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Australasian Pleistocene cometary impact and its effects in Thailand

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Abstract

Tektites are silica-rich glasses distributed in 4 strewn fields around 3 definite impact craters in the USA, Ghana and Germany and the Australasian strewn field around possibly one or more craters in Indochina. The distribution, morphology, size, mineralogy, geochemistry and contained gases of Australasian tektites confirms their terrestrial origin from a sandstone target rock of approximately Jurassic age and an impact site or sites within or offshore Indochina. The Indochina impact is dated at about 788 ka. Layered tektites are known from a more limited area and probably are proximal to the impact crater or craters. The largest layered tektites weigh up to 24 kg and come from Ubon Ratchathani Province in NE Thailand or perhaps from neighbouring Laos. Dumbbell, spherical, teardrop and disc shaped splash-form tektites are found across SE Asia and southern China. Aero-ablated tektites (australite buttons) extend to the Indian Ocean and Australia and microtektites are found in Antarctica and in deep-sea cores from the Indian Ocean and the marginal seas of the western Pacific. In many deep-sea cores, microtektites occur just below the Matuyama-Brunhes magnetic reversal dated at about 772.9 ± 5.4 ka. and occur with high pressure minerals such as coesite. Coesite and reidite along with silt-size detrital minerals within layered tektites are conclusive evidence of an impact origin. The abundance and distribution of iridum and microtektites in ocean cores has led several authors to calculations of a single crater size of between 15 km and >120 km with a most likely diameter of about 40 + km.

Both layered tektites and splash-form tektites occur at the junction of laterite and a loess-like sand or rarely within the loess, across much of SE Asia and this stratigraphic relationship is especially clear on the Khorat Plateau in NE Thailand. The widespread loess is different to typical Chinese loess, is palaeoclimatically anomalous and is considered herein as 'catastroloess' – the result of the 788 ka impact event.

Unreworked, tektites, including one very fragile hollow sphere, are also found in fluvial sands dated by thermoluminescence as 748 ka in Nakhon Ratchasima (Khorat) Province along with large, unusually very abundant charcoalified and partially charcoalified trees and smaller plant matter such as bamboo. This section of the sandpits along the palaeo-Mun River contains Pleistocene vertebrates in the upper sections and Miocene vertebrates below the tektite horizon. The tektite horizon occurs close to the Matuyama-Brunhes magnetic reversal. The sandpits are argued to contain globally unique evidence of a large extraterrestrial impact event.

Impact craters and abundant impact glasses at the Zhamanshin crater in Kazakhstan (c. 920-650 ka) and at the Darwin Crater in Tasmania, Australia (816 ± 7 ka) are argued to be contemporaneous with the Australasian strewn field and the result of a comet travelling southeastwards and disintegrating, creating catastrophic impacts first in Kazakhstan, then in Indochina and finally in Tasmania. This hypothetical trail of impacts is comparable to the disintegration and multiple impacts of the Shoemaker-Levy comet fragments into Jupiter's atmosphere in 1994.

These multiple impacts on Earth would have had profound effects on faunas, climate and sedimentation along the comet's path including on our immediate ancestor Homo erectus in

China, in Java and possibly in Lampang and Nan in Thailand. More evidence of impact in Thailand may be present near Nan and Phrae in northern Thailand and at Sra Kaeo in eastern Thailand where sao din or earth pillars are eroded 'catastroloess' and at Bo Phloi in western Thailand where sand-pits contain abundant charcoalified logs. Large trees within river terrace gravels at Khorat (with a tektite) and at Tak in NW Thailand may also be due to the impact.

Other proposed impact effects on probable Miocene fish mortality in Phetchabun, Miocene-Pleistocene mammal mortality in Australia, probably Holocene shell-beds around Bangkok and the Inthanon Uplift in northern Thailand should be considered but are more speculative.

Key words: burnt trees, cometary impact, loess, megaflood sediments, Quaternary, Shan-Thai Terrane, tektites, wildfire

Editorial Preface

The late Dr Sangad Bunopas was the first to relate the Australasian tektite strewn field, the loess covering most of NE Thailand and parts of Laos and Vietnam and the burnt logs and Pleistocene fauna in the Mun River sand deposits of Khorat to an extraterrestrial collision event at about 800 ka. With typical intellectual exuberance, he explained the demise of Miocene fish in Lomsak, Phetchabun, Miocene mammals in Khorat, shell-beds near Bangkok, Miocene and Pliocene marsupials in Australia, epeirogenic uplift in northern Thailand, glaciation in the southern hemisphere and definite glass-producing impacts in Kazakhstan and Tasmania as all caused by a cometary collision. To do this he travelled widely, communicated with experts worldwide and read voraciously in the scientific literature including, palaeontology, sedimentology, geophysics, meteoritics and astronomy. The first list has been partially validated by subsequent work; the second list has not been validated and would be regarded rightly or wrongly as unlikely or very unlikely. His main argument, though, that a major extraterrestrial impact or impacts at about 800 ka had widespread environmental effects throughout SE Asia can hardly be denied and has received considerable support. It remains to be seen whether or not his hypothesis relating the Zhamanshin impact in Kazakhstan to the Indochina impact and to the Tasmanian Darwin Crater impact is correct. A recent paper argues that both the K/T impact and the Zhamanshin Crater were caused by comet impacts thereby providing support for Dr Sangad's hypothesis ((Siraj and Loeb, 2021). His new and controversial ideas have provoked much research and brought together researchers from usually isolated scientific communities. Hopefully this partial publication of his magnum opus will encourage interest from a younger generation of scientists and provoke considerably more research on tektites, impacts and on the Quaternary sediments and biota of Thailand and beyond. The editor has removed much of Dr Sangad's speculations due to copyright issues but anyone interested in his numerous provocative ideas may obtain a 250 MB copy of his original manuscript from members of the TGJ editorial committee.

Dr Sangad's monumental work was submitted for editing in 2020 but, unfortunately, the manuscript contained too much copyright material which had to be deleted for publication. Professor Kieren Howard (New York) has kindly edited and given permission to include diagrams, photographs and substantial text from his unpublished theses on the Ban Tha Chang sandpits in Nakhon Ratchasima (Khorat) and on the Darwin Crater in Tasmania (Australia). Dr Peter Haines (Perth, Australia) has also generously provided unpublished diagrams and photographs of the Nakhon Ratchasima (Khorat) sandpits studied in Haines et al. (2004). Other deleted figures have been replaced with public domain 'creative commons' figures. The editor has corrected Dr Sangad's English expression where necessary but much of Sangad's inimitable writing style has been retained where his meaning is clear. Where the pronoun 'we' is kept it refers solely to Dr Sangad. Several editorial comments are included in italics, for clarification and in order to bring the manuscript up-to-date.

