13_065 - 24	0.07119	0.0009	0.16116	0.00206	1.5817	0.02289	0.05426	0.00178	962.9	25.18	963.2	11.46	963	9	1067.9	34.11	60
T13_065 - 25	0.08031	0.00104	0.19309	0.00248	2.1379	0.03139	0.05798	0.00157	1204.7	25.19	1138.1	13.41	1161.1	10.16	1139.3	30.04	105
T13_065 - 26	0.09819	0.00119	0.25531	0.00325	3.4559	0.04872	0.08332	0.00231	1590	22.55	1465.8	16.7	1517.2	11.1	1617.7	43.04	100
T13_065 - 27	0.11848	0.00148	0.34227	0.00438	5.59024	0.07996	0.10355	0.00298	1933.4	22.14	1897.6	21.03	1914.6	12.32	1991.6	54.5	53

T13_065 - 28	0.05778	0.00095	0.07641	0.00101	0.60868	0.0107	0.02351	0.00072	521.4	35.91	474.7	6.03	482.7	6.75	469.7	14.17	99
T13_065 - 29	0.11381	0.00144	0.33045	0.00422	5.18459	0.07477	0.09217	0.00279	1861.1	22.69	1840.6	20.45	1850.1	12.28	1782.1	51.65	102
713_065 - 30	0.10915	0.00149	0.06515	0.00084	0.98025	0.01483	0.02605	0.00081	1785.2	24.71	406.9	5.09	693.7	7.6	519.7	15.96	107
T13_065 - 31	0.06297	0.00104	0.06793	0.0009	0.58981	0.01038	0.02228	0.00052	707.4	34.81	423.7	5.4	470.7	6.63	445.4	10.29	90
T13_065 - 32	0.05797	0.00085	0.0735	0.00095	0.58747	0.0094	0.02147	0.00047	528.4	32.04	457.2	5.68	469.3	6.01	429.3	9.39	91
32 T13_065 - 33	0.0584	0.00123	0.07151	0.00099	0.57581	0.01239	0.02184	0.00056	544.9	45.33	445.2	5.93	461.8	7.98	436.7	11.16	88
33 T13_065 - 34	0.05553	0.00074	0.05951	0.00075	0.45563	0.00679	0.01828	0.00042	433.2	28.82	372.7	4.58	381.2	4.73	366.1	8.24	93
T13_065 -	0.0665	0.00086	0.07479	0.00095	0.68578	0.01003	0.01587	0.00038	822.2	26.89	464.9	5.67	530.3	6.04	318.3	7.58	102
35 T13_065 - 36	0.09583	0.00112	0.12012	0.0015	1.5872	0.02161	0.02852	0.00068	1544.4	21.88	731.3	8.64	965.2	8.48	568.3	13.36	50
T13_065 - 37	0.10981	0.00135	0.32079	0.00404	4.857	0.06815	0.08838	0.00216	1796.2	22.22	1793.6	19.73	1794.8	11.81	1711.7	40.02	54
T13_065 - 38	0.10803	0.00145	0.3172	0.00407	4.72468	0.07029	0.08755	0.00229	1766.4	24.32	1776	19.9	1771.6	12.47	1696.4	42.52	105
T13_065 - 39	0.12137	0.00147	0.29891	0.00374	5.00213	0.06922	0.08608	0.00222	1976.5	21.35	1685.9	18.55	1819.7	11.71	1668.9	41.23	103
T13_065 - 40	0.07349	0.0009	0.1466	0.00183	1.48538	0.0208	0.04204	0.00112	1027.4	24.65	881.9	10.28	924.4	8.5	832.4	21.69	104
40 T13_065 - 41	0.06083	0.0008	0.06785	0.00085	0.56902	0.00834	0.02124	0.00058	633.1	28.02	423.2	5.13	457.4	5.4	424.8	11.48	57
T13_065 - 42	0.06021	0.00094	0.07333	0.00094	0.60879	0.01015	0.02232	0.00065	611.3	33.32	456.2	5.65	482.8	6.41	446.3	12.86	102
T13_065 - 43	0.11008	0.00202	0.06638	0.00091	1.00742	0.01882	0.03816	0.00121	1800.7	32.99	414.3	5.51	707.6	9.52	757	23.59	87
T13_065 - 44	0.05439	0.00131	0.05884	0.00082	0.44121	0.01067	0.01744	0.00059	387	52.95	368.6	5.01	371.1	7.52	349.4	11.72	86
T13_065 - 45	0.0737	0.00094	0.12341	0.00153	1.25404	0.01796	0.03687	0.00116	1033.4	25.31	750.1	8.8	825.2	8.09	731.8	22.68	88
T13_065 - 46	0.19995	0.00224	0.46769	0.00564	12.89114	0.16551	0.1431	0.00291	2825.8	18.17	2473.4	24.77	2671.7	12.1	2703.4	51.42	73
T13_065 - 47	0.08019	0.00097	0.17292	0.0021	1.91158	0.0259	0.056	0.00115	1201.8	23.66	1028.2	11.53	1085.1	9.03	1101.3	22.03	95
T13_065 - 48	0.05742	0.00094	0.07055	0.00089	0.55843	0.0096	0.01999	0.00044	507.2	36.11	439.5	5.36	450.5	6.25	400	8.78	23
T13_065 - 49	0.07175	0.00085	0.16681	0.00202	1.64968	0.02209	0.04697	0.00104	978.7	24.04	994.5	11.14	989.4	8.46	927.7	19.99	75
T13_065 - 50	0.06258	0.00077	0.06325	0.00077	0.54564	0.00751	0.0171	0.00038	694.1	26.15	395.4	4.65	442.1	4.94	342.7	7.5	67
T13_065 - 51	0.10582	0.00122	0.3219	0.00389	4.69503	0.06163	0.08455	0.0019	1728.6	21.09	1799	18.97	1766.4	10.99	1640.5	35.4	86
T13_065 - 52	0.10508	0.00125	0.31536	0.00383	4.56725	0.06122	0.08673	0.00208	1715.7	21.78	1767	18.79	1743.3	11.17	1681.2	38.65	85
T13_065 - 53	0.05517	0.00094	0.07084	0.0009	0.53864	0.00951	0.02053	0.00051	419	37.23	441.2	5.41	437.5	6.28	410.8	10.18	101
T13_065 - 54	0.07226	0.00171	0.08737	0.00124	0.8702	0.02047	0.02744	0.00079	993.4	47.48	540	7.33	635.7	11.11	547.1	15.59	100
T13_065 - 55	0.05739	0.00079	0.03968	0.00049	0.31384	0.00466	0.01105	0.00028	506.3	29.7	250.8	3.02	277.2	3.6	222.2	5.54	47
T13_065 - 56	0.07044	0.00116	0.16017	0.00205	1.55495	0.02666	0.0439	0.00117	941.3	33.31	957.7	11.4	952.5	10.59	868.4	22.74	57
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T13_065 - 57	0.07929	0.00096	0.18496	0.00225	2.02105	0.02737	0.04893	0.00131	1179.3	23.75	1094	12.22	1122.6	9.2	965.6	25.21	86
T13_065 - 58	0.10724	0.00132	0.27199	0.00332	4.01955	0.055	0.07107	0.00196	1753	22.27	1550.9	16.83	1638.2	11.13	1387.7	36.9	82
T13_065 - 59	0.06925	0.00087	0.13575	0.00166	1.29542	0.01804	0.03879	0.00111	906.1	25.72	820.6	9.4	843.7	7.98	769.2	21.62	87
T13_065 - 60	0.14276	0.00172	0.37222	0.00452	7.32263	0.09876	0.08284	0.00243	2261	20.63	2039.8	21.25	2151.6	12.05	1608.6	45.37	60
T13_065 - 61	0.07135	0.00091	0.17487	0.00219	1.71987	0.02464	0.05033	0.00123	967.5	25.73	1038.9	12.01	1016	9.2	992.6	23.68	23
T13_065 - 62	0.16644	0.00196	0.49094	0.00612	11.26347	0.15303	0.12596	0.00313	2522.2	19.65	2574.7	26.46	2545.2	12.67	2397.9	56.16	99
T13_065 - 63	0.07115	0.00085	0.15995	0.00198	1.56877	0.02151	0.04972	0.00175	961.8	24.16	956.5	11.02	957.9	8.5	980.8	33.7	91
T13_065 - 64	0.06134	0.00087	0.05493	0.00069	0.46448	0.00718	0.01729	0.00047	651.1	29.99	344.7	4.24	387.4	4.98	346.5	9.37	98
T13_065 - 65	0.08344	0.00108	0.21953	0.00276	2.52486	0.03663	0.06789	0.00204	1279.2	25.1	1279.4	14.58	1279.2	10.55	1327.6	38.62	92
T13_065 - 66	0.07051	0.00088	0.16575	0.00207	1.611	0.02288	0.05004	0.00142	943.2	25.47	988.6	11.43	974.5	8.9	986.8	27.35	94
T13_065 - 67	0.09946	0.00124	0.16264	0.00203	2.22996	0.0315	0.03868	0.00111	1614	23.02	971.4	11.26	1190.5	9.9	767.1	21.52	100
T13_065 - 68	0.07761	0.00098	0.18867	0.00235	2.01858	0.02877	0.05521	0.00163	1137	24.86	1114.2	12.77	1121.8	9.68	1086.1	31.24	101
T13_065 - 69	0.05373	0.00116	0.05328	0.00073	0.3946	0.0087	0.01668	0.00056	359.4	48.24	334.6	4.44	337.7	6.33	334.4	11.2	100
T13_065 - 70	0.08524	0.00108	0.13672	0.00171	1.60649	0.02303	0.04776	0.00153	1320.8	24.48	826.1	9.68	972.7	8.97	943	29.42	96
T13_065 - 71	0.08355	0.00111	0.21309	0.00268	2.45444	0.03625	0.06116	0.002	1281.9	25.65	1245.3	14.23	1258.7	10.66	1199.8	38.1	88
T13_065 - 72	0.07692	0.00103	0.18277	0.0023	1.93814	0.02888	0.04257	0.00146	1119.1	26.49	1082.1	12.52	1094.4	9.98	842.6	28.25	100
T13_065 - 73	0.11098	0.00147	0.16828	0.00211	2.57483	0.03803	0.05977	0.00208	1815.6	23.87	1002.6	11.67	1293.5	10.8	1173.3	39.69	86
T13_065 - 74	0.06826	0.00117	0.05525	0.00072	0.51997	0.00934	0.01829	0.0007	876.6	35	346.7	4.42	425.1	6.24	366.3	13.85	96
T13_065 - 75	0.06302	0.00101	0.07749	0.001	0.67322	0.01147	0.02606	0.001	708.8	33.59	481.1	5.97	522.7	6.96	520	19.72	62
T13_065 - 76	0.06077	0.00089	0.10659	0.00134	0.89292	0.01412	0.0315	0.00069	631.1	31.3	652.9	7.8	647.9	7.57	626.8	13.57	77
T13_065 - 77	0.0723	0.00086	0.1347	0.00165	1.3425	0.01823	0.04886	0.00116	994.4	24.08	814.6	9.38	864.3	7.9	964.3	22.44	61
T13_065 - 78	0.07759	0.00096	0.18501	0.00228	1.9789	0.02748	0.05036	0.00118	1136.5	24.31	1094.3	12.42	1108.3	9.37	993.1	22.8	98
T13_065 - 79	0.0914	0.00116	0.25749	0.00321	3.24416	0.04614	0.07468	0.00183	1454.9	24.04	1477	16.46	1467.8	11.04	1455.8	34.5	90
T13_065 - 80	0.06459	0.00079	0.05319	0.00066	0.47357	0.00655	0.01527	0.00038	761.1	25.55	334.1	4.01	393.7	4.52	306.3	7.59	93
T13_065 - 81	0.05935	0.00081	0.07673	0.00096	0.62771	0.00947	0.02295	0.00059	579.9	29.55	476.6	5.75	494.7	5.91	458.6	11.65	80
T13_065 - 82	0.11495	0.00139	0.22951	0.00285	3.63647	0.04992	0.07097	0.00189	1879.1	21.57	1331.9	14.92	1557.6	10.93	1385.8	35.65	84
T13_065 - 83	0.05787	0.00088	0.07694	0.00098	0.61366	0.01	0.02317	0.00066	524.5	33.15	477.8	5.86	485.9	6.29	463	13	29
T13_065 - 84	0.05871	0.00092	0.06631	0.00085	0.53653	0.00897	0.02126	0.00064	556.2	33.73	413.9	5.14	436.1	5.92	425.2	12.76	91
T13_065 - 85	0.07132	0.00109	0.13378	0.00172	1.31499	0.02157	0.04171	0.00124	966.5	30.9	809.4	9.8	852.3	9.46	825.9	24.1	95

T13_065 - 86	0.06163	0.00089	0.0802	0.00102	0.68127	0.01074	0.02398	0.00073	661.5	30.74	497.3	6.09	527.5	6.49	478.9	14.42	93
T13_065 - 87	0.05432	0.00075	0.0588	0.00074	0.44015	0.00668	0.01989	0.00065	384.2	30.56	368.3	4.52	370.4	4.71	398	12.96	37
T13_065 - 88	0.10648	0.00136	0.3049	0.00384	4.47395	0.06452	0.09187	0.00295	1739.9	23.34	1715.6	18.99	1726.2	11.97	1776.5	54.66	84
T13_065 - 89	0.05592	0.00081	0.07301	0.00093	0.56266	0.00892	0.02233	0.00074	449	31.54	454.3	5.6	453.3	5.8	446.3	14.69	100
T13_065 - 90	0.13545	0.00175	0.38591	0.00489	7.20283	0.10495	0.11063	0.00377	2169.8	22.37	2103.8	22.76	2136.9	12.99	2120.9	68.56	81
Sap Bon	Formatio	n															
Sample	T14_002 -	Carbona	atic/silty	Sandst	ones												
T14_002 - 1	0.05573	0.00089	0.06789	0.00094	0.52157	0.00927	0.02019	0.0005	441.5	34.7	423.4	5.67	426.2	6.18	404.1	9.99	98
T14_002 - 2	0.15682	0.00249	0.41062	0.00575	8.87777	0.15397	0.1046	0.00461	2421.7	26.74	2217.8	26.26	2325.5	15.83	2010.7	84.35	99
T14_002 - 3	0.07137	0.00131	0.15308	0.00211	1.50614	0.02902	0.04571	0.00188	968.1	36.92	918.2	11.82	932.9	11.76	903.4	36.31	93
T14_002 - 4	0.10669	0.00121	0.31095	0.00399	4.5739	0.06245	0.0822	0.00165	1743.7	20.57	1745.4	19.63	1744.5	11.38	1596.7	30.75	96
T14_002 - 5	0.05187	0.00078	0.04483	0.00061	0.32055	0.00546	0.01453	0.00037	279.8	34.22	282.7	3.76	282.3	4.2	291.5	7.35	90
T14_002 - 6	0.20085	0.00296	0.55249	0.00761	15.29666	0.25371	0.15054	0.00626	2833.1	23.83	2835.5	31.61	2833.9	15.81	2834.4	110.04	102
T14_002 - 7	0.05752	0.00113	0.05865	0.00084	0.46518	0.00965	0.0162	0.00063	511.3	42.88	367.4	5.09	387.9	6.69	324.7	12.56	78
T14_002 - 8	0.08309	0.00109	0.21707	0.00289	2.48662	0.03792	0.06348	0.0016	1271.3	25.3	1266.4	15.3	1268.1	11.04	1244	30.36	88
T14_002 - 9	0.09287	0.00138	0.25941	0.00362	3.32111	0.05609	0.07512	0.00258	1485.1	28	1486.8	18.54	1486	13.18	1464	48.46	84
T14_002 - 10	0.05819	0.00095	0.07152	0.00097	0.57377	0.01017	0.02145	0.00057	536.3	35.73	445.3	5.81	460.5	6.56	429	11.23	64
T14_002 - 11	0.07825	0.00097	0.20179	0.00269	2.17695	0.03233	0.05759	0.00161	1153.3	24.36	1184.9	14.41	1173.7	10.33	1131.8	30.67	55
T14_002 - 12	0.07549	0.00174	0.1446	0.00204	1.50503	0.03454	0.04222	0.00182	1081.6	45.64	870.6	11.48	932.4	14	835.9	35.25	92
T14_002 - 13	0.0573	0.00078	0.06988	0.00092	0.552	0.0086	0.02274	0.00064	502.6	29.6	435.4	5.56	446.3	5.63	454.6	12.72	93
T14_002 - 14	0.18597	0.00228	0.47492	0.0063	12.17643	0.17911	0.10596	0.00322	2706.8	20.09	2505.1	27.52	2618.1	13.8	2035.6	58.85	93
T14_002 - 15	0.0605	0.00152	0.05577	0.00086	0.46521	0.01195	0.01705	0.00072	621.6	53.38	349.9	5.25	387.9	8.28	341.7	14.4	79
T14_002 - 16	0.07846	0.00108	0.17804	0.00246	1.92531	0.03088	0.04644	0.0015	1158.6	26.98	1056.3	13.47	1089.9	10.72	917.6	28.96	87
T14_002 - 17	0.05902	0.00124	0.0576	0.00082	0.46854	0.01016	0.01245	0.00034	568	44.91	361	4.99	390.2	7.03	250.1	6.82	109
T14_002 - 18	0.12462	0.00142	0.35837	0.00456	6.15574	0.08327	0.05583	0.00128	2023.3	20.05	1974.4	21.63	1998.2	11.82	1098	24.59	105
T14_002 - 19	0.09767	0.00119	0.29269	0.00379	3.93971	0.05629	0.07679	0.00207	1580	22.65	1654.9	18.89	1621.9	11.57	1495.4	38.95	116
T14_002 - 20	0.08802	0.00137	0.22634	0.00328	2.74581	0.04885	0.06353	0.00239	1382.9	29.6	1315.3	17.22	1341	13.24	1245	45.34	90
T14_002 - 21	0.07618	0.00112	0.18368	0.00245	1.92881	0.03134	0.05166	0.00147	1099.9	29.11	1087.1	13.34	1091.1	10.86	1018	28.24	98
T14_002 - 22	0.0752	0.00124	0.16532	0.00216	1.7131	0.02974	0.04051	0.00201	1074	32.73	986.3	11.97	1013.4	11.13	802.6	39.01	102

