Geol. Mag. **155** (*7*), *2018, pp. 1449–1464.* © *Cambridge University Press 2017*
doi:10.1017/S0016756817000322

Early Permian radiolarians from the extension of the Sa Kaeo Suture in Cambodia – tectonic implications

MONGKOL UDCHACHON*‡, HATHAITHIP THASSANAPAK*† & CLIVE BURRETT‡§

*Applied Palaeontology and Biostratigraphy Research Unit, Department of Biology, Faculty of Science, Mahasarakham University, 44150, Thailand
‡Palaeontological Research and Education Centre, Mahasarakham University, 44150, Thailand
§School of Physical Sciences, University of Tasmania, Hobart, Box 79, Tasmania, 7001, Australia

(*Received* 4 April 2016; *accepted* 8 March 2017; *first published online* 24 April 2017)

Abstract – A reconnaissance survey of part of western Cambodia has found quarries in and near the town of Pailin containing chert, basalt, volcaniclastic rocks, gabbro and serpentinite. Abandoned quarries contain chert and basalt clasts in a volcaniclastic matrix and may constitute a mélange. A new, recently active, quarry contains these rock units in close and coherent contact but they lack the serpentinitic matrix of the Thung Kabin Mélange of eastern Thailand. The rock units are in close contact and may best be described collectively as a dismembered ophiolite. The mélange–ophiolite association constitutes a 3 km wide, 20 km long E–W belt separating a northern 200 km^2 block of the mainly amphibolitic Pailin Crystalline Complex from a southern area of Triassic submarine fan siliciclastic rocks. The cherts yield the first documented radiolarian fauna from Cambodia and include a moderately well-preserved Asselian–Sakmarian age fauna consisting of *Pseudoalbaillella sakmarensis*, *Pseudoalbaillella scalprata* morphotype *scalprata*, *Pseudoalbaillella* sp. cf. *P. simplex*, *Pseudoalbaillella u-forma* morphotype II, *Pseudoalbaillella* sp. cf. *P. elegans*, *Pseudoalbaillella* sp. cf. *P. lomentaria*, *Albaillella* sp., *Pseudoalbaillella* spp., *Trilonche*? sp., Latentifistularia gen. et sp. indet. and Entactinaria gen. et sp. indet. The Pailin ophiolitic rocks, mélange and volcanic rocks occur within a generally E–W-trending belt, which suggests that the Sa Kaeo Suture does not extend southeastwards paralleling the Thai–Cambodian border, nor extend under the Cardamom Mountains but, rather, extends eastwards into Cambodia and possibly then turns southwards along the strike of the Pursat–Kampot Fold Belt.

Keywords: tectonics, Permian, radiolarians, chert, ophiolite, mélange, Cambodia

1. Introduction

In eastern Thailand, the Sa Kaeo Suture is the boundary between the Permo-Triassic Sukhothai Arc Terrane and the Loei–Petchabun Fold-Belt Terrane (Fig. 1a) and has been linked to the Nan Suture in northern Thailand (Bunopas, 1982). Both sutures are generally now regarded as remnants of a Permo-Triassic back-arc basin that closed prior to the intrusion of granites in Late Triassic time (e.g. Metcalfe 1996; Ueno & Charoentitirat, 2011). However, recently acquired Devonian (e.g. Yang *et al.* 2009; Shen *et al.* 2010) dates on mafic igneous rocks within the Nan Suture zone suggest that the two are not linked and that the Nan Suture may be a remnant of a larger and long-lived ocean as originally envisaged by Bunopas (1982). No fossils or mafic igneous rocks older than Permian have yet been found in the Sa Kaeo Suture, which supports the general assumption that it is a Permo-Triassic back-arc basin.

There are three main proposals (Fig. 1b) for the southerly to easterly extension of the Sa Kaeo Suture. One suggests a southerly route paralleling the Thai–Cambodian border (e.g. Chutakositkanon & Hisada, 2008; Nuchanong, 2014; Arboit *et al.* 2016), based on the general strike of strata in easternmost Thailand (e.g. Ridd & Morley, 2011; Arboit *et al.* 2016). A second proposal suggests a southeasterly trend heading into Cambodia beneath the Mesozoic terrestrial sandstones of the Cardamom Mountains (e.g. Sone, Metcalfe & Chaodumrong, 2012; Morley *et al.* 2013; Nie *et al.* 2016) for which there is little evidence, and the third proposal suggests a route directed around the Cardamom Mountains, following the general trend of pre-Mesozoic rocks (e.g. Khin Zaw *et al.* 2014).

Our reconnaissance survey of western Cambodia has found the eastern extension of the Sa Kaeo Suture, which includes cherts with Early Permian radiolarians and supports the proposal of Khin Zaw *et al.* (2014) (Fig. 1b, alternative 3i). These are the first radiolarians to be described from Cambodia.

Because of political instability and wars, there has been very little modern geological work in western Cambodia. Owing to a lack of good base maps and infrastructure, many of the published maps are

†Author for correspondence: bthaithip@yahoo.com

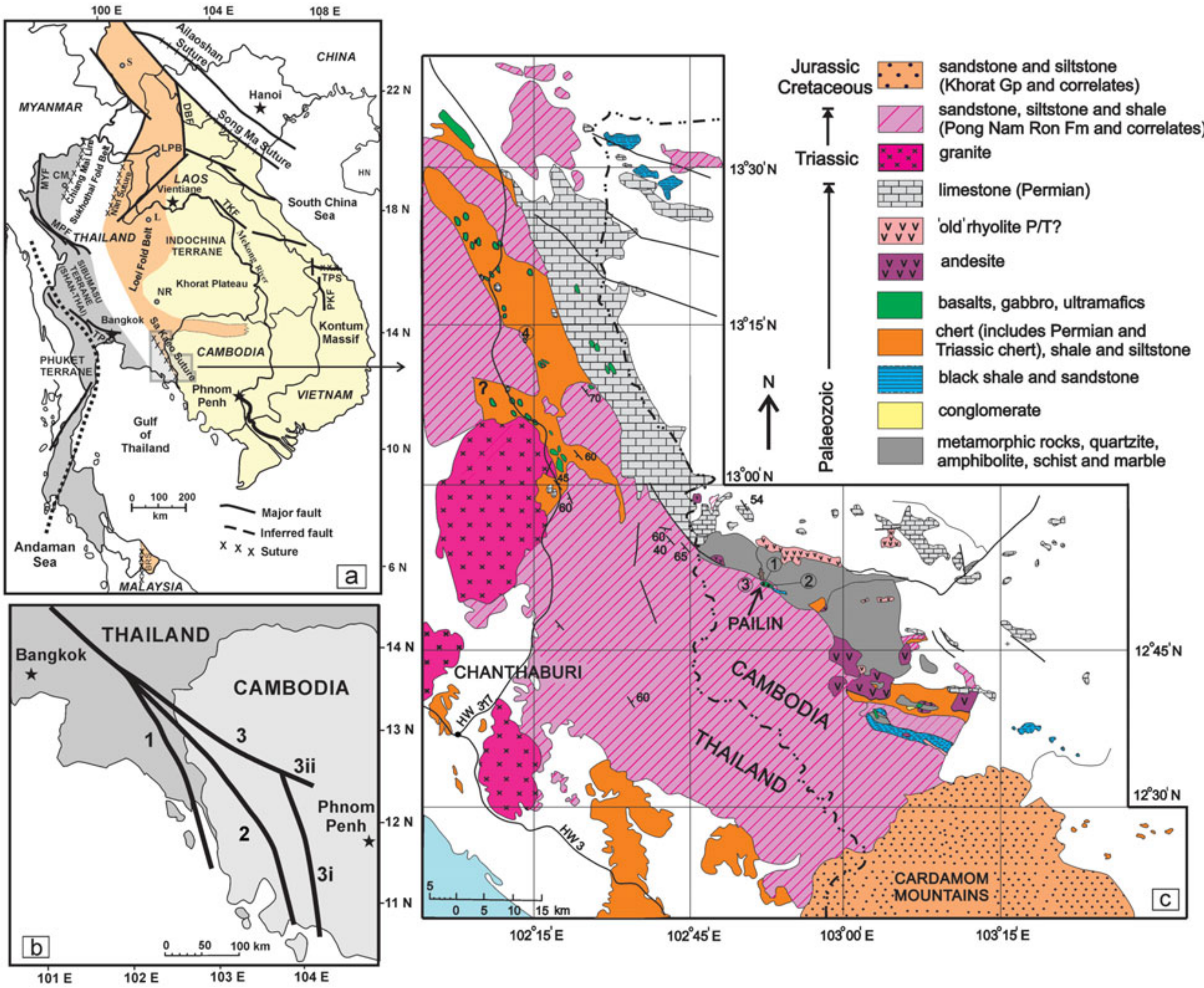

Figure 1. (Colour online) (a) Simplified terrane map of mainland South East Asia with major terranes and sutures showing study area locations. BRS – Bentong–Raub Suture; CM – Chiangmai; DBF – Dien Bien Phu Fault; HN – Hainan Island; LPB – Luang Prabang; MPF – Mae Ping Fault; MYF – Mae Yuem Fault; NR – Nakhon Ratchasima (Khorat); PKF – Poko Fault Zone; S – Simao; TPF – Three Pagodas Fault; TPS – Tamky–Phuoc Son Suture; TKF – Thakhek Fault. (b) Diagrammatic map showing the three main postulated trends of the continuation of the Sa Kaeo Suture from or in SE Thailand into Cambodia from various authors. 1 – Paralleling the Thai–Cambodian border and following the imposed Indosinian Orogenic grain within Thailand (e.g. Arboit *et al*. 2016). 2 – Southeasterly trend beneath the Jurassic–Cretaceous terrestrial sandstones of the Cardamom Mountains in Cambodia (e.g. Qian *et al*. 2016; Sone, Metcalfe & Chaodumrong, 2012). 3 – Easterly trend following the northern margin of the Cardamom Mountains and then either continuing east (3ii) or trending south along the Pursat–Kampot Fold Belt (3i) (e.g. Khin Zaw *et al*. 2014). (c) Simplified compilation of relevant geology in eastern Thailand and western Cambodia. SE Thailand based on Hada *et al*. (1997), Chutakositkanon & Hisada (2008) and maps of the Geological Survey Bureau, Department of Mineral Resources, Bangkok. Western Cambodia geology is based on 1:500 000 scale map of the Pak Nam sheet mapped by J. Gubler in 1935 with additional mapping by E. Saurin in 1962 for the Service Géologiques de l'Indochine and the 1:200 000 BRGM map of the Pothisat sheet by Dottin & Zinszner (1972). Although originally regarded as Devonian, the Cambodian cherts are now, at least in part, reliably dated herein as Early Permian in age. By comparison with cherts in adjacent parts of Thailand, it is probable that both the cherts and the other sedimentary rocks near Pailin are also Permian. South of Pailin, the turbiditic sandstones are correlated with the Triassic submarine fan deposits of the Pong Nam Ron Formation. Point 1 – old abandoned quarries on eastern outskirts of Pailin; Point 2 – new, recently active, quarry to east of Pailin, lat. 12° 49′ 51″ N, long. 102° 36′ 43.44″ E, elevation 227 m; Point 3 – Phnom Kiaow, steeply dipping succession of shale/sandstone with poorly sorted sandstone-greywacke at top of hill, near waterfall at lat. 12° 47′ 48.835″ N, long. 102° 36′ 56.270″ E; Point 4 – Lower Permian radiolarian–conodont chert – basalt locality of Saesaengseerung *et al.* (2009) at Khao Phasuk (lat. 13° 14′ 733″ N, long. 102° 13′ 807″ E) in Thailand.

inaccurate and many of the rock units are either undated or incorrectly dated. As elsewhere in Indochina, metamorphic rocks were often assumed to be of Precambrian or older Palaeozoic age, and tenuous chronological correlations of sedimentary sequences were made on the basis of very little or no evidence.