Dr Sangad introduced several new terms. These are catastroloess which includes all sediments produced as a result of the 0.788 impact event. It includes loess-like sands that cover much of NE Thailand Khorat Plateau and surrounding areas and also includes sands and gravels in the valleys that cross the plateau. He uses the term DCIM - Destructive and Constructive Impact Materials in order to emphasise the important role of the impact, not only in destruction, but also in supplying building material and fertile farmland throughout the region. Dr Sangad refers to the 0.788 impact event as the Buntharik Event named after Buntharik in Ubon Ratchathani Province following his belief that a crater of that age is present there and that most of the features of the impact features, such as large layered tektites, may also be examined there. The term Buntharik Event is retained until such time as a definite crater or craters can be identified.

For non-Thailand based readers the place Khorat is the short-form name of both a provincial capital city and the largest province in Thailand - Nakhon Ratchasima.. Khorat also gives its name to the extensive Khorat Plateau that encompasses most of NE Thailand and to the Mesozoic Khorat Group sandstones and correlates that may have been the tektite target rocks.

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1. Introduction

The main purpose of this paper is to suggest that impacts from a fragmenting comet at about 0.78 Ma caused the Australasian tektites and microtektites, the impact craters and their impact glasses from Kazakhstan to Indochina to Tasmania and Antarctica along with widespread catastroloess, fire, mega-floods and mass mortality in NE Thailand and very possibly across much of the region. A cometary impact on earth was difficult for scientists, particularly geoscientists, to believe until the 1994 Shoemaker-Levy 9 orbital break-up into 21 fragments and their subsequent impacts on Jupiter was both predicted and well documented (Figs. 1-3). In this paper it is argued that cometary impacts formed craters, tektites, impactites and catastroloess. Tektites are well known in Thailand but, on the contrary, catastroloess was known only very recently. It has long been known that yellowish, apparently wind-blown sands and silts cover much of northeast Thailand and are very similar in appearance to the yellow-earth of northern China and Europe which were deposited in arid environments close to Pleistocene ice sheets. The loess ranges from about 3 m thickness around Khon Kaen to less than 1 m in Laos and on the Khorat Plateau, in Laos and in Vietnam overlies a laterite horizon the upper surface of which contains tektites. This loess has a somewhat different grain-size distribution to that of ‘normal’ Chinese and European loess and extends across the northern half of Thailand.

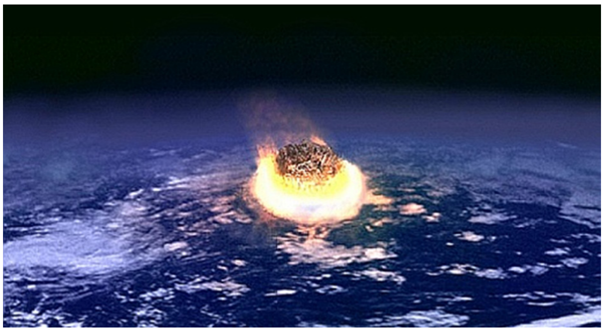


Fig. 1: Artist’s impression of asteroid hitting Earth. Author is Fredrik. Public domain NASA image. The discovery of high pressure/high temperature minerals such as coesite and reidite in Muong Nong (layered tektites) from Thailand and Laos (Cavosie et al., 2018; Glass et al., 2020) indicate Australasian impact temperatures of >1673°C and pressures >30 GPa.

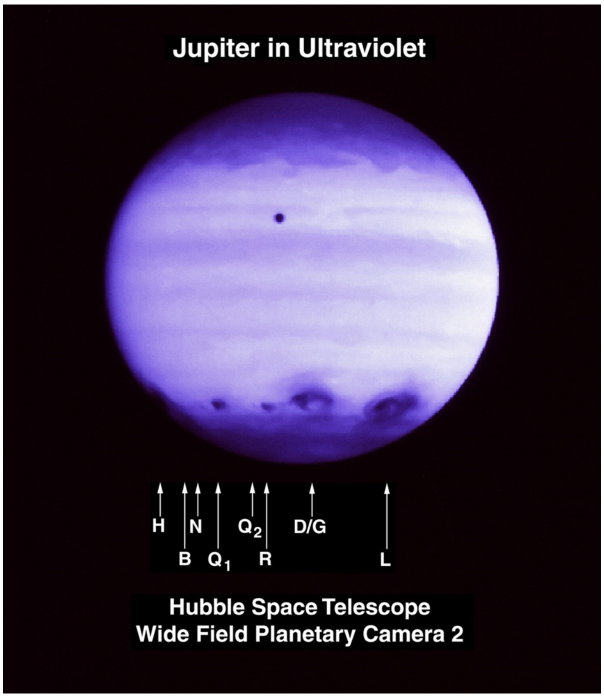


Fig. 2: Impacts of Shoemaker-Levy comet fragments (labelled) on Jupiter . The large mass of Jupiter attracts both comets and asteroids and acts as a sentinel that saves earth from many impact events. Black circle in upper part is the moon Io. From Hubble Space telescope. Open source NASA website.

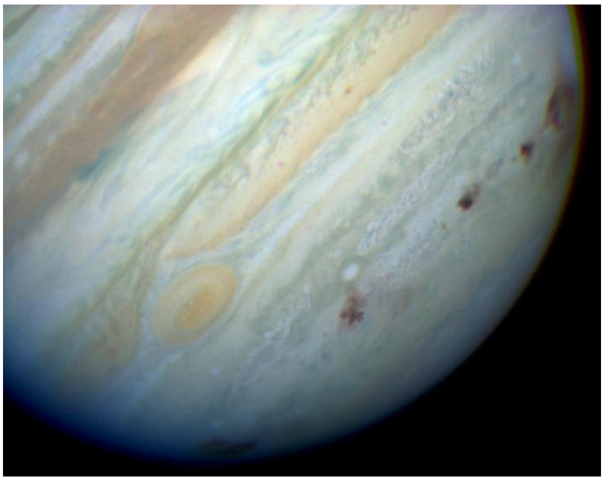


Fig. 3: Impact of fragments of comet Shoemaker-Levy on Jupiter in 1994. The oval red spot is 16,350 km wide – larger than the earth (12,742 km). Dark spots are explosions several hundred kilometres across. Image from Hubble telescope. NASA open source. http://hubblesite.org/newscenter/archive/releases/1994/1994/

In a tropical setting it is considered rather anomalous (Nichol and Nichol, 2015) and overlies fluvial sands along the palaeo-Mun River in Nakhon Ratchasima (Khorat) Province. These fluvial gravels, sands and muds are included here in the new term 'catastroloess' in order to emphasise the catastrophic origin of both sediments. [Ed: It may have been better to keep the genetic 'catastroloess' for the loess-like sediments and the term 'catastrophic fluvial sediments' for the sediments found in the palaeo-valleys, but the term 'catastroloess' is, nevertheless, retained here].