1 1	T14_002 -	0.05467	0.0008	0.07367	0.00095	0.55518	0.0089	0.02265	0.00061	398.8	32.25	458.2	5.69	448.4	5.81	452.6	12.03	69
Th4.00: 0.5693 0.0022 0.4833 0.9592 0.1838 0.1592 0.0012 2696 1.8 2174 2641 2896 1.39 1.10 2756 7.6 8 1.100: 6.4077 0.0017 0.0091 0.0026 0.0011 0.1390 0.001 1.100 1.100 1.100 1.100 0.0011 0.1705 0.0026 1.801 0.0011 1.100 1.100 1.100 0.0011 0.1705 0.0026 1.802 0.0011 0.1705 0.0026 1.801 0.0012 1.100 1.100 1.100 0.0011 0.1705 0.0026 0.0077 0.0010 0.0077 0.0096 0.0077 0.0096 0.0077 0.0096 0.0077 0.0096 0.0077 0.0011 0.1007 0.0011 0.1007 0.0011 0.1007 0.0011 0.1007 0.0011 0.0017 0.0011 0.0017 0.0011 0.0017 0.0011 0.0017 0.0011 0.0017 0.0011 0.0017 0.0011 0.	T14_002 -	0.07141	0.00108	0.16589	0.00219	1.63285	0.02679	0.0473	0.00144	969.1	30.43	989.4	12.08	983	10.33	934.2	27.82	91
TH 402: 0.8036 0.90391 0.00394 0.20397 0.10394 0.20397 0.10394 0.20397 0.10341 0.2126 0.1043 0.2136 0.1043 0.2164 0.114 0.2106 0.111 0.2106 0.0111 0.2106 0.0111 0.2106 0.0111 0.2106 0.0111 0.2106 0.0111 0.2106 0.0111 0.2106 0.0111 0.2106 0.0111 0.2106 0.0111 0.2107 0.0031 0.1117 0.0031 0.1116 0.0111 0.0111 0.0037 0.1111 0.0031 0.1116 0.0111 0.0031 0.1111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 0.01111 <td>T14_002 -</td> <td>0.16918</td> <td>0.00222</td> <td>0.44533</td> <td>0.00592</td> <td>10.38388</td> <td>0.15642</td> <td>0.09182</td> <td>0.0031</td> <td>2549.6</td> <td>21.81</td> <td>2374.4</td> <td>26.41</td> <td>2469.6</td> <td>13.95</td> <td>1775.6</td> <td>57.43</td> <td>83</td>	T14_002 -	0.16918	0.00222	0.44533	0.00592	10.38388	0.15642	0.09182	0.0031	2549.6	21.81	2374.4	26.41	2469.6	13.95	1775.6	57.43	83
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	T14_002 -	0.26176	0.00307	0.63918	0.00804	23.06287	0.31221	0.15296	0.00418	3257.3	18.36	3185.8	31.61	3229.6	13.17	2876.9	73.24	101
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	T14_002 -	0.09818	0.00125	0.27784	0.00361	3.75979	0.05521	0.06174	0.00211	1589.9	23.68	1580.5	18.2	1584.2	11.78	1210.9	40.08	96
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	T14_002 -	0.0791	0.00113	0.17025	0.00226	1.85627	0.02963	0.0417	0.00154	1174.7	28.07	1013.5	12.47	1065.7	10.53	825.7	29.81	97
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	T14_002 -	0.06076	0.0008	0.0596	0.00075	0.49921	0.00728	0.01574	0.00047	630.6	27.97	373.2	4.56	411.2	4.93	315.6	9.39	86
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	T14_002 -	0.08812	0.00113	0.21989	0.00277	2.67111	0.03837	0.05818	0.00192	1385.1	24.42	1281.3	14.64	1320.5	10.61	1142.9	36.74	96
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	T14_002 -	0.10554	0.00145	0.30777	0.00408	4.47745	0.06906	0.09718	0.00299	1723.7	24.94	1729.7	20.12	1726.8	12.8	1874.5	55	89
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	T14_002 -	0.05921	0.00132	0.09661	0.00134	0.78847	0.01779	0.03115	0.00081	575	47.89	594.5	7.88	590.3	10.1	620	15.83	105
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	T14_002 -	0.08515	0.0011	0.13273	0.00175	1.55802	0.0233	0.05647	0.00133	1318.9	24.95	803.4	9.98	953.7	9.25	1110.2	25.41	101
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	T14_002 -	0.05454	0.00098	0.05068	0.00065	0.38093	0.00704	0.01464	0.00045	393.6	39.59	318.7	3.97	327.7	5.18	293.7	9.01	96
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	T14_002 -	0.05598	0.00074	0.06987	0.00087	0.53925	0.00792	0.02144	0.00047	451.3	28.75	435.4	5.26	437.9	5.22	428.8	9.22	104
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	T14_002 -	0.12317	0.00156	0.36079	0.00453	6.12468	0.08687	0.10546	0.0033	2002.6	22.28	1985.9	21.44	1993.8	12.38	2026.5	60.26	113
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	T14_002 -	0.08789	0.00119	0.12848	0.00178	1.55645	0.02494	0.03322	0.00122	1380	25.74	779.2	10.19	953.1	9.9	660.6	23.81	97
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	T14_002 -	0.06083	0.00073	0.09786	0.00124	0.82066	0.01144	0.02777	0.00066	633.3	25.61	601.8	7.27	608.4	6.38	553.6	13.05	78
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	T14_002 -	0.07131	0.00086	0.14438	0.00183	1.41938	0.01992	0.03744	0.00093	966.4	24.53	869.4	10.32	897.1	8.36	742.9	18.05	76
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	T14_002 -	0.05377	0.00138	0.05641	0.00079	0.41813	0.01071	0.01788	0.00052	361.2	56.76	353.8	4.83	354.7	7.66	358.2	10.29	102
42^{-}	T14_002 -	0.05169	0.00075	0.04364	0.00057	0.31099	0.00501	0.0132	0.00038	271.9	32.76	275.3	3.54	274.9	3.88	265.1	7.55	103
43^{-} $ -$		0.07904	0.00095	0.19791	0.00252	2.15662	0.03018	0.0577	0.00152	1173.2	23.6	1164.1	13.55	1167.2	9.71	1133.9	28.97	97
44^{-} $ -$		0.15192	0.00253	0.37164	0.00541	7.78357	0.1419	0.09884	0.00429	2367.6	28.18	2037.1	25.44	2206.3	16.4	1905.2	78.83	96
45^{-} 145^{-} 114_{002} 0.0095 0.08384 0.00108 0.67413 0.01164 0.00248 0.0072 541.1 35.92 519 6.44 523.2 7.06 492.8 14.19 89 114_{-002}^{-} 0.11741 0.00138 0.0047 5.71173 0.07814 0.0995 0.0223 1917.1 20.86 1948.3 21.31 11.82 1923.6 41.07 90 114_{-002}^{-} 0.05944 0.0096 0.07308 0.0098 0.59892 0.0152 0.0216 0.0056 583.3 34.72 454.7 5.9 476.5 6.68 423.2 11.13 82 114_{-002}^{-} 0.01675 0.00192 0.43675 0.00551 10.08603 0.13626 0.12194 0.00295 2532.8 19.14 2336.1 24.73 2442.7 12.48 2325.6 53.16 92 114_{-002}^{-} 0.06416 0.00093 0.0141 </td <td></td> <td>0.0603</td> <td>0.0008</td> <td>0.0993</td> <td>0.00127</td> <td>0.82537</td> <td>0.01234</td> <td>0.0296</td> <td>0.00089</td> <td>614.2</td> <td>28.47</td> <td>610.3</td> <td>7.42</td> <td>611</td> <td>6.86</td> <td>589.6</td> <td>17.52</td> <td>93</td>		0.0603	0.0008	0.0993	0.00127	0.82537	0.01234	0.0296	0.00089	614.2	28.47	610.3	7.42	611	6.86	589.6	17.52	93
46 -16 <th< td=""><td></td><td>0.05551</td><td>0.00098</td><td>0.0721</td><td>0.00094</td><td>0.55173</td><td>0.01017</td><td>0.02133</td><td>0.00061</td><td>432.5</td><td>38.4</td><td>448.8</td><td>5.64</td><td>446.1</td><td>6.66</td><td>426.5</td><td>11.99</td><td>79</td></th<>		0.05551	0.00098	0.0721	0.00094	0.55173	0.01017	0.02133	0.00061	432.5	38.4	448.8	5.64	446.1	6.66	426.5	11.99	79
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		0.05832	0.00095	0.08384	0.00108	0.67413	0.01164	0.02468	0.00072	541.1	35.92	519	6.44	523.2	7.06	492.8	14.19	89
48 -		0.11741	0.00138	0.35287	0.00447	5.71173	0.07814	0.09985	0.00223	1917.1	20.86	1948.3	21.31	1933.1	11.82	1923.6	41.07	90
49		0.05944	0.00096	0.07308	0.00098	0.59892	0.01052	0.02116	0.00056	583.3	34.72	454.7	5.9	476.5	6.68	423.2	11.13	82
50 -		0.1675	0.00192	0.43675	0.00551	10.08603	0.13626	0.12194	0.00295	2532.8	19.14	2336.1	24.73	2442.7	12.48	2325.6	53.16	92
		0.06416	0.00093	0.10365	0.00141	0.91685	0.01506	0.0366	0.00128	746.8	30.23	635.8	8.22	660.7	7.98	726.6	24.86	91
51	T14_002 - 51	0.05657	0.00079	0.08262	0.00104	0.64439	0.00979	0.02535	0.00067	474	30.71	511.7	6.16	505	6.05	505.9	13.25	83

T14_002 - 52	0.09756	0.00135	0.28168	0.00353	3.78893	0.05638	0.07236	0.00194	1578	25.6	1599.8	17.78	1590.4	11.95	1412.1	36.55	86
T14_002 - 53	0.18351	0.00237	0.51993	0.00596	13.15528	0.1769	0.15032	0.00573	2684.9	21.22	2698.9	25.29	2690.9	12.69	2830.5	100.59	90
T14_002 - 54	0.08306	0.00131	0.21264	0.00267	2.43536	0.04007	0.06468	0.00258	1270.6	30.43	1242.9	14.22	1253.1	11.84	1266.9	49.04	74
T14_002 - 55	0.05241	0.00094	0.04372	0.0006	0.31595	0.00606	0.01333	0.00049	303.3	40.16	275.9	3.72	278.8	4.67	267.7	9.74	78
T14_002 - 56	0.0553	0.00107	0.06849	0.00088	0.52235	0.01027	0.02231	0.00088	424.2	42.17	427.1	5.31	426.7	6.85	445.9	17.42	85
T14_002 - 57	0.06758	0.00092	0.12777	0.00164	1.19044	0.01816	0.04533	0.00157	855.6	28.08	775.1	9.4	796.2	8.42	896.1	30.34	73
T14_002 - 58	0.05611	0.00092	0.05721	0.00072	0.44261	0.00761	0.01797	0.00057	456.3	35.83	358.6	4.39	372.1	5.35	360	11.23	85
T14_002 - 59	0.16849	0.0021	0.24166	0.00304	5.61441	0.07917	0.07679	0.00256	2542.7	20.79	1395.3	15.77	1918.3	12.15	1495.4	47.99	90
59 T14_002 - 60	0.09638	0.00125	0.17558	0.00223	2.33335	0.03404	0.04702	0.00166	1555.2	24.13	1042.8	12.21	1222.5	10.37	928.7	32.1	85
T14_002 - 61	0.0582	0.00128	0.07915	0.00099	0.63535	0.01365	0.02552	0.00112	536.7	48.06	491.1	5.9	499.4	8.47	509.3	22.03	103
T14_002 - 62	0.07004	0.00118	0.15229	0.00197	1.4706	0.02576	0.04783	0.00124	929.4	34.13	913.8	11.04	918.4	10.59	944.4	23.92	103
T14_002 - 63	0.05642	0.00087	0.06937	0.00093	0.5396	0.0092	0.02125	0.00058	468.2	34.09	432.4	5.62	438.2	6.07	425	11.51	103
T14_002 - 64	0.05889	0.00151	0.09029	0.0013	0.73307	0.01876	0.02678	0.00082	563	54.9	557.3	7.69	558.4	10.99	534.2	16.08	109
T14_002 - 65	0.05719	0.00092	0.0802	0.00108	0.63225	0.01111	0.02317	0.00065	498.3	35.16	497.3	6.45	497.5	6.91	462.9	12.78	107
T14_002 - 66	0.05788	0.00074	0.06696	0.00083	0.53435	0.00766	0.01706	0.00041	524.8	28.04	417.8	5.04	434.7	5.07	341.9	8.12	98
T14_002 - 67	0.09699	0.00129	0.27059	0.00336	3.61872	0.05229	0.07872	0.00211	1567.1	24.66	1543.8	17.04	1553.7	11.49	1531.5	39.45	98
T14_002 - 68	0.07741	0.00092	0.19163	0.00237	2.04527	0.02781	0.05546	0.00145	1131.8	23.48	1130.2	12.83	1130.7	9.27	1090.9	27.75	100
T14_002 - 69	0.05606	0.00083	0.07726	0.00098	0.59718	0.00958	0.02153	0.00058	454.4	32.25	479.8	5.88	475.4	6.09	430.5	11.48	107
T14_002 - 70	0.05723	0.00079	0.07585	0.00096	0.59848	0.00908	0.01959	0.00053	499.8	30.05	471.3	5.74	476.3	5.76	392.1	10.52	103
T14_002 - 71	0.16239	0.00197	0.47602	0.00589	10.6579	0.14596	0.12598	0.0037	2480.7	20.28	2509.9	25.71	2493.8	12.71	2398.3	66.4	99
T14_002 - 72	0.07642	0.00104	0.19358	0.00235	2.03972	0.02991	0.05621	0.00195	1106.2	27.07	1140.7	12.71	1128.9	9.99	1105.4	37.33	97
T14_002 - 73	0.0902	0.00117	0.25273	0.00315	3.14312	0.04523	0.05954	0.0019	1429.7	24.54	1452.5	16.2	1443.3	11.08	1169	36.23	105
T14_002 - 74	0.17507	0.00217	0.50657	0.00624	12.22739	0.16955	0.12299	0.00407	2606.7	20.49	2642	26.69	2622	13.02	2344.5	73.17	100
T14_002 - 75	0.07176	0.00102	0.16622	0.00213	1.64442	0.0256	0.0449	0.00145	979.2	28.55	991.2	11.79	987.4	9.83	887.7	27.98	104
T14_002 - 76	0.05411	0.00083	0.04532	0.00062	0.33802	0.00582	0.01212	0.00034	375.5	34.07	285.7	3.85	295.7	4.42	243.4	6.77	103
T14_002 - 77	0.05425	0.00119	0.06115	0.00083	0.4574	0.01017	0.01758	0.00044	381.5	48.3	382.6	5.02	382.4	7.08	352.2	8.75	101
T14_002 - 78	0.05275	0.00098	0.05187	0.00068	0.37725	0.00731	0.01467	0.00035	318.2	41.72	326	4.17	325	5.39	294.3	7.06	102
T14_002 - 79	0.05796	0.00074	0.08271	0.00105	0.66085	0.00957	0.02151	0.00049	527.8	27.93	512.3	6.26	515.1	5.85	430.1	9.6	100
T14_002 - 80	0.05589	0.00099	0.0724	0.00097	0.55781	0.01042	0.01938	0.00053	447.6	38.46	450.6	5.83	450.1	6.79	388	10.59	103
				1				1									

T14_002 - 81	0.07192	0.00146	0.16524	0.00233	1.6385	0.03411	0.04475	0.00196	983.7	40.7	985.8	12.88	985.1	13.13	884.9	37.99	102
T14_002 - 82	0.06527	0.00139	0.07752	0.00115	0.69669	0.01548	0.01972	0.00134	783	44.14	481.3	6.88	536.8	9.27	394.7	26.48	103
T14_002 - 83	0.0769	0.00098	0.19636	0.00242	2.08192	0.02931	0.04523	0.00115	1118.6	25.22	1155.7	13.01	1142.9	9.66	894.1	22.23	108
T14_002 - 84	0.05603	0.00152	0.07346	0.00103	0.5675	0.01529	0.01936	0.00058	453.4	59.23	457	6.18	456.4	9.9	387.5	11.52	99
T14_002 - 85	0.05912	0.00145	0.07899	0.00112	0.64375	0.01575	0.01841	0.0006	571.5	52.33	490.1	6.7	504.6	9.73	368.7	12	107
T14_002 - 86	0.07374	0.00183	0.17682	0.00255	1.7975	0.04394	0.04481	0.00177	1034.4	49.36	1049.6	13.99	1044.5	15.95	886	34.25	97
T14_002 - 87	0.30749	0.00375	0.72348	0.00902	30.67105	0.41998	0.16819	0.0048	3508.4	18.71	3509.1	33.73	3508.6	13.46	3142.1	82.99	99
T14_002 - 88	0.05415	0.00096	0.0585	0.00073	0.43677	0.00795	0.01557	0.00045	377.1	39.46	366.5	4.48	368	5.62	312.2	9	104
T14_002 - 89	0.06303	0.00098	0.09999	0.00129	0.86891	0.0144	0.02195	0.00083	709.1	32.62	614.4	7.58	635	7.83	438.8	16.39	104
T14_002 - 90	0.11114	0.00152	0.33353	0.00409	5.11024	0.07431	0.08283	0.00288	1818.1	24.6	1855.5	19.76	1837.8	12.35	1608.5	53.79	100

Table 1. Sample details with locations and summary on the U/Pb data carried out in this work. A) stratigraphic unit; b) lithology; c) sample; d) Hf analysis; e)
 number of samples on which has been done Hf analysis; f) Major U-Pb detrital age Peaks (Ma); g) N* of U-Pb analyses; h) N*of > 10% conc. U-Pb analyses; i)
 Youngest > 10% concentration U-Pb analysis Ma (MDA).