2. Geological setting

2.a. Geological setting of eastern Thailand

Hada *et al.* (1997) mapped and subdivided the 60 km wide, NW–SE-trending Sa Kaeo – Chantaburi Suture Zone into a western 'Chantaburi Chert–Clastic Sequence' and an eastern Thung Kabin Mélange. The

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

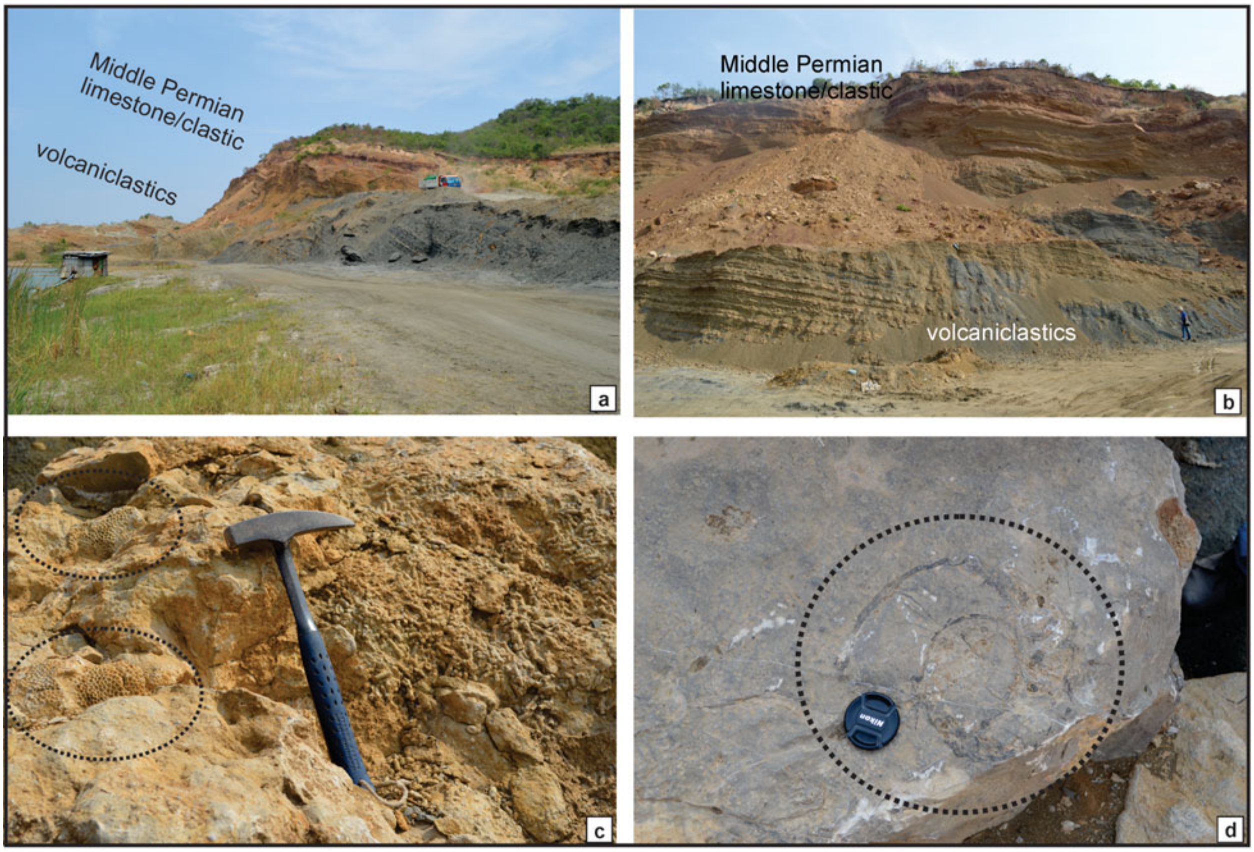

Figure 2. (Colour online) Photograph of the Permian Sisophon Limestone and andesitic volcaniclastic rocks in an active quarry, at Phnom Svai west of Sisophon town. The sequences contain highly diverse and abundant fossils. (a) At least 20 m of dark grey poorly consolidated, shallow-marine, andesitic volcaniclastic rocks (tuff) of Member A of Ishii *et al.* (1969) overlain by brown clastic/carbonate sequences of Middle Permian age. (b) Well-bedded volcaniclastic rocks and limestones. Height of person for scale is 1.75 m. (c) Massive and fasciculate corals in limestone. Length of hammer for scale is 33 cm. (d) Ammonoid. Diameter of lens cap for scale is 5.5 cm. The thick basal andesitic tuff suggests an active volcanic arc in this area during Early Permian time approximately contemporaneous with the deep-water cherts further south at Pailin.

western chert–clastic sequence consists of tectonic slices of alternating red chert, containing Middle to Late Triassic radiolarians, and coarse clastic units, interpreted as an accretionary complex. The eastern Thung Kabin Mélange consists of strongly foliated serpentinite matrix surrounding ‘inclusions’ of dominantly basalt, limestone and chert with minor sandstone, conglomerate, metamorphic rocks and granite. The cherts contain Early, Middle and Late Permian radiolarians and, rarely, conodonts and the limestone blocks contain Early, Middle and Late Permian fusulinids (Fig. 1c, point 4) (Hada *et al.* 1997; Saesaengseerung *et al.* 2009; Ueno & Charoentitirat, 2011). Zircons from a granite clast are U–Pb dated as 486.5 ± 5 Ma, which is close to the age of the Cambrian–Ordovician boundary. Basalt blocks ranging from a few to several hundred metres in length are geochemically E-type MORB, characteristic of anomalous ridge segments and hot-spot related ocean islands (Hada *et al.* 1997).

More recently, Chutakositkanon & Hisada (2008) defined new units within the accretionary complex and mapped numerous megablocks within the mélange units (Fig. 1a). The Khao Taa Ngog Formation in Thailand and the Sisophon Limestone in Cambodia (Fig. 2) are Permian shallow-water carbonates, with a coherent stratigraphy, that may be followed from one monadnock to the next (Ishii *et al.* 1969; Ueno & Charoentitirat, 2011). In quarries west of Sisophon, Mid Permian limestone overlies andesitic volcaniclastic rocks (tuffs) of the Member A of Ishii *et al.* (1969) (Fig. 2). The sequences can be correlated with Permian limestone and tuff and tuffites in the east of the Khao Khwang Platform in the Loei Fold Belt (e.g. Wielchowsky & Young, 1985; Altermann, 1989), which suggests extension of the Loei Fold Belt into Cambodia (Fig. 1a, c). Diverse and abundant fossils such as fusulinids, brachiopods, corals, alatoconchid bivalves and others are present in these sequences and indicate a tropical regime. The lithological and faunal similarities of these Permian sequences in Thailand and Cambodia suggest a common palaeogeography or close proximity during Permian time. The Pong Nam Ron Formation and correlates in Cambodia are submarine fan deposits post-dating the accretionary prism rocks and pre-dating Late Triassic granite

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

(Chaodumrong, Bookanpay & Seeyunghan, 2010; Ueno & Charoentitirat, 2011) (Fig. 1c).

Sangsomphong *et al.* (2013) used enhanced airborne magnetic and radiometric data to identify geophysical domains in eastern Thailand. A highly magnetic 'Central Domain' separates less magnetic domains and its strongly magnetic character suggests the presence of serpentinites and basalts; we equate this broad zone to both the Loei Terrane (Burrett *et al.* 2014; Khin Zaw *et al.* 2014) and to the Sa Kaeo Suture along the domain's southern margin. The southern domain would then represent the Triassic Sukhothai Arc Terrane and also include the Sibumasu Terrane further south.

2.b. General geology of NW Cambodia

Gubler (1935) mapped metamorphic and igneous rocks which he included in his 'Crystallin de Pailin'. He regarded these rocks as a Hercynian (or Variscan) Massif and this was accepted by most subsequent authors. For instance, Fontaine & Workman (1978, p. 672) suggested that the metamorphic and igneous rocks constituted 'possibly a largely concealed Variscan massif in NW Kampuchea (Cambodia), the area of Precambrian and Devonian–Carboniferous around Pailin being the edge of it'.

Because of a lack of good base maps and poor infrastructure, very little locality information and very few maps were provided by Gubler (1935), and many of the place names that he used are no longer recognized. Gubler (1935) constructed several highly diagrammatic cross-sections and mentioned the occurrence of poorly located igneous rocks, including peridotite, pyroxenite, gabbro, diorite, basalt and rhyolite. He recognized that there was an 'old' deformed basalt and a younger, Quaternary gem-bearing basalt. He also recognized two ages of rhyolite. Gubler (1935) identified sedimentary cherts in many localities and recognized abundant radiolarians and sponge spicules within them. He suggested a Devonian age for the radiolarian cherts by general lithological comparison to sequences in France. On the basis of the Lower Carboniferous to Upper Permian (to Triassic?) foraminifera *Geinitzina* and also '*Endothyra*' he suggested a Carboniferous age for the sandstones and shales, which he placed in his 'Serie Schisto–Greseuse'. This shale–sandstone sequence is, by comparison with sequences across the border in Thailand, more likely to be either Permian or Triassic in age (Fig. 1c). A thick sequence of coherent, steeply dipping, turbiditic siliciclastic rocks between Pailin and the Thai–Cambodian border on the track ascending Phnom Kiaow (Green Mountain) in the Todeth Mountains (Fig. 1c, point 3) is lithologically identical to the Mid Triassic Pong Nam Ron Formation in adjacent areas of Thailand.

Relatively modern mapping by geologists of the Bureau de Récherches Géologiques et Minieres (BRGM) (Dottin & Zinszner, 1972) as summarized in Figure 1c indicates small areas of a variety of sedimentary, igneous and metamorphic rocks.

To the west of Sisophon town, an active quarry contains abundant fossils of fusulines, corals, brachiopods, bryozoans and ammonoids (Fig. 2). The sequence consists of bedded calcareous tuff overlain by limestone, shale and limestone in ascending order, which are assigned to members A–D of Ishii *et al.* (1969). This sequence may be assigned a Middle Permian age as indicated by the *Neoschwagerina* to *Yabeina* fusuline zones (Ishii *et al.* 1969; Fontaine, 2002). Highly fossiliferous Mid Permian limestones and associated rocks are also present to the south of Sisophon in Battambang and nearby areas in the west of Cambodia (e.g. Gubler, 1935; Ishii *et al.* 1969; Fontaine, 2002).

2.c. Geology of the Pailin area

Our reconnaissance survey in western Cambodia found mafic igneous rocks and cherts within quarries in an E–W belt of hills within the eastern outskirts of and to the east of the town of Pailin (Fig. 3). This 20 km long, 1.5–2 km wide belt lies between steeply dipping greywackes and sandstones of the Todeth Group to the south and the Pailin Crystalline Complex to the north (Berrangé & Jobbins, 1976). The Todeth Group is lithologically identical to the contiguous Triassic, Pong Nam Ron Fm in Thailand (Fig. 1c). The Pailin Crystalline Complex is 'largely amphibolitic (metavolcanic)' but also includes 'granodiorite, diorite, gneiss, schist, greenstone, quartzite and basic dykes' (Berrangé & Jobbins, 1976). One K–Ar date of 245 Ma is noted in this complex on the BRGM map (Dottin & Zinszner, 1972) and, pending modern dating, there is no reason to ascribe the Pailin Crystalline Complex or even its protoliths to the Precambrian or older Palaeozoic. Berrangé & Jobbins (1976) mapped the belt between the Pailin Crystalline Complex and the Todeth Group as the O Smoet 'Formation' containing 'jasper, chert, acid volcanics, quartzite, schist, phyllite, siltstone and shale'. To the west of Pailin they mapped small areas of 'Permian' limestone within the O Smoet 'Formation' as the Ba Tong Member (Fig. 3a).