Catastroloess was known from the work of Howard, (1999) and Haines et al. (2004) at Ban Tha Chang and Chum Phuang east Khorat. Later Bunopas et al. (2007) proposed the name catastroloess and is newly studied in Thailand. It was formerly called unmelted ejecta and received little interest. Catastroloess is the most destructive to lives in either breathing and covered to death and also block sun light many years so the climate became cool. The proposed comet entered at a low angle, relatively west of North Pole in N-NW direction travelled southeast, produced craters, induced tektites, impact glasses and catastroloess and other DCIMs, (Destructive and Constructive Impact Materials) with moderate angle from Kazakhstan across Asia and ended at Mt. Darwin, Tasmania, Australia. Microtektites reached the South Pole (Fig. 4).

The comets in every period enter a little west of North Pole (in N-NW direction) leading to South Pole on either the Planet-X Theory or the Nemesis Theory on low angle route from the impact to the end (could be in the sea or on land). The Planet X (or Planet 9) theory proposes a hypothetical planet beyond the orbit of Pluto that periodically disturbs the asteroidal belts of the solar system and dislodges asteroids or comets towards the inner solar system. Similarly the Nemesis 'Theory' hypothesizes a dwarf star dislodging comets or asteroids towards the inner solar system. [Ed: There has been some support for the existence of Planet 9 recently (e.g. Batygin and Brown, 2016) but neither the Planet X or Nemesis hypotheses are needed to explain a cometary impact on Earth. Dr Sangad has emphasised the importance of Jupiter as protecting earth from cometary impacts due to its large mass and called Jupiter a castle or sentinel protecting our planet from most impacts].

Planet X follows a sharply inclined elliptical orbit that continuously shifts because of gravitational tug of the other planets. As Planet X passes through the disk, it dislodges comets and sends the comets towards earth. Australasian tektite event or Cenozoic's Australasian cometary impact was the most complete journey, when linked those tektite fields together, starting from Kazakhstan, via Indochina (and Thailand) to Australia and the Darwin crater. Comet entered N-NW the continued clockwise S-SW to impact Darwin crater.

In Australasian cometary impact most living die because of dense dusty sands, dusty ejecta or dusty catastroloess, burying or being in the contemporaneous flood, as at Khorat. Thailand.

Cometary impact induced firstly melted ejecta that were tektites, Irghizites and Darwin Glasses, with also equivalent micro-melting. The second is unmelted ejecta that was catastroloess which was different from glacial-related loess or weathering loess.

The destruction could be the following effects of the Cometary Impact:

- Temperature-cooling, leading to frigid conditions for months to years.
- Dust cloud-extensive. Covering surface with chocking loess- killing vegetation. No food sources for fauna for months to years.
- Darkness- no photosynthesis, no light for weeks-months.
- Acid rain-poisonous sulphurous fumes for weeks-months. No food sources.

- Wild fires- caused by initial thermal pulse and then by a rain of hot tektites- immediately killing flora and fauna – fires continuing for weeks to months.
- Floods- megafloods- immediate and blocking streams with detritus- killing aquatic life.
- Mass flow and landslide deposits killing trees and blocking rivers.
- Blast wave removes surface vegetation leading to mass faunal mortality.

The story of the Australasian cometary impact primarily began with the work [Ed: studies instigated, inspired and supported by Sangad Bunopas] of Howard, (1999) and later of Haines et al. (2004) on the ancient flood sands on the Mun River's bank at Ban Tha Chang east of Nakhon Ratchasima (or Khorat), Thailand, which were later included by Bunopas et al. (2007) in catastroloess. Catastroloess on land is widespread in Thailand, except in the south, under different local names, and is also newly recognized in SW China. The beginning of the Australasian cometary impact account started here. The comet trail was from the North Pole to Kazakhstan, South China, South-East Asia (Indochina Peninsula) to the Darwin Crater in Tasmania, SE Australia and then to Antarctica (Fig. 4).

The type areas where the cometary impact has been in mind since Barnes and Pitakpaivan (1962) discovered a 12.5 kg. layered tektite, in Ubon Ratchathani Province and donated it to the Department of Mineral Resources (DMR). Tektites are common shiny glasses that look very different from rare meteorites that are dull and rock-like. These must have different in origin and tektites melting condition (Bunopas, 1990, 1992) from a catastrophic event. After exploration on tektites over all upper Thailand (Ford, 1988) and for crater and layered tektites (Wasson, 1991; Wasson et al., 1995; Fiske, Putthapiban and Wasson 1996, and Xu et al., 1989) had an extensive meeting in China, we still could not find any evidence of a cometary collision, until we visited the sand quarry at Ban Tha Chang, east of Nakhon Ratchasima (Khorat) in 1997 (Bunopas, et al., 1999). Other later known localities are at Chum Phuang, Sa-Auong, Bo Phloi, and Kamphaengpet.

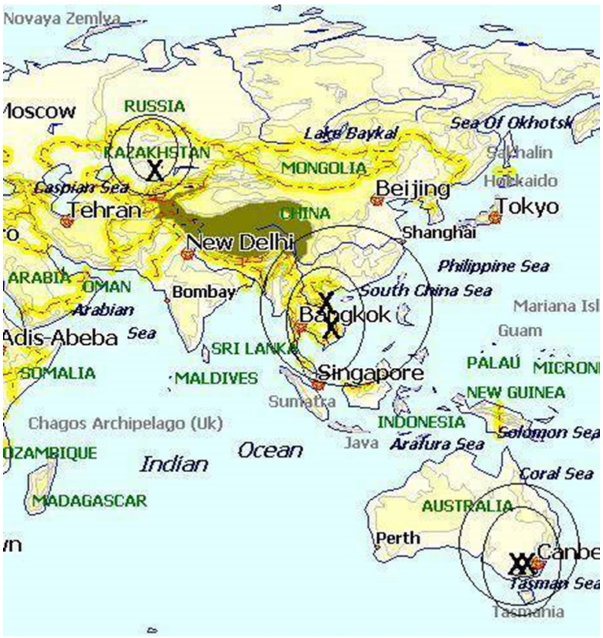


Fig. 4: Showing the positions of the Zhamanshin Crater in Kazakhstan, Indochina and Australia. *[Ed: The Darwin Crater in western Tasmania is south of the xx'x marked on the map].*

