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The Man Who Made Impact – The Scientific Work of Dr Sangad Bunopas

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Abstract

Sangad Bunopas published extensively on the geology of Thailand and left a legacy of maps, reports, stratigraphic nomenclature and insightful papers covering most of the kingdom. His 1981 PhD thesis published in 1982 laid the foundation of modern Thai stratigraphy. His highly cited papers on the tectonics of South East Asia, often with Professor Paul Vella, were based on Sangad's extraordinary first-hand knowledge of Thai geology which allowed him to draw the first reliable tectonic subdivisions of the whole country. Although controversial at the time, these tectonic subdivisions and hypotheses have since been accepted as generally correct in that the Shan-Thai Terrane (as part of Sibumasu) rifted from Australian crust in the early Permian, drifted and warmed as it crossed the Palaeotethyan Ocean and collided with the Indochina Terrane in the late Triassic. His stimulating palaeomagnetically constrained, combined palinspastic-palaeogeographic maps for the Permian to Cenozoic were well in advance at the time and have not been attempted again in the subsequent 40 years.

His controversial later work, which attempted to explain the widespread, anomalous loess in northeast Thailand, the Australasian tektite strewn field, the fluvial deposits in Nakhon Ratchasima (Khorat) Province and their middle Pleistocene faunas and flora as the result of a cometary impact at 788 ka has received some support and some criticism but has nevertheless stimulated a considerable research and a lot of discussion.

Over more than 50 years, Sangad made many major contributions to Thai geology, South East Asian tectonics and meteoritic research. His wit, wisdom and iconoclastic approach to earth and planetary science will be sorely missed by his numerous friends and colleagues.

Keywords: biography, cometary impact, loess, Quaternary stratigraphy, Shan-Thai Terrane, tectonics, Thailand

1. INTRODUCTION

Dr Sangad Bunopas (1937-2020) was born and raised in Chaiyaphum near the edge of the Khorat Plateau in northeastern Thailand, surrounded by areas of scenic geology and geomorphology. To the east lay the Mesozoic sandstones of the Khorat Plateau and to the west the Central Plains with Cenozoic cover of marine Palaeozoic rocks. After graduating from Chulalongkorn University in 1960, Sangad joined the Department of Mineral Resources (DMR) in July 1961. Within a few years, he was sponsored to study abroad by the DMR and supported initially by a Colombo Plan scholarship. He was encouraged and helped in his overseas studies by his wife and by senior DMR staff Pisoot Sudasna Na Ayudhaya (who became Deputy Permanent Secretary of the Minister of Industry), Saman Buravas, Manus Veraburras and significantly, in the light of his pioneering work on tektites, by Dr Kaset Pitakpaivan who later became Director-General of the Department of Industrial Promotion.

Sangad completed the rigours of a BSc (Honours) degree before progressing to an MSc programme (1965-6) in New Zealand. He returned to regional mapping in Thailand and then from 1977 to 1981 completed a PhD at the Victoria University of Wellington supervised by Professor Paul Vella. Sangad was lucky to study at

Fig. 1 Sangad Bunopas. Photos kindly supplied by the Bunopas family

Victoria University as the geology of New Zealand is diverse, rugged, spectacular and active (Figs. 2-3) and the local geologists are renowned for their excellence, enthusiasm for fieldwork and all-round abilities. This was excellent training which he later put to good use working on Thai geology. He graduated with an MSc in 1966 at a time when the theory of plate tectonics was being developed and then applied to orogenic belts around the world. Sangad's regional mapping and his PhD work on palaeomagnetism would soon lay the foundations for his new ideas on the tectonics of South East Asia

2. REGIONAL GEOLOGY OF THAILAND

His early work for the DMR, based in Bangkok, was in regional mapping and special projects. Unlike today, there was little infrastructure in Thailand in the late 1960's to 1970's. Roads were very bad, vehicles old and poorly maintained, road cuts were limited and thick jungle still covered large areas of the country. Communist insurgency made some areas dangerous for government personnel. "Traverses of the Western Mountains and some parts of the Sukhothai Foldbelt often require transportation by elephant…" (Raksaskulwong and Bunopas,1985, p.9). With some understatement they reported that progress on foot and by elephant made mapping very slow.

His early assignments were in several provinces on a wide variety of rocks and economic deposits. He investigated the geology and mineral resources of Amphoe Mae Thaeng in Chiang Mai Province in 1961, lignite and oil shale in Li, Lamphun Province (1962 and 1963), the geology of Song in Phrae Province in 1967, the geology of the Nam Phrom Dam in Chaiyaphum Province (Bunopas, 1971) and tin deposits in Rayong Bay in eastern Thailand in 1973. With DMR colleagues, Sangad produced 1: 250,000 maps and reports for geologically significant quadrangles in central Thailand such as Phitsanalok (Bunopas, 1974b and 1976a), Nakhon Sawan (Bunopas, 1976c, 1980) and Suphanburi (Bunopas, 1976d). Part of the Suphanburi mapping project led to an important paper in the first volume of the Journal of the Geological Society of Thailand on the fascinating geology of Bo Phloi and Uthai Thani in western Thailand (Bunopas and Bunjitradulya, 1975). They mapped a variety of Palaeozoic rocks, metamorphic and igneous rocks with comments on the economic resources including the famous Bo Phloi sapphires. They discussed the confusing lithostratigraphic nomenclature at the time concerning the Kanchanaburi Series, Phuket Group and Tanaosri Group and most significantly recognised the several thrust faults such as the large, low-angle Chong Insi Thrust where the Siluro-Devonian rocks are overthrust on gneisses. The inclusion of structural data, and especially the recognition of thrust faults, was very unusual for Thai geology at that time and was a feature of many of Sangad's (with DMR colleagues) regional papers including the still very interesting structural geology chapter 7 of his 1981 thesis. An example of his emphasis on structural geology is shown in Fig. 4.