Abandoned and highly weathered quarries ('old quarries' herein) in the belt mapped as O Smoet 'Formation', within the eastern outskirts of Pailin City, contain strongly deformed basalts and micro-unfossiliferous cherts (Fig. 4, 5). Also present, are chert and basalt blocks within a volcaniclastic matrix (Fig. 5), which may constitute a mélange. However, the rocks in the old quarries differ from the Thung Kabin Mélange of Thailand in lacking a mainly serpentinitic matrix and some of the possible megablocks are in contact. About 1 km further east, a 150 m long, recently active quarry ('new quarry' herein) contains less weathered and less deformed, bentonized volcanic ash, volcanic breccia, basalt, dolerite, gabbro,

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

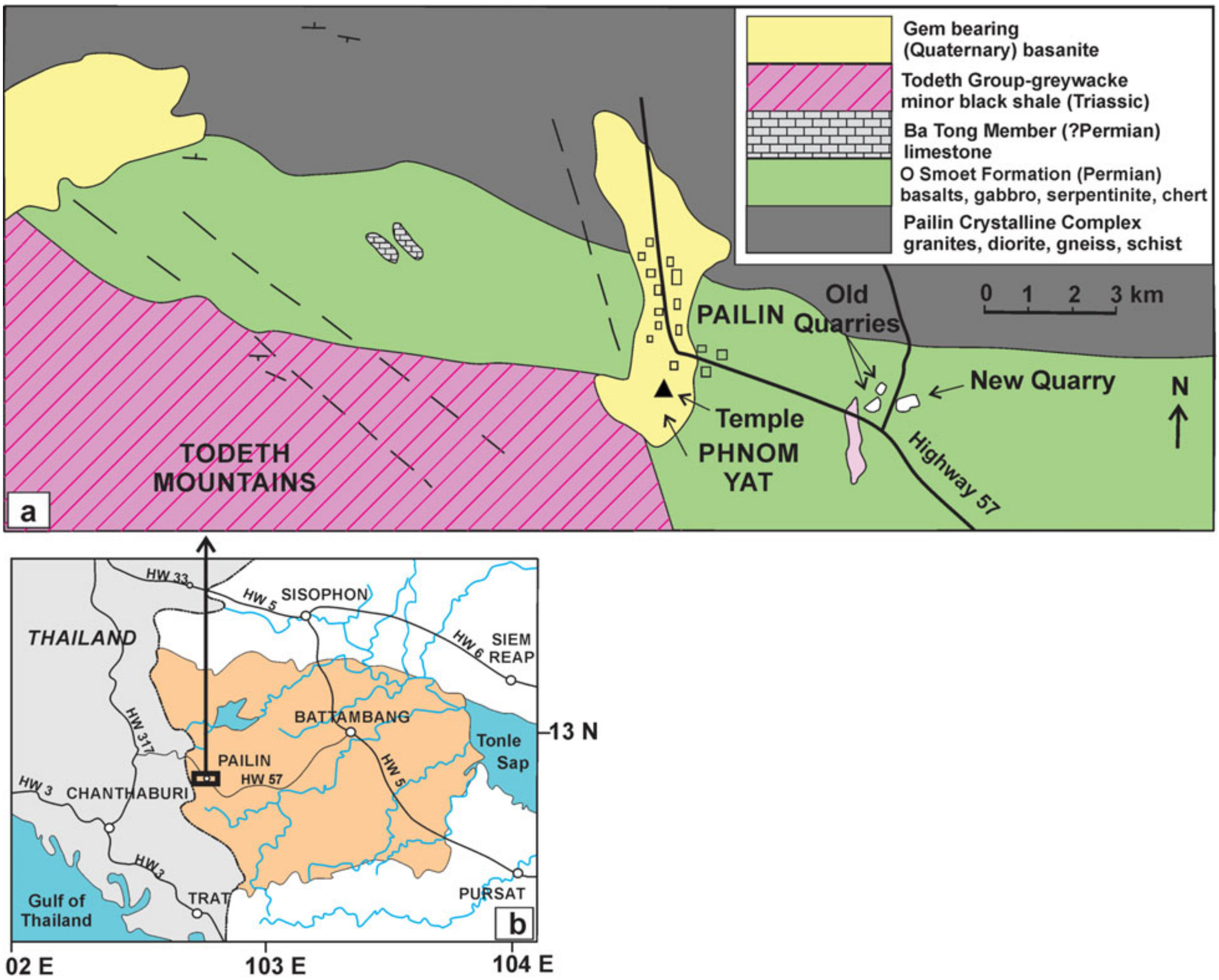

Figure 3. (Colour online) Locality maps of western Cambodia. (a) Locality map of Pailin area in western Cambodia showing quarry localities. Radiolarians have been obtained from the western end of the 'new', recently active, quarry at lat. 12° 49′ 51″ N, long. 102° 36′ 43.44″ E, elevation 227 m which is *c*. 900 m west of three 'old' abandoned quarries. The E–W-trending range of hills continues for at least 10 km to the east and 6 km to the west. Mapped units and names are from Berrangé & Jobbins (1976) and may be based on geographic names not in current use. (b) Location of Pailin, Battambang, Sisophon, Siem Reap and Pursat in western Cambodia and Chantaburi and Trat in SE Thailand. Shaded area is Battambang Province, western Cambodia.

Figure 4. (Colour online) View of Pailin 'old' abandoned quarries from 'new', recently active, quarry looking west. Hill with mast in distance is Phnom Yat just above the main temple (see Fig. 2a).

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

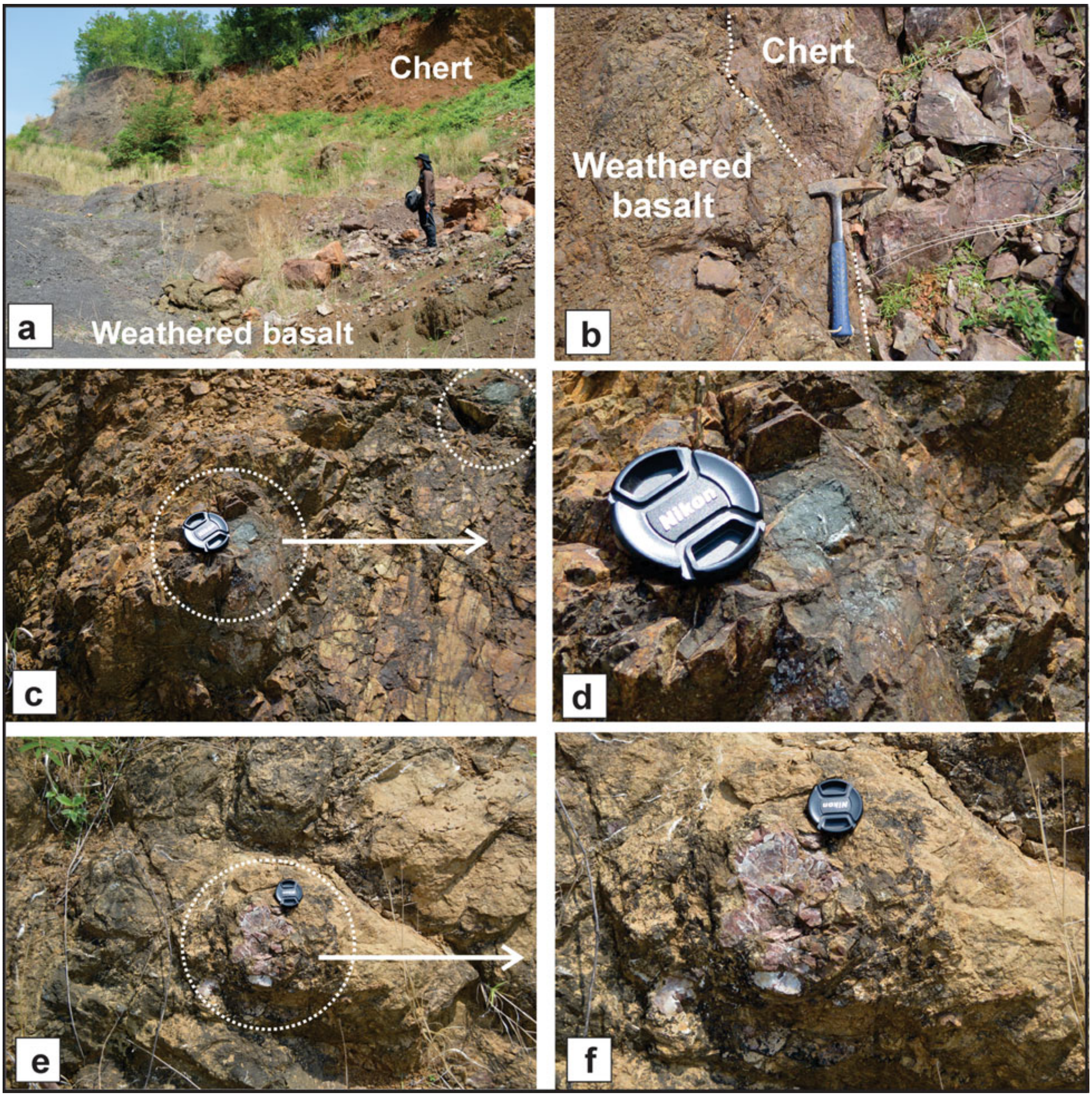

Figure 5. (Colour online) Photographs of 'old' abandoned quarry. (a) Chert and weathered basalt in 'old' quarry; (b) sharp contact between basalt and chert in 'old' quarry; (c) a probable part of mélange consisting of clast of mafic volcanic embedded in clastic rocks; (d) enlargement of (c); (e) clast of chert embedded in clastic rocks in probable mélange; (f) magnification of (e). Height of person is 1.75 m, length of hammer is 33 cm and diameter of lens cap is 5.5 cm.

serpentinized probable ultramafic rocks and thinly bedded radiolarian chert (Fig. 6). The rocks, in the new quarry, do not constitute a mélange as the contacts between the units are either non-conformable, intrusive or faulted. Cherts are found in both the eastern and western parts of the quarry (Fig. 6). The rocks in the new quarry form a semi-coherent assemblage which is best termed a dismembered ophiolite. Separate blocks of serpentinite, basalt, chert or basalt with chert have been described on the Thai side of the border, but a variety of mafic volcanic and sedimentary rocks have not been found together in close contact. Further field and laboratory work will define the detailed extent, composition, tectonic setting and ages of these units.

3. Material and method

Reconnaissance field work and sampling took place during the summer of 2014 in the west of Cambodia. Seventeen chert samples were collected from the new, active quarry in Pailin (Figs 3, 6). Five samples of chert were collected from the abandoned quarry (Figs 4, 5). All samples were prepared and treated in the Applied Palaeontology and Biostratigraphy Research Unit's laboratory at Mahasarakham