2. Tektites

2.1 Generalizations about tektites

Tektites are small (generally less than 5 cm across, Wasson, 1985), glassy objects that commonly show heat altered zones characteristic of passage through the atmosphere. They appear to be melted ejecta produced by major impacts on to silica-rich sedimentary terrains. The absence of silica-rich lunar rocks rules out a suggested lunar origin for these objects. The explosions apparently were so large that the expanding vapour cloud "blew off" the overlying atmosphere and launched tektites into arching ballistic trajectories and transported them hundreds of kilometers away from the impact site. In 3 cases and possibly 4 cases, the parent crater is known. The tektites consist almost entirely of terrestrial material, though in some case a bit of "meteoric spice" is present.

Tektites, as described by Wasson and Heins (1993) are silica-rich impact glasses (1) devoid of crystallines (2) having very low contents of relict minerals and (3) very low H_2O contents. The majority of tektites have shapes indicting melt solidification while spinning; such spin form (or splash form) tektites are commonly found at location ten or more crater radii away from suspected source crater, thus long-distance transport in required. Morphological evidence for atmospheric ablation following solidification is common only tektites found in Australia, though probable ablation features are occasionally found in tektites from Indonesia.

Tektites are found scattered over large areas of the Earth's surface in areas called strewn-fields. The tektites from a given strewn-field are believed to be the result of a single event or tektite shower; and tektites from each strewn-field are characterised by distinctive compositions and age.

Australasian microtektites also extend to Antarctica. This is the youngest of the 4 strewn fields. Part of the Ivory Coast strewn field (1.07 Ma) derived from the Bosumtwi Crater in Ghana is shown. The Central European strewn field (shown as Czechoslovakian) is composed of moldavites (dated as 15.1 Ma) derived from the Ries Crater in Germany. The North American strewn field (not shown) consists of bediasite tektites derived from the Chesapeake Bay Crater dated at 35.5 Ma.

The youngest of these fields, the Australasian strewn-field (Figs. 5,6), has an age of about 0.788 Ma. (Zahringer, 1963, Jourdan et al., 2019). Tektites belonging to the Australasian strewn-field are found in Australia, Indonesia (Borneo, Java and Belitung Island), Malaysia, Vietnam, Cambodia, Laos, Thailand, southern China and the Philippines. Microtektites belonging to the Australasian strewn field have been found in deep-sea sediments from the Indian Ocean, the western Pacific Ocean, and the Philippine Sea (Glass et al., 1979).

Older Ivory Coast tektites have a radiometric age of 1.07 Ma. Tektites from this strewn - field are rare, though Ivory Coast microtektites are sometimes found in the eastern equatorial Atlantic Ocean. Tektites found in Czechoslovakia, called moldavites, are 15.1 Ma old (Gentner et al., 1967) and constitute the Central European Strewn Field. These tektites are distinguished by their transparency and green colour.

The oldest strewn-field is the North American, which has an age of ~ 35.5 Ma (Zahringer, 1963). Tektites belonging to this strewn-field have been found in Texas (bediasites) and Georgia (georgianites). Microtektites belonging to the North American strewn-field have been found in the Gulf of Mexico, the Caribbean Sea, Barbados, and on the continental slope off New Jersey (Glass and Zwart, 1979; Sanfilippo et al., 1985; Keller et al., 1987; Thein, 1987).

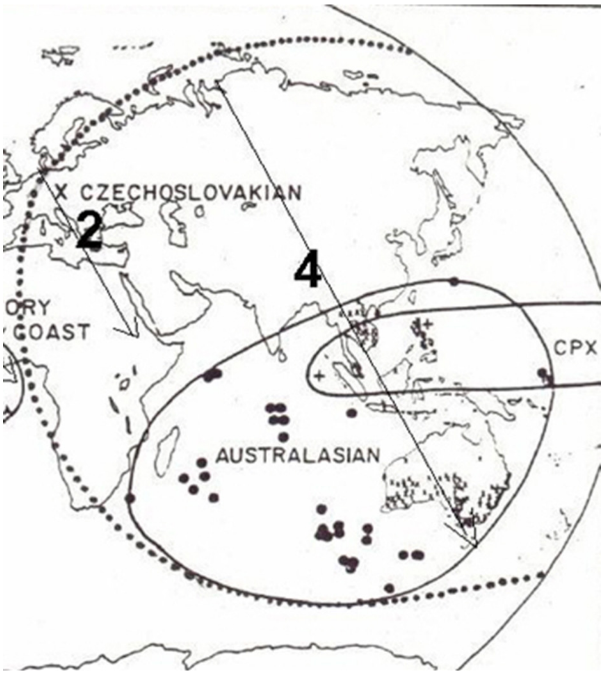


Fig. 5: Showing the distribution of the Australasian tektite strewn field dated as 788 ka.

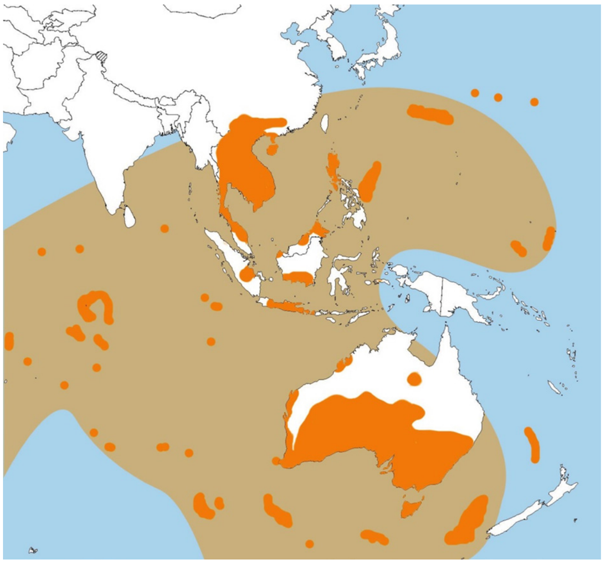


Fig. 6: Australasian tektite strewn field. This strewn-field also extends to Antarctica (Folco et al., 2008, 2009, 2010) Only one ablated tektite has been found in oceanic sediments – in the Indian Ocean. Areas with microtektites in DSDP and ODP cores are shown. By syncmedia Creative Commons licence CC0- 1.0 Wikipedia.