An important study on the famous (and as a prison, infamous) island of Ko Tarutao in southern Thailand followed in 1978 with DMR colleagues Sahat Muenlek and Veerapong Tansuwan (Bunopas et al., 1978). Cambrian

Fig. 2 Gladstone East Coast Road. Cold and wet South Island, New Zealand – a long way from tropical Thailand. (From Bunopas, 1966, MSc thesis, Victoria University, New Zealand).

Fig. 3 Eringa Cyclothem, near Eringa Station, New Zealand. The area was studied in Wairarapa, a little north of Wellington. In the Wainuiru River Valley in Gladstone near Masterton. Miocene and Pliocene mudstones younging west (left hand), are overlain by limestone cyclothems with coquina limestones and the terrestrial Hawera Series (From Bunopas, 1966, Victoria University, Wellington, MSc thesis).

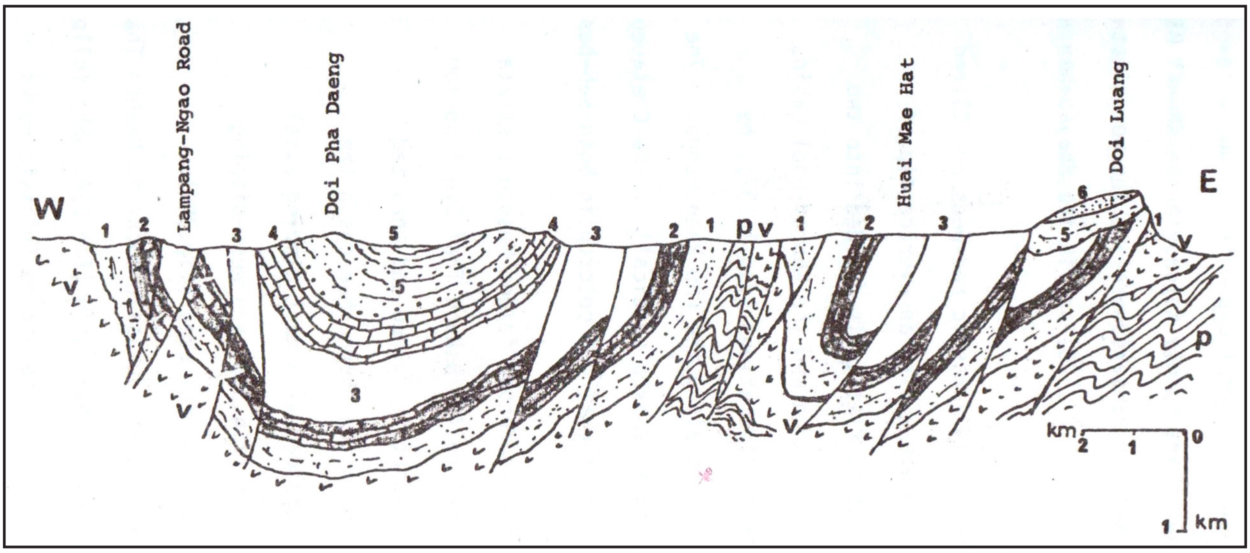

Fig. 4 From Bunopas (1982, fig.42) showing an example of the structural cross-sections in his thesis. Section from north of Lampang to west of Phrae, northern Thailand.

fossils had previously been found there by DMR Director Saman Buravas in 1958 and described by Teichii Kobayashi but little work had been done on these important and fossiliferous Lower Palaeozoic sections in the intervening 20 years. They mapped and described the sandstones and limestones and recognised important faults thereby laying the foundations of scores of palaeontological papers, reports and theses in subsequent years. Work on Ko Tarutao and in mainland Satun was strongly encouraged and supported by Sangad. These foundational studies and discoveries eventually led to Satun being recognised as the first UNESCO Geopark in Thailand.

Another regional study of note was written-up by Lertsin Raksakulwang and Sangad in 1985 on the complex geology of 3000 square kilometres of Mae Hong Son Province in northwest Thailand. They included structural, lithostratigraphic and sedimentological details including many cross sections, stratigraphic columns and Landsat maps of lineaments with much of the work carried out on elephants and on foot across mountainous terrain. Within a few years this area became another well-studied and palaeontologically and tectonically significant area.

Sangad also produced several important and influential syntheses of stratigraphic correlations across Thailand (Bunopas 1974a, 1976, 1983, 1992b, 1994). Some of these papers were written prior to his massive encyclopedia of Thai geology (his PhD thesis) and others subsequent to Bunopas (1981, 1982). All were influential and there is hardly a chapter of recent books on the geology of Thailand that do not quote these studies extensively.

A paper with Sirot Salypongse, Father Henri Fontaine and Daniel Vachard (Bunopas et al., 1983) summarised the Permian stratigraphy of Thailand and included important new palaeontological data. Sangad also worked with Father Fontaine on the fossiliferous Devonian limestone of Loei Province, in northeastern Thailand. This was followed by many significant papers and monographs by Fontaine, Vachard and DMR colleague Dr Voravudh Suteethorn, mainly on the Devonian to Permian palaeontology of Thailand.

Throughout his career, Sangad emphasised the importance of biostratigraphy to Thai geology. From the 1970's he cooperated with palaeontologists in many countries and had at least three species named after him. These are the Triassic bivalved arthropod *Euestheria bunopasi* (Kobayashi, 1975), the Permian brachiopod *Rhamneria bunopasi* Waterhouse 1981, and the Ordovician trilobite *Rossaspis bunopasi* Stait, Burrett and Wongwanich 1984.