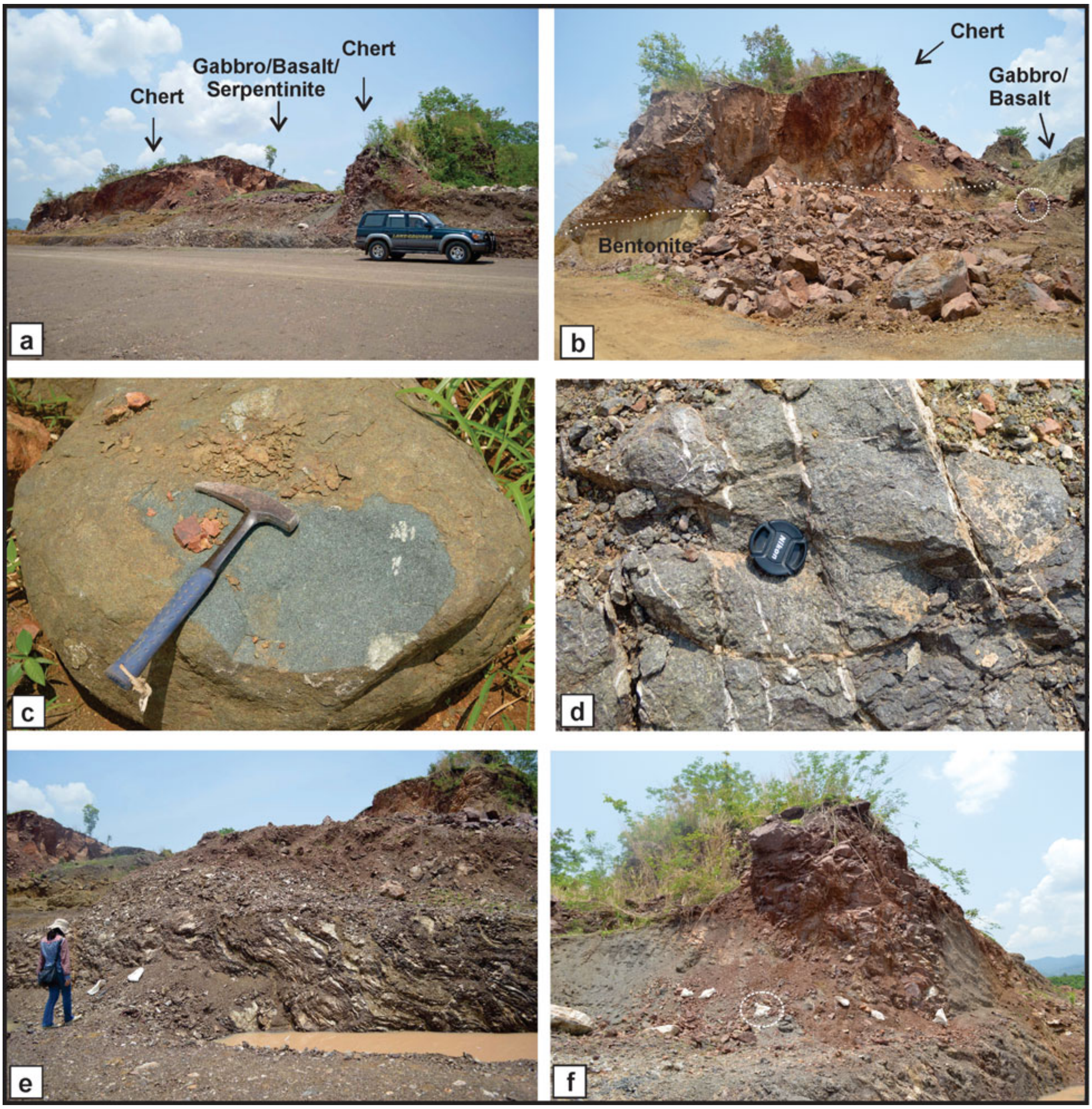

Figure 6. (Colour online) Photographs of 'new', recently active, quarry at 12° 49′ 51″ N and 102° 36′ 43.44″ E. (a) View of quarry looking southeast. Radiolarian samples from western end of quarry – above vehicle; (b) chert and silicified mudstone at western end of quarry, overlying light coloured bentonized volcanic ash; (c) basalt; (d) magnification of serpentinite from (a); (e) thin-bedded chert dipping east; sample bags show collection points; (f) westerly dipping chert at western end and entrance to quarry; bags show radiolarian collection points. Height of person is 1.60 m, length of hammer is 33 cm and diameter of lens cap is 5.5 cm.

University. The chemical treatment method, using hydrofluoric acid, is adapted from Pessagno & Newport (1972). Selected specimens were then picked from dry residues and mounted onto metal stubs for scanning electron microscopy (SEM) in the Faculty of Science, Mahasarakham University.

4. Radiolarian faunas from Pailin, Cambodia

Poorly to moderately well-preserved radiolarians were obtained from three samples including sample numbers QPL1405, QPL1407 and QPL1408 (Fig. 6f). The other samples yield very poorly preserved, recrystallized indeterminable radiolarian tests. However, radiolarians were not found from five samples of chert collected from the old abandoned quarry. Radiolarians from a new, recently active quarry in the east of Pailin, Cambodia are mainly composed of albaillellarians with some latentifistularians and entactinarians. Because of their high abundance and biostratigraphic importance, only albaillellarians are described herein.

4.a. Systematic description of radiolarians

All radiolarian specimens described herein are classified following De Wever *et al.* (2001).

Class ACTINOPODA
Subclass RADIOLARIA Müller, 1858
Superorder POLYCYSTIDA Ehrenberg 1838, emend. Riedel, 1967
Order ALBAILLELLARIA Deflandre 1953, emend. Holdsworth, 1969
Family ALBAILLELLIDAE Deflandre 1952, emend. Holdsworth, 1977
Genus *Albaillella* Deflandre, 1952; emend. Holdsworth, 1966; emend. Ormiston & Lane, 1976

Type species. Albaillella paradoxa Deflandre, 1952

Albaillella sp.
Figure 7a–d

Remarks. The illustrated specimens exhibit a shape resembling *Albaillella asymmetrica* Ishiga & Imoto in the outlines of the apical cone and the pseudoabdomen. The apical cone shows weak segmentation, is distally tapered and changes into a spine (Fig. 7a). The pseudoabdomen is flattened with two asymmetrical wings (Fig. 7c). Unfortunately, our specimens are too poor to classify to species level and are referred to genus only.

Range. Early Permian.

Occurrence. Pailin, Cambodia

Family FOLLICUCULLIDAE Ormiston & Babcock, 1979
Genus *Pseudoalbaillella* Holdsworth & Jones, 1980

Type species. *Pseudoalbaillella scalprata* Holdsworth & Jones, 1980

Pseudoalbaillella sakmarensis (Kozur, 1981)
Figures 7q–t, 8a–c

1981 *Parafollicucullus sakmarensis* Kozur, pl. 1, figs 1, 3.
1982 *Pseudoalbaillella sakmarensis* (Kozur); Ishiga, Kito & Imoto, pl. 1, fig. 8.
1985 *Pseudoalbaillella sakmarensis* (Kozur); Ishida, pl. 1, figs 2, 3.
1989 *Pseudoalbaillella* cf. *sakmarensis* (Kozur); Wu & Li, pl. 1, fig. 17.
1989 *Pseudoalbaillella sakmarensis* (Kozur); Isozaki &Tamura, pl. 1, figs 4, 10.
1994 *Pseudoalbaillella sakmarensis* (Kozur); Wang, Cheng & Yang, p. 182, pl. 1, figs 9–11.
1997 *Pseudoalbaillella sakmarensis* (Kozur); Jasin & Ali, pl. 1, fig. 3.
1998 *Pseudoalbaillella sakmarensis* (Kozur); Xian & Zhang, pl. 2, figs 15–18.
2009 *Parafollicucullus* sp. cf. *P. postsakmarensis*; Saesaengseerung *et al.*, p. 128, figs 7.10, 7.11.

Remarks. Apical cone lacking segmentation. Spherical thorax with two asymmetrical wings. The long pseudoabdomen is composed of three segments with the last one strongly curved in the apertural margin.

Range. Early Permian.

Occurrence. Ural, Japan, South China, Malaysia and eastern Thailand.

Pseudoalbaillella scalprata Holdsworth & Jones, 1980 morphotype *scalprata* Ishiga, 1983
Figure 8g, h

1980 *Pseudoalbaillella scalprata* Holdsworth & Jones, p. 284, appendix fig. 1 (A, B).
1980 *Pseudoalbaillella* sp. cf. *Ps. scalprata* Holdsworth & Jones; Ishiga & Imoto, pl. 2, figs 4–8.
1982 *Pseudoalbaillella scalprata* Holdsworth & Jones; Ishiga, Kito & Imoto, pl. 1, figs 11, 12.
1983 *Pseudoalbaillella scalprata* Holdsworth & Jones morphotype *scalprata*; Ishiga, pl. 1, figs 1–18.
1984 *Pseudoalbaillella* sp. aff. *Ps. scalprata* Holdsworth & Jones; Ishiga *et al.*, pl. 1, figs 4–8.
1985 *Pseudoalbaillella scalprata* Holdsworth & Jones; Ishida, pl. 1, figs 7–9.
1985 *Pseudoalbaillella scalprata* Holdsworth & Jones; Sheng & Wang, pl. 2, figs 9–12.
1985 *Pseudoalbaillella scalprata* Holdsworth & Jones; Yoshida & Murata, pl. 1, figs 8, 9.
1985 *Pseudoalbaillella scalprata* Holdsworth & Jones; Cornell & Simpson, pl. 1, fig. 5.
1992 *Pseudoalbaillella scalprata* Holdsworth & Jones; Blome & Reed, figs 10.19–10.21.
1993 *Pseudoalbaillella scalprata* Holdsworth & Jones; Nazarov & Ormiston, pl. 7, fig. 10.
1994 *Pseudoalbaillella scalprata* Holdsworth & Jones; Wang, Cheng & Yang, p. 182, pl. 1, figs 20–22.
1996 *Pseudoalbaillella scalprata* Holdsworth & Jones; Spiller, pl. 3, figs 6, 7.
1998 *Pseudoalbaillella scalprata* Holdsworth & Jones; Sashida *et al.*, p. 13, figs 11–11, 12, 13.
2006 *Pseudoalbaillella scalprata* Holdsworth & Jones; Shimakawa & Yao, pl. 1, figs 16–18.
2009 *Pseudoalbaillella scalprata* Holdsworth & Jones; Saesaengseerung *et al.*, figs 7.28, 7.29.
2011 *Pseudoalbaillella scalprata* Holdsworth & Jones; Jasin & Harun, pl. 4, fig. 4.
2011 *Pseudoalbaillella scalprata* Holdsworth & Jones; Xie *et al.*, p. 214, figs 2A, S.

Remarks. The illustrated specimens of *Pseudoalbaillella scalprata* by Ishiga (1983) seem to show rather wide variation in the length of the apical horn and pseudoabdomen and the angle between the two shoulders. Our specimens are characterized by the