Some kinds of terrestrial impacts for the origin of tektites were suggested since Barnes and Pitakpaivan (1962), Ford (1988), Wasson (1991), Wasson and Heins (1993), Bunopas (1992), McHone et al. (1994), Fiske et al. (1996), Bunopas et al. (1999) in Thailand; Yuan (1981), Xu et al. (1989) in Hainan, south China; and many others' studies of Australasian tektites of the Australasian tektite strewn field, but Izokh and An (1988) stressed an extraterrestrial impact. Glass (1990), Glass and Pizzutto (1994), and Glass and Wu (1993) introduced an interesting coverage field of these Australasian tektites and made further studies from Asia, Australia and from South China Sea and Indian Ocean deep-sea cores.

Since the first scientific description of an Australasian tektite by Charles Darwin (1844) there has been considerable speculation on their origin. The argument was initially clouded by the fortuitous occurrence of moldavites in Europe and glass at Mt Darwin, Tasmania, along approximately the same great circle, leading David et al. (1927) to propose an extra-terrestrial source to account for this distribution. This led ultimately to the name 'glassy meteorites' for tektites and speculations about a lunar source. Tektites are found in southern Australia, and in the Indian Ocean (Glass, 1990; Glass and Wu, 1993), and microtektites to as far as Antarctica (Folco et al., 2006, 2008, 2009, 2010) The Australasian strewn-field, which is by far the largest identified so far, is about 0.709 Ma old (Gentner et al., 1969) to 0.770±0.020 Ma (in Wasson and Heins, 1993) and is represented by a wide variety of tektite morphologies. The geochemical data indicates that the major components are consistent from China to Antarctica and suggest a common terrestrial source. [Editor's note: Jourdan et al. (2019) have recently provided a reliable 'high precision' date of 788 ± 3 ka for Australasian tektites from Thailand.] Darwin glass from Darwin crater in Tasmania gave an Ar/Ar date of 816 ± 7 ka. A large Muong Nong Tektite (lodged at the Department of Mineral Resources, Bangkok, Thailand) has a diameter of about 0.3 m and weighs 12.5 kilograms.

Tektites are generally small, black, rounded glass objects that superficially resemble obsidian (Fig. 7B). They occur on four widely separated regions of the Earth's surface called strewn fields which range in age from 0.788 to 35 Ma from 4 strewn-fields (Glass, 1990). The presence in tektites of lechatelierite, coesite, baddeleyite and reidite proves a high pressure impact origin.

The Australasian strewn-field contains a radial sequence of tektite shapes ranging from unmodified impactite (layered or Muong Nong type, Fig 7A), through dumbbells and discs (thailandites, indochinites), and spheres (phillipinites, billitonites, and javanites) to ablated button shapes (australites) (Figs. 8-12). This sequence extends from a suspected impact area in Laos or Cambodia or offshore Vietnam following an approximate southeasterly bearing to southeastern Australia and Tasmania. Australasian microtektites are found in a huge area covering much of the Indian ocean and extends across the South China Sea to the Philippines and to Antarctica.

The Australasian strewn-field and the Kazakhstan Zhamanshin impact structure (Florensky and Dabizha, 1980) and tektites to Darwin glasses (Howard, 2004) suggest a cometary impact. In the case of the Australasian Comet, it ended up with the collision of the Earth at the Darwin Crater dated at 0.816 ± 7 Ma.

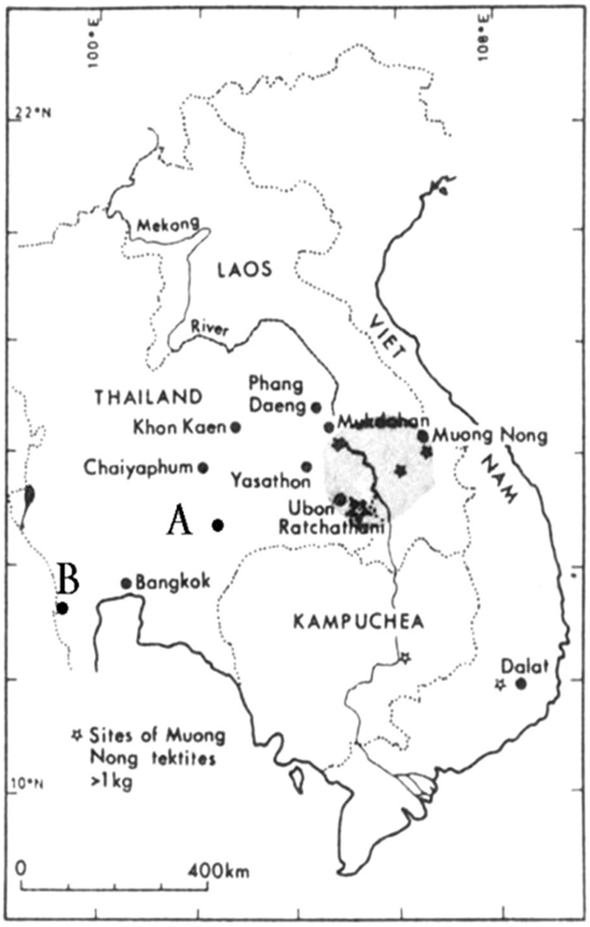


Fig. 7A: Sites of large Muong Nong or layered tektites in Indochina.