а	b	с	d	е	f	g	h	i
Sap Bon Fm	Qtz ssn	T14_002	Y	32	~400, 1100	90	53	275 ± 4
Pang Asok Fm	Qtz ssn	T13_003 - T13_005	Y - Y	42	~250, 450, 1400, 1700	180	120	251 ± 3
Siam City Cement Quarry	Qtz ssn	T13_016 - T13_065	Y - Y	36	~300, 450, 900, 1200, 1800	165	93	268 ± 4
Clastic 4	volc ssn	T15_PK1	Y	68	~450, 900, 1400, 1650	135	128	224 ± 4
Clastic 5	volc ssn	Т15_РКЗ	Y	55	~450, 1000, 1400	147	136	205 ± 6
Clastic 4	volc ssn	Т15_РК4	Y	38	~450, 850, 1100, 1400	120	112	217 ± 4

9991	Table 2.								
	Indochina	C Vietnam	Sukhothai	East Malaysia	Ailaoshan	Sibumasu	Loei	Inthanon	Phuket
Indochina	0	0.43846153	0.33618489	1 0.230769231	0.758055152	0.807692308	0.19736326	0.713204119	0.807692308
C Vietnam	0.43846153	8 0	0.55087961	4 0.6	1	1	0.597733711	0.940944882	1
Sukhothai	0.33618489	0.55087961	14 0	0.330941704	0.780269058	0.802690583	0.313342395	0.705465909	0.807174888
East Malaysia	a 0.23076923	0.6	0.33094170	4 0	0.75	0.75	0.181303116	0.688582677	0.78902439
Ailaoshan	0.75805515	52 1	0.78026905	8 0.75	0	0.150943396	0.755465284	0.145297876	0.215830649
Sibumasu	0.80769230	08 1	0.80269058	3 0.75	0.150943396	0	0.83286119	0.102362205	0.155600723
Loei	0.1973632	6 0.59773371	0.31334239	5 0.181303116	0.755465284	0.83286119	0	0.738997569	0.841359773
Inthanon	0.71320411	.9 0.94094488	32 0.70546590	9 0.688582677	0.145297876	0.102362205	0.738997569	0	0.152871135
Phuket	0.80769230	08 1	0.80717488	8 0.78902439	0.215830649	0.155600723	0.841359773	0.152871135	0
Khorat P	0.39573804	6 0.75337837	0.45950490	8 0.39527027	0.386537481	0.493243243	0.386704693	0.40777293	0.510135135
T15_PK1	0.70733173	0.984375	0.74786294	8 0.703125	0.201356132	0.28125	0.63653063	0.194512795	0.32183689
Т15_РКЗ	0.64185520	0.96323529	0.69453969	9 0.626470588	0.297308546	0.397058824	0.51812198	0.316755442	0.419117647
T15_PK4	0.70920329	0.98214285	0.74451473	4 0.705357143	0.341981132	0.357142857	0.646575273	0.303922947	0.412238676
T13_003-005	0.59743589	0.98333333	0.68673393	1 0.591666667	0.281289308	0.408333333	0.554532578	0.339304462	0.441666667
T13_016-065	0.68775847	/8 1	0.74709484	5 0.667741935	0.217285453	0.33781362	0.667001736	0.273981881	0.376344086
T14_002	0.67416545	57 1	0.73094170	4 0.643396226	0.301886792	0.341020266	0.591319686	0.297652652	0.429590428
S China	0.63503427	3 0.9900990	1 0.70030635	4 0.631188119	0.241173174	0.376237624	0.590946063	0.273875419	0.376237624
NE Vietnam	0.61098901	.1 0.95918367	0.66971721	4 0.607142857	0.29283789	0.308012094	0.583453778	0.302346135	0.401443504
Truong Son	0.55447667	0.9344262	3 0.64953809	2 0.485245902	0.407000722	0.423952641	0.430919983	0.382384579	0.523723844
9992						_			
Khorat P	T15_PK1	Т15_РКЗ	Т15_РК4	T13_003-005	T13_016-065	T14_002	S China	NE Vietnam	Truong Son
0.395738046	0.707331731	0.641855204	0.709203297	0.597435897	0.687758478	0.674165457	0.635034273	0.610989011	0.554476671
0.753378378	0.984375	0.963235294	0.982142857	0.983333333	1	1	0.99009901	0.959183673	0.93442623
0.459504908	0.747862948	0.694539699	0.744514734	0.686733931	0.747094845	0.730941704	0.700306354	0.669717214	0.040500000
0.39527027	0.703125							0.003717214	0.649538092
0.386537481		0.626470588	0.705357143	0.591666667	0.667741935	0.643396226	0.631188119	0.607142857	0.649538092
	0.201356132	0.626470588 0.297308546	0.705357143 0.341981132	0.591666667 0.281289308	0.667741935 0.217285453				
0.493243243	0.201356132 0.28125					0.643396226	0.631188119	0.607142857	0.485245902
		0.297308546	0.341981132	0.281289308	0.217285453	0.643396226	0.631188119 0.241173174	0.607142857 0.29283789	0.485245902 0.407000722
0.493243243	0.28125	0.297308546 0.397058824	0.341981132 0.357142857	0.281289308 0.408333333	0.217285453 0.33781362	0.643396226 0.301886792 0.341020266	0.631188119 0.241173174 0.376237624	0.607142857 0.29283789 0.308012094	0.485245902 0.407000722 0.423952641
0.493243243 0.386704693	0.28125 0.63653063	0.297308546 0.397058824 0.51812198	0.341981132 0.357142857 0.646575273	0.281289308 0.408333333 0.554532578	0.217285453 0.33781362 0.667001736	0.643396226 0.301886792 0.341020266 0.591319686	0.631188119 0.241173174 0.376237624 0.590946063	0.607142857 0.29283789 0.308012094 0.583453778	0.485245902 0.407000722 0.423952641 0.430919983
0.493243243 0.386704693 0.40777293	0.28125 0.63653063 0.194512795	0.297308546 0.397058824 0.51812198 0.316755442	0.341981132 0.357142857 0.646575273 0.303922947	0.281289308 0.408333333 0.554532578 0.339304462	0.217285453 0.33781362 0.667001736 0.273981881	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579
0.493243243 0.386704693 0.40777293 0.510135135	0.28125 0.63653063 0.194512795 0.32183689	0.297308546 0.397058824 0.51812198 0.316755442 0.419117647	0.341981132 0.357142857 0.646575273 0.303922947 0.412238676	0.281289308 0.408333333 0.554532578 0.339304462 0.441666667	0.217285453 0.33781362 0.667001736 0.273981881 0.376344086	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652 0.429590428	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419 0.376237624	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135 0.401443504	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579 0.523723844
0.493243243 0.386704693 0.40777293 0.510135135 0	0.28125 0.63653063 0.194512795 0.32183689 0.317778716	0.297308546 0.397058824 0.51812198 0.316755442 0.419117647 0.257551669	0.341981132 0.357142857 0.646575273 0.303922947 0.412238676 0.314430502	0.281289308 0.408333333 0.554532578 0.339304462 0.441666667 0.238288288	0.217285453 0.33781362 0.667001736 0.273981881 0.376344086 0.298823017	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652 0.429590428 0.284612443	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419 0.376237624 0.25140487	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135 0.401443504 0.222007722	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579 0.523723844 0.223877566
0.493243243 0.386704693 0.40777293 0.510135135 0 0.317778716	0.28125 0.63653063 0.194512795 0.32183689 0.317778716 0	0.297308546 0.397058824 0.51812198 0.316755442 0.419117647 0.257551669 0.173253676	0.341981132 0.357142857 0.646575273 0.303922947 0.412238676 0.314430502 0.188616071	0.281289308 0.408333333 0.554532578 0.339304462 0.441666667 0.238288288 0.144791667	0.217285453 0.33781362 0.667001736 0.273981881 0.376344086 0.298823017 0.095430108	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652 0.429590428 0.284612443 0.129716981	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419 0.376237624 0.25140487 0.268177599	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135 0.401443504 0.222007722 0.233418367	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579 0.523723844 0.223877566 0.278645833
0.493243243 0.386704693 0.40777293 0.510135135 0 0.317778716 0.257551669	0.28125 0.63653063 0.194512795 0.32183689 0.317778716 0 0.173253676	0.297308546 0.397058824 0.51812198 0.316755442 0.419117647 0.257551669 0.173253676 0	0.341981132 0.357142857 0.646575273 0.303922947 0.412238676 0.314430502 0.188616071 0.144957983	0.281289308 0.408333333 0.554532578 0.339304462 0.441666667 0.238288288 0.144791667 0.190196078	0.217285453 0.33781362 0.667001736 0.273981881 0.376344086 0.298823017 0.095430108 0.202403542	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652 0.429590428 0.284612443 0.129716981 0.134850166	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419 0.376237624 0.25140487 0.268177599 0.231581246	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135 0.401443504 0.222007722 0.233418367 0.210984394	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579 0.523723844 0.223877566 0.278645833 0.239392478
0.493243243 0.386704693 0.40777293 0.510135135 0 0.317778716 0.257551669 0.314430502	0.28125 0.63653063 0.194512795 0.32183689 0.317778716 0 0.173253676 0.188616071	0.297308546 0.397058824 0.51812198 0.316755442 0.419117647 0.257551669 0.173253676 0 0.144957983	0.341981132 0.357142857 0.646575273 0.303922947 0.412238676 0.314430502 0.188616071 0.144957983 0	0.281289308 0.408333333 0.554532578 0.339304462 0.441666667 0.238288288 0.144791667 0.190196078 0.22202381	0.217285453 0.33781362 0.667001736 0.273981881 0.376344086 0.298823017 0.095430108 0.202403542 0.193068356	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652 0.429590428 0.284612443 0.129716981 0.134850166 0.124494609	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419 0.376237624 0.25140487 0.268177599 0.231581246 0.138702263	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135 0.401443504 0.222007722 0.233418367 0.210984394 0.144132653	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579 0.523723844 0.223877566 0.278645833 0.239392478 0.290690867
0.493243243 0.386704693 0.40777293 0.510135135 0 0.317778716 0.257551669 0.314430502 0.238288288	0.28125 0.63653063 0.194512795 0.32183689 0.317778716 0 0.173253676 0.188616071 0.144791667	0.297308546 0.397058824 0.51812198 0.316755442 0.419117647 0.257551669 0.173253676 0 0.144957983 0.190196078	0.341981132 0.357142857 0.646575273 0.303922947 0.412238676 0.314430502 0.188616071 0.144957983 0.22202381	0.281289308 0.408333333 0.554532578 0.339304462 0.441666667 0.238288288 0.144791667 0.190196078 0.22202381	0.217285453 0.33781362 0.667001736 0.273981881 0.376344086 0.298823017 0.095430108 0.202403542 0.193068356 0.147849462	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652 0.429590428 0.284612443 0.129716981 0.134850166 0.124494609 0.165251572	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419 0.376237624 0.25140487 0.268177599 0.231581246 0.138702263 0.312953795	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135 0.401443504 0.222007722 0.233418367 0.210984394 0.144132653 0.245918367	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579 0.523723844 0.223877566 0.278645833 0.239392478 0.290690867 0.269672131
0.493243243 0.386704693 0.40777293 0.510135135 0 0.317778716 0.257551669 0.314430502 0.238288288 0.298823017	0.28125 0.63653063 0.194512795 0.32183689 0.317778716 0 0.173253676 0.188616071 0.144791667 0.095430108	0.297308546 0.397058824 0.51812198 0.316755442 0.419117647 0.257551669 0.173253676 0 0.144957983 0.190196078 0.202403542	0.341981132 0.357142857 0.646575273 0.303922947 0.412238676 0.314430502 0.318616071 0.144957983 0 0.22202381 0.193068356	0.281289308 0.408333333 0.554532578 0.339304462 0.441666667 0.238288288 0.144791667 0.190196078 0.22202381 0 0.147849462	0.217285453 0.33781362 0.667001736 0.273981881 0.376344086 0.298823017 0.095430108 0.202403542 0.193068356 0.147849462 0	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652 0.429590428 0.284612443 0.129716981 0.134850166 0.124494609 0.165251572 0.113613309	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419 0.376237624 0.25140487 0.268177599 0.231581246 0.138702263 0.312953795 0.217076546	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135 0.401443504 0.222007722 0.233418367 0.210984394 0.144132653 0.245918367 0.217467632	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579 0.523723844 0.223877566 0.278645833 0.239392478 0.290690867 0.269672131 0.280980081
0.493243243 0.386704693 0.40777293 0.510135135 0 0.317778716 0.257551669 0.314430502 0.238288288 0.298823017 0.284612443	0.28125 0.63653063 0.194512795 0.32183689 0.317778716 0 0.173253676 0.188616071 0.144791667 0.095430108 0.129716981	0.297308546 0.397058824 0.51812198 0.316755442 0.419117647 0.257551669 0.173253676 0 0.144957983 0.190196078 0.202403542 0.134850166	0.341981132 0.357142857 0.646575273 0.303922947 0.314430502 0.314430502 0.188616071 0.144957983 0.22202381 0.193068356 0.124494609	0.281289308 0.408333333 0.554532578 0.339304462 0.441666667 0.238288288 0.144791667 0.190196078 0.22202381 0 0.147849462 0.165251572	0.217285453 0.33781362 0.667001736 0.273981881 0.376344086 0.298823017 0.095430108 0.202403542 0.193068356 0.147849462 0 0 0.113613309	0.643396226 0.301886792 0.341020266 0.591319686 0.297652652 0.429590428 0.284612443 0.129716981 0.134850166 0.124494609 0.165251572 0.113613309 0	0.631188119 0.241173174 0.376237624 0.590946063 0.273875419 0.376237624 0.25140487 0.268177599 0.231581246 0.138702263 0.312953795 0.217076546 0.164206987	0.607142857 0.29283789 0.308012094 0.583453778 0.302346135 0.401443504 0.222007722 0.233418367 0.210984394 0.144132653 0.245918367 0.217467632 0.192144782	0.485245902 0.407000722 0.423952641 0.430919983 0.382384579 0.523723844 0.223877566 0.278645833 0.239392478 0.290690867 0.269672131 0.280980081 0.223321992

9991 Table 2. KS Dissimilarity Matrix

Appendix C

10034		•	sprupine descriptions for analysed samples from the R	5
Sample Number	Rock Name	Coordinates	Field Description	Petrographic Description
				Abundant volcanic glass (largely altered in chlorite) in a fine groundmass of fine-grained to cryptocrystalline plagiocalse and
T13_015	Basalt	14°37'24.2" - 101°06'22.5"	Massive green to gray flow next to massive volcanic-lapilli tuffaceous body	scattered altered horneblende. Pronounced opacity probably related to formation of magnetite/ilmenite by iron oxidation
			Massive volcaninc (Sill) layer bounded by carbonates of the Khao Khad Fm.	
T13_075	Basalt	14°37'34.1" - 101°04'40.9"	both at top and bottom	Abundant volcanic glass surrounding sericized plagioclase, relict orthopyroxene and rare olivine and poly-cristalline quartz
742 027			Metric Dyke running through the hinge of a fault bend fold after the main	Groundmass of alkali with abundant volcanic glass. Cryptocrystalline plagioclase and subordinate feldspar, secondary hematite and
T13_027	Basalt	14°42'00.8" - 100°53'02.1"	folding event	sericite alteration, rare microcrystals of pyroxene (?)
T13_029	Andesite porphyry	14°42'01.1" - 100°53'02.8"	Green dyke partially folded in some parts by fold bend fold	Sanidine and plagiocalse phenocristals altered in sericite in a fine-grained equigranular quartzofeldspatic groundmass with volcanic glass altered in chlorites
				Plagioclase, orthpyroxene, olivine and accessory cryptic hornblende. Hornblende partially turned in cummingtonite/epidote
T13_040	Gabbro	14°34'51.6" - 101°06'16.9"	Intruasion within an isolate quarry	indicating a lower degree of regional metamorphism (green shist facies), accessory magnetite and ilmenite
				Plagioclase, orthpyroxene, olivine and accessory cryptic hornblende. Hornblende partially turned in epidote, actinolite and chlorite
T13_042	Gabbro	14°34'51.6" - 101°06'16.9"	Intruasion within an isolate quarry	indicating a lower degree of regional metamorphism (green shist facies), accessory magnetite
T13 049	Basaltic andesitic	14°37'40.5" - 101°04'26.7"	Folded layer within shale outcrop	Massive orthpyroxene, hornblende accessory augire and ploycristalline quartz in a matrix of cryptic quartzofeldspatic groundmass
T13_060		14°37'38.4" - 101°04'25.0"	Layer of green to gray tuff folded parallel to layers of shale	Abundant plagioclase in a groundmass of alkali and rare cryptocrystalline augite
 T13_072	Basaltic andesitic	14°45'55.5" - 100°53'48.1"	Layer of dark tuff folded parallel to thrust	Hornblende and minor orthopyroxene in a fine grained plagioclase groundmass, accessory magnetite and ilmenite
T13_074	Gabbroic basalt	14°37'34.1" - 101°04'40.9"	Massive volcanic body partially metamorphosed, evidence of weathering	plagiocalse and feldspar in an alkali fine grained groundmass, minor relict pyroxene and hematite
				Mostly fine grained groundmass of plagioclase and scattered cryptocrystalline olivine and pyroxene, presence of amygdales and
T13_076	Basaltic tuff	14°42'42.1" - 100°53'13.1"	Dyke running through the hinge of a fault propagation fold	voids filled by chalcedony roses
				Groundmass and microcrystals alkali in composition with relict felspar phenocrysts and biotite with sericite alteration has more
T13_055	Andesite	14°42'05.7" - 100°53'07.9"	Dyke running through carbomates of the Khao Khad Fm without being folded	abundant carbonate crystals
				Groundmass of feldspar and alkali with relict felspar phenocrysts and muscovite with sericite alteration. Hematite that seems to
T13_081	Andesite	14°43'43.6" - 100°53'49.8"	Volcanic body intruded within a secondary thrust	have replaced feldspar
				Quarty and altered foldener with autodral to cub outodral placeness altered in covinite, contrared duranismus in a
T1/4000	Rhyolite	14°32'16.7" - 100°57'03.4"	Massive volcanic body south of Highway 2	Quartz and altered feldspar with euhedral to sub-euhedral plagiocase altered in sericite, scattered clynopiroxene in a cryptocrystalline matrix of polycristalline quartz and alkali, scattered amygdales partially rimmed by plagioclase and filled by quartz
T14100035	· · · ·	14 52 10.7 - 100 57 03.4	wassive voicanic body south of highway 2	u sprou stanne matrix of portristanne quartz and alkan, stattered anyguales partiany minned by plagiociase and filled by quartz
10036				
10037				
10038				
10039				
10040				
10041				
10041				
10043				
10044				
10045	Table 2. X	RF and ICP-MS for	analysed samples from the KKFTB igneous and volcar	ic suite, values of trace elements and REE (ppm), of major elements (% wt)