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

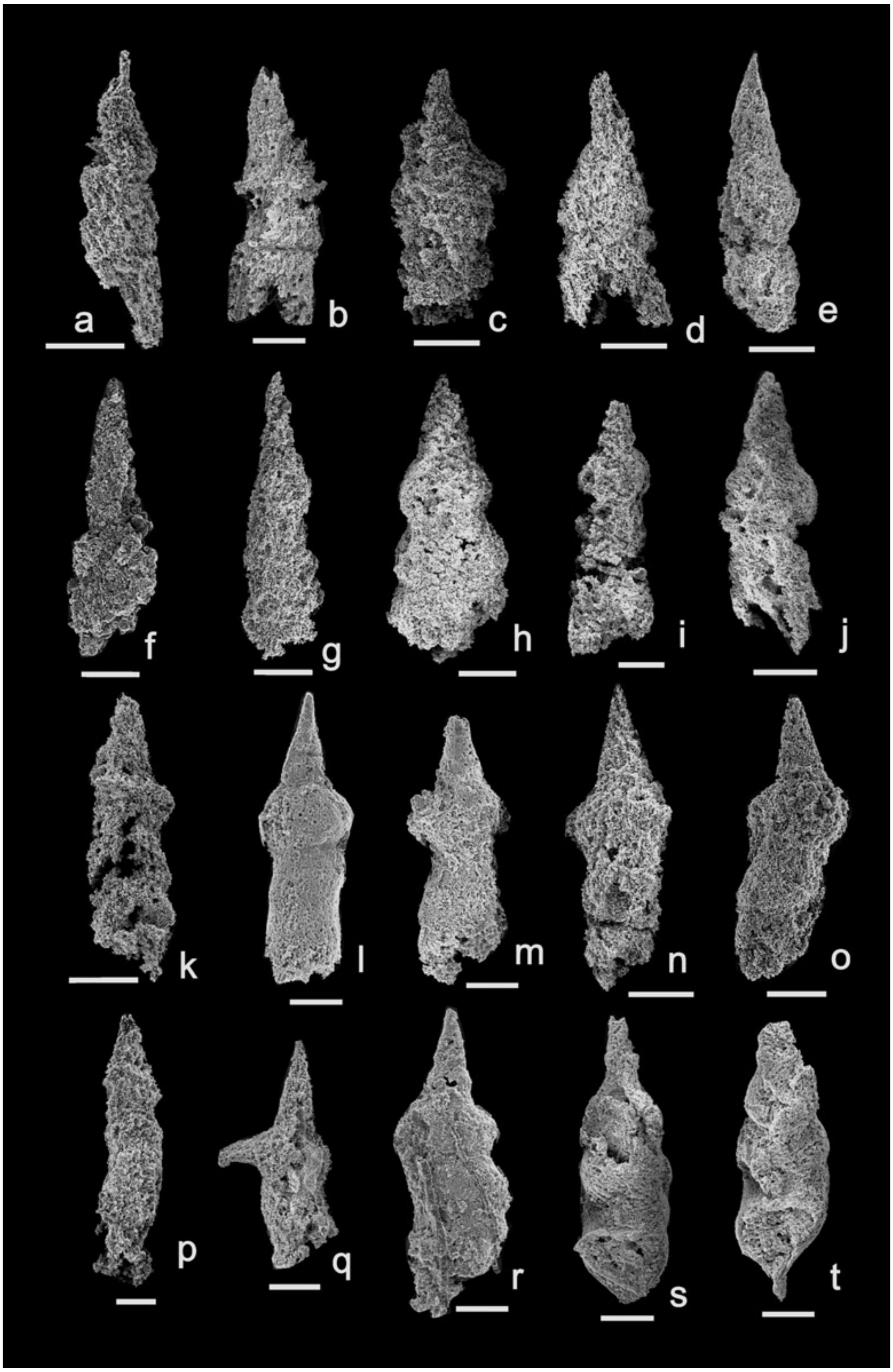

Figure 7. Scanning electron micrographs (SEM) of Early Permian radiolarians from Pailin, west of Cambodia. All scale bars = 50 μm. PRC numbers are specimen numbers in the Palaeontological Research Centre of Mahasarakham University. (a–d) *Albaillella* sp., sample QPL1405 ((a) PRC584, (b) PRC585, (c) PRC586, (d) PRC587); (e–g) *Pseudoalbaillella* spp., samples QPL1405, QPL1408 ((e) PRC588, (f) PRC589, (g) PRC590); (h–k) *Pseudoalbaillella* sp. cf. *P. lomentaria* Ishiga & Imoto, 1980, sample QPL1405 ((h) PRC591, (i) PRC592, (j) PRC593, (k) PRC594); (l–p) *Pseudoalbaillella* sp. cf. *P. elegans* Ishiga & Imoto, 1980, samples QPL1405, QPL1408 ((l) PRC595, (m) PRC596, (n) PRC597, (o) PRC598, (p) PRC599); (q–t) *Pseudoalbaillella sakmarensis* (Kozur, 1981), sample QPL1408 ((q) PRC600, (r) PRC601, (s) PRC602, (t) PRC603).

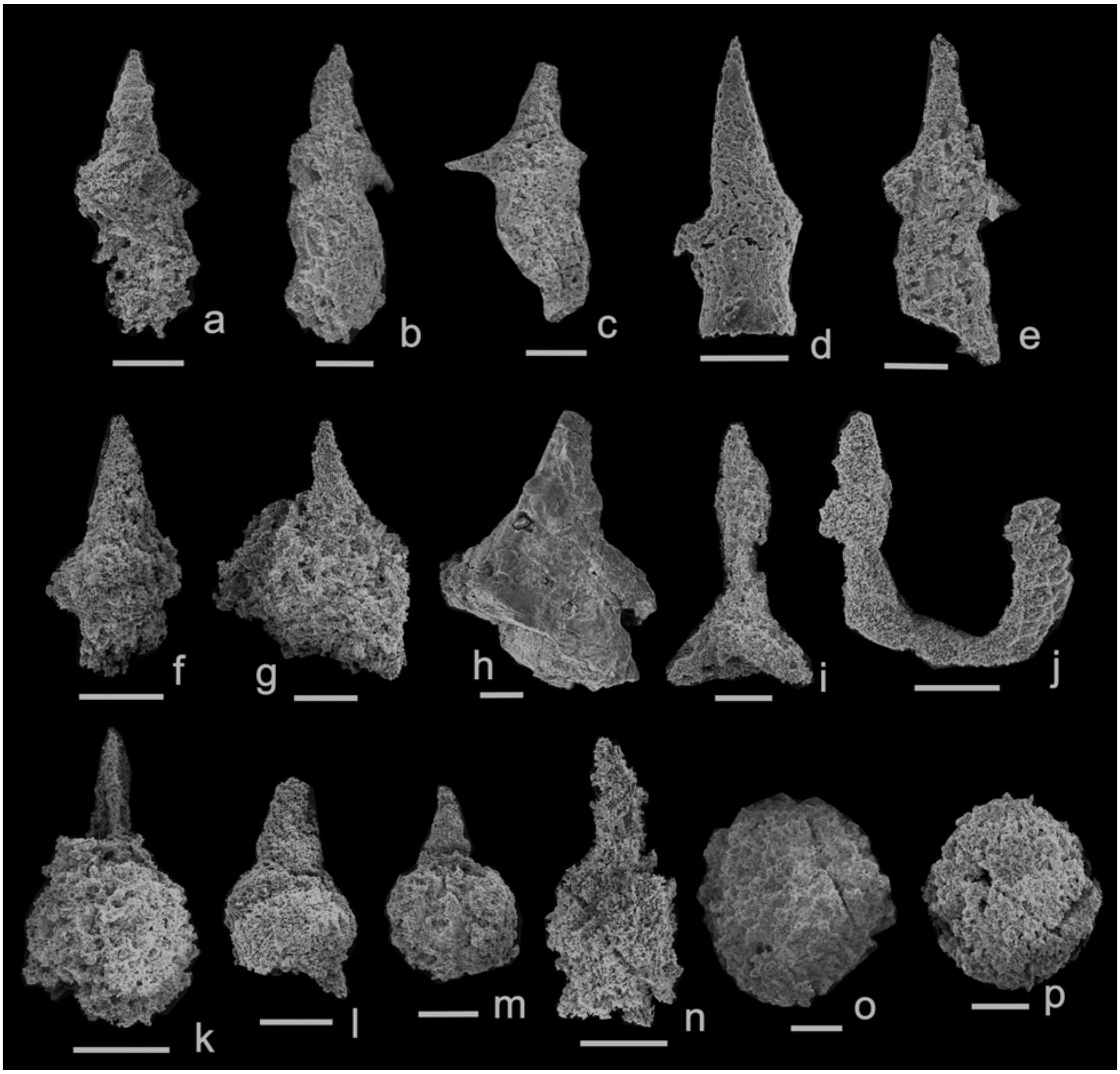

Figure 8. Scanning electron micrographs (SEM) of Early Permian radiolarians from Pailin, Cambodia. All scale bars = 50 μm. PRC numbers are specimen numbers in the Palaeontological Research Centre of Mahasarakham University. (a–c) *Pseudoalbaillella sakmarensis* (Kozur, 1981), samples QPL1405, QPL1408 ((a) PRC604, (b) PRC605, (c) PRC606); (d–f) *Pseudoalbaillella* sp. cf. *P. simplex* Ishiga & Imoto, 1980, samples QPL1405, QPL1408 ((d) PRC607, (e) PRC608, (f) PRC609); (g, h) *Pseudoalbaillella scalprata* Holdsworth & Jones, 1980 morphotype *scalprata* Ishiga, 1983, samples QPL1405, QPL1408 ((g) PRC610, (h) PRC611); (i) Latentifistularia gen. et sp. indet., sample QPL1407 (PRC612); (j) *Pseudoalbaillella u-forma* Holdsworth & Jones, 1980, morphotype II (Ishiga, Imoto, Yoshida & Tanabe, 1984), sample QPL1408 (PRC613); (k) *Trilonche*? sp. sample QPL1405 (PRC614); (l–n) *Pseudoalbaillella* spp., samples QPL1405, QPL1407 ((l) PRC615, (m) PRC616, (n) PRC617); (o, p) Entactinaria gen. et sp. indet, samples QPL1405, QPL1408 ((o) PRC618, (p) PRC619).

diagnostic features of this species in having a small and slightly curved apical horn. The pseudothorax is sub-globular with two slightly flattened wings. The pseudoabdomen with two flaps is extending downwards.

Range. Early–Middle Permian.

Occurrence. Japan, West Texas, Oregon, China, peninsular Malaysia, northern, eastern and NE Thailand.

Pseudoalbaillella sp. cf. *P. simplex* Ishiga & Imoto, 1980
Figure 8d–f

1980 *Pseudoalbaillella simplex* Ishiga & Imoto, pl. 1, figs 13–18.
1982 *Pseudoalbaillella simplex* Ishiga & Imoto; Hattori & Yoshimaru, pl. 1, fig. 2.
1985 *Pseudoalbaillella simplex* Ishiga & Imoto; Ling, Forsythe & Douglass, fig. 3L, M.

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

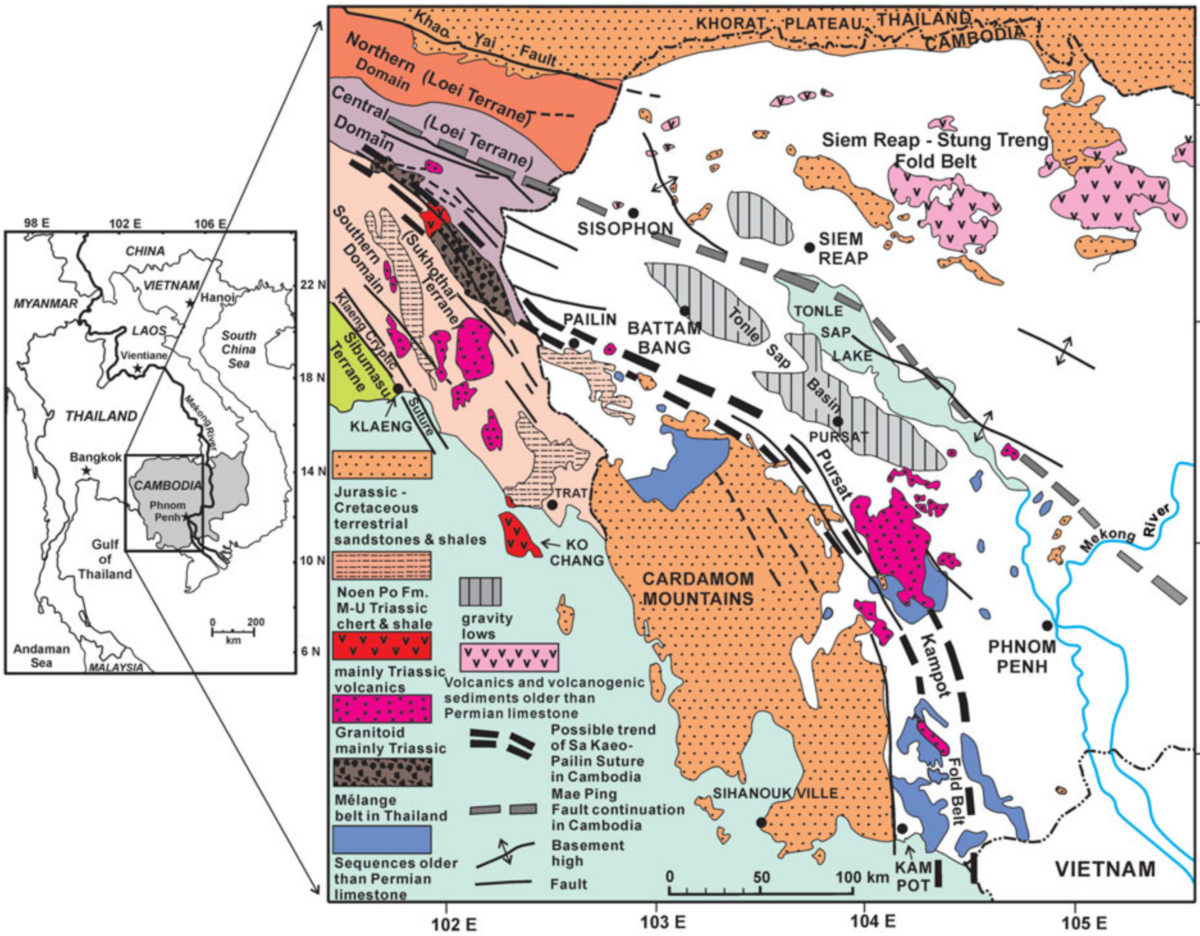

Figure 9. (Colour online) Speculative diagrammatic map showing possible trend of the Sa Kaeo–Pailin Suture eastwards and then southwards along the Pursat–Kampot Fold Belt in Cambodia, based mainly on information on the distribution of ultramafic and mafic igneous rocks and cherts in Gubler (1935). Other Cambodian data are from United Nations (1993). Thailand data are from Sangsomphong *et al*. (2013) and Ridd & Morley (2011) and DMR geological maps. Gravity lows and 'basement' highs in Cambodia are from Te Duong Tara (2006).