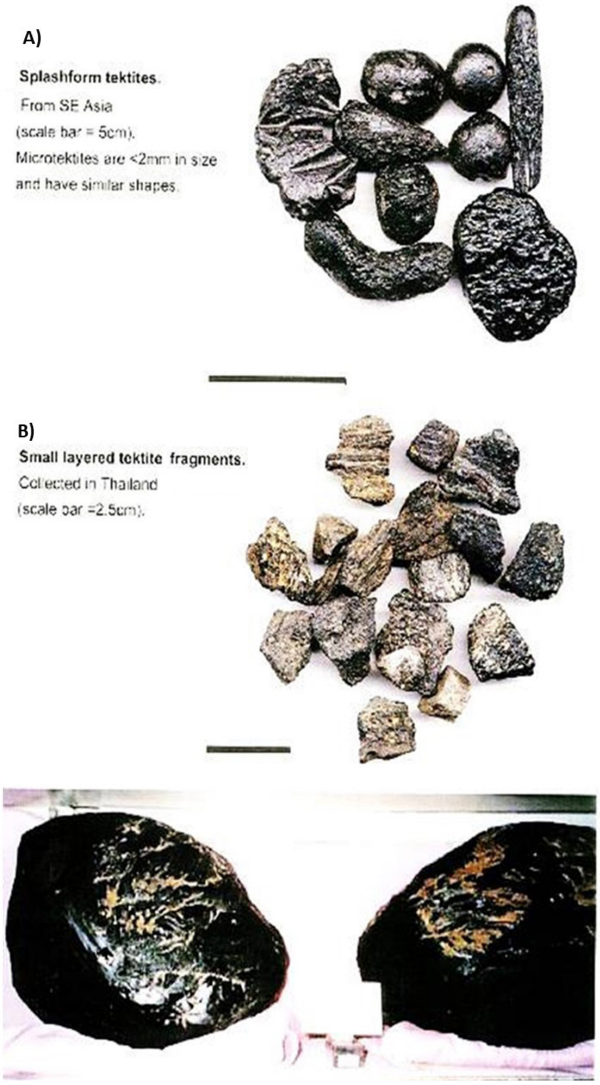


Fig. 7B: Types of tektites. A. Splash-form tektites. B. Small layered tektites. Largest layered tektites known (about 24.5 kg. each). Photographed at the House of Gems in Bangkok, Thailand by Kieren Howard. These specimens are either from Ubon Ratchathani Province or possibly from Laos.

For more than half a century, scientists were mystified by the origin of tektites - were they formed by cometary impact, or meteor or asteroid impact, through terrestrial impact or were they formed by a volcanic explosion on the moon? Recently dozens, of undoubtedly terrestrial impact origin of tektites, and many others DCIMs (Destructive and Constructive Impact Materials) were discovered in Thailand, SE Asia, China, Australia, and many others places, from Kazakhstan to Antarctica. Tektite-like, Irghizites from Kazakhstan, Australasian tektites, Darwin glass (Howard, 2004), were the products on the trail of that comet, ~0.8 Ma ago. Dating of the event is provided by radiometric ages of tektites, real-time correlation is provided by catastroloess.

Layered tektites in NE Thailand (Barnes and Pitakpaivan, 1962, Fudalli and Wasson, 1993, and Wasson et al., 1994, Fiske et al., 1995,1999), excavated layered tektites at Buntharik in Ubon Ratchathani Province. Tektite strewn fields have been associated with known impact craters, and tektites from one strewn field have been found associated with impact ejecta (here-catastroloess). Some of the tektite events may be associated with other terrestrial events, such as geomagnetic reversals, climatic changes and changes in marine biota (Glass, 1990; Wasson and Heins, 1993), or terrestrial biota (this discovery in Thailand). Tektites defined the date of the impact event and of the impact structure, of the Australasian Cometary Impact, as also other 3 strewn-field tektites.

Irghizites, Australasian tektites (Glass, 1990), and Darwin Glass are silica rich with close dates, their out looked differences could be the same from impact rocks. We link the sites of Irghizites, southern Kazakhstan Zhamanshin impact structure (Florensky and Dabizha, 1980) in Kazakhstan; Indochina tektite field in tektites (Ford, 1988; Glass, 1990; Wasson, 1991, Wasson and Heins, 1993), and the Australasian impact field; to Mt. Darwin glass, now first thoroughly investigated (Howard, 2004).

Microtektites belonging to the Australasian strewn field have been found in deep-sea sediments from the Indian Ocean, the western Pacific Ocean, and the Philippine Sea (Glass et al., 1979). There is now also tentative evidence of Australasian microtektites being found in Chinese Cenozoic loess (Heins et al., 1991; Li et al., 1991). Australasian microtektites have a stratigraphic and formation age of 0.7 Ma (Gentner et al., 1970). Age dating of the Australian tektites by ^{40}Ar/^{39}Ar laser fusion gives a date of 0.770 ± 0.020 Ma. (Izett and Obradovich, 1992). There is no evidence of a 0.8-0.9 Ma age for a micro-australite layer in deep-sea cores (Glass, 1976).

Based on the number (mass) of microtektites per unit area at each site, Glass et al. (1979) calculated that there are approximately 100 million, 20 million and 1,000 million tons in the Australasian, Ivory Coast and North American strewn-fields, respectively.

Other glasses that have been associated with tektites include Darwin Glass, irghizites and Libyan Desert Glass. Darwin Glass in Tasmania is found in a small, radially arranged strewn-field centred on a small crater – Darwin Crater (Fudali and Ford, 1979). Darwin glasses were investigated and studied by Howard (2004), and may have been formed by the Australasian cometary coma that collided on Lower Paleozoic quartzite and limestone in Tasmania. Irghizites are found in the Zhamanshin impact structure in Kazakhstan. They have compositions and ages similar to the Australasian tektites, but many have a composite form consisting of numerous droplets welded together. Libya Desert Glass refers to silica-rich glass bodies found in the Egyptian desert (Week et al., 1984). They have been likened to tektites, but they do not have typical splash shapes and they are composed primarily of silica (>97 %). These glasses have an age of 28 Ma (Storzer and Wagner,1971). Microtektite-like bodies, some with glass preserved in their interiors, have been found in sediments associated with the K-T boundary and some other impact events (e.g., Izett et al. 1991; Sigurdsson et al., 1991).

Tektites could be easily reworked to a higher level at present surface. This is true from the pits at Khorat sandpits where tektites can be found at any level up to the present surface. With regarding the time of the event, we must count the lowest stratigraphic position of tektite.

For many years the occurrence of tektites dating to about 800-700 ka within much older sedimentary rocks in Australia or apparently unabraded within much younger sedimentary rocks as in Vietnam was known as the tektite age-paradox. The Australian age-paradox was dismissed by the NASA geologist, crater-study pioneer and astronomer co-discoverer of the Shoemaker-Levy Comet using an old fashioned, but effective, plane-table method of surveying critical outcrops (Shoemaker and Uhlherr, 1999). Tektites are easily reworked and great care should be taken in assessing tektites and their abraded surfaces for possible reworking. Downslope reworking and redeposition is more likely in hilly or mountainous terrains and less likely on plateaux such as the Khorat Plateau of northeast Thailand.