Table 1. Locations and petrographic descriptions for analysed samples from the KKFTB igneous and volcanic suite

| Sample | SiO | TiO ₂ | Al ₂ O ₃
 | Fe ₂ O ₃ | MnO | MgO
 | CaO | Na ₂ O | K,0
 | P2O5 | Loss | Sum | S% | Sc

 | Ba

 | v
 | Cr | Co | Ni | Cu
 | Zn (
 | a As | RI
 |) Sr | · Y
 | Zr | Nb | Mo | Sn | w | Pb
 | U | Th | La | Ce | Nd
 |
|---|--|---
--|---
---|---|---|---
--|--|--|---|---
--
--
--
--
--
--|--|---|---
--
--

--
--|--|---
--|---|--|--|--|--
---|--|--|--|
| T-13-1 | 47.6 | 0.728 | 13.6
 | 7.29 | 0.129 | 10.3
 | 12.8 | 2.20 | 0.91
 | 0.238 | 3.62 | 99.44 | 0.03 | 21.3

 | 267

 | 181
 | 616 | 60.7 | 325 | 45.6
 |
 | .2 <3 | 23.
 | | -
 | 98.7 | 2.8 | <0.5 | <1 | 62.4 | 7.7
 | <2 | 4.5 | 17.6 | 36.1 | 14.5
 |
| T-13-2 | 62.2 | 0.376 | 17.0
 | 4.21 | 0.076 | 2.68
 | 2.29 | 6.53 | 0.57
 | 0.168 | 3.61 | 99.72 | 0.06 | 11.2

 | 268

 | 90.4
 | 26.6 | 40.0 | 9.0 | 19.1
 |
 | .8 <3 |
 | |
 | 110 | 1.2 | <0.5 | <1 | 84.2 | <1
 | <2 | <2 | 8.3 | 24.1 | 6.1
 |
| T-13-7 | 49.3 | 0.482 | 15.0
 | 5.63 | 0.071 | 6.22
 | 8.27 | 5.52 | 0.43
 | 0.129 | 4.72 | 95.74 | 0.04 | 30.6

 | 166

 | 237
 | 744 | 53.0 | 228 | 64.1
 |
 | .7 <3 |
 | |
 | 68.4 | 1.0 | < 0.5 | <1 | 43.1 | 64.9
 | <2 | <2 | 9.3 | 15.9 | <4
 |
| T-13-9 | 41.8 | 0.869 | 15.8
 | 11.6 | 0.184 | 12.2
 | 11.1 | 0.89 | 0.73
 | 0.228 | 4.72 | 100.20 | < 0.01 | 35.8

 | 175

 | 324
 | 1168 | 78.1 | 404 | 79.5
 | 81.6 1
 | .3 <3 | 6.1
 | L 502 | 2 13.6
 | 61.1 | 1.1 | 0.7 | <1 | 20.5 | <1
 | <2 | <2 | 7.7 | 16.7 | 5.2
 |
| T-13-13 | 40.9 | 0.782 | 13.8
 | 10.2 | 0.129 | 10.8
 | 9.04 | 2.75 | 0.58
 | 0.252 | 1.23 | 90.52 | < 0.01 | 36.1

 | 104

 | 182
 | 880 | 64.8 | 310 | 17.3
 | 61.8 1
 | .4 5.5 | 5.4
 | 1 20: | 1 13.0
 | 52.7 | 1.2 | 0.8 | <1 | 10.7 | 2.9
 | <2 | <2 | 7.1 | 14.5 | <4
 |
| T-13-15 | 47.5 | 1.455 | 16.0
 | 11.3 | 0.149 | 6.73
 | 8.88 | 3.15 | 0.93
 | 0.393 | 3.67 | 100.20 | <0.01 | 32.8

 | 134

 | 295
 | 201 | 48.9 | 91.2 | 30.3
 | 95.0 1
 | .0 <3 | 7.8
 | 3 45 | 2 23.3
 | 131 | 4.4 | <0.5 | <1 | 47.8 | 1.6
 | <2 | <2 | 9.2 | 24.4 | 8.9
 |
| T-13-17 | 47.3 | 0.717 | 18.1
 | 10.2 | 0.206 | 3.69
 | 7.80 | 4.76 | 0.14
 | 0.504 | 6.74 | 100.12 | 0.34 | 17.6

 | 38.7

 | 262
 | 2.5 | 26.9 | <1 | 23.6
 | 104 1
 | .3 <3 | 2.8
 | 3 111 | 4 18.0
 | 67.1 | 1.4 | < 0.5 | 1.8 | 8.1 | 4.3
 | <2 | 2.4 | 8.1 | 19.8 | 10.8
 |
| T-13-20 | 48.4 | 0.767 | 16.7
 | 9.95 | 0.129 | 7.90
 | 2.97 | 3.20 | 3.57
 | 0.140 | 6.17 | 99.94 | < 0.01 | 39.6

 | 369

 | 358
 | 324 | 30.4 | 75.9 | 34.1
 | 56.8 14
 | .2 <3 |
 | |
 | 54.1 | 1.0 | 0.9 | <1 | 24.6 | <1
 | <2 | <2 | 7.4 | 13.8 | 4.7
 |
| T-13-21 | 45.0 | 0.963 | 15.5
 | 8.71 | 0.094 | 4.86
 | 10.6 | 2.81 | 0.47
 | 0.185 | 1.20 | 90.36 | 0.08 | 32.8

 | 202

 | 223
 | 244 | 51.7 | 65.4 |
 |
 | .0 7.0 |
 | |
 | 85.7 | 4.7 | <0.5 | <1 | 41.6 | 2.3
 | <2 | <2 | 7.1 | 19.5 | 7.1
 |
| T-13-25 | 38.9 | 0.961 | 14.6
 | 8.72 | 0.121 | 4.98
 | 13.9 | 0.10 | 0.67
 | 0.207 | 4.03 | 87.23 | 0.31 | 32.7

 | 94.1

 | 216
 | 369 | 29.9 | 95.0 | 51.6
 |
 | .5 13.0 |
 | |
 | 93.9 | 8.1 | 3.7 | 1.6 | <2 | <1
 | <2 | <2 | 12.0 | 23.3 | 7.4
 |
| T-13-27 | 46.3 | 0.799 | 15.9
 | 8.68 | 0.137 | 3.36
 | 8.51 | 2.92 | 1.32
 | 0.446 | 3.53 | 91.91 | 3.12 | 17.5

 | 247

 | 237
 | 34.3 | 21.3 | 16.1 | 119
 |
 | .0 <3 |
 | |
 | 129 | 4.1 | <0.5 | 2.2 | 32.5 | <1
 | <2 | <2 | 20.3 | 39.3 | 17.4
 |
| T-13-30 | 49.4 | 0.905 | 17.6
 | 9.76 | 0.194 | 3.60
 | 8.64 | 3.20 | 0.12
 | 0.414 | 5.79
3.49 | 99.71
93.87 | 0.26 | 17.9

 | 47.3

 | 246
 | 4.4
224 | 35.8 | <1 | 31.5
 | 103 20
 | |
 | |
 | 86.5 | 3.3 | <0.5 | 1.7 | 44.0
20.4 | 4.4
 | <2 | <2 | 10.0 | 25.7
8.7 | 10.9
<4
 |
| T-13-35
T-13-40 | 52.4 | 0.506 | 15.7
 | 6.02 | 0.062 | 6.70
8.60
 | 5.23 | 3.45 | 0.27
 | 0.110 | 3.49 | 93.87 | <0.01 | 56.1

 | 62.8
118

 | 171
585
 | 224 | 46.2
58.4 | 128
62.6 | 36.8
 | 93.9 1
 | .8 <3
.4 <3 |
 | |
 | 65.6
37.5 | 1.3 | 0.6 | <1 | 20.4 | <1
 | <2 | <2
<2 | 5.2
<4 | 8.7 | <4
 |
| T-13-40 | 42.5 | 1.365 | 19.2
 | 14.2 | 0.202 | 6.65
 | 14.3 | 1.40 | 0.28
 | 0.508 | 0.51 | 100.20 | 0.19 | 36.5

 | 64.9

 | 456
 | 31.4 | 57.1 | 14.5 | 44.9
 | 104 2
 | |
 | |
 | 35.6 | 1.7 | <0.5 | 1.4 | 72.9 | <1
 | <2 | <2 | 6.4 | 12.0 | <4
 |
| T-13-42 | 45.8 | 0.387 | 14.0
 | 6.02 | 0.165 | 5.20
 | 24.7 | 0.12 | 0.01
 | 0.765 | 3.31 | 100.41 | 0.10 | 31.2

 | 5.4

 | 393
 | 55.5 | 38.1 | 25.6 | 29.4
 |
 | .2 <3 |
 | |
 | 22.1 | 2.5 | 1.3 | <1 | 65.7 | <1
 | <2 | 2.9 | 11.0 | 21.7 | 7.6
 |
| T-13-44 | 51.7 | 0.554 | 17.7
 | 7.74 | 0.160 | 2.74
 | 8.88 | 5.08 | 0.04
 | 0.636 | 5.17 | 100.36 | 0.44 | 10.1

 | 35.7

 | 122
 | 3.0 | 19.3 | <1 | 28.8
 |
 | .9 <3 |
 | |
 | 84.0 | 1.7 | 0.5 | <1 | 40.1 | 5.0
 | <2 | <2 | 12.4 | 31.8 | 14.5
 |
| T-13-49 | 45.4 | 0.967 | 14.3
 | 11.9 | 0.235 | 9.11
 | 12.1 | 1.76 | 0.98
 | 0.319 | 3.01 | 100.08 | 0.14 | 56.4

 | 212

 | 414
 | 163 | 45.7 | 60.4 | 52.6
 |
 | .2 <3 |
 | |
 | 48.7 | 1.5 | < 0.5 | 1.3 | 40.2 | <1
 | <2 | <2 | 4.2 | 16.4 | 7.1
 |
| T-13-51 | 40.9 | 0.818 | 13.3
 | 10.3 | 0.163 | 10.0
 | 10.3 | 0.02 | 0.21
 | 0.274 | 1.08 | 87.45 | 0.32 | 42.5

 | 40.6

 | 348
 | 593 | 46.1 | 195 | 61.6
 | 74.0 1
 | |
 | |
 | 53.9 | 4.8 | 0.8 | 3.2 | <2 | <1
 | <2 | <2 | 6.3 | 17.4 | 5.1
 |
| T-13-54 | 48.5 | 0.665 | 16.0
 | 6.44 | 0.105 | 6.75
 | 5.96 | 0.01 | 0.72
 | 0.158 | 1.57 | 86.88 | <0.01 | 17.2

 | 57.9

 | 172
 | 126 | 39.8 | 66.2 | 26.9
 | 105 1
 | .7 <3 | 17.
 | 7 12 | 0 15.3
 | 87.5 | 2.4 | 0.5 | 1.2 | 19.0 | <1
 | <2 | <2 | 4.3 | 14.8 | <4
 |
| T-13-55 | 59.1 | 0.366 | 15.7
 | 3.88 | 0.075 | 2.15
 | 5.04 | 1.74 | 1.31
 | 0.128 | 1.10 | 90.53 | 0.01 | 10.2

 | 464

 | 71.2
 | 16.5 | 19.1 | 12.5 | 7.8
 | 48.7 1
 | .0 <3 | 33.
 | 5 33 | 3 12.8
 | 90.1 | 2.0 | 0.5 | <1 | 33.9 | 1.8
 | <2 | <2 | 7.6 | 18.7 | 4.5
 |
| T-13-57 | 47.5 | 0.762 | 19.3
 | 11.0 | 0.137 | 3.82
 | 4.60 | 5.13 | 0.44
 | 0.509 | 6.21 | 99.40 | 1.03 | 18.3

 | 66.0

 | 292
 | 1.7 | 33.5 | <1 | 16.8
 | 98.1 19
 | .9 <3 |
 | |
 | 64.6 | 1.9 | <0.5 | <1 | 23.4 | 3.6
 | <2 | <2 | 10.4 | 22.6 | 9.2
 |
| T-13-60 | 47.4 | 0.674 | 17.6
 | 9.80 | 0.211 | 3.55
 | 7.34 | 4.97 | 0.24
 | 0.490 | 5.50 | 97.76 | 0.61 | 16.3

 | 38.3

 | 246
 | 1.5 | 9.7 | <1 |
 |
 | .4 4.5 |
 | |
 | 82.3 | 0.7 | <0.5 | 1.0 | 26.7 | <1
 | <2 | <2 | 9.8 | 21.9 | 7.4
 |
| T-13-62 | 46.4 | 1.294 | 15.9
 | 9.67 | 0.147 | 7.95
 | 7.80 | 3.12 | 0.26
 | 0.306 | 6.73 | 99.52 | 0.09 | 22.0

 | 111

 | 235
 | 414 | 47.4 | 171 | 21.5
 |
 | .2 <3 |
 | |
 | 86.7 | 4.9 | <0.5 | <1 | 21.0 | <1
 | <2 | <2 | 10.4 | 23.8 | 6.5
 |
| T-13-66 | 47.5 | 1.187 | 17.9
 | 9.57 | 0.179 | 3.59
 | 6.24 | 4.26 | 1.76
 | 0.322 | 6.64 | 99.16 | 0.94 | 24.1

 | 324

 | 326
 | 2.9 | 17.8 | 12.2 | 15.8
 |
 | .4 <3 |
 | |
 | 89.1 | 2.7 | 1.2 | <1 | 27.5 | 3.2
 | <2 | <2 | 12.9 | 25.6 | 11.3
 |
| T-13-68
T-13-70 | 41.9 | 0.905 | 16.9
14.2
 | 8.67
6.18 | 0.187 | 3.15
7.83
 | 11.4 | 2.65 | 1.70
 | 0.340 | 1.21 | 89.03
90.52 | 0.31 | 19.3
24.2

 | 357
179

 | 240
237
 | 3.7
670 | 29.0
45.4 | <1
266 | 18.3
53.9
 |
 | .5 <3 |
 | |
 | 86.9
104 | 3.9 | <0.5 | 1.7 | 17.1
13.5 | 1.1
 | <2 | <2 | 14.2
20.7 | 31.3 | 13.6
17.9
 |
| T-13-70
T-13-71 | 44.5
44.3 | 0.782 | 14.2
 | 9.57 | 0.075 | 3.64
 | 7.20 | 1.65 | 1.75
 | 0.260 | 1.91 | 90.52
88.46 | 4.21 | 24.2

 | 339

 | 310
 | 50.6 | 45.4
36.8 | 25.8 | 183
 | 200 2
 | |
 | |
 | 104 | 3.2
4.9 | <0.5
1.2 | <1 | 24.4 | 2.4
 | <2
<2 | 4.5
3.2 | 20.7 | 39.8 | 17.9
 |
| T-13-71
T-13-72 | 44.3 | 1.301 | 15.0
 | 12.1 | 0.130 | 7.93
 | 10.1 | 2.47 | 0.63
 | 0.430 | 5.24 | 99.53 | 0.34 | 44.7

 | 254

 | 452
 | 166 | 50.8 | 65.8 |
 | 85.8 1
 | |
 | |
 | 85.2 | 2.8 | <0.5 | <1 | 19.6 | 1.4
 | <2 | <2 | 14.8 | 22.9 | 7.7
 |
| T-13-72 | 44.5 | 0.745 | 12.7
 | 10.2 | 0.169 | 14.1
 | 9.97 | 1.37 | 1.09
 | 0.231 | 4.57 | 99.68 | <0.01 | 31.2

 | 169

 | 302
 | 1303 | 60.7 | 438 |
 | 68.1 1
 | |
 | |
 | 72.4 | 1.5 | 1.1 | <1 | 19.4 | 1.4
 | <2 | <2 | 12.4 | 26.5 | 13.3
 |
| T-13-75 | 31.2 | 0.551 | 9.8
 | 7.54 | 0.164 | 8.13
 | 20.5 | 1.90 | 1.405
 | 0.210 | 1.94 | 83.42 | 0.01 | 28.5

 | 172

 | 283
 | 1114 | 73.2 | 184 | 28.7
 | 57.2 9
 | .6 <3 |
 | |
 | 57.0 | 1.2 | 0.9 | 3.1 | 12.4 | <1
 | <2 | <2 | 7.9 | 22.1 | 5.9
 |
| T-13-76 | 45.3 | 0.577 | 13.3
 | 6.60 | 0.088 | 7.49
 | 10.6 | 1.77 | 0.48
 | 0.274 | 2.87 | 89.39 | 0.32 | 21.6

 | 216

 | 189
 | 504 | 49.1 | 288 | 43.1
 | 74.9 14
 | .2 <3 | 8.4
 | 122 | 0 10.6
 | 99.2 | 1.7 | <0.5 | <1 | 12.5 | 6.1
 | <2 | <2 | 23.8 | 45.3 | 16.5
 |
| T-13-79 | 47.9 | 0.884 | 17.0
 | 7.90 | 0.064 | 5.77
 | 9.50 | 2.49 | 0.08
 | 0.115 | 4.89 | 96.59 | 0.26 | 30.6

 | 56.8

 | 191
 | 164 | 43.3 | 26.6 | 56.2
 | 63.0 1
 | .2 <3 | <0.
 | 5 104 | 3 15.5
 | 82.2 | 2.0 | < 0.5 | 1.1 | 35.7 | <1
 | <2 | <2 | 4.3 | 11.8 | <4
 |
 | | |
 | | |
 | | | | |