1984 *Pseudoalbaillella simplex* Ishiga & Imoto; Ishiga *et al*., pl. 1, figs 17–22.
1989 *Pseudoalbaillella simplex* Ishiga & Imoto; Isozaki & Tamura, pl. 4, figs 11, 12.
1994 *Pseudoalbaillella simplex* Ishiga & Imoto; Wang, Cheng & Yang, p. 183, pl. 1, figs 3, 4, 19.
2002 *Pseudoalbaillella simplex* Ishiga & Imoto; Sashida & Salyapongse, p. 696, fig. 3.3.
2008 *Pseudoalbaillella simplex* Ishiga & Imoto; Kurihara & Kametaka, p. 537, fig. 5.9.
2011 *Pseudoalbaillella simplex* Ishiga & Imoto; Xie *et al*., p. 215, fig. 2I, J.
2016 *Pseudoalbaillella simplex* Ishiga & Imoto; Shi *et al*., p. 5, fig. 4.5.

Remarks. Apical cone is long without segmentation and the ventral side is slightly curved. Pseudothorax is weakly inflated with two small wings. The constriction between the pseudothorax and the pseudoabdomen is weak. Although these specimens are broken, they are comparable to the type specimen (Ishiga & Imoto, 1980, pl. 1, fig. 18) so we have assigned them to *Pseudoalbaillella* sp. cf. *P. simplex.*

Range. Early Permian.

Occurrence. South China, SW Japan and Chile.

Pseudoalbaillella u-forma Holdsworth & Jones, 1980, morphotype II (Ishiga *et al.* 1984)
Figure 8j

1980 *Pseudoalbaillella u-forma* Ishiga & Imoto, pl. 1, figs 6–8.
1982 *Pseudoalbaillella u-forma* Ishiga & Imoto; Ishiga, Kito & Imoto, pl. 1, fig. 1.
1984 *Pseudoalbaillella u-forma* Holdsworth & Jones morphotype II; Ishiga *et al*., pl. 1, fig. 5.
2006 *Pseudoalbaillella u-forma* Holdsworth & Jones morphotype II; Shimakawa & Yao, pl. 1, figs 10–11.
2009 *Parafollicucullus u-formus* (Holdsworth & Jones) m II; Saesaengseerung *et al*., figs 7.6, 7.7.

Remarks. Although the illustrated specimen is poorly preserved and broken, it closely resembles *Pseudoalbaillella u-forma* (Holdsworth & Jones)

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

morphotype II, in having a slender apical cone, small pseudothorax and a U-shaped pseudoabdomen.

Range. Early Permian.

Occurrence. South China, Japan, Alaska (United States) and eastern Thailand.

Pseudoalbaillella sp. cf. *P. elegans* Ishiga & Imoto, 1980
Figure 7l–p

1980 *Pseudoalbaillella elegans* Ishiga & Imoto, p. 31, pl. 1, figs 9–12.
1982 *Pseudoalbaillella elegans* Ishiga & Imoto; Ishiga, Kito & Imoto, pl. 1, figs 2, 3.
1987 *Pseudoalbaillella elegans* Ishiga & Imoto; Ling & Forsythe, p. 257, pl. 1, fig. 9.
1989 *Pseudoalbaillella elegans* Ishiga & Imoto; Isozaki & Tamura, pl. 4, figs 7–9.
1993 *Pseudoalbaillella elegans* Ishiga & Imoto; Sashida *et al*., figs 6, 1–4.
1994 *Pseudoalbaillella elegans* Ishiga & Imoto; Wang, Cheng & Yang, pp. 179, 180, pl. 1, figs 7, 8.
1998 *Pseudoalbaillella elegans* Ishiga & Imoto; Sashida *et al*., p. 11, figs 11, 12–15.
2011 *Pseudoalbaillella elegans* Ishiga & Imoto; Xie *et al*., p. 210, figs 2U, V.
1994 *Pseudoalbaillella elegans* Ishiga & Imoto; *Pseudoalbaillella* sp. aff. *P. elegans* Ishiga & Imoto; Wu, Xian & Kuang, pl. 2, fig. 6.
1996 *Pseudoalbaillella elegans* Ishiga & Imoto; Spiller, pl. 4, figs 5, 6.
2009 *Pseudoalbaillella* sp. cf. *P. elegans* Ishiga & Imoto; Saesaengseerung *et al*., p. 129, figs 7.12, 7.13.
2016 *Pseudoalbaillella elegans* Ishiga & Imoto; Shi *et al*., p. 5, fig. 4.11.

Remarks. Apical cone is without segmentation with no sinuosity in the shell. However, the pseudoabdomen of our specimens is shorter than the type specimens and they may be broken. The pseudothorax is also larger than in the type specimens (e.g. Fig. 7l, o).

Range. Early Permian.

Occurrence. South China, Japan, Chile, peninsular Malaysia and northern, eastern and NE Thailand.

Pseudoalbaillella sp. cf. *P. lomentaria* Ishiga & Imoto, 1980
Figure 7h–k

1980 *Pseudoalbaillella lomentaria* Ishiga & Imoto, p. 32, pl. 2, figs 9–15.
1992 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Kuwahara, pl. 2, fig. 14.
1992 *Pseudoalbaillella* sp. cf. *P. lomentaria* Ishiga & Imoto; Blome & Reed, pl. 10, figs 7, 8.
1993 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Sashida *et al*., figs 6–5, 6.
1994 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Wang, Cheng & Yang, p. 181, pl. 1, figs 12, 13.
1994 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Wu, Xian & Kuang, pl. 2, fig. 8.
1995 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Sashida, p. 39, figs 1–18, 19.
1997 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Jasin & Ali, p. 331, pl. 1, fig. 1.
1998 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Sashida *et al*., p. 13, figs 11–16–18.
2002 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Sashida & Salyapongse, p. 696, figs 3.4, 3.5.
2005 *Pseudoalbaillella* aff. *lomentaria* Ishiga & Imoto; Suzuki *et al*., p. 696, figs 7.1–7.6.
2009 *Parafollicucullus lomentarius* (Ishiga & Imoto); Saesaengseerung *et al*., p. 127, fig. 7.14.
2016 *Pseudoalbaillella lomentaria* Ishiga & Imoto; Shi *et al*., p. 5, fig. 4.12.

Remarks. The examined specimens are similar to *P. lomentaria* in having a slightly curved apical cone, spherical pseudothorax and three-segmented pseudoabdomens. But our specimens do not possess a pair of flattened wings.

Range. Early Permian.

Occurrence. South China, Japan, Chile, North America, Malaysia, Far East Russia and northern, eastern and NE Thailand.

Pseudoalbaillella spp.
Figures 7e–g, 8l–n

Remarks. The specimens are not well preserved. The test consists of a relatively large cone with an apical cone. The pseudothorax is inflated and spherical in outline. The pseudoabdomen is inflated and cylindrical. There is a constriction between the pseudoabdomen and the pseudothorax.

Range. Early Permian

Occurrence. Pailin, Cambodia.

4.b. Age assignment of the Pailin radiolarian fauna

More than eight species and three undetermined radiolarians (Figs 7, 8) are reported from Pailin and comprise: *Pseudoalbaillella sakmarensis* (Kozur, 1981); *Pseudoalbaillella scalprata* morphotype *scalprata* Ishiga, 1983; *Pseudoalbaillella* sp. cf. *P. simplex* Ishiga & Imoto 1980; *Pseudoalbaillella u-forma* morphotype II (Ishiga *et al.* 1984); *Pseudoalbaillella* sp. cf. *P. elegans* Ishiga & Imoto, 1980; *Pseudoalbaillella* sp. cf. *P. lomentaria* Ishiga & Imoto, 1980; *Albaillella* sp.; *Pseudoalbaillella* spp.; *Trilonche*? sp.; Latentifistularia gen. et sp. indet.; and Entactinaria gen. et sp. indet.

Among this radiolarian fauna, albaillellarians are most abundant. The biostratigraphically important species are *Pseudoalbaillella sakmarensis*,

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

Pseudoalbaillella scalprata m. *scalprata*, *Pseudoalbaillella simplex* and *Pseudoalbaillella u-forma* m. II, *Pseudoalbaillella* sp. cf. *P. elegans* and *Pseudoalbaillella* sp. cf. *P. lomentaria*. They have a similarity with faunas reported from Lower Permian strata in Japan (Ishiga, 1982, 1986, 1990; Sashida, 1995), West Texas (Cornell & Simpson, 1985), Cis–Ural (Kozur & Mostler, 1989), Oregon, United States (Blome & Reed, 1992), South China (Wang, Cheng & Yang, 1994; Shimakawa & Yao, 2006; Wang & Yang, 2011), Malaysia (Jasin & Ali, 1997; Jasin, 2008), Far East Russia (Suzuki *et al*. 2005) and central, eastern and northeastern Thailand (Sashida & Nikornsri, 1997; Sashida *et al*. 1998; Sashida & Salyapongse, 2002; Saesaengseerung *et al.* 2009; Burrett *et al*. 2015). *Pseudoalbaillella u-forma* m. II, *Pseudoalbaillella elegans* and *Pseudoalbaillella simplex* are the representative species of the *Pseudoalbaillella u-forma* m. II Assemblage Zone (early to middle Wolfcampian) of Ishiga (1986, 1990), which can be correlated with the *Pseudoalbaillella simplex* Assemblage of Sashida & Salyapongse (2002), *Pseudoalbaillella u-forma* m. II Zone of Shimakawa & Yao (2006) and *Pseudoalbaillella u-forma – P. elegans* Assemblage Zone of Wang & Yang (2011). Those zones correspond with the Lower Permian (Asselian). *Pseudoalbaillella lomentaria*, *Pseudoalbaillella sakmarensis* and *Pseudoalbaillella scalprata* m. *scalprata* are indicative of the *Pseudoalbaillella lomentaria* Assemblage Zone (middle to late Wolfcampian) of Ishiga (1986, 1990), which is correlated to the *Pseudoalbaillella lomentaria* Assemblage of Sashida & Salyapongse (2002), *Pseudoalbaillella lomentaria* Zone of Shimakawa & Yao (2006) and *Pseudoalbaillella lomentaria – P. sakmarensis* Assemblage Zone of Wang & Yang (2011). These zones are Lower Permian ranging in age from the Asselian to the Sakmarian, although Zhao *et al.* (2016) put the *P. lomentaria* Zone in or up to include the lower Artinskian. In the Chantaburi area along the Sa Kaeo Suture zone, eastern Thailand, Saesaengseerung *et al.* (2009) reported the co-occurrence of conodonts (*Streptognathodus constrictus*) that also indicate an Asselian–Sakmarian age. It can be suggested that some taxa probably range up to late Early Permian time or even existed in early Middle Permian (Roadian) time such as *P. lomentaria*, *P. simplex*, *P. scalprata* and *P. elegans* reported from Hubei, China (Shi *et al.* 2016).

The radiolarian faunas in the samples from Pailin, Cambodia correspond to the radiolarian zonal faunas of the *Pseudoalbaillella u-forma* m. II Assemblage Zone to the *Pseudoalbaillella lomentaria* Assemblage Zone of Ishiga (1986, 1990), which indicates an Early Permian (Asselian–Sakmarian) age.