Tektites show a number of common features in that they are: (1) devoid of crystallites, (2) have very low content of relict minerals, and (3) very low H_2O content (Wasson and Heins, 1993). Mineral inclusions range from 20-150 micron and include zircon, chromite, rutile, quartz and corundum (Glass and Barlow, 1979). Inclusions in Muong Nong-type tektites (indochinites) always show evidence of various degrees of shock metamorphism (e.g. fracturing, droplet formation, x-ray asterism). It appears that indochinites were formed by shock melting of a well sorted, silt-size, sedimentary material (Glass and Barlow, 1979). Trapped gases are similar in composition to the atmosphere or a little lighter (Hennecke et al., 1975).

The best known tektite field, the Australasian strewn-field consists of two kinds of tektites in Thailand:

Layered tektites (Barnes, 1971; Barnes and Pitakpaivan, 1962 and Wasson, 1991), alternatively known as stratified or Muong Nong tektites (Bunopas et al., 1997) have distinctive banding and relicts of incomplete melted parent materials. These tektites were solidified on the ground shortly after impact and were distributed close to the source crater(s). Layered tektites in or near the Hainan-Indochina-Thailand impact center(s) can be up to 12.8 kg (Barnes, 1971) or even 24 kg (Wasson, 1991). In China, Yuan et al. (1981); and Futrell and Wasson (1993) reported the occurrence of a layered tektite weighing 10.8 kg from Wenchang, Hainan Island, south China.

Splash-form tektites (Wasson, 1971) or formed tektites (Bunopas et al., 1997) are found in various forms and shapes, distributed further away from craters. Many splashed tektites have shapes that indicate melt solidification while spinning. Such spinning form (or splashed form) tektites are commonly found at locations ten or more crater radii away from suspected source craters; thereby requiring long distance transport. Aero-ablated forms, common in Australia, were ejected into space and fell down at sites more than 3,000 km from the source, reaching points as distant as Tasmania. Atmospheric ablation following solidification is common only for tektites found in Australia, though probable ablation features are occasionally found in Indonesian tektites. Splashed tektites are usually small, with weights of less than 0.3-0.5 kg.

Both varieties of tektites consist of >70% SiO_2, 12% Al_2O_3, 5% Fe_2O_3+FeO, with the remainder constituted by TiO_2, MnO, CaO, Na_2O and K_2O (Glass, 1990; Glass and Koeberl, 1989; Wasson, 1991). A model for the Australasian tektite field must incorporate explanations for Muong Nong types, discs, dumbbells, spheres, tear-drops and australite buttons. An empirical model for the Australasian tektite field of Ramsay J. Ford (1988) explains this distribution.

The Australasian strewn-field contains a radial sequence of tektite shapes ranging from unmodified impactite (layered or Muong Nong type), through dumbbells and discs (thailandites, indochinites), and spheres (phillipinites, billitonites, and javanites) to ablated button shapes (australites) (Figs. 8-12). This sequence extends from a suspected impact area in Indochina following an approximate southeasterly bearing to southeastern Australia and Tasmania.

“Field work in northeastern Thailand has confirmed that the tektites lie on the surface of a laterite layer below the normal soil profile (Barnes and Pitakpaivan 1962; Fontaine & Workman, 1978; E. Gangadaram pers. comm. 1986). Muong Nong tektites were collected from northeast Thailand near the centres of Ubon Ratchathani and Yasothon. Smaller fragments were found near Chaiyaphum to the west indicating a distribution of fragments of decreasing size in that direction. Muong Nong tektites collected from Hainan Island are also generally small (a few centimetres in diameter). When compared with the large Muong Nong types from the type locality and elsewhere in Laos (Lacroix, 1935), near Dalat in Vietnam (Fontaine, 1966), and near Mukdahan in Thailand (K. Pitakpaivan pers. comm. 1986), there is an apparent radial variation of fragment size of Muong Nong tektites about an area in northeast Cambodia near the Laotian border”.

“In summary, tektites from the mainland of South-East Asia have shapes derived from uncongealed spinning glassy fragments passing through the atmosphere. An event, comparable with that responsible for the South-East Asian strewn-field, must have a characteristic set of fragment trajectories. In the first 400 km from impact there are large Muong Nong tektites; between 400 and 1000 km there are disc and dumbbell shapes (e.g. thailandites, indochinites); between 1000 and 3000 km, spherical and tear-drop shaped phillipinites, billitonites and javanites occur; and at distances greater than 3000 km ablated tektites (australites) would be most abundant. The button form of australites (Fig.8) is unique to the Australian strewn-field and is produced by travelling more than 3000 km from the source”. Ford (1988)

2.2 Impact Model for Tektite Origin

The presence in tektites of lechatelierite, coesite, baddeleyite, and shocked relict crystal fragments suggests formation in an impact event. A multiple impact origin for Australasian tektites was documented by intensive laboratory work and field observation by Wasson (1991). High-precision neutron-activation studies of Southeast Asian tektites confirm their close compositional relationship to well-mixed continental sediment. In confirmation of early studies, concentrations of the volatile metals Zn, Ga, As and Sb are 2-4 times lower in splashed-form tektites than in layered (or Muong Nong-type) tektites. The Th:U ratio is higher in splash-form than in layered tektites; which implies a loss of about 30 % of initial U from splashed-form tektites. Volatile contents of layered tektites are

Fig. 8: Aero-ablated australite button from Australia. Note typical ablated flange. These buttons usually range from 1 to 2 cm in diameter. From Wikipedia article on tektites. H.Raab (user: Vesta) Creative Commons licence : CC BY. SA.3.0

Fig. 9: Dumbbell (c.10 cm long) and teardrop splash-form tektites from Thailand. Photograph by Broken Inaglory, under Creative Commons licence CC BY-SA 3-0. Wikipedia article on tektites.

similar to those in continental sediments indicating minor or negligible loss during formation. A remarkably consistent relationship between Cr and Co and an associated Ni-Co correlation indicates the variable presence of a minor ultramafic component with an atypically low Cr/Co ratio.

“The chief compositional difference between SE Asian layered and splash tektites is that the former have higher contents of volatile elements (Taylor and McLennan, 1979; Shaw and Wasserburg, 1982) and, possibly, higher Fe^{3+}/Fe^{2+} ratios (Fudali et al., 1987). The two classes are remarkably similar in their contents of non-volatile incompatible elements, chondrite-normalized rare-earth elements (REE) patterns for layered tektites from Laos, Thailand and Vietnam as well as for splash tektites from Australia reveal patterns that are essentially identical for layered and splash tektites”.