3. TECTONICS OF SOUTH EAST ASIA

Armed with an enormous data-base of Thai geology acquired after detailed studies in every corner of the kingdom, Sangad developed a new tectonic model for the whole of South East Asia with his mentor and supervisor Professor Paul Vella. This model was first published in Bunopas and Vella (1978) and enlarged on in

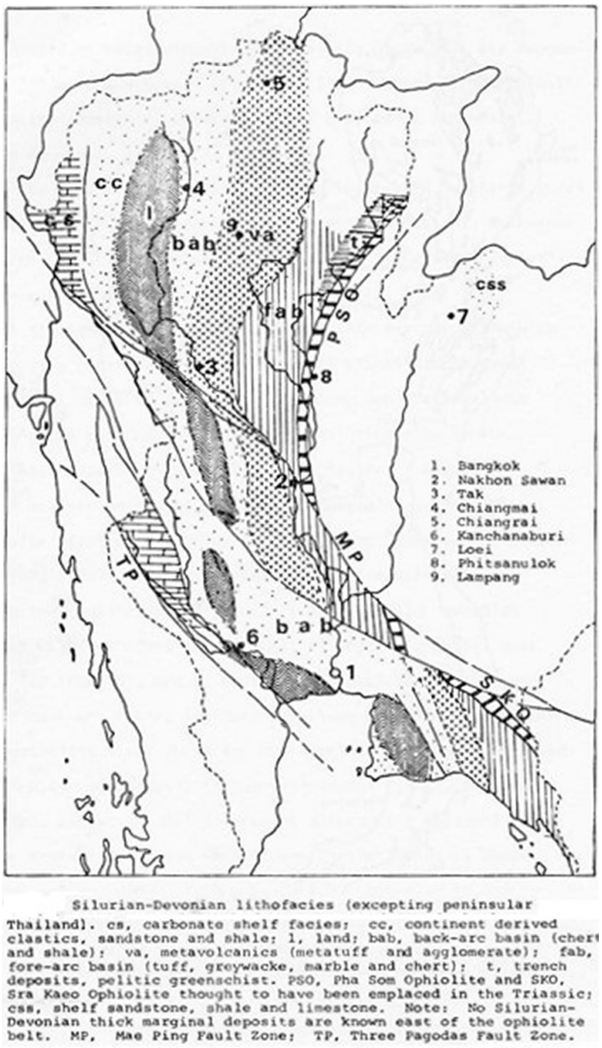

Fig. 5 From Bunopas (1982, fig 141b) showing one of several diagrams outlining Sangad's major tectonic subdivisions of Thailand (for the Siluro-Devonian) offset by major transcurrent faults. Note the recognition, mapping and offset of the Sra Kaeo ophiolite in eastern Thailand and the proposed back-arc basin in northern Thailand in what we would now term the Inthanon Zone (or terrane).

subsequent years (Bunopas and Vella 1983a, Bunopas et al., 1990, 2003, 2004). The model was developed fully in chapter 9 of his 801 page tour de force PhD from Wellington which was then published as special paper number 5 of the Geological Survey of the DMR (Bunopas, 1981, 1982). Unusually for a PhD thesis, the first 443 pages is a comprehensive, country-wide summary and it may well be considered the first book on the geology of Thailand. It has been cited over 400 times. Any geologist working in Thailand can still dip into these chapters and find something significant that they either did not know or had forgotten.

The first 443 pages of Sangad's thesis contains numerous maps and useful lithostratigraphic and correlation charts with the text full of new paleontological lists and sedimentological insights. Sangad included thin section descriptions and numerous chemical analyses of igneous rocks. He redefined and clarified old, loosely defined lithostratigraphic units and on almost every page named and defined numerous new formations and groups, many of which are still in every-day use. Bunopas (1982) may be regarded as the foundation of modern Thai stratigraphy.

The 100 pages of Chapter 8 of his thesis concern Sangad's palaeomagnetic studies on both Palaeozoic and Mesozoic rocks. His preliminary palaeomagnetic results were published with Dr Kaset Pitakpaivan and J. Sukroo in 1978 (Bunopas et al., 1978). His conclusions on the rotation of Indochina and his Mesozoic results have been confirmed by later work. Unfortunately, many of his Permian samples had high alpha 95's ('statistical uncertainty' or scatter) which were unacceptably large but even his low inclination results with moderate alpha 95's on Permian limestones appear to have been validated by recent studies. Sangad fully realised the limitations of his Palaeozoic palaeomagnetic studies and on returning from Wellington collected a large number of orientated cores on Cambrian and younger Palaeozoic rocks. Sadly, hardware and software problems meant that no further reliable results could be obtained.

Generally Sangad's basic tectonic concepts have stood the test of time. He drew his Shan-Thai Terrane to include western Thailand and Malaysia and eastern Myanmar and regarded what is now termed the Inthanon Zone or Terrane as a back-arc basin of his Sukhothai Arc. He identified the ophiolitic Nan Suture and for the first time suggested its extension to the ophiolite of Sra Kaeo in eastern Thailand which he briefly described - also for the first time. He emphasised the contrast between the late Carboniferous and early Permian faunas of the Shan-Thai (cool Gondwana) and Indochina (tropical Cathaysian) terranes which were separated by the Nan-Sra Kaeo suture. He subdivided Thailand into distinctive tectonic belts, offset by major transcurrent faults and showed their palaeogeographic evolution through time (Fig. 5).