5. Discussion

At Pailin in western Cambodia, an E–W-trending, 1.5 to 2 km wide, 20 km long belt of ophiolitic rocks including Lower Permian radiolarian cherts and volcanic rocks is contiguous with the Lower Permian mélange of the Sa Kaeo Suture in Thailand and indicates that the suture extends eastwards into Cambodia (Fig. 9). Mouret (1994) suggested an E–W trend for an ultramafic belt, near Pursat (Fig. 9), which he termed the Pursat Line.

Mentions of chert, basalt and gabbro surrounding the Jurassic–Cretaceous terrestrial sedimentary sequence of the Cardamom Mountains (Gubler, 1935; Dottin & Zinszner, 1972) suggest that the suture may also follow the general trend of the Pursat–Kampot Fold Belt towards the south (Fig. 9) as suggested by Khin Zaw *et al*. (2014) (Fig. 1).

The gravity lows that help define the Tonle Sap Basin to the south of Tonle Sap Lake in Cambodia (Te Duong Tara, 2006) align with the central geophysical domain of Sangsomphong *et al.* (2013) in Thailand. This also suggests an easterly rather than a south–southeasterly alignment of the suture within Cambodia (Fig. 9).

Morley *et al.* (2013) constructed a pre-Cenozoic palinspastic reconstruction for Cambodia and eastern Thailand by translation and rotation of a northern Indochina block around the Cenozoic Mae Ping Fault. A slightly smaller rotation could explain both the initiation and deformation of the Tonle Sap Basin to the south of Tonle Sap Lake (Fig. 9). Speculatively, an Early Permian volcanic arc extended eastwards from Sisophon to follow the Siem Reap – Stung Treng Fold Belt (Fig. 9) (the Rovieng Line of Mouret, 1994), and the ophiolitic/mélange assemblages at Pailin may have formed within a back-arc basin sphenochasm. The volcanic rocks at Sisophon were then conformably overlain by platform carbonates of Middle Permian age and deformed during phases of the Triassic Indosinian orogeny (Arboit *et al*. 2016). Arc magmatism continued well into Late Triassic time along the Sukhothai Terrane in Thailand until its collision with the Loei Terrane during Norian time.

6. Conclusions

The mélange–ophiolitic rocks from Pailin occur in an E–W-trending belt and are a continuation of the Sa Kaeo Suture of eastern Thailand. The first illustrated and identified Cambodian radiolarians are described herein from the Pailin chert and are the same Early Permian age as those from the Sa Kaeo Suture. The E–W trend of the Pailin ophiolitic/mélange rocks and their contacts with the metamorphic rocks of the largely amphibolitic Pailin Crystalline Complex, to the north, suggest that the main suture separating the Loei Terrane from the volcanic arc Sukhothai Terrane follows the northern margin of the Jurassic–Cretaceous age terrestrial sandstones of the Cardamom Mountains. Speculatively, the suture (Fig. 9) may then follow the eastern margin of the Cardamom Mountains southwards along the geologically very poorly known Pursat–Kampot Fold Belt.

Acknowledgements. The project was supported by Mahasarakham University and the National Research Council of Thailand. We appreciate the help of Mr Sa-ngaun Choochang, Mr Komkrit Uttarawiset and other colleagues in Cambodia. We thank Drs Sangad Bunopas, Sirot Salypongse and Bob Findlay for their help in Thailand. Drs Tsuyoshi Ito and Zhong-Qiang Chen provided thorough and very helpful reviews.

References

Altermann, W. 1989. The Permo-Carboniferous facies development in Thailand: a plate-tectonic discussion. *Comptes Rendus des Seances de l'Academie des Sciences (Paris)* **4**, 119–26.

Arboit, F., Collins, A. S., Morley, C. K., King, R. & Amrouch, K. 2016. Detrital zircon analysis of the southwest Indochina terrane, central Thailand: unravelling the Indosinian orogeny. *Geological Society America Bulletin* **128**, 1024–43.

Bunopas, S. 1982. Palaeogeographic history of western Thailand and adjacent parts of South East Asia–a plate tectonics interpretation. *Geological Survey of Thailand Special Paper* **5**, 1–810.

Berrangé, J. & Jobbins, E. 1976. The geology, gemmology, mining methods and economic potential of the Pailin ruby and sapphire gemfield, Khmer Republic. *British Geological Survey, Overseas Division Report* **35**, 1–68.

Blome, C. D. & Reed, K. M. 1992. Permian and Early (?) Triassic radiolarian faunas from the Grindstone terrane, central Oregon. *Journal of Paleontology* **66**, 351–83.

Burrett, C. F., Khin Zaw, Meffre, S., Lai, C. K., Khositanont, S., Chaodumrong, P., Udchachon, M., Ekins, S. & Halpin, J. 2014. The configuration of Greater Gondwana—evidence from U–Pb geochronology of detrital zircons from the Palaeozoic and Mesozoic of Southeast Asia and China. *Gondwana Research* **26**, 31–51.

Burrett, C., Udchachon, M., Thassanapak, H. & Chitnarin, A. 2015. Conodonts, radiolarians and ostracodes from the Permian E-lert Formation, Loei Fold Belt, Indochina Terrane. *Geological Magazine* **152**,106–42.

Chaodumrong, P., Bookanpay, N. & Seeyunghan, N. 2010. *Field Guide to Eastern Thailand*. Bangkok, Thailand: Bureau Geological Survey, Department of Mineral Resources (in Thai).

Chutakositkanon, V. & Hisada, K. 2008. Tectonostratigraphy of the Sa Kaeo–Chantaburi accretionary complex, eastern Thailand: reconstruction of tectonic evolution of oceanic plate–Indochina collision. In *Proceedings of the International Symposia on Geoscience Resources and Environments of Asian Terranes (GREAT 2008)* (eds M. Choowong & T. Thitimakorn), pp. 330–38. Chulalongkorn University, Thailand.

Cornell, W. & Simpson, R. D. 1985. New Permian albaillellid radiolarians from West Texas. *Micropaleontology* **31**, 271–9.

Deflandre, G. 1952. *Albaillela* nov. gen., Radiolaire fossile du Carbonifere inferieur, type d'une lignite aberrante teinte. *Comptes Rendus des Seances de l'Academie des Sciences (Paris)* **234**, 872–4.

Deflandre, G. 1953. Radiolaires fossils. In *Traite de Zoologie volume 1* (ed. P. D. Grasse), pp. 398–436. Paris: Masson.

De Wever, P., Dumitrica, P., Caulet, J. P., Nigrini, C. & Caridroit, M. 2001. *Radiolarians in the Sedimentary Record*. Singapore: Gordon and Breach Science Publishers.

Dottin, O. & Zinszner, B. 1972. *Feuille Pothisat, 1:200,000*. Paris, France: Bureau de Récherches Géologiques et Minieres (BRGM).

Ehrenberg, C. G. 1838. Uber die Bildung der Kreidefelsen und des Kreidmergels durch unsichtbare Organismen. *Abhandlungen der Konigliche Akademie des Wissenschaften zu Berlin Jahrgang* **1838**, 59–147.

Fontaine, H. 2002. Permian of Southeast Asia: an overview. *Journal of Asian Earth Science* **20**, 567–88.

Fontaine, H. & Workman, D. 1978. Review of the geology and mineral resources of Kampuchea, Laos and Vietnam. In *Third Regional Conference on Geology and Mineral Resources of Southeast Asia* (ed. P. Nutalaya), pp. 54–603. Bangkok, Thailand.

Gubler, J. 1935. Études géologiques au Cambodge occidental. *Bulletin du service géologique de l'Indochine* **22** (3), 1–174.

Hada, S., Bunopas, S., Ishii, K. & Yoshikura, S. 1997. Rift–drift history of Shan–Thai and Indochina/East Malaya blocks. In *The International Conference on Stratigraphy and Tectonic Evolution of Southeast Asia and the South Pacific* (ed. P. Dheeradilok), pp. 105–18. Bangkok, Thailand.

Hattori, I. & Yoshimaru, M. 1982. Lithofacies distribution and radiolarian fossils in the Nanjo area in Fukui prefecture, central Japan. *News of Osaka Micropaleontologists Special Volume* **5**, 103–16 (in Japanese).

Holdsworth, B. K. 1966. Radiolaria from the Namurian of Derbyshire. *Palaeontology* **9**, 319–29.

Holdsworth, B. K. 1969. Namurian Radiolaria of the genus *Ceratoikiscum* from Staffordshire and Derbyshire, England. *Micropaleontology* **15**, 221–9.

Holdsworth, B. K. 1977. Paleozoic Radiolaria; stratigraphic distribution in Atlantic borderlands. In *Stratigraphic Micropaleontology of Atlantic Basins and Borderlands* (ed. F. M. Swain), pp. 167–84. Amsterdam: Elsevier.

Holdsworth, B. K. & Jones, D. L. 1980. Preliminary radiolarian zonation for Late Devonian through Permian time. *Geology* **8**, 281–5.

Ishida, K. 1985. Discovery of Permian radiolarians from the pelitic rocks in the Middle Zone of the Chichibu Belt in eastern part of Tokushima Prefecture, Shikoku. *The Journal of the Geological Society of Japan* **91**, 155–6 (in Japanese).

Ishiga, H. 1982. Late Carboniferous and Early Permian radiolarians from the Tamba Belt, Southwest Japan. *Earth Science (Chikyu Kagaku)* **36**, 333–9.

Ishiga, H. 1983. Morphological change in the Permian Radiolaria, *Pseudoalbaillella scalprata* in Japan. *Transactions and Proceedings of the Palaeontological Society of Japan, new series* **129**, 1–8.

Ishiga, H. 1986. Late Carboniferous and Permian radiolarian biostratigraphy of southwest Japan. *Journal of Geoscience, Osaka City University* **29**, 89–100.

Ishiga, H. 1990. Paleozoic radiolarians. In *Pre-Cretaceous Terranes of Japan* (eds K. Ichikawa, S. Mizutani, I, Hara, S. Hada & A. Yao), pp. 285–95. Osaka, Japan: Nihon–Insatsu.

Ishiga, H. & Imoto, N. 1980. Some Permian radiolarians in the Tamba District, Southwest Japan. *Earth Science (Chikyu Kagaku)* **34**, 333–45.

Ishiga, H., Imoto, N., Yoshida, M. & Tanabe, T. 1984. Early Permian radiolarians from the Tamba Belt, southwest Japan. *Earth Science (Chikyu Kagaku)* **38**, 44–52.

Ishiga, H., Kito, T. & Imoto, N. 1982. Permian radiolarian biostratigraphy. *News of Osaka Micropaleontologists, Special Volume* **5**, 17–26.

Ishii, K., Kato, M. & Nakamura, K. 1969. Permian limestones of west Cambodia–lithofacies and biofacies. *Palaeontological Society of Japan Special Paper* **14**, 41–55.

Isozaki, Y. & Tamura, H. 1989. Late Carboniferous and Early Permian radiolarians from the Nagato Tectonic Zone and their implication to geologic evolution of the Inner Zone, southwest Japan. *The Memoirs of the Geological Society of Japan* **33**, 167–76 (in Japanese with English abstract).

Jasin, B. 2008. Some Permian radiolarians from Bukit Yoi, Pokok Sena, Kedah. *Bulletin of the Geological Society of Malaysia* **54**, 53–8.

Jasin, B. & Ali, C. A. 1997. Lower Permian Radiolaria from the Pos Blau area, Ulu Kelantan, Malaysia. *Journal of Asian Earth Sciences* **15**, 327–39.

Jasin, B. & Harun, Z. 2011. Radiolarian biostratigraphy of peninsular Malaysia–an update. *Bulletin of the Geological Society of Malaysia* **57**, 27–38.

Khin Zaw, Meffre, S., Lai, C., Burrett, C., Santosh, M., Graham, I., Manaka, T., Salam, A., Kamvong, T. & Cromie, P. 2014. Tectonics and metallogeny of mainland Southeast Asia — a review and contribution. *Gondwana Research* **26**, 5–30.

Kozur, H. W. 1981. Albaillellidea (Radiolaria) aus dem Unterperm des Vorurals. *Geologisch–Paläontologische Mitteilungen Innsbruck* **10**, 263–74.