 |

 |
 | | | |
 |
 | |
 | |
 | | | | | |
 | | | | |
 |
| T-13-110046 | 60.2 | 0.355 | 16.2
 | 3.82 | 0.060 | 2.29
 | 3.79 | 3.09 | 1.13
 | 0.157 | 2.39 | 93.46 | 0.22 | 12.5

 | 72.7

 | 86.4
 | 63.8 | 24.6 | 13.5 | 14.2
 | 112 1
 | .0 3.7 | 19.
 | 4 27 | 3 12.0
 | 98.3 | 1.9 | 0.5 | <1 | 53.4 | 3.2
 | <2 | <2 | 8.7 | 15.2 | <4
 |
| | 60.2
Ba B | |
 | 3.82
Ga | | 2.29
Nb Rh
 | | 3.09
Sr | 1.13
Ta
 | | 2.39
U V | 93.46
Cr | 0.22
W Zr |

 | 72.7
La C

 |
 | 63.8
Nd | 24.6
Sm | 13.5
Eu G |
 |
 | .0 3.7
Io Er | 19.
Tm
 | 4 27
Yb | 3 12.0
Lu Mo
 | 98.3
Cu | | 0.5
Zn N | <1 | 53.4 |
 | | <2
Ag A | | 15.2
Ti | <4
Se
 |
| T-13-11-13-1 | Ba Be
271 < | e Co
1 37.2 | Cs
1.9
 | Ga
13.5 | Hf 2.5 | Nb Rh
2.6 21.6
 | 5 Sn
6 <1 | Sr
742.5 | Ta
0.1
 | Th
4.5 | U V
0.9 157 | Cr
7 616 | W Zr
49.4 84.3 | Y
16.4

 | La C
19.1 37

 | e Pr
.7 5.03
 | Nd
19.7 | Sm
4.05 | Eu G
1.12 3. | d Tb
30 0.50
 | Dy 2.88 (
 | Io Er
.52 1.56 | Tm
0.23
 | Yb
1.38 | Lu Mo
0.22 0.8
 | Cu
46.1 | Pb
5.3 | Zn N
43 20 | <1
Ni As
2.3 2.2 | 53.4
Cd
<0.1 | 3.2
Sb
<0.1
 | Bi
<0.1 | Ag A
<0.1 3 | u Hg
.2 <0.01 | Ti
1 11.13 | Se
<0.5
 |
| T-13 BOO46
Sample
T-13-1
T-13-2 | Ba Be
271 <
290 3 | e Co
1 37.2
19.4 | Cs
1.9
0.6
 | Ga
13.5
14.4 | Hf 2.5
2.7 | Nb Rh
2.6 21.0
1.7 10.2
 | 5 Sn
6 <1
2 <1 | Sr
742.5
1028.5 | Ta
0.1
0.2
 | Th
4.5
2.0 | U V
0.9 157
0.6 77 | Cr
7 616
7 26.6 | W Zr
49.4 84.3
85.7 94.3 | Y
16.4
12.6

 | La C
19.1 37
9.9 20

 | e Pr
7 5.03
4 2.86
 | Nd
19.7
11.5 | Sm
4.05
2.49 | Eu G
1.12 3.
0.77 2. | d Tb
30 0.50
19 0.34
 | Dy 2.88 (
2.10 (
 | Io Er
52 1.56
.46 1.25 | Tm
0.23
0.19
 | Yb
1.38
1.30 | Lu Mo
0.22 0.8
0.21 0.7
 | Cu
46.1
21.4 | Pb
5.3
0.8 | Zn N
43 200
44 13 | <1
Ni As
2.3 2.2
3.6 <0.5 | 53.4
Cd
<0.1
5 <0.1 | 3.2
Sb
<0.1
<0.1
 | Bi
<0.1
<0.1 | Ag A
<0.1 3
<0.1 <0 | u Hg
.2 <0.01
0.5 <0.01 | Ti
1 11.13
1 4.96 | Se
<0.5
<0.5
 |
| T-13-11-13-1 | Ba Be
271 < | e Co
1 37.2
19.4
1 33.1 | Cs
1.9
0.6
0.9
 | Ga
13.5 | Hf 2.5
2.7
1.7 | Nb Rh
2.6 21.6
 | 5 Sn
6 <1
2 <1
8 <1 | Sr
742.5 | Ta
0.1
 | Th
4.5
2.0
1.9 | U V
0.9 157 | Cr
7 616
2 744 | W Zr
49.4 84.3 | Y
16.4
12.6
15.8

 | La C
19.1 37

 | e Pr
7 5.03
4 2.86
9 2.44
 | Nd
19.7 | Sm
4.05
2.49
2.67 | Eu G
1.12 3. | d Tb
80 0.50
19 0.34
93 0.40
 | Dy 2.88 (0
2.10 (0
2.41 (0
 | Io Er
.52 1.56 | Tm
0.23
 | Yb
1.38 | Lu Mo
0.22 0.8
 | Cu
46.1 | Pb
5.3 | Zn N
43 200
44 13
53 190 | <1
Ni As
2.3 2.2 | 53.4
Cd
< | 3.2
Sb
<0.1
 | Bi
<0.1
<0.1
<0.1 | Ag A
<0.1 3
<0.1 <0 | u Hg .2 <0.01 | Ti
1 11.13
1 4.96
6.89 | Se
<0.5
 |
| T-13 10046
Sample
T-13-1
T-13-2
T-13-2
T-13-7
T-13-9
T-13-13 | Ba Be 271 < | e Co
1 37.2
19.4
1 33.1
1 51.4
1 43.7 | Cs
1.9
0.6
0.9
1.5
1.7
 | Ga
13.5
14.4
14.3
10.8
10.7 | Hf 2.5
2.7
1.7
1.6
1.3 | Nb Rh
2.6 21.0
1.7 10.7
1.1 17.8
0.9 6.5
0.7 5.1
 | Sn 6 <1 | Sr
742.5
1028.5
435.7
528.8
201.5 | Ta
0.1
0.2
0.1
<0.1
<0.1
 | Th
4.5
2.0
1.9
1.1
0.9 | U V
0.9 155
0.6 77
0.5 172
0.3 280
0.3 150 | Cr
7 616
7 26.6
2 744
0 1168
0 880 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 6.8 46.2 | Y
16.4
12.6
15.8
14.2
11.9

 | La C
19.1 37
9.9 20
9.3 17
9.2 21
8.1 17

 | e Pr
7 5.03
4 2.86
9 2.44
0 2.96
7 2.53
 | Nd
19.7
11.5
10.9
13.7
12.3 | Sm
4.05
2.49
2.67
3.00
2.83 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. | d Tb 30 0.50 19 0.34 03 0.40 27 0.41 59 0.35
 | Dy 2 2.88 0 2.10 0 2.41 0 2.65 0 2.30 0
 | Io Er 52 1.56 46 1.25 49 1.51 48 1.38 43 1.19 | Tm
0.23
0.19
0.21
0.20
0.18
 | Yb
1.38
1.30
1.33
1.19
1.06 | Lu Mo
0.22 0.8
0.21 0.7
0.22 0.2
0.19 0.1
0.16 <0.1
 | Cu
46.1
21.4
62.0
66.1
7.8 | Pb
5.3
0.8
2.1
0.3
0.8 | Zn N 43 200 44 13 53 194 46 319 26 25 | <1
Ni As
2.3 2.2
3.6 <0.5
8.2 <0.5
9.4 <0.5
7.3 1.0 | 53.4
Cd
Cd
Cd
Cd
Cd
Cd
Cd
Cd
Cd
Cd | 3.2
Sb
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
 | Bi
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1 | Ag A
<0.1 3
<0.1 <0
<0.1 1
<0.1 0
<0.1 3 | Hg Hg .2 <0.01 | Ti
1 11.13
1 4.96
6.89
1 13.36
1 12.32 | Se
<0.5
<0.5
<0.5
<0.5
<0.5
<0.5
 |
| T-13 CO46
Sample
T-13-1
T-13-2
T-13-7
T-13-9
T-13-13
T-13-15 | Ba B 271 < | e Co
1 37.2
19.4
1 33.1
1 51.4
1 43.7
42.3 | Cs
1.9
0.6
0.9
1.5
1.7
0.6
 | Ga
13.5
14.4
14.3
10.8
10.7
14.9 | Hf 2.5
2.7
1.7
1.6
1.3
3.0 | Nb Rh 2.6 21.0 1.7 10.2 1.1 17.3 0.9 6.5 0.7 5.1 3.7 7.0
 | Sn Sn 6 <1 | Sr
742.5
1028.5
435.7
528.8
201.5
468.1 | Ta
0.1
0.2
0.1
<0.1
<0.1
<0.1
0.3
 | Th
4.5
2.0
1.9
1.1
0.9
0.8 | U V
0.9 157
0.6 77
0.5 172
0.3 280
0.3 150
0.2 258 | Cr
7 616
7 26.6
2 744
0 1168
0 880
8 201 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 6.8 46.2 50.7 122.7 | Y
16.4
12.6
15.8
14.2
11.9
22.9

 | La C
19.1 37
9.9 20
9.3 17
9.2 21
8.1 17
11.3 25

 | e Pr
7 5.03
4 2.86
9 2.44
0 2.96
7 2.53
3 3.75
 | Nd
19.7
11.5
10.9
13.7
12.3
17.3 | Sm
4.05
2.49
2.67
3.00
2.83
4.08 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. 1.45 4. | d Tb 30 0.50 19 0.34 03 0.40 27 0.41 59 0.35 74 0.69
 | Dy
 | Io Er 52 1.56 46 1.25 49 1.51 48 1.38 43 1.19 77 2.43 | Tm
0.23
0.19
0.21
0.20
0.18
0.35
 | Yb
1.38
1.30
1.33
1.19
1.06
2.30 | Lu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.1 0.16 <0.1
 | Cu
46.1
21.4
62.0
66.1
7.8
25.2 | Pb
5.3
0.8
2.1
0.3
0.8
0.8
0.5 | Zn N 43 200 44 13 53 194 46 314 26 255 71 64 | <1
Ni As
2.3 2.2
3.6 <0.5
8.2 <0.5
9.4 <0.5
7.3 1.0
1.2 <0.5 | 53.4
Cd
cd
cd
cd
cd
cd
cd
cd
cd
cd
cd
cd
cd
cd | 3.2
Sb
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
 | Bi
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1 | Ag A
<0.1 3
<0.1 <0
<0.1 1
<0.1 0
<0.1 3
<0.1 1 | Au Hg 1.2 <0.01 | Ti
1 11.13
1 4.96
6.89
1 13.36
1 12.32
1 18.78 | Se
<0.5
<0.5
<0.5
<0.5
<0.5
<0.5
<0.5
<0.5
 |
| T-13 10046
Sample
T-13-1
T-13-2
T-13-2
T-13-7
T-13-9
T-13-13 | Ba Be 271 < | e Co
1 37.2
19.4
1 33.1
1 51.4
1 43.7
42.3
1 26.0 | Cs
1.9
0.6
0.9
1.5
1.7
0.6
0.7
 | Ga
13.5
14.4
14.3
10.8
10.7 | Hf 2.5
2.7
1.7
1.6
1.3
3.0 | Nb Rh
2.6 21.0
1.7 10.7
1.1 17.8
0.9 6.5
0.7 5.1
 | Sn Sn 6 <1 | Sr
742.5
1028.5
435.7
528.8
201.5 | Ta
0.1
0.2
0.1
<0.1
<0.1
 | Th
4.5
2.0
1.9
1.1
0.9
0.8
1.5 | U V
0.9 155
0.6 77
0.5 172
0.3 280
0.3 150 | Cr
7 616
7 26.6
7 26.6
7 26.6
7 26.6
8 201
1168
8 201
3 2.5 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 6.8 46.2 | Y
16.4
12.6
15.8
14.2
11.9
22.9
16.9

 | La C
19.1 37
9.9 20
9.3 17
9.2 21
8.1 17

 | e Pr
7 5.03
4 2.86
9 2.44
0 2.96
7 2.53
3 3.75
7 3.50
 | Nd
19.7
11.5
10.9
13.7
12.3 | Sm
4.05
2.49
2.67
3.00
2.83
4.08
3.97 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. | d Tb 80 0.50 19 0.34 03 0.40 27 0.41 59 0.35 74 0.69 09 0.53
 | Dy 2 2.88 0 2.10 0 2.41 0 2.65 0 2.30 0 4.42 0 3.38 0
 | Io Er 52 1.56 46 1.25 49 1.51 48 1.38 43 1.19 | Tm
0.23
0.19
0.21
0.20
0.18
 | Yb
1.38
1.30
1.33
1.19
1.06 | Lu Mo
0.22 0.8
0.21 0.7
0.22 0.2
0.19 0.1
0.16 <0.1
 | Cu
46.1
21.4
62.0
66.1
7.8 | Pb
5.3
0.8
2.1
0.3
0.8 | Zn N 43 200 44 13 53 194 46 319 26 25 | <1
Ni As
2.3 2.2
3.6 <0.9
8.2 <0.9
9.4 <0.9
7.3 1.0
1.2 <0.9
1.4 1.7 | 53.4 Cd 2 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 7 0.1 | 3.2
Sb
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
 | Bi
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1 | Ag A
<0.1 3
<0.1 <0
<0.1 1
<0.1 0
<0.1 3 | Hg Hg .2 <0.01 | Ti 1 11.13 4.96 6.89 1 13.36 1 12.32 1 18.78 1 10.76 | Se
<0.5
<0.5
<0.5
<0.5
<0.5
<0.5
 |
| T-13 0046
Sample
T-13-1
T-13-2
T-13-7
T-13-9
T-13-13
T-13-13
T-13-15
T-13-15
T-13-15
T-13-15
T-13-20
T-13-20
T-13-21 | Ba Be 271 < | e Co
1 37.2
19.4
1 33.1
1 51.4
1 43.7
42.3
1 26.0
1 35.5 | Cs
1.9
0.6
0.9
1.5
1.7
0.6
0.7
1.7
0.6
0.7
1.7
6.1
 | Ga
13.5
14.4
14.3
10.8
10.7
14.9
17.6
12.0
13.5 | Hf 2.5 2.7 1.7 1.6 1.3 3.0 1.3 1.5 1.7 | Nb Rb 2.6 21.6 1.7 10.7 1.1 17.3 0.9 6.5 0.7 5.1 3.7 7.0 1.5 2.9 0.7 26.0 4.2 10.3
 | Sn Sn 6 <1 | Sr 742.5 1028.5 435.7 528.8 201.5 468.1 1137.9 128.4 1031.5 | Ta
0.1
0.2
0.1
<0.1
<0.1
<0.1
0.3
<0.1
<0.1
0.3
 | Th 4.5 2.0 1.9 1.1 0.9 0.8 1.5 1.9 0.9 | U V
0.9 155
0.6 77
0.5 172
0.3 280
0.3 150
0.2 258
0.7 213
0.5 296
0.4 180 | Cr Cr 7 616 7 25.6 2 744 0 1168 0 880 8 201 3 2.5 6 324 0 244 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 6.8 46.2 50.7 122.7 22.1 48.6 23.2 50.9 39.8 68.1 | Y 16.4 :: 12.6 : 15.8 : 14.2 : 11.9 : 22.9 : 16.9 : 9.4 :

 | La C
19.1 37
9.9 20
9.3 17
9.2 21
8.1 17
11.3 25
10.9 23
8.0 16
7.9 16

 | e Pr
7 5.03
4 2.86
9 2.44
0 2.96
7 2.53
3 3.75
7 3.50
7 2.57
7 2.59
 | Nd
19.7
11.5
10.9
13.7
12.3
17.3
16.5
11.5
12.1 | Sm
4.05
2.49
2.67
3.00
2.83
4.08
3.97
2.75
3.04 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. 1.45 4. 1.42 3. 0.77 2. 0.99 3. | d Tb 30 0.50 19 0.34 03 0.40 27 0.41 59 0.35 44 0.69 99 0.53 366 0.35 34 0.48
 | Dy
 | Io Er .52 1.56 .46 1.25 .49 1.51 .48 1.38 .43 1.19 .63 1.87 .39 1.15 .62 1.74 | Tm
0.23
0.19
0.21
0.20
0.18
0.35
0.28
0.15
0.26
 | Yb 1.38 1.30 1.33 1.19 1.06 2.30 1.85 0.96 1.63 | Lu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.1 0.16 <0.1
 | Cu
46.1
21.4
66.0
66.1
7.8
25.2
24.3
26.5
52.4 | Pb 5.3 0.8 2.1 0.3 0.8 0.5 2.6 1.0 | Zn N 43 200 44 13 53 194 46 314 26 25 71 64 91 0 41 53 62 53 | <1 Ni As 2.3 2.2 3.6 <0.9 | 53.4 Cd 2 <0.1 |
3.2
Sb
<0.1
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<0.1
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<0.1
<0.1
<0.1
<0.1
<0. | Bi <0.1 | Ag A <0.1 | Image: Number of the system Image: Hg .2 <0.01 | Ti 1 11.13 4.96 6.89 1 13.36 1 12.32 1 18.78 1 10.76 1 10.37 1 13.12
 | Se <0.5 |
| T-13 0046
Sample
T-13.1
T-13.2
T-13.7
T-13.9
T-13-13
T-13-13
T-13-13
T-13-13
T-13-13
T-13-13
T-13-20
T-13-21
T-13-25 | Ba Be 271 < | e Co
1 37.2
19.4
1 33.1
1 51.4
1 43.7
42.3
1 26.0
1 35.0
1 35.5
1 27.6 | Cs
1.9
0.6
0.9
1.5
1.7
0.6
0.7
1.7
6.1
6.4
 | Ga
13.5
14.4
14.3
10.8
10.7
14.9
17.6
12.0
13.5
12.4 | Hf 1 2.5 2.7 1.7 1.6 1.3 3.0 1.3 1.5 1.7 2.1 | Nb Rb 2.6 21.6 1.7 10.7 1.1 17.4 0.9 6.5 0.7 5.1 3.7 7.0 1.5 2.9 0.7 26.0 4.2 10.3
 6.4 16.3 | b Sn 6 <1 | Sr 742.5 1028.5 435.7 528.8 201.5 468.1 1137.9 128.4 1031.5 490.9 | Ta
0.1
0.2
0.1
<0.1
<0.1
<0.1
0.3
<0.1
<0.1
0.3
0.4
 | Th 4.5 2.0 1.9 1.1 0.9 0.8 1.5 1.9 0.9 0.9 1.10 | U V
0.9 157
0.6 77
0.5 177
0.3 280
0.3 150
0.2 258
0.7 213
0.5 296
0.4 180
0.5 170 | Cr Cr 7 616 7 26.6 2 744 0 1168 0 880 0 880 3 2.5 6 324 0 244 0 369 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 6.8 46.2 50.7 122.7 22.1 48.6 23.2 50.9 39.8 68.1 7.8 82.1 | Y 16.4 :: 12.6 : 15.8 : 14.2 : 11.9 : 22.9 : 16.9 : 9.4 : 16.6 : 15.8