Sangad suggested Shan-Thai rifted from the Australian sector of Gondwana, with the

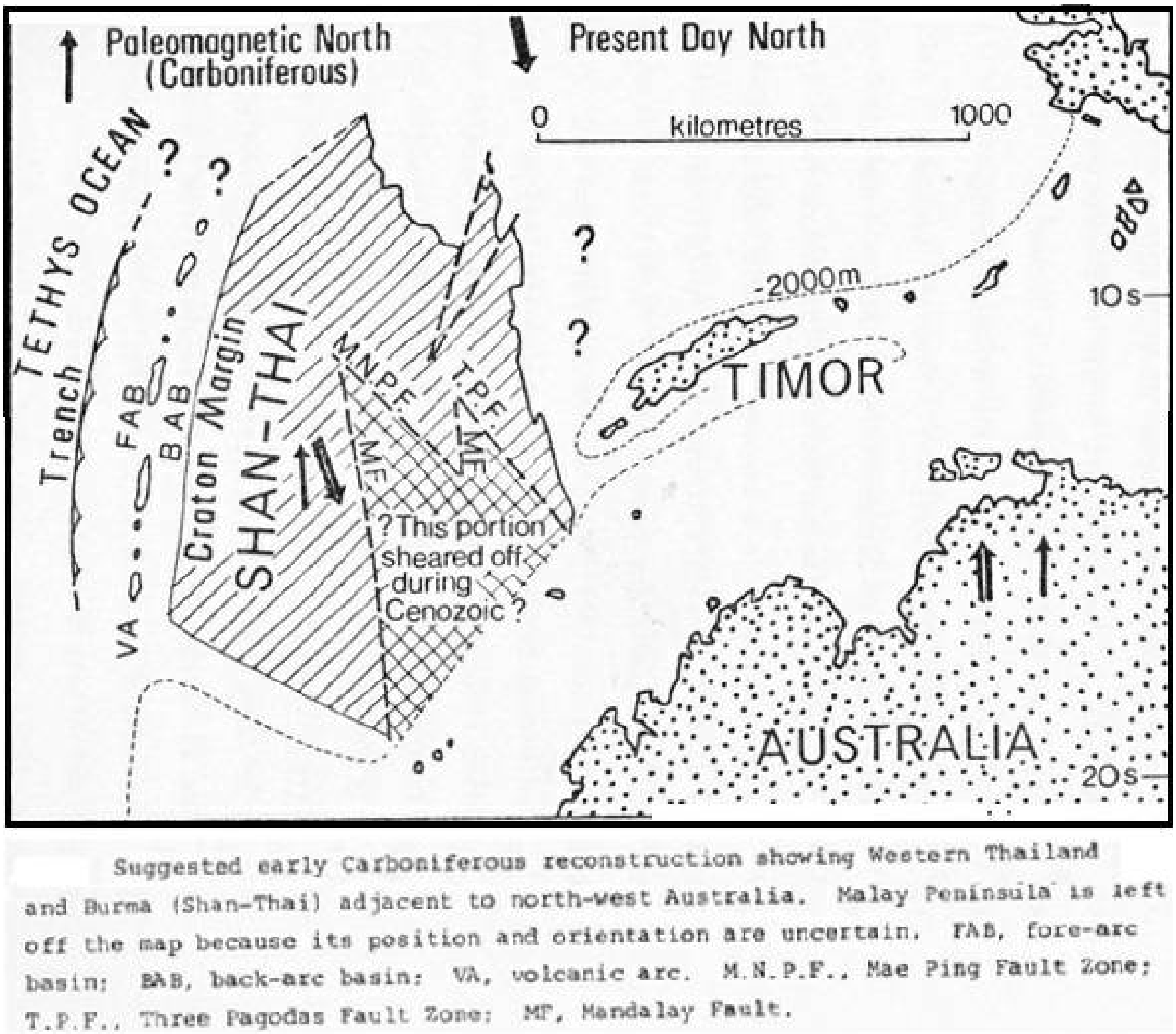

Fig. 6 A novel and iconoclastic palinspastic reconstruction of Thailand adjacent to northwest Australia in the early Carboniferous, figure 144 in Bunopas (1981, 1982). This is one of many stimulating and provocative palinspastic reconstructions in his thesis.

deposition of the glacial pebbly mudstones of the Kaeng Krachan Group (Bunopas and Vella, 1984, 1989) in the early Permian, drifted into lower and warmer palaeolatitudes during the middle Permian to Early Triassic and collided with Indochina in the Norian (Late Triassic).

Sangad did not confine himself to the Palaeozoic-Triassic but wrote an interesting paper on Cenozoic rifting and the development of the Gulf of Thailand (Bunopas and Vella, 1983b). Unusually, he attempted to remove Mesozoic deformation and Cenozoic faults and their movements and incorporated his palaeomagnetic results, showing block rotations, in order to draw combined palinspastic palaeogeographic restorations for South East Asia (Bunopas 1981, Figs. 151-155b).

These restorations (Fig. 6) have not been attempted to the same level of detail since and contrast markedly with the inchoate ‘blobs’ drawn on many recent palaeogeographic maps. A feature here is that Sangad bravely extended his initial ideas where most conventional geologists would have finished. This pushing of hypotheses to their limits - and sometimes beyond was also characteristic of his later work on impacts.

Apart from the excision of the Upper Palaeozoic limestones and Devonian to Triassic cherts of the Inthanon Zone from the Shan-Thai Terrane, arguments on subduction directions and the inclusion of Shan-Thai in an enlarged Sibumasu Terrane, his initially controversial proposals, have been confirmed by most subsequent studies. Today few would disagree with his major conclusion that Shan-Thai (as a part of Sibumasu) was part of northwest Australian crust that rifted off in the early Permian, warmed-up in its drift across Palaeo-Tethys and collided with Indochina in the Late Triassic.

4. IMPACTS, TEKTITES, LOESS AND COMETS

DMR Director General Dr Kaset Pitakpaivan was one of the first to study tektites in Thailand and it was not surprising that he influenced the young Sangad to eventually study them. Dr Kaset worked with Dr Virgil Barnes from Texas and made the first regional scientific study of these fascinating black glasses at about the same time that Sangad joined the DMR (Barnes and Pitakpaivan, 1962). At the time, many prominent and brilliant planetary scientists argued that tektites were extraterrestrial with the most prominent theory being that they were blasted from volcanoes on the moon (Chapman and Larsen, 1963; O'Keefe, 1976). Barnes and Pitakpaivan collected tektites throughout northeast Thailand and emphasised the importance of layered or Muong Nong tektites including the large 12.8 kg specimen donated by Dr Kaset to the DMR museum (Barnes, 1971).