“The coherence of the trace-element patterns is further demonstrated by comparing key ratios between incompatible elements: Cl-normalized La/Lu. Eu/Sm, Zr/Hf. and Th/Sc ratios are plotted against Th/U in Wasson (1991). To help resolve the points, splash tektites are shown with dot symbols, layered tektites with open symbols. The difference in Th/U between layered and splash tektites was unexpected; average ratios in the splash tektites are 30% higher. This observation almost certainly indicates that a significant fraction of U was lost as a volatile from the smaller splash tektites. The Eu/Sm, Zr/Hf and Th/Sc ratios are the same in layered and splash tektites: the mean La/Lu ratio in splash tektites is about 2-3% higher than that in the layered tektites, but this difference may not be significant.” Wasson 1991.

Wasson and Heins (1993) found that tektites are derived from the impact melting of continental sediments, and based this proposal on close similarities of elemental abundance patterns (Taylor and McLennan, 1979; Koeberl, 1986; 1992; Wasson, 1991) as well as similarities in isotopic ratio (Shaw and Wasserburg, 1982; Blum et al., 1992).

Fiske et al. (1996) analysed shape, composition and spatial distribution for 6 kg of layered tektite fragments excavated from a 9 m^2 area near Ban Huai Sai, north of Amphoe Buntharik in northeast Thailand Their analysis suggests that the fragments represent a single homogeneous mass that underwent ancient fragmentation and has experienced little disturbance since its deposition. They have also studied the stratigraphic occurrence of layered tektites exposed in-situ near Ban Huai Om. Tektites were found along a disconformable paleo-erosion surface, covered by recent aeolian sand (partly reworked catastroloess) and in a manner similar to their occurrence elsewhere in Southeast Asia. This stratigraphic relationship provides little chronostratigraphic information and does not constitute a stratigraphic ‘age paradox’ for Australasian tektites. The present-day surface density of layered tektites in this area is 2 to 20 g/m^2.

Iridium anomaly associated with the Australasian tektite-producing impact from masses regarded as the impactor of the Australasian tektites was restricted due to at least three orders of magnitude smaller than that impactor at the end of Cretaceous (Schmidt et al., 1993).

Basement rocks in Thailand prior to melting had originally been continental sandstones from the Jurassic-Cretaceous continental red-beds (Khorat Group). Thin decomposed sandy soil has also been identified in the region, a finding confirmed by our latest field investigation (Bunopas et al., 1997). Blum et al. (1992) found that Nd and Sr isotope data provide evidence that all Australasian tektites were derived from single sedimentary formation with an age close to 170 Ma. Moreover Blum et al. (1992) propose that such tektites are explained by a single impact event. Tektites are constituted by molten terrestrial material and in the impact process they undergo no geochemical change. The absence of geochemical disparity between tektites and their terrestrial source has been attested to by chemical analyses, rare earth studies, mineral fluid inclusions and trace elements (McLennan, 1989, Schwarcz, 1962; Glass, 1970, 1972; Glass and Barlow, 1979; Glass and Koeberl, 1989; Koeberl, 1986; Muller and Genter, 1973; Taylor, 1962; Taylor and McLennan, 1979; Shaw and Wasserberg, 1982; Wasson,1991; Blum et al., 1992). A possible offshore impact site has been suggested (Schnetzler et al. 1988) with Hartung, (1990) nominating Tonle Sap for site candidacy. More recently a site within the Bolaven Plateau of Laos has been suggested (Sieh et al., 2020).

2.3 Contending Views of Tektites

Although most investigators believe that tektites are impact-produced glasses, their origin was controversial (e.g., Taylor, 1973; O'Keefe, 1976; Wasson, 1991). During the 1970's and 80's, the idea of extraterrestrial origin for the Australasian tektite strewn field was popular (Izokh and Le Dyk An, 1988). It was indicated by the dimensions of the belt itself, the lack of impact craters, an absence of known impactites, and little indication of concentric zonation relative to possible terrestrial source (O'Keefe, 1976). However, the overall chemistry of tektites is terrestrial, bubbles in tektites contain atmospheric gases and layered tektites contain silt-size clasts derived from a sedimentary source.

The number of associated impact craters is a hotly debated topic. Two models for the origin of Australasian tektites compete in recent research.

Ford (1988) used satellite imagery to define an elliptical depression 10km x 6km in Phnum Voeene, northeast Cambodia, a formation claimed to be caused by the impact of an extraterrestrial object. This single-crater hypothesis has been endorsed by Blum et al. (1992), Koeberl (1992) and Schnetzler (1992). Based on the study of trace elements in Muong Nong-type tektites from Indochina, Koeberl (1989) interpreted a single, slightly heterogeneous source, rather than different source regions.

However, Wasson (1991) argued that large layered tektites (with thickness of 2-3 cm and masses up to 24 kg), found throughout northeast Thailand and other Indochinese regions, implied a multicrater centre with minimum dimensions of 800 x 1124 km, extending from Hainan Island Vietnam (Izokh an An, 1988) and Cambodia. This represents a major centre containing numerous impact craters with a collective size thousands of times larger than that estimated by Ford (1988). Wasson did not overlook the possibility of a fragmented extraterrestrial object or a large comet as being responsible for forming such an extra-large cratering centre. The largest impacts ejected the microtektites (Yuan, 1981; Futrell and Wasson, 1993) to southern regions and some splashed form tektites above the atmosphere, while numerous smaller impacts produced a nearly continuous sheet of impact melt across much of Southeast Asia (Wasson, 1991; Wasson and Heins, 1993; Wasson et al., 1995).

There is compelling evidence indicating that layered tektites formed as sheets or pools of melt. From a lens-shaped mass of tektites excavated near Phang Daeng, it was concluded that layered tektites represented 'puddles' of melted soil resultant from the impact of a large 'diffused body' and the consequent fireball (Barnes, 1989). Because there are difficulties with the impact transport of melt at distances >600 km, tektite distribution across a field >1140 km in length is inconsistent with their formation in a single crater. Layered tektites should therefore be deposited within a few crater radii of their parent crater, and many craters are required to account for their distribution across a field >1140 km long.

2.4 Investigation of Tektites in Thailand and Southeast Asia

It is 60 years since investigation of tektites began in Thailand (Barnes, 1963, 1964; Barnes and Pitakpaivan, 1962) that included the discovery of the largest known documented tektite (Barnes, 1971). Early research on tektites in Thailand progressed slowly.

Preliminary collection of tektites was undertaken by the Geological Survey Division, Department of Mineral Resources (1960) and Barnes and Pitakpaivan (1962). More recent collections, investigative of the nature and distribution of tektites, were assembled by Ford (1988) and Bunopas (1990, 1992). Tektites in Ford