 | La C
19.1 37
9.9 20
9.3 17
9.2 21
8.1 17
11.3 25
10.9 23
8.0 16
7.9 16
9.9 21

 | e Pr 7 5.03 4 2.86 9 2.44 0 2.96 7 2.53 3 3.75 7 3.50 7 2.57 7 2.57 7 2.59 4 3.09
 | Nd 19.7 11.5 10.9 13.7 12.3 17.3 16.5 11.5 12.1 14.0 | Sm 4.05 2.49 2.67 3.00 2.83 4.08 3.97 2.75 3.04 3.32 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. 1.45 4. 0.77 2. 0.89 3. 0.77 2. 0.99 3. 1.08 3. | d Tb 30 0.50 99 0.34 33 0.40 27 0.41 39 0.35 44 0.69 99 0.53 56 0.35 54 0.48 52 0.50
 | Dy 2.88 (C) 2.10 (C) (C) (C) 2.41 (C) (C) (C) (C) 2.30 (C) (C) (C) (C) (C) 4.42 (C)
 | Io Er 52 1.56 46 1.25 49 1.51 48 1.38 43 1.19 63 1.87 39 1.15 62 1.74 | Tm
0.23
0.19
0.21
0.20
0.18
0.28
0.15
0.28
0.15
0.26
0.25
 | Yb 1.38 1.30 1.33 1.19 1.06 2.30 1.85 0.96 1.63 1.59 | Lu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.1 0.16 <0.1
 | Cu
46.1
21.4
66.1
7.8
25.2
24.3
26.5
52.4
46.2 | Pb 5.3 0.8 2.1 0.3 0.8 0.5 2.6 1.0 1.3 | Zn N 43 200 44 13 53 194 46 319 26 25 71 64 91 00 41 53 62 53 63 79 | <1 Ni As 2.3 2.2 3.6 <0.9 | 53.4 Cd 2 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 0 <0.1 1 <0.1 |
3.2
Sb
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
<0.1
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| T-13 0046
Sample
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T-13-20
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T-13-21 | Ba Be 271 < | e Co
1 37.2
19.4
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42.3
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13.5 | Hf 1 2.5 2.7 1.7 1.6 1.3 3.0 1.3 1.5 1.7 2.1 2.7 2.7 | Nb Rb 2.6 21.6 1.7 10.7 1.1 17.3 0.9 6.5 0.7 5.1 3.7 7.0 1.5 2.9 0.7 26.0 4.2 10.3
 | Sn Sn 6 <1 | Sr 742.5 1028.5 435.7 528.8 201.5 468.1 1137.9 128.4 1031.5 | Ta
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0.2 258
0.7 212
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7 616
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2 744
0 1168
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8 201
3 2.5
6 324
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12.1 | Sm 4.05 2.49 2.67 3.00 2.83 4.08 3.97 2.75 3.04 3.32 4.49 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. 1.45 4. 1.42 3. 0.77 2. 0.99 3. | d Tb 30 0.50 19 0.34 193 0.40 27 0.41 59 0.35 74 0.69 99 0.53 56 0.35 34 0.48 52 0.50 12 0.57
 | Dy 2.88 0 2.88 0 0 0 2.41 0 0 0 0 2.41 0 0 0 0 0 2.41 0
 | Io Er .52 1.56 .46 1.25 .49 1.51 .48 1.38 .43 1.19 .63 1.87 .39 1.15 .62 1.74 | Tm
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 | Yb 1.38 1.30 1.33 1.19 1.06 2.30 1.85 0.96 1.63 | Lu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.1 0.16 <0.1
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 6.4 16.5 4.3 26.6 0.7 4.5 | Sn Sn 6 -41 2 -41 8 -41 5 -41 0 -41 0 -41 5 -41 5 -41 5 -41 5 -41 5 -41 5 -41 5 -41 5 -41 5 -41 | Sr 742.5 1028.5 435.7 528.8 201.5 468.1 1137.9 128.4 1031.5 490.9 1508.4 771.7 285.2 | Ta 0.1 0.2 0.1 <0.1
 | Th 4.5 2.0 1.9 1.1 0.9 1.1 0.9 1.5 1.9 0.9 1.0 2.5 1.4 0.3 | U V
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0.1 128 | Cr 7 616 7 26.6 2 744 0 1168 880 8 201 3 2.5 5 324 0 244 0 369 0 34.3 4 4.4 8 224 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 50.7 122.7 22.1 48.6 50.7 122.7 23.2 50.9 39.8 68.1 27.9 100.1 47.5 74.4 10.6 57.8 | Y
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12.0 26
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 | e Pr 7 5.03 4 2.86 .9 2.44 .0 2.96 .7 2.53 .3 3.75 .3 3.75 .7 2.57 .7 2.59 .4 3.09 .7 4.96 .7 3.95 .7 3.95 .7 1.40
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 | Dy 2.88 2.10 0 2.41 0 2.41 0 2.43 0 2.30 0 4.42 0 3.38 0 2.17 0
 | Io Er 552 1.56 46 1.25 448 1.38 43 1.19 777 2.43 63 1.87 39 1.15 62 1.74 62 1.78 69 1.85 64 1.29 | Tm 0.23 0.19 0.21 0.20 0.18 0.35 0.28 0.15 0.26 0.25 0.26 0.27 0.18
 | Yb
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1.35 | Lu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.1 0.32 0.2 0.55 0.5 0.15 <0.1
 | Cu
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36.5 | Pb 5.3 0.8 2.1 0.3 0.8 0.5 2.6 1.0 1.3 3.4 2.1 0.3 | Zn N 43 200 44 13 53 194 46 311 26 255 71 64 91 0. 41 53 62 53 63 79 103 15 89 1. 45 98 | <1 Vii Ass 2.3 2.2 3.6 <0.0 | 53.4 Cd 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 5 <0.1 7 0.1 5 <0.1 1 <0.1 3 0.3 5 <0.1 |
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 | Se <0.5 |
| T-132€0046 Sample T-131 T-132 T-132 T-133 T-1315 T-1315 T-1315 T-1321 T-1321 T-1325 T-1326 T-1326 T-1321 T-1323 T-1324 T-1330 T-1325 T-1326 T-1330 T-1340 T-1340 T-1340 | Ba Bu 271 < | e Co
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 | Sn Sn 6 <1 2 <1 3 <1 5 <1 0 <1 0 <1 0 <1 0 <1 3 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 5 <1 <1 5 <1 <1 | Sr 742.5 1028.5 435.7 528.8 201.5 468.1 1137.9 128.4 1031.5 490.9 1508.4 771.7 285.2 666.6 | Ta 0.1 0.2 0.1 <0.1 | Th
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0.7 214
0.1 122 | Cr Cr 7 616 7 26.6 2 744 0 1168 0 8800 8 201 3 2.5 5 324 0 244 0 369 0 34.3 4 4.4 8 224 5 207 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 6.8 46.2 50.7 122.7 93.8 68.1 7.8 82.1 27.9 100.1 47.5 74.4 10.6 57.8 57.8 26.9 | Y
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 | Nd 19.7 11.5 10.9 13.7 12.3 17.3 16.5 11.5 12.1 14.0 22.0 17.9 6.7 11.5 11.5 | Sm 4.05 2.49 2.67 3.00 2.83 4.08 3.97 2.75 3.04 3.32 4.49 4.32 1.96 3.33 1.96 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. 1.45 4. 1.42 3. 0.77 2. 0.99 3. 1.08 3. 1.30 4. 1.36 4. 0.665 2. 1.12 4. | d Tb 80 0.50 19 0.34 133 0.40 27 0.41 199 0.35 74 0.69 199 0.53 66 0.35 44 0.48 52 0.50 12 0.57 19 0.33 00 0.61
 | Dy 2.88 0 2.10 0 2.41 0 2.41 0 2.65 0 2.30 0 4.42 0 3.38 0 2.17 0 3.21 0 3.21 0 3.51 0 3.40 0 2.17 0 3.73 0
 | Ho Er 10 Er 52 1.56 54 1.25 49 1.51 48 1.38 43 1.19 77 2.43 63 1.87 39 1.15 62 1.74 62 1.78 69 1.85 62 1.66 43 1.29 69 1.99 | Tm 0.23 0.19 0.21 0.20 0.18 0.35 0.28 0.15 0.26 0.27 0.29 0.27 0.18 0.23
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 6.4 16.5 4.3 26.6 0.7 4.5 | Sn Sn 6 41 2 41 8 41 5 41 0 41 0 41 0 41 5 41 5 41 5 41 5 41 5 41 5 41 5 41 5 41 5 41 6 41 7 41 | Sr 742.5 1028.5 435.7 528.8 201.5 468.1 1137.9 128.4 1031.5 490.9 1508.4 771.7 285.2 | Ta 0.1 0.2 0.1 <0.1
 | Th 4.5 2.0 1.9 0.9 0.8 1.1 0.9 0.8 1.9 0.9 0.8 1.9 0.9 1.0 0.9 1.1 0.9 1.0 0.9 1.1 0.9 0.0 2.5 1.4 0.3 <0.2 | U V
0.9 155
0.6 777
0.5 172
0.3 286
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0.2 258
0.7 211
0.5 296
0.4 186
0.5 177
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0.1 128 | Cr 7 616 7 26.6 6 2 744 0 1168 0 880 8 201 3 2.5 5 324 0 369 0 369 0 369 0 369 0 34.3 4 4.4 8 224 6 207 3 31.4 31.4 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 50.7 122.7 22.1 48.6 50.7 122.7 23.2 50.9 39.8 68.1 27.9 100.1 47.5 74.4 10.6 57.8 | Y
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19.1 37
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 | e Pr 7 5.03 .4 2.86 9 2.44 0 2.96 .7 2.53 .3 3.75 .7 3.50 .7 2.57 .7 2.59 .4 3.09 .7 4.96 .7 3.95 .7 1.406 .3 2.08 .4 2.38
 | Nd 19.7 11.5 10.9 13.7 12.3 17.3 16.5 11.5 12.1 14.0 22.0 17.9 6.7 | Sm 4.05 2.49 2.67 3.00 2.83 4.08 3.97 2.75 3.04 4.08 3.97 2.75 3.04 4.49 4.32 1.96 3.33 3.37 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. 1.45 4. 1.42 3. 0.77 2. 0.99 3. 1.08 3. 1.30 4. 1.36 4. 0.66 2. | d Tb 80 0.50 99 0.34 93 0.40 99 0.35 74 0.69 99 0.53 56 0.35 84 0.48 92 0.57 99 0.53 100 0.57 19 0.54 80 0.62
 | Dy 2.88 () 2.10 () () () 2.41 () () () 2.65 () () () 2.30 () () () 3.38 () () () 3.12 () () () 3.21 () () () 3.40 () () () 3.73 () () () 3.94 () () ()
 | Io Er 552 1.56 46 1.25 448 1.38 43 1.19 777 2.43 63 1.87 39 1.15 62 1.74 62 1.78 69 1.85 64 1.29 | Tm 0.23 0.19 0.21 0.20 0.18 0.35 0.28 0.15 0.26 0.25 0.26 0.27 0.18
 | Yb
1.38
1.30
1.33
1.19
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1.35 | Lu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.1 0.32 0.2 0.55 0.5 0.15 <0.1
 | Cu
46.1
21.4
62.0
66.1
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36.5 | Pb 5.3 0.8 2.1 0.3 0.8 0.5 2.6 1.0 1.3 3.4 2.1 0.3 | Zn N 43 20. 44 13 53 199 46 311 26 25 71 64 91 0. 41 53 62 53 63 79 103 15 89 1. 45 98 33 33 33 33 31 7. | <1 Vii Ass 2.3 2.2 3.6 <0.0 | 53.4 Cd 2 -0.1 5 -0.1 5 -0.1 5 -0.1 5 -0.1 5 -0.1 5 -0.1 5 -0.1 5 -0.1 5 -0.1 5 -0.1 6 -0.1 8 0.2 6 -0.1 5 -0.1 5 -0.1 5 -0.1 |
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 | Se <0.5 |
| T-13 ² €0046 Sample Ti34 Ti32 Ti33 Ti33 Ti335 Ti330 Ti332 Ti333 Ti333 Ti334 Ti330 Ti332 Ti333 Ti333 Ti333 Ti3330 Ti3330 Ti3331 Ti3332 Ti3332 Ti3340 Ti343 Ti343 Ti343 | Ba Ba 271 < | e Co. 1 37.2 19.4 19.4 1 33.1 1 51.4 4 37.7 42.3 42.3 1 35.0 1 35.0 1 25.0 1 25.7 1 24.2 27.7 24.1 1 52.7 1 24.2 1 52.7 1 21.6 1 21.6 1 19.7 | Cs 1.9 0.6 0.9 1.5 1.7 0.6 0.7 1.7 6.1 6.4 2.8 0.7 2.9 0.6 0.1 <0.6
 | Ga
13.5
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14.3
10.7
14.9
17.6
12.0
13.5
12.4
15.3
18.0
12.8
16.2
19.3
11.9
13.4 | Hf 2 2.5 2.7 1.7 1.6 1.3 3.0 1.5 1.7 2.1 2.7 2.7 1.8 0.9 1.0 1.0 1.8 | Nb Rt R2.6 21.4 1.7 10.0 1.1 17.1 0.9 6.5 0.7 5.1 3.7 7.0 1.5 2.9 0.7 26.4 4.2 10.3
6.4 16.6 4.3 26.5 2.5 2.6 0.7 4.5 1.6 6.0 1.6 1.9 1.4 <0.3 | Sn Sn 6 Ad 2 Ad 3 Ad 4 Ad 5 Ad 6 Ad 7 Ad 9 Ad 9 Ad 9 Ad 9 Ad 15 Ad 5 Ad 5 Ad 9 Ad 10 Ad 11 Ad 12 Ad 13 Ad | Sr
742.5
1028.5
435.7
528.8
201.5
468.1
1137.9
128.4
1031.5
490.9
1508.4
771.7
285.2
666.6
897.7
136.9
1375.8 | Ta 0.1 0.2 0.1 <0.1
 | Th 4.5 2.0 1.9 1.1 0.9 0.8 1.5 1.9 0.10 2.5 1.4 0.3 <<0.2 | U V
09 155
0.6 77
0.5 172
0.5 296
0.4 186
0.7 212
0.5 296
0.4 186
0.7 212
0.5 177
0.8 186
0.7 214
(0.1 122
(0.1 403
0.5 316
0.5 316 | Cr Cr 7 616 7 26.6 2 744 0 1168 0 880 8 201 3 2.5 6 324 0 244 0 369 0 34.3 4 4.4 6 207 3 31.4 0 55.5 7 3.0 | W Zr 69.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 50.7 122.7 22.1 48.6 23.2 50.9 39.8 66.1 27.9 100.1 47.5 74.4 10.6 57.8 57.8 26.9 91.4 22.7 73.4 25.8 61.4 22.7 73.0 61.2 | Y 16.4 12.6 15.8 14.2 11.9 22.9 1 16.6 15.8 1 16.6 15.8 1 17.5 1 1 18.3 19.9 1 18.6 2 20.0 1
 | La C
19.1 37
9.9 20
9.3 17
9.2 21
8.1 17
11.3 25
10.9 23
8.0 16
9.9 21
18.5 37
12.0 26
4.6 9
5.5 13
12.7 24
12.7 24
12.7 24
12.7 24
15.4 32
15.4 32
16.4 32
17.4 3