Huge samples of Muong Nong tektites which were offered for sale by Mr Boomun Poonyathiro, owner of the House of Gems, Bangkok weigh up to 24 kg (Fig. 7). Detailed field studies in Ubon Ratchathani by P. Fiske, Prinya Phutthapiban and John Wasson (1996) confirmed the abundance and stratigraphic position of Muong Nong tektites on a lateritic surface overlain by loess. All subsequent workers showed conclusively that Australasian strewn field tektites are not extraterrestrial but the result of a bolide impact or impacts at 788 ka, centred in the Indochina region that blasted tektites all the way to Tasmania and as microtektites across the Indian Ocean, western Pacific Ocean and all the way to Antarctica. Tektites are so abundant in South East Asia that in some areas almost every villager has a collection and jewellery shops in Charoen Krung, Bangkok literally have buckets full of them.

In 1987 Dr Ramsay Ford (with the writer and Sangad) toured northeast Thailand (Isarn) and collected tektites from almost every province. We found a large disk tektite horizontally embedded in the middle of a 3- thick section of loess near Khon Kaen and found that the majority of tektites were restricted to the junction of a distinctive laterite and an overlying section of loess or rarely within the loess itself (Ford,

Fig. 7 Probably the largest Muong Nong tektite yet found and was on display at the House of Gems in Charoen Krung, Bangkok. This and related specimens may be from Ubon Ratchathani on the Thai-Lao border or possibly from Laos. This specimen was shown to Sangad Bunopas, Ramsay Ford, Clive Burrett and Kieren Howard at various times by Mr Boomun Poonyathiro. Weight is 24 kg. 1999 photograph kindly supplied by Prof. Kieren Howard.

1988). The loess covers NE Thailand extends to the Central Plain and varies between 4 m and 1 m in thickness and compares with the famous yellow earth of China but differs in detail (Sibava, 1993; Nichol and Nichol, 2015, see Bunopas, 2021 this volume). An interesting study by Paul Vella, Sangad and Vorakul Kaewyana that does not appear to have been followed-up, showed that loess extends to northern Thailand and covers river terrace deposits. This potentially provides constraints on dating river terraces and also provides clues to uplift rates (Vella et al., 1987).

Loess in Europe and China is related to windy environments close to glaciated areas and its ubiquity in northeastern Thailand is anomalous and difficult to explain on current models of loess formation (Nichol and Nichol, 2015). Sangad was already interested in the tektite problem and he soon wrote papers on the catastrophic effects of a large impact in Indochina close to the area of the large Muong Nong tektites eastern Isarn, Laos and Vietnam (Bunopas, 1989, 1990, 1992a). He specifically included the loess as a result of an impact and therefore suggested a c.800 ka age on the basis of finding pristine tektites within and just below this enigmatic deposit. Sirot Salyapongse and Kaset Pitakpaivan studied the Thai loess and compared it to Chinese loess. They found glass beads in the Thai loess and also, interestingly, in Pleistocene trees (Salyapongse and Pitakpaivan, 1999).

Sangad coined the term catastroloess for the Thailand loess. He included fluvial deposits from along the palaeo-Mun River valley, which clearly are not loess and it is unlikely that this term will survive.

He soon extended the catastrophic impact model to include the fluvial sands along the Mun River Valley of Nakhon Ratchasima Province (Khorat) containing large charcoalified and partially burnt logs, small plant material and pollen (some burnt) and numerous vertebrate fossils (Bunopas and Khositanont, 1999c, Bunopas et al., 1997, 1998, 1999 a, b, 2001, 2002a, b, 2003, 2004, 2005 and 2007; Charusiri et al., 2002). When Sangad showed me the Khorat sandpits and their abundant apparently burnt logs, I was immediately struck by the resemblance to the multitude of trees felled by the huge air-blast of the Tunguska, Siberia explosion in 1908. Sangad's correlation of the Khorat sands with the 788 ka impact was a step too far for many as it was already apparent that many but not all of the vertebrates in the sandpits are Miocene in age and not Pleistocene (Chaimanee, 2004, 2007; Duangkrayom et al., 2017). The situation is complicated by the sandpit operators who use high-powered hoses to sort and collect the poorly consolidated sands. As a result, vertebrate fossils are rarely found in situ but are found either much lower in the stratigraphy or at the bottom of the pits. The biostratigraphic situation was clarified by Sato (2002) and it appears that definite in situ though of course, fluvially transported, Miocene fossils are generally found in the basal parts of the pits and middle Pleistocene such as Stegodon, crocodiles and turtles in the upper parts (e.g. Lauprasert et al., 2019; Naksri et al., 2019). Of course, in a flood-prone, fluvial environment older vertebrates may be reworked into younger sands so the biostratigraphic and taphonomic context becomes complicated. The situation in northeast Thailand and beyond is also complicated by the difficulties dating Quaternary deposits with all available methods being subject to considerable problems, caveats and uncertainties.