Kozur, H. & Mostler, H. 1989. Radiolarien und Schwammskleren aus dem Unterperm des Vorurals. *Geologische–Paläeontologische Mitteilungen Innsbruck* **2**, 147–275.

Kurihara, T. & Kametaka, M. 2008. Radiolaria-dated Lower Permian clastic-rock sequence in the Fukuji area of the Hida-gaien terrane, central Japan, and its interterrane correlation across Southwest Japan. *Island Arc* **17**, 531–45.

Kuwahara, K. 1992. Late Carboniferous to Early Permian radiolarian assemblages from Miyagawa area, Mie prefecture, Japan. *News of Osaka Micropaleontologists* **8**, 1–7 (in Japanese with English abstract).

Ling, H. Y. & Forsythe, R. D. 1987. Late Paleozoic pseudoalbaillellid radiolarians from southernmost Chile and their geologic significance. In *Gondwana Six: Structure, Tectonics, and Geophysics* (ed. G. D. McKenzie), pp. 253–260. American Geophysical Union, Geophysical Monograph vol. 40. Washington, DC, USA.

Ling, H. Y., Forsythe, R. D. & Douglass, R. C. 1985. Late Paleozoic microfaunas from southernmost Chile and their relation to Gondwanaland forearc development. *Geology* **13**, 357–60.

Metcalfe, I. 1996. Gondwanaland dispersion, Asian accretion and evolution of eastern Tethys. *Australian Journal of Earth Sciences* **43**, 605–23.

Morley, C. K., Ampaiwan, P., Thanudamrong, S., Kuenphan, N. & Warren, J. 2013. Development of the Khao Khwang fold and thrust belt: implications for the geodynamic setting of Thailand and Cambodia during the Indosinian Orogeny. *Journal of Asian Earth Sciences* **63**, 705–19.

Mouret, C. 1994. Geological history of northeastern Thailand since the Carboniferous relations with Indochina and Carboniferous–early Cenozoic evolution model. In *Proceedings of the International Symposium on Stratigraphic Correlation of Southeast Asia* (eds P. Angsuwathana, T. Wongwanich, W. Tansathein, S. Wongsomsak & J. Tulyatid), pp. 132–58. Bangkok, Thailand: Department of Mineral Resources.

Müller, J. 1858. Über die Thalassicollen, Polycystinen und Acanthometren des Mittelmeeres. *Abhandlungen der Preussischen Akademie der Wissenschaften zu Berlin, Jahrgang* **1858**, 1–62.

Nazarov, B. B. & Ormiston, A. R. 1993. New biostratigraphically important Paleozoic Radiolaria of Eurasia and North America. In *Radiolaria of Giant and Subgiant Fields in Asia* (eds J. Blueford & B. Murchey), pp. 22–60. Micropaleontology Press, Special Publication no. 6.

Nie, X., Feng, Q., Metcalfe, I., Baxter, A. & Liu, G. 2016. Discovery of a Late Devonian magmatic arc in the southern Lancanjiang zone, western Yunnan: geochemical and zircon–Pb geochronological constraints on the evolution of Tethyan ocean basins in SW China. *Journal of Asian Earth Sciences* **118**, 32–50.

Nuchanong, T. 2014. *Geology of Thailand*. Bangkok, Thailand: Department of Mineral Resources.

Ormiston, A. R. & Babcock, L. 1979. *Follicucullus*, new radiolarian genus from the Guadalupian (Permian) Lamar Limestone of the Delaware Basin. *Journal of Paleontology* **53**, 328–34.

Ormiston, A. R. & Lane, H. R. 1976. A unique radiolarian fauna from the Sycamore Limestone (Mississippian) and its biostratigraphic significance. *Palaeontographica Abt A* **154**, 158–80.

Pessagno, J. E. A. & Newport, R. L. 1972. A new technique for extracting radiolaria from radiolarian chert. *Micropaleontology* **18** (2), 231–4.

Qian, X., Feng, Q. L., Wang Y., J., Chonglakmani, C. & Monjai, D. 2016. Geochronological and geochemical constraints on the mafic rocks along the Luang Prabang zone: Carboniferous back-arc setting in northwest Laos. *Lithos* **245**, 60–75.

Ridd, M. & Morley, C. K. 2011. The Khao Yai Fault on the southern margin of the Khorat Plateau and the pattern of faulting in southeast Thailand. *Proceedings of the Geologists' Association* **122**, 143–56.

Riedel, W. R. 1967. Protozoa, Subclass Actinopoda. In *The Fossil Record* (eds W. B. Harland, C. H. Holland, M. R. House, N. F. Hughes, A. B. Reynolds, M. J. S. Rudwick, G. E. Satterthwaite, L. B. H. Tarlo & E. C. Willey), pp. 291–8. London: The Geological Society of London.

Saesaengseerung, D., Agematsu, S., Sashida, K. & Sardsud, A. 2009. Discovery of Lower Permian radiolarian and conodont faunas from the bedded chert of the Chanthaburi area along the Sra Kaeo suture zone, eastern Thailand. *Paleontological Research* **13**, 119–38.

Sangsomphong, A., Tulyatid, D., Thitimakorn, T. & Charusiri, P. 2013. Tectonic blocks and suture zones of eastern Thailand: evidence from enhanced airborne geophysical analysis. *Annals of Geophysics* **56**, 1–12.

Sashida, K. 1995. Late Carboniferous and Early Permian radiolarian biostratigraphy in the chert block embedded in the Jurassic Kawai Formation, Kanto Mountains, central Japan. *Annual Reports of the Institute of Geoscience, University of Tsukuba* **21**, 33–40.

Sashida, K., Igo, H., Adachi, S., Ueno, K., Nakornsri, N. & Sardsud, A. 1998. Late Paleozoic radiolarian faunas from northern and northeastern Thailand. *Science Reports of the Institute of Geoscience, University of Tsukuba* **B 19**, 1–17.

https://doi.org/10.1017/S0016756817000322 Published online by Cambridge University Press

SASHIDA, K., IGO, H., HISADA, K., NAKORNSRI, N. & AMPORNMAHA, A. 1993. Occurrence of Paleozoic and Early Mesozoic Radiolaria in Thailand (preliminary report). *Journal of Southeast Asia Earth Sciences* **8**, 97–108.

SASHIDA, K. & NIKORNSRI, N. 1997. Lower Permian radiolarian faunas from the Khanu Chert Formation distributed in the Sukhothai area, northern central Thailand. In *Proceedings of the International Conference on Stratigraphy and Tectonic Evolution of Southeast Asia and the South Pacific* (eds P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien,W., C. Utha–aroon, N. Sattayarak, T. Nuchanong, T. & S. Techawan), pp. 101–8. Bangkok, Thailand: Department of Mineral Resources.

SASHIDA, K. & SALYAPONGSE, S. 2002. Permian radiolarian faunas from Thailand and their paleogeographic significance. *Journal of Asian Earth Sciences* **20** (6), 691–701.

SHEN, S., FENG, Q., YANG, W., ZHANG, Z. & CHONGLAKMANI, C. 2010. Study on the geochemical characteristics of ocean-ridge and ocean island volcanic rocks in the Nan–Uttaradit zone, northern Thailand. *Chinese Journal of Geochemistry* **29**, 175–81.

SHENG, J. & WANG, Y. 1985. Fossil radiolaria from Kufeng formation at Longtan, Nanjing. *Acta Palaeontologica Sinica* **24**, 171–80.

SHI, L., FENG, Q., SHEN, J., ITO, T., & CHEN, Z.-Q. 2016. Proliferation of shallow-water radiolarians coinciding with enhanced oceanic productivity in reducing conditions during the Middle Permian, South China: evidence from the Gufeng Formation of western Hubei Province. *Palaeogeography, Palaeoclimatology, Palaeoecology* **444**, 1–14.

SHIMAKAWA, M., & YAO, A. 2006. Lower–Middle Permian radiolarian biostratigraphy in the Qinzhou area, South China. *Journal of Geosciences, Osaka City University* **49** (3), 31–47.

SONE, M., METCALFE, I. & CHAODUMRONG, P. 2012. The Chantaburi Terrane of southeastern Thailand: stratigraphic confirmation as a disrupted segment of Sukhothai Arc. *Journal of Asian Earth Sciences* **61**, 16–32.

SPILLER, F. C. P. 1996. Late Paleozoic radiolarians from the Bentong-Raub suture zone, Peninsular Malaysia. *Island Arc* **5**, 91–103.

SUZUKI, N., KOJIMA, S., KANO, H., YAMAKITA, S., MISAKI, A., EHIRO, M., OTOH, S., KURIHARA, T. & AOYAMA, M. 2005. Permian radiolarian faunas from chert in the Khabarovsk Complex, Far East Russia, and the age of each lithologic unit of the Khabarovsk Complex. *Journal of Paleontology* **79**, 687–701.

Te Duong Tara. 2006. Petroleum development, a Cambodian perspective: offshore Cambodian areas and onshore Tonle Sap Basin. In *4th Asian Petroleum Technology Symposium*, pp 1–20. Siem Reap, Cambodia.

UENO, K. & CHAROENTITIRAT, T. 2011. Carboniferous and Permian. In *The Geology of Thailand* (eds M. Ridd, A. Barber & M. Crow), pp. 71–136. London: The Geological Society of London.

United Nations. 1993. *Cambodia Explanatory Brochure*. Economic and Social Commission for Asia and the Pacific Atlas of Mineral Resources of the ESCAP Region Volume 10.

WANG, Y., CHENG, Y. & YANG, Q. 1994. Biostratigraphy and systematics of Permian radiolarians in China. *Palaeoworld* **4**, 172–202.

WANG, Y. J. & YANG, Q. 2011. Biostratigraphy, phylogeny and paleobiogeography of Carboniferous–Permian radiolarians in South China. *Palaeoworld* **20**, 134–45.

WIELCHOWSKY, C. C. & YOUNG, J. D. 1985. Regional facies variation in Permian rocks of the Phetchabun Fold and Thrust Belt, Thailand. In *Proceedings on Geology and Mineral Resources Development of Northeastern Thailand* (eds P. Thanvarachorn, S. Hokjaroen & W. Youngme), pp. 41–55. Khon Kaen University, Thailand.

WU, H. R. & LI, H. S. 1989. Carboniferous and Permian radiolarian in the Menglian area, western Yunnan. *Acta Palaeontologica Sinica* **6** (4), 337–43.

WU, H. R., XIAN, X. Y. & KUANG, G. D. 1994. Late Paleozoic radiolarian assemblages of southern Guangxi. *Scientia Geologica Sinica* **29** (4), 339–45 (in Chinese, with English abstract).

XIAN, W. & ZHANG, N. 1998. Early to Middle Permian radiolarians from the Kuhfeng Formation in southeastern Guangxi, South China. *Earth Science (Chikyu Kagaku)* **52**, 188–202.

XIE, L., YANG, W. Q., LIU, G. C. & FENG, Q. L. 2011. Late Paleozoic Radiolaria from the Upper Triassic sedimentary mélange in Shangrila, Southwest China and its geological significance. *Palaeoworld* **20**, 203–17.

YANG, W. Q., FENG, Q. L., SHEN, S. Y. & CHONGLAKMANI, C. 2009. Constraints of U–Pb zircon dating on the evolution of the Nan–Uttaradit suture zone in northern Thailand. *Acta Geoscientica Sinica* **30** (1), 88–9.

YOSHIDA, H. & MURATA, M. 1985. Permian radiolarian biostratigraphy from the north-eastern part of Saiki City, Oita Prefecture, Japan. *Journal of the Geological Society of Japan* **91**, 525–53 (in Japanese).

ZHAO, Z., HUANG, X., ZHANG, X., YANG, B., CHEN, Z.-Q. & XIONG, F. 2016. Permian radiolarians from the A'nyemaqen mélange zone in the Huashixia area of Madoi County, Qinghai Province, Western China, and their implications on regional tectonism. *Journal of Earth Sciences* **27**, 623–30.