 | e Pr 7 5.03 4 2.86 9 2.44 0 2.96 7 2.53 3 3.75 7 3.50 7 2.57 7 2.59 4 3.09 7 4.96 7 3.496 7 1.40 3 2.08 4 2.38 2 3.87 0 4.62
 | Nd 19.7 11.5 10.9
 13.7 16.5 11.5 10.9 17.3 16.5 11.5 10.9 17.3 16.5 11.5 12.1 14.0 22.0 17.9 6.7 11.5 13.1 17.4 20.4 | Sm
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3.00
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3.97
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3.04
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3.74
4.45 | Eu G 1.12 3. 0.77 2. 0.87 2. 1.03 3. 0.89 2. 1.45 4. 1.42 3. 0.77 2. 0.99 3. 1.30 4. 1.36 4. 0.666 2. 1.12 4. 1.32 4. 1.12 4. 1.12 4. 1.12 4. 1.12 4. 1.12 4. 1.12 4. 1.12 4. 1.12 4. 1.12 4. 1.12 4. | d Th 80 0.50 191 0.34 133 0.40 179 0.41 199 0.35 14 0.69 199 0.53 16 0.35 16 0.48 12 0.57 19 0.53 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.61 10 0.62 16 0.60 15 0.64 10 0.61 | Dy 2.88 (2) 2.10 (2) 2.41 (2) 2.65 (2) 3.38 (2) 3.12 (2)
 3.51 (2) 3.40 (2) 3.40 (2) 3.73 (2) 3.94 (2) 3.68 (2) | Io Er 52 1.56 44 1.28 43 1.19 77 2.43 6.3 1.87 7.39 1.15 6.2 1.74 6.2 1.78 6.9 1.85 6.2 1.66 4.3 1.29 6.2 1.66 1.63 1.67 7.2 2.02 6.5 1.75 7.2 2.02
 | Tm 0.23 0.19 0.21 0.20 0.18 0.35 0.28 0.15 0.26 0.25 0.29 0.27 0.18 0.23 0.23 0.23 0.23 | Yb
1.38
1.30
1.33
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1.06
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1.85
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 | Lu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.1 0.16 <0.1 | Cu
46.1
21.4
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100.3 | Pb 5.3 0.8 2.1 0.3 0.8 0.5 2.6 1.0 1.3 3.4 2.1 0.3 0.7 0.8 0.4 3.3 | Zn N Za 200 44 33 53 190 46 311 26 255 71 64 91 0.0 41 53 62 53 63 79 45 98 33 33 31 7. 11 14 72 0.0
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| $ \begin{array}{c} \overline{r} - 1 \stackrel{*}{\underbrace{\bullet}} 0 0 4 6 \\ \hline Sample \\ \overline{r} - 1 3 4 \\ \overline{r} - 1 3 2 \\ \overline{r} - 1 3 \\ \overline{r} - 1 3 2 \\ \overline{r} - 1 \\ r$ | Ba Ba 271 < | e Co 1 37.2 19.4 19.4 1 33.1 1 51.4 1 51.4 1 43.7 42.3 1 1 26.0 1 35.5 1 27.6 1 24.1 1 52.7 1 24.1 1 52.7 1 52.7 1 40.9 1 16.1 1 19.7 40.5 1 | Cs 1.9 0.6 0.9 1.5 1.7 0.6 0.7 0.7 2.8 0.7 2.9 0.6 0.1 0.1 0.1 0.3
 | Ga
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13.4
13.6 | Hf 2 2.5 2.7 1.7 1.6 1.3 3.0 1.3 1.5 1.7 2.1 2.7 2.2 1.8 0.9 1.0 1.0 1.8 1.3 | Nb Rth 2.6 21.41 1.7 10.01 1.1 17.40 0.9 6.55 0.7 5.11 3.7 7.02 1.5 2.99 0.7 26.41 6.4 16.5 4.3 26.5 2.5 2.6 0.7 4.51 1.6 6.00 1.6 1.9 1.4 <0.71 | Sn Sn 6 S1 6 41 2 41 8 41 5 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 9 41 10 41 11 41 12 41
 | Sr
742.5
1028.5
435.7
528.8
201.5
468.1
1137.9
128.4
1031.5
460.9
1508.4
771.7
265.2
666.6
897.7
136.9
1375.8
749.6 | Ta 0.1 0.2 0.1 <0.1 | Th 4.5 2.0 1.9 1.9 1.1 0.9 1.5 1.9 1.0 2.5 1.0 2.5 1.0 2.5 1.4 0.3 < | U V
09 155
0.6 77
0.5 177
0.3 288
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0.7 213
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16.4 :: 12.6 : 15.8 : 14.2 : 11.9 : 22.9 : 16.9 : 9.4 : 15.8 : 15.8 : 15.3 : 19.9 : 18.4 : 19.9 : 18.6 : 20.0 :
 | La C 19.1 37 9.9 20 9.3 17 9.2 21 8.1 17 11.3 25 8.0 16 9.9 21 8.0 16 8.0 16 8.0 16 9.9 21 8.5 37 8.0 26 9.9 21 8.5 37 8.5 31 5.5 13 12.7 24 15.4 32 8.1 17

 | e Pr 7 5.03 4 2.86 9 2.44 0 2.96 7 2.53 3 3.75 7 3.50 7 2.57 7 2.59 4 3.09 7 4.96 7 3.92 7 1.40 3 2.08 4 2.38 2 3.87 0 4.64
 | Nd 19.7 11.5 10.9 13.7 13.3 17.3 16.5 11.5 12.1 14.0 22.0 17.9 6.7 11.5 13.1 17.4 20.4 12.4 | Sm
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2.67
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4.08
3.97
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3.74
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 | Eu G 1.12 3. 0.77 2. 0.88 2. 1.103 3. 0.89 2. 1.45 4. 1.42 3. 0.077 2. 0.99 3. 1.30 4. 1.36 4. 1.36 4. 1.32 4. 1.12 4. 1.42 4. 1.64 4. 1.07 3. | d Tb 30 0.50 19 0.34 33 0.40 97 0.41 99 0.53 66 0.35 94 0.48 92 0.50 99 0.53 66 0.35 94 0.48 92 0.50 102 0.57 99 0.53 10 0.61 82 0.62 105 0.61 105 0.64 | Dy 2.88 0 2.10 0 2.41 0 2.41 0 2.65 0 2.33 0 2.41 0 3.38 0 2.17 0 3.51 0 3.51 0 3.51 0 3.40 0 2.17 0 3.40 0 3.40 0 3.40 0 3.40 0 3.44 1 3.40 0 3.44 1 3.40 0 3.44 1 3.40 0 3.44 1 3.40 0 3.44 1 3.45 0 3.45 0
 | In Er 10 Er 22 1.56 44 1.25 49 1.51 48 1.38 43 1.19 77 2.43 63 1.87 39 1.15 62 1.74 62 1.74 62 1.64 43 1.29 669 1.99 72 202 65 1.75 75 2.18 56 1.49 | Tm 0.23 0.19 0.21 0.20 0.18 0.35 0.28 0.15 0.26 0.27 0.13 0.23 0.23 0.23 0.32 0.23
 | Yb
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1.19
1.06
2.30
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1.63
1.59
1.83
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1.34 | Lu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.1 0.32 0.2 0.35 0.4 0.25 0.5
 0.15 <0.1 | Cu
46.1
21.4
62.0
66.1
7.8
25.2
24.3
26.5
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7.4 | Pb 5.3 0.8 2.1 0.3 0.8 0.5 2.6 1.0 1.3 3.3 0.3 0.3 0.7 0.8 0.4 3.3 1.1 | Zn N 43 200.01 44 13 53 19 46 31 26 25 71 64 91 0. 41 53 62 53 63 79 103 15 89 1. 45 98 33 33 31 7. 11 14 72 0.0 50 32 | <1 Ni As 2.3 2.2 3.6 <0.9
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 1 13.61 1 13.62 1 13.61 1 13.92 1 13.22 1 13.24 1 13.69 1 13.61 1 13.61 1 13.61 1 13.61 1 13.61 1 13.61 1 13.74 1 14.74 | Se
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| T-13 CO46 Sample | Ba Ba 271 < | e Co. 1 37.2 19.4 19.4 1 33.1 1 51.4 1 43.7 42.3 1 26.0 35.0 1 35.5 1 27.6 1 24.1 1 52.7 1 24.1 1 52.7 1 21.6 1 97.6 4 42.5 4 42.5 | Cs 1.9 0.6 0.9 1.5 1.7 0.6 0.7 1.7 6.1 6.4 2.8 0.7 2.9 0.6 0.11 0.11 0.33
 | Ga
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14.4
14.3
10.8
10.7
14.9
17.6
12.0
13.5
12.4
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12.8 | Hf 1 2.5 2.7 1.7 1.6 1.3 3.0 1.3 1.5 1.7 2.1 2.7 1.8 0.9 1.0 1.0 1.8 1.3 1.3 | Nb Rt 2.6 21.4 1.7 10.0 1.7 10.0 0.9 6.5 0.7 5.1 3.7 7.0 1.5 2.9 0.7 26.6 4.2 10.0
 6.4 16.5 2.5 2.6 0.7 4.5 1.6 6.0 1.6 1.9 1.4< | Sn Sn 6 Al 2 Al 3 Al 5 Al 5 Al 5 Al 5 Al 6 Al 7 Al 9 Al 11 Al 12 Al 13 Al 14 Al 15 Al 16 Al 17 Al 18 Al 19 10< | Sr 742.5 1028.5 435.7 528.8 201.5 468.1 1137.9 128.4 1031.5 490.9 1508.4 771.7 285.2 666.6 897.7 1375.8 749.6 195.4 | Ta 0.1 0.2 0.1 <0.1 | Th 4.5 2.0 1.9 1.1 0.9 0.8 1.5
 1.9 0.8 1.5 1.9 0.9 0.8 1.5 1.0 2.5 1.4 0.3 <<<0.2 | U V U.9 157 0.6 77 0.5 177 0.3 288 0.3 288 0.7 213 0.5 529 0.4 186 0.5 177 0.8 188 0.7 214 0.1 122 0.1 126 0.1 498 0.5 317 0.8 100 0.4 350 0.3 255 | Cr Cr 7 616 7 26.6 2 744 0 1168 0 880 8 201 3 2.5 6 324 0 2444 0 2444 6 207 3 314.4 4 4.4 5 207 3 314.4 0 55.5 7 3.0 0 168 5 593 | W Zr 69.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 50.7 122.7 22.1 48.6 90.6 68.1 27.9 10.6 57.8 26.9 9.6 68.1 27.9 10.6 57.8 26.9 61.4 22.7 37.0 61.2 37.0 61.2 37.0 61.2 37.9 38.2 37.0 61.2 37.3 38.2 | Y 16.4 12.6 15.8 14.2 11.9 22.9 16.9 15.8 15.8 15.8 16.6 15.8 18.4 17.5 11.0 18.3 19.9 18.6 20.0 15.3 15.3 12.3

 | La C 19.1 37 9.9 20 9.3 17 9.2 22 8.1 17 11.3 25 8.0 16 7.9 16 9.9 21 8.0 16 18.5 37 12.0 26 4.6 9 5.0 11 5.5 12 12.7 24 15.4 32 8.1 17 9.6 17

 | e Pr 7 5.03 4 2.86 9 2.44 0 2.96 7 2.53 3 3.75 7 3.50 7 2.59 4 3.09 7 4.96 7 3.95 7 1.40 3 2.08 4 2.387 0 4.64 3 2.53 8 2.44
 | Nd 19.7 11.5 10.9 13.7 13.3 16.5 11.5 12.3 17.3 16.5 11.5 12.1 14.0 22.0 17.9 6.7 11.5 13.1 17.4 20.4 11.0 | Sm
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3.74 4.452 3.29 2.45 3.22 | Eu G 1.12 3. 0.77 2. 0.88 2. 1.103 3. 0.89 2. 1.45 4. 1.42 3. 0.077 2. 0.99 3. 1.30 4. 1.36 4. 1.36 4. 1.32 4. 1.12 4. 1.42 4. 1.64 4. 1.07 3. | d Tb 80 0.50 19 0.34 38 0.40 77 0.41 69 0.35 44 0.69 199 0.53 66 0.35 44 0.48 12 0.57 12 0.57 12 0.57 19 0.54 10 0.61 18 0.62 16 0.60 15 0.64 10 0.41 38 0.37 | Dy 2.88 (2.10 (2.41 (2.65 (2.30 (3.38 (3.38 (3.31 (3.351 (3.36 (2.17 (3.38 (2.17 (3.38 (2.17 (3.40 (3.40 (3.40 (3.40 (3.40 (3.40 (3.40 (3.40 (3.40 (3.40 (3.40 (3.40 (3.40 (3.41 (3.42 (3.43 (3.44 (3.45 (
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0.3 < | U V V 0.9 157 0.6 777 0.5 177 0.3 288 0.7 212 0.8 186 0.5 177 0.8 186 0.7 214 0.8 186 0.7 214 0.8 186 0.7 214 0.8 186 0.7 214 0.8 186 0.7 214 0.8 186 0.1 498 0.1 498 0.1 498 0.3 255 0.2 126 0.3 255 0.2 126 0.4 51 0.3 255 0.2 126 0.4 51 0.7 224 | Ct Ct 7 616 7 26.6 2 744 0 1168 0 880 8 201 3 2.5 6 324 0 244 0 369 0 34.3 4 4.4 8 224 5 503 0 5555 7 3.0 0 5559 5 593 6 126 1 1.7 | W Zr 49.4 84.3 85.7 94.3 32.6 58.1 14.1 52.2 50.7 122.7 48.6 23.2 50.9 122.1 48.6 88.1 7.8 82.1 7.9 100.1 47.5 74.4 10.6 57.8 57.8 25.9 61.4 22.7 73.4 25.8 37.0 61.2 31.9 38.2 5.9 47.3 38.0 79.6 37.7 82.2 30.3 51.6 | Y 16.4 :: 12.6 : 15.8 : 14.2 : 11.9 : 22.9 : 16.6 : 15.8 : 16.6 : 15.3 : 19.9 : 16.6 : 15.3 : 19.9 : 16.6 : 15.3 : 12.3 : 13.6 : 12.4 :

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 | Zn N 43 200 44 13 53 199 46 311 26 25 71 64 91 0. 41 53 63 79 103 15 89 1. 45 99 33 33 31 72 11 14 67 42 34 8. 67 42 34 8. 84 2. | <1 ×i As 2.3 2.2 2.4 2.2 9.4 -0.9 9.4 -0.9 9.4 -0.1 7.3 1.0 1.2 -0.9 3.3 -0.0 9.7 13.3 5.9 3.8 9.9 -0.5 3.0 -0.0 9.9 -0.5 3.0 -0.0 5.5 1.5 5.5 1.5 5.5 1.5 5.5 1.5 2.5 1.5 2.3 1.1 2.6 -0.6 6.6 0.6 | 53.4 Cd - <td>3.2
Sb
 3.2 Sb </td> <td>Bi </td> <td>Ag A 40.1 3 40.1 1 40.1 0 40.1 1 40.1 0 40.1 1 40.1 1 40.1 0 40.1 3 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4</td> <td>Image Hg un Hg 2.2 <0.01</td> 1.5 <0.01 | 3.2
Sb
 3.2 Sb | Bi | Ag A 40.1 3 40.1 1 40.1 0 40.1 1 40.1 0 40.1 1 40.1 1 40.1 0 40.1 3 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1
 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 40.1 4 | Image Hg un Hg 2.2 <0.01 | Ti 1 11.13 4.96 6.89 6.89 13.36 1 12.37 1 13.36 1 12.32 1 10.37 1 13.21 1 13.22 1 13.26 1 13.27 1 3.26 1 13.27 1 3.26 1 13.27 1 3.27 1 12.25 1 9.91 5.47 10.06 | Se 405 |
| T-13€0046 Sample T-134 T-135 T-137 T-138 T-139 T-131 T-133 T-1317 T-1325 T-1326 T-1327 T-1330 T-1323 T-1324 T-1333 T-1340 T-1342 T-1343 T-1340 T-1343 T-1343 T-1343 T-1343 T-1343 T-1343 T-1344 T-1345 T-1355 T-1350 T-1350 T-1350 T-1350 T-1350 | Ba Ba 271 < | e Co. 1 37.2 19.4 33.1 1 51.4 1 42.3 1 25.0 1 35.0 2 27.7 1 24.1 1 22.7 1 24.1 1 52.7 1 24.1 1 52.7 1 40.9 1 15.2 1 42.5 1 42.5 1 42.1 1 12.1.6 1 14.1 1 14.1 27.9 24.4 | Cs 19 0.6 0.9 1.5 1.7 0.6 0.7 1.7 6.4 2.8 0.7 2.9 0.6 0.1 0.7 0.1 0.6 0.1 0.1 0.3 2.9 0.6 0.1 0.3 2.0 6.5 11.8 1.4 0.8 0.8
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| $ \begin{array}{c} T-13 00046 \\ \hline Sample \\ \hline T-134 \\ \hline T-134 \\ \hline T-132 \\ \hline T-137 \\ \hline T-1330 \\ \hline T-1335 \\ \hline T-1335 \\ \hline T-1335 \\ \hline T-1340 \\ \hline T-1344 \\ \hline T-1344 \\ \hline T-1344 \\ \hline T-1344 \\ \hline T-1351 \\ \hline T-1355 \\ \hline T-1357 \\ \hline T-1357 \\ \hline \end{array} $ | Ba Ba 271 < | e Co 1 37.2 19.4 33.1 1 31.1 1 51.4 42.3 42.3 1 26.0 1 35.5 1 27.6 1 24.2 27.7 40.9 1 24.1 52.7 21.6 1 21.6 1 21.6 1 14.1 27.9 43.0 43.3 33.8 | Cs 19 0.6 0.9 1.5 0.6 0.7 1.7 6.4 2.8 0.7 0.7 0.7 2.8 0.7 0.17 6.1 6.2 0.1 0.1 0.1 0.1 0.1 0.3 2.00 6.5 11.8 1.4 0.8
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0.54 90 0.54 90 0.54 90 0.54 90 0.54 90 0.54 90 0.54 90 0.55 90 0.54 90 0.54 90 0.54 90 0.54 91 0.41 92 0.33 91 0.45 92 0.53 93 0.60 94 0.51 95 0.51 91 0.34 92 0.33 94 0.10 94</td><td>Dy 2.88 0 2.88 0 2.10 0 2.41 0 2.41 0 2.65 0 2.63 0 3.83 0 2.17 0 3.51 0 3.51 0 3.51 0 3.51 0 3.60 0 2.17 0 3.61 0 3.41 0 2.17 0 3.43 0 3.40 0 2.17 0 3.41 0 2.66 0 3.42 2.66 0 0 2.63 3.18 0 0 2.65 0 0 2.23 3.87 0 3.32 0 3.83 0 0 0 0 2.05 0 0 0 0 2.05 0 0 0 0 2.05 0 0 0 <t< td=""><td>Image: Second Second</td><td>Tm 0.23 0.19 0.21 0.23 0.35 0.26 0.27 0.38 0.20 0.21 0.22 0.23 0.24 0.25 0.29 0.21 0.21 0.21 0.22 0.23 0.24 0.25 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.27 0.28 0.29 0.26 0.27 0.28 0.29 0.29 0.20 0.21 0.22 0.23 <!--</td--><td>Yb 1.38 1.30 1.31 1.32 1.33 1.33 1.31 1.32 1.33 1.33 1.33 1.33 1.33 1.63 1.53 1.55 1.55 1.55 1.53 1.64 1.70 1.160 1.70 1.161 1.20 1.21 1.22 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.28 1.29 1.21 1.20 1.21 1.22 1.23 1.24 1.25 1.26 1.27 1.26 1.26 1.26 1.26</td><td>Hu Mo 0.22 0.8 0.21 0.7 0.22 0.2 0.19 0.11 0.16 <0.1</td> 0.22 0.2 0.25 0.9 0.25 0.4 0.25 0.4 0.25 0.4 0.25 0.4 0.25 0.2 0.22 0.22 0.22 0.22 0.22 0.22 0.23 0.4 0.20 0.22 0.21 0.11 0.25 0.9 0.26 0.9 0.27 0.21 0.21 0.11 0.25 0.4 0.29 0.24 0.20 0.22 0.24 0.52 0.25 0.4 0.32 0.8 0.29 0.2 0.29 0.2 0.29 0.2 0.29 0.4</td><td>Cu
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Table 3. Results from the Sm-Nd isotope analyses