Sangad encouraged detailed work on the Khorat sand-pits by Kieren Howard (1999) and then with Howard collaborated with Dr Peter Haines (Australia) and palaeomagneticist Professor Jason Ali (Hong Kong) (helped by the late Dr Somboon Khositanont and the writer) in a magnetostratigraphic study of the pits. The advantage of magnetostratigraphy is that if consecutive units are present then it is unlikely that they have not been reworked or reset. The disadvantage is that short geomagnetic excursions, such as within the Brunhes Epoch, may be mistaken for epoch boundaries or vice versa. Haines et al. (2004) revealed a transition from present-day Normal magnetization to Reversed at 14 m depth at Ban Tha Chang and at 9 m depth 40 km away at Chum Phuang (Fig. 8). This was interpreted as the transition from the Matuyama Epoch (R) to the Brunhes Chron (N) which polarity reversal is now dated at 773 +/- 5 ka (Haneda et al., 2020). The magnetism of the older samples from the pits below the Reversed level was equivocal and so the reversal could be the result of short-lived magnetic excursions during the late Pleistocene as interpreted by magnetostratigraphic studies at Khok Sung also in Nakhon Ratchasima (Khorat) Province (Suraprasit et al., 2015). However, the discovery of an in situ, rare, un-abraded, delicate and hollow sphere, and definitely unreworked Australasian tektite, at the reversal level (Fig. 8) strongly supports Sangad's and Peter Haines et al's (2004) interpretation. The stratigraphic situation in the Khorat sandpits is further complicated by the detailed palynological work of Yang and Grote (2018 a, b) who reported thermoluminescence dating on 7 samples and two C14 dates ranging from 172,739 +/- 22,400 a BP to 27,332 +/- 3000 a BP in a 3.25 m section from about 13.5 m to 10.0 m depths which covers the same depth interval as the study by Haines et al. (2004). Yang and Grote (2018 b) suggest major vegetational and palaeoclimatic changes from cool to warm to cool, and correlation to parts of two glacial periods (Riss and Wurm) during the deposition of this 3.25m of sediments.

Whether or not Sangad (and Howard, 1999, 2011a, b; Howard et al., 2003 and Haines et al., 2004) were correct in ascribing some parts of the upper sections of the sandpits and their contained biota to the 788 ka Australasian impact event, the importance of the studies in the Khorat sandpits to a wide variety of earth, planetary and biological sciences suggest that more efforts should be made on dating studies along with palaeontological, sedimentological and palynological studies in the sandpits. The pits are ephemeral and most, if not all, will end up filled with water. More careful interdisciplinary studies such as at Khok Sung by Dr. Jaroon

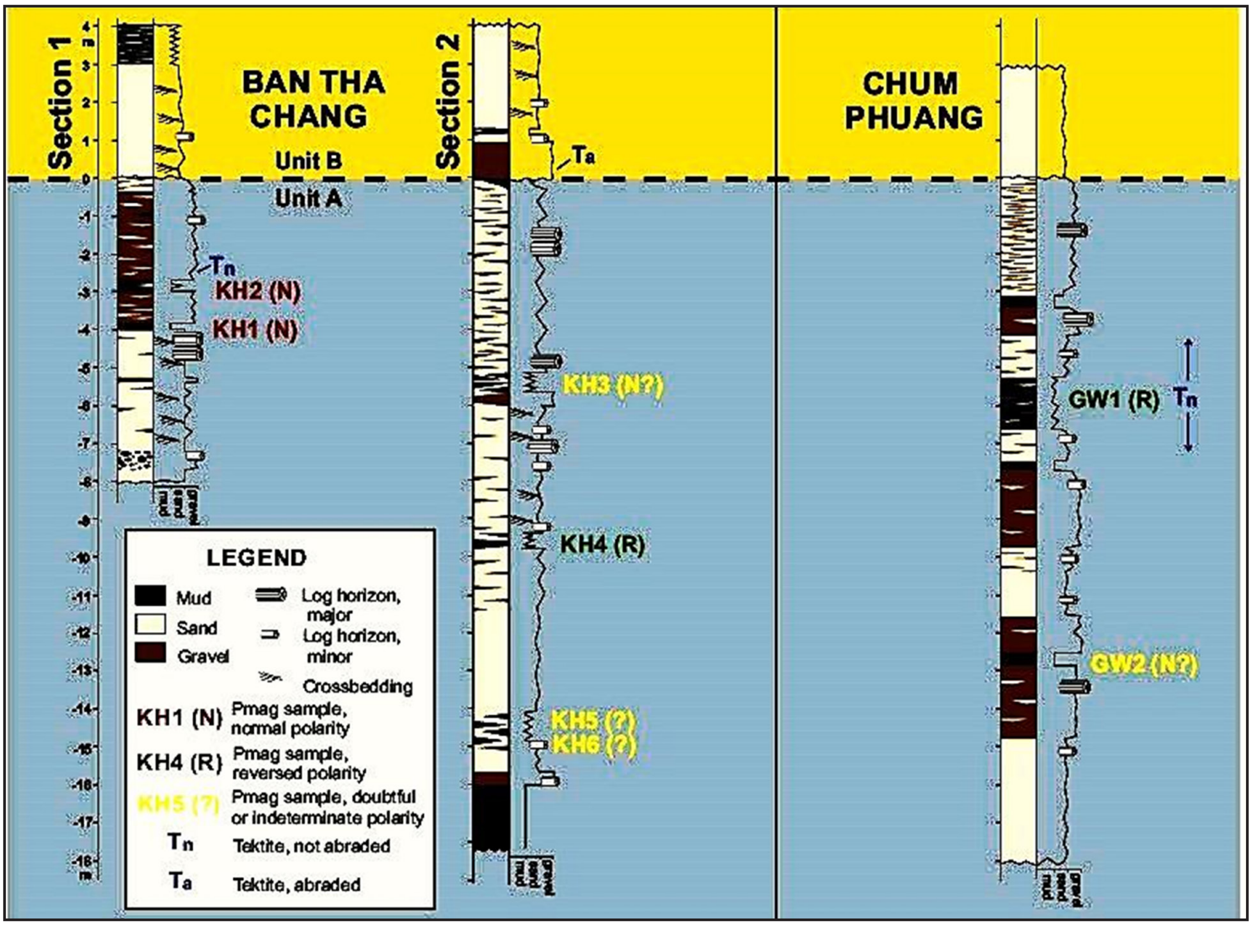

Fig. 8 Stratigraphic sections through the 22 m of the Ban Tha Chang and Chum Phuang sandpits in Nakhon Ratchasima Khorat) Province showing Normal (N=Brunhes) and Reversed (R= Matuyama) magnetostratigraphy. Unabraded, hollowsphere, tektite in Chum Phuang section shown as Tn and reworked abraded tektites as Ta. From Haines et al., (2004). Colourslide kindly supplied by Dr Peter Haines (Australia).