Rock type		Rb	Sr	Sm	Nd	measured	measured	measured	measured		εNd(0)	εNd(T)		T _{DM}
		[ppm]	[ppm]	[ppm]	[ppm]	¹⁴³ / ¹⁴⁴ Nd	¹⁵⁰ / ¹⁴⁴ Nd	¹⁴⁷ / ¹⁴⁹ Sm	¹⁵² / ¹⁴⁹ Sm					(Ma)
basalts	-	5.1	523.4	4.56	22.1	.512747	.492876	5.43335	1.88552	-	1.03	3.22	-	758
microgabbro	-	3.1	958.4	3.39	14.5	.512789	.496912	4.77357	1.85985	-	1.83	3.41	-	974
andesite	-	26.5	1508.4	4.49	22.0	.512837	.472676	4.81292	1.87726	-	2.87	5.16	-	679

Supplementary data 1. Results from the U-Pb analysis

Analysis	²⁰⁷ Pb/ ²⁰⁶ Pb	±2σ	²⁰⁶ Pb/ ²³⁸ U	±2σ	²⁰⁷ Pb/ ²³⁵ U	±2σ	²⁰⁸ Pb/ ²³² Th	±2σ	²⁰⁷ Pb/ ²⁰⁶ Pb	±2σ	²⁰⁶ Pb/ ²³⁸ U	±2σ	²⁰⁷ Pb/ ²³⁵ U	±2σ	²⁰⁸ Pb/ ²³² Th	±2σ	Concordancy
004_01	0.07184	0.00118	0.03336	0.00046	0.33042	0.00587	0.01095	0.00022	981.3	33.17	211.6	2.85	289.9	4.48	220.1	4.4	76
004_02	0.09707	0.00113	0.03463	0.00046	0.46342	0.00654	0.01113	0.00022	1568.6	21.65	219.5	2.85	386.6	4.53	223.8	4.45	58
004_03	0.05002	0.00175	0.03215	0.00055	0.22169	0.00773	0.00949	0.00038	195.9	79.3	204	3.45	203.3	6.42	191	7.67	94
004_04	0.05025	0.00088	0.03135	0.00041	0.21723	0.00399	0.01015	0.00026	206.8	39.99	199	2.56	199.6	3.33	204	5.17	102
004_05	0.05211	0.00069	0.03258	0.00043	0.23403	0.00356	0.01073	0.00024	290.4	29.82	206.6	2.67	213.5	2.93	215.6	4.89	101
004_06	0.05028	0.00076	0.03268	0.00044	0.22653	0.00384	0.01008	0.00025	207.8	34.8	207.3	2.76	207.3	3.18	202.8	4.9	98
004_07	0.05007	0.00186	0.03232	0.00057	0.22307	0.00822	0.00855	0.00039	198	84.02	205	3.59	204.5	6.82	172.1	7.81	84
004_08	0.04992	0.00111	0.03294	0.00044	0.22672	0.00506	0.01057	0.00043	191.4	50.96	209	2.72	207.5	4.19	212.5	8.53	102
004_09	0.05226	0.00255	0.03828	0.00077	0.2758	0.01311	0.012	0.00085	297	107.7	242.1	4.79	247.3	10.43	241.1	16.89	97
004_10	0.05127	0.00084	0.03284	0.00046	0.2321	0.00423	0.00953	0.00028	252.9	37.34	208.3	2.87	211.9	3.48	191.6	5.55	90
004_11	0.05075	0.00084	0.03369	0.00048	0.2357	0.00436	0.00871	0.00028	229.3	37.94	213.6	3	214.9	3.59	175.3	5.54	82
004_12	0.05061	0.00095	0.03281	0.00046	0.22889	0.00457	0.00924	0.00028	223	42.65	208.1	2.88	209.3	3.78	185.8	5.65	89
004_13	0.0514	0.00229	0.03313	0.00063	0.2347	0.01026	0.00939	0.00081	258.7	99.33	210.1	3.95	214.1	8.44	188.9	16.26	88
004_14	0.08256	0.00193	0.03332	0.00052	0.37922	0.00915	0.0105	0.00059	1258.9	44.87	211.3	3.26	326.5	6.74	211.1	11.72	65
004_15	0.05055	0.0015	0.03364	0.00054	0.23442	0.00699	0.01067	0.00079	220.4	67.04	213.3	3.4	213.8	5.75	214.4	15.87	100
004_16	0.05016	0.00331	0.03358	0.00081	0.23195	0.01482	0.01053	0.00115	202.4	146.49	212.9	5.05	211.8	12.21	211.7	22.92	100
004_17	0.05021	0.00103	0.03354	0.00051	0.23211	0.00515	0.00911	0.00037	204.7	47.05	212.7	3.19	211.9	4.24	183.2	7.37	86
004_18	0.05078	0.00105	0.03396	0.00048	0.23771	0.00515	0.01047	0.00029	230.7	46.86	215.3	3.02	216.5	4.22	210.6	5.86	97
004_19	0.05036	0.00244	0.03228	0.00065	0.22387	0.01064	0.00976	0.00076	211.5	108.58	204.8	4.05	205.1	8.83	196.4	15.19	96
004_20	0.06982	0.00105	0.03338	0.00047	0.32129	0.00554	0.00786	0.00024	922.9	30.67	211.7	2.94	282.9	4.25	158.3	4.85	56
004_21	0.05037	0.0011	0.03349	0.00051	0.23255	0.00541	0.00986	0.00039	212.2	49.96	212.4	3.17	212.3	4.45	198.4	7.89	93
004_22	0.05114	0.00117	0.03257	0.00049	0.22964	0.00548	0.01059	0.00039	247	51.76	206.6	3.05	209.9	4.53	212.9	7.76	101
004_23	0.0557	0.00121	0.03432	0.00051	0.26356	0.00601	0.01082	0.00039	440.1	47.22	217.5	3.18	237.5	4.83	217.5	7.8	92
004_24	0.21322	0.00513	0.03748	0.00063	1.1016	0.02542	0.00529	0.00028	2930.2	38.38	237.2	3.94	754.1	12.28	106.6	5.65	14
004_25	0.0505	0.00155	0.03264	0.00053	0.2273	0.00702	0.01047	0.00061	217.9	69.75	207.1	3.3	208	5.81	210.5	12.11	101
004_26	0.11427	0.00376	0.0339	0.00065	0.53397	0.01734	0.01041	0.00087	1868.3	58.23	214.9	4.05	434.4	11.48	209.3	17.33	48
004_27	0.051	0.00158	0.03699	0.0006	0.26006	0.00807	0.01118	0.0006	240.8	69.96	234.1	3.7	234.7	6.51	224.7	11.91	96
004_28	0.05071	0.00108	0.03608	0.00051	0.25227	0.00559	0.01098	0.00049	227.7	48.61	228.5	3.17	228.4	4.53	220.8	9.79	97
004_29	0.05048	0.00088	0.03576	0.0005	0.24887	0.00473	0.01084	0.00042	217	39.88	226.5	3.11	225.7	3.85	217.9	8.38	97
004_30	0.05175	0.00155	0.03354	0.00056	0.23928	0.00727	0.00975	0.00086	274.2	67.36	212.7	3.5	217.8	5.96	196	17.16	90

Appendix D

Table 1. Experimental determination of the brittle strength of the Saraburi limestone and marble

Saraburi Limestone and Marble									
Diameter	Length	D/L	Load at failure	Confining Pressure	Axial Stress at Failure				
(mm)	(mm)	ratio	(kN)	(Mpa)	(Mpa)				
see capt.	see capt.	0.5	0	0	-8.5				
53.9	100.7	0.5	174	1.7	76.2				
53.9	100.8	0.5	250	3.4	109.5				
54.1	100.1	0.5	274	6.9	119.8				
54	102.8	0.5	284	13.8	124.4				
54	100.3	0.5	386	20.7	169.1				

Table 2. Parameters and data set used in Mohr construction to quantify effective principal stressmagnitudes

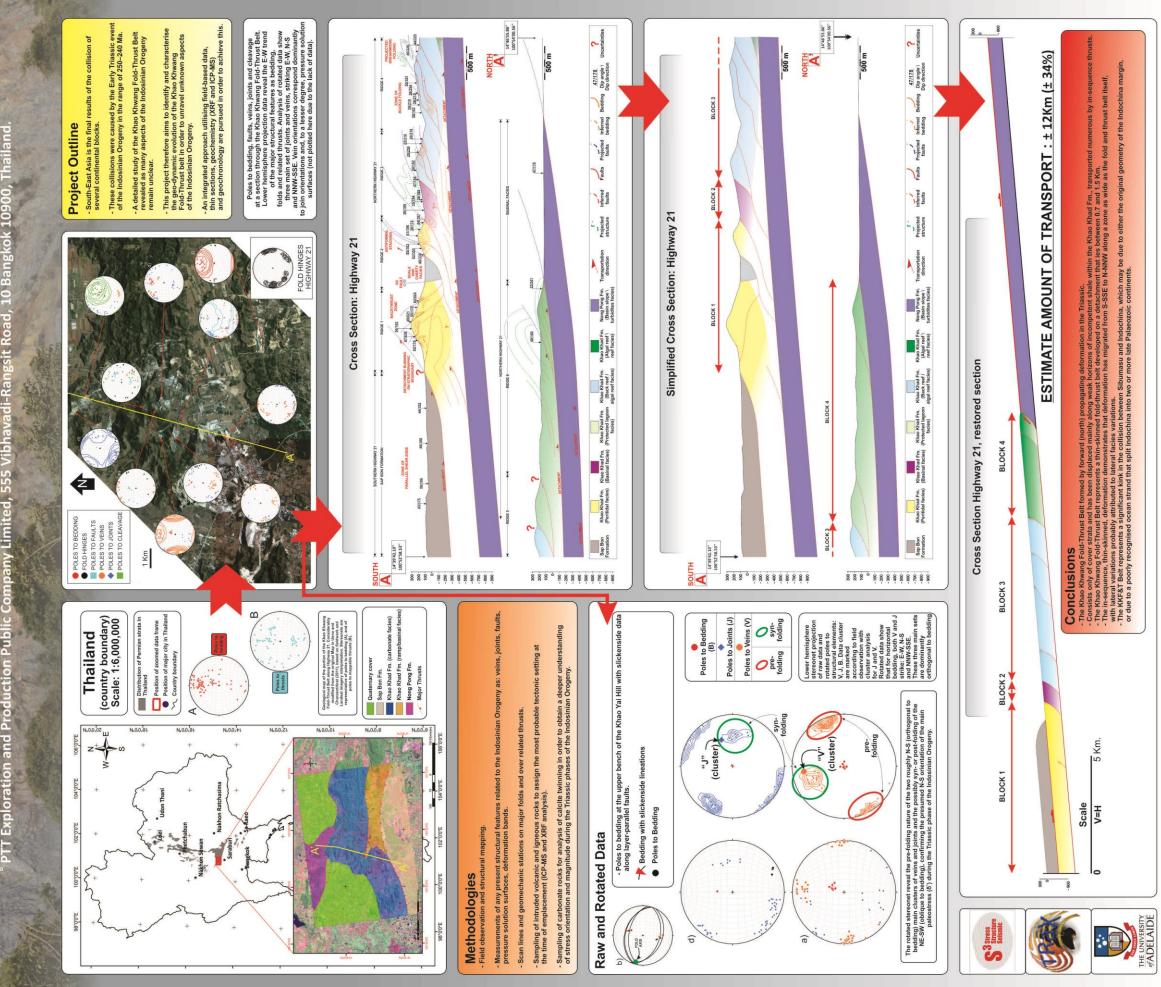
Stress Stage	Sample Number	Bedding (Dip Dir - Dip)	Vein (Dip Dir - Dip)	Stress Ratio (Φ)	Different ial Stress (σ1- σ3) (MPa)	Stress Regime	Magnitud e of σ3 (MPa)	Magnitud e of σ2 (MPa)	Magnitud e of σ1 (MPa)
SI	T020	174/14	068/88	0.6	84±17	EXT	[-2]	[42]	[78]
SI	T029	352/39	235/80	0.4	76±15	EXT	"	н	
SI	T019b	160/40	251/72	0.3	37±7	EXT	-5	8	38
SII	T029b	352/39	358/82	0.4	58±12	PC	-4	26	54
SII	T083b	175/59	HOST	0.9	35±7	SS	-4	±30	40
SII	T018vb	160/40	138/25	0.8	38±7	SS	"	п	н
SIII	T011b	178/60	HOST	0.5	66±13	SS	13	21	87
SIII	T019	160/40	322/71	0.2	62±12	PC	"	н	
SIII	T018v	160/40	322/71	0.5	68±13	SS	"	н	
SIII	T011	178/60	HOST	0.5	72±15	SS	н	н	н
SIV	T081	175/59	140/78	0.3	71±14	PC	12	16	66
SIV	T082	175/59	217/75	0.1	55±11	PC	"	п	"
SIV	T080b	175/59	255/52	0.8	38±7	SS	12	55	66
SV	T081b	175/59	281/42	0.4	51±10	SS	46	30	72
SV	T082b	175/59	261/49	0.3	46±9	SS	"	н	н
SV	T083	175/59	045/87	0.6	52±11	PC	"	н	н
SV	T080	175/59	337/85	0.7	70±14	PC	н	н	н

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Structure of the Sibumasu-Indochina collision, Thailand: A section through the Khao Khwang Fold-Thrust Be Centra

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RaX), Department of Earth Sciences, The University of Adelaide, SA 5005, / mpany Limited, 555 Vibhavadi-Rangsit Road, 10 Bangkok 10900, Thailand ces and Exploration (TRaX), De **TT Exploration and Production Public Centre for Tectonics Resound**



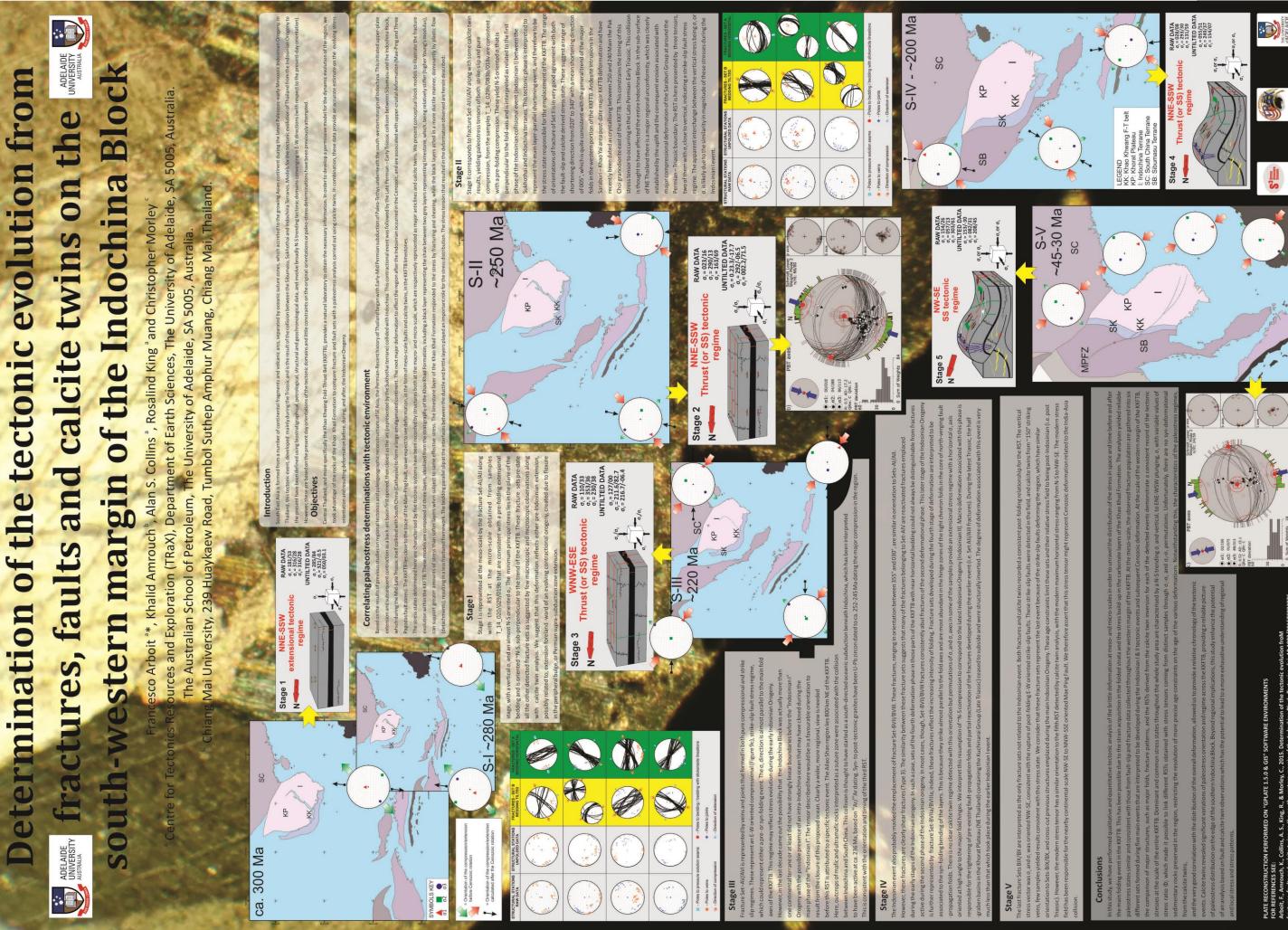


PLATE RECONSTRU FOR REFERENCES S Arboit, F., Amrouch