Duangkrayom et al. (2014) are needed. If Sangad was correct, then northeastern Thailand contains globally unique evidence of the catastrophic environmental effects of a major impact event. This is, of course, of global scientific interest but is also important as a possible tourist attraction that will bring employment to the local community.

With characteristic intellectual exuberance Sangad then extended his hypothesis to include events far from Khorat. He included the demise of Miocene vertebrates throughout Thailand (including Khorat) in his model which is highly unlikely. However, his speculation should prompt all who work in Khorat to carefully demarcate the Miocene biota from the Pliocene and Pleistocene and, if possible, the early from the later Pleistocene faunas and floras. He further suggested that the well-known, almost certainly, Miocene, fish beds in Phetchabun Province and shell beds near Bangkok, most likely to be Holocene, were also the result of the impact. These speculations are possible but unlikely on present evidence.

He further extended his hypothesis to the extinction of Miocene faunas in Australia. Although the widespread occurrence of unreworked tektites is a very useful horizon in Australian Quaternary stratigraphy and the 788 ka event may well have had environmental and biotic consequences on that huge continent, any correlation with Quaternary megafaunal extinctions in Australia is very unlikely.

However, his suggestion that our hominid ancestor Homo erectus witnessed and probably suffered from the tektite fall is well supported by studies in Java and in Yunnan (Hou et al., 2000). The effects throughout SE Asia of the 788 ka ‘cataclysm’ on Homo erectus are recently well documented by Li et al. (2021) and provide considerable support for another of Sangad’s ‘wild’ ideas.

Sangad suggested that the eroded pillars known as Sao Din (earth pillars) (Fig. 9) found from northern Thailand to Sra Kaeo include deposits of loess caused by the 788 ka impact. These deposits remain undated directly but

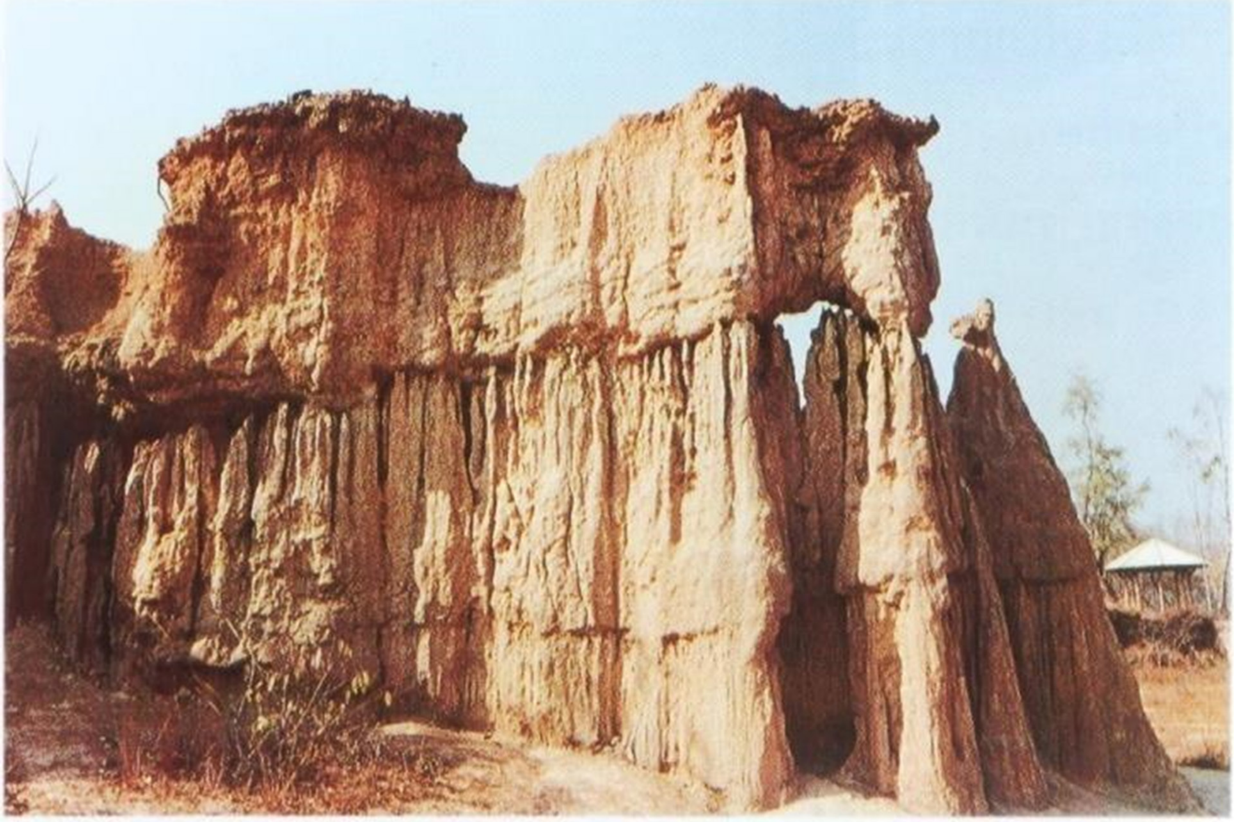

Fig.9 "Sao Din" earth pillars at Nanoi, south of Nan city northern Thailand.

archaeological excavations in the Nanoi Basin, south of Nan in northern Thailand have found stone tools very similar to those in the Chinese Bose Basin closely associated with tektites as discussed by Li et al. (2021) and Hou et al. (2000). Zeitoun et al. (2012) suggest an age of 1 to 0.5 Ma for the Sao Din stone tools so perhaps this is another of Sangad's 'wild ideas' that will soon be proven correct.

Sangad also claimed that the 788 ka impact in Indochina led to epeirogenesis in northern Thailand which he named the Inthanon Uplift. However, the uplifted deposits in northern Thailand (see Bunopas, 2021, this volume) are not well dated and this idea must, on present knowledge, be labelled as speculative. However, the huge Indochina impact or impacts must have caused severe ground shaking and the writer and others have observed faults in the Pleistocene sections of northeastern Thailand that may be due to this event. The tectonic effects of this cataclysmic impact event should certainly be considered.

Almost a hundred years ago the famous Australian geologist Sir Edgeworth David and colleagues noted that several tektite-like glasses plotted on a great circle band around the earth and suggested an extraterrestrial origin (David et al., 1927). On the basis of extensive geochemical studies all meteoritic workers now accept that tektites are molten target rocks due to impacts by either asteroids or comets. Ramsay Ford (1988) suggested a similar path from SE Asia to Tasmania for the Australasian tektites. A date of 816 +/- 7 ka for the impact glass known as Darwin Glass scattered around Darwin Crater in western Tasmania (Howard, 2004) almost overlaps (to within 18 ka) with the best date for Australasian tektites (788 +/- 3 ka) and, with dates for the Zhamanshin crater in Kazakhstan (about 920-650 ka) led to the great circle idea being resurrected by several authors. Influenced by the work of Professor John Wasson (UCLA), Sangad postulated a cometary impact. In 1994, Sangad was strongly impressed by the well documented impact of huge fragments of the Shoemaker-Levy comet on Jupiter. Sangad envisaged a similar mechanism for the possibly simultaneous production of the Zhamanshin, Indochina and Darwin craters, their impact glasses and strewn fields. He suggested an initial impact of a comet fragment in Kazakhstan, followed by an impact in Indochina and then at Mount Darwin, Tasmania (Bunopas, 2021, this volume). This scenario is possible and the Shoemaker-Levy comet break-up and massive impacts into Jupiter's atmosphere substantially increases the plausibility of Sangad's hypothesis. However, general acceptance of the idea is delayed because of the at least 18,000 year difference between the Darwin Crater and Australasian tektites and the, as yet, poorly dated glasses and crater at Zhamanshin.

The recent announcement of the discovery of a possible Australasian tektite source crater beneath Quaternary basalt of the Bolaven Plateau in Laos would, if correct, be the final crater to be identified and associated with a major tektite strewn field (Sieh et al., 2020). The crater is in the most likely position within the strewn field based on tektite morphology, microtektite and tektite geochemistry and sand-stone target rock age and chemistry (Ford, 1988; Howard, 2011a, b). Our work on the same outcrops as Professor Sieh and colleagues does not support their conclusions but if Sieh et al. (2019) are found to be correct then their small 15 km diameter crater would probably support the late Professor John Wasson's hypothesis of multiple small impact craters rather than one major Indochina crater (Wasson, 1991). If correct, then the Bolaven Crater impact was of sufficient size to account for the events summarised by Sangad in northeast Thailand but possibly not large enough to account for the whole Australasian strewn field.

5. MENTORING

One of Sangad's greatest contributions was to encourage and support both the study and research of Thai geologists at overseas universities and foreign geologists both senior and junior to carry on research in Thailand. He mentored, helped and encouraged DMR geologists Drs Thanis Wongwanich and Pol Chaodumrong to pursue PhD studies at the University of Tasmania in Australia and Somkiet Maranate and Worakul (Vorakul) Kaewayna to complete MSc degrees respectively on palaeomagnetism and Quaternary sedimentology at Victoria University in New Zealand.

He helped and encouraged Clive Burrett, Steve Carey, Ramsay Ford, Peter Haines, John Long, John Shergold and Kieren Howard (from Australia), John Wasson and Gudron Wasson (from USA) and Shigeki Hada (from Japan) and initially Father Henri Fontaine (from France) on a wide variety of fruitful projects all of which led to many publications in the international scientific literature.

Sangad helped graduate students from Tasmania who studied the Permian glacial deposits in Phuket (John Hills), the Lower Palaeozoic on Ko Tarutao (Tim Akerman and Roger Mason) and Kieren Howard who studied the fluvial deposits in Khorat.

6. CONCLUSIONS

Had Sangad retired without publishing his work on tectonics and impacts he would be remembered as a helpful, inspiring, pioneering, widely read, highly productive and influential geologist and as the father of Thai stratigraphy. By using his unrivalled and hard-won knowledge of Thai geology to construct, tectonic subdivisions of Thailand and an original and provocative tectonic model of South East Asia he placed Thai geology on a global stage, mentored generations of young Thai geologists and induced many foreign scientists to carry-out collaborative research in the kingdom.

Like the pioneer of continental drift theory, Alfred Wegener, Sangad extended his impact theory too far, making outrageous claims that could be easily criticized often leading to the dismissal of all of his ideas. Although some of Sangad's extreme ideas on the effects of the 788 ka impact will be consigned to the waste basket of disproved hypotheses (joining some of Wegener's) many of his ideas on the Quaternary have gained support and are being currently cited and favourably discussed (e.g. Li et al., 2021; Zak et al., 2019).

Sangad had and continues to have a huge influence on Thai geoscience and with his seminal work on tectonics and cometary collisions continues to have a big impact on international earth and planetary science.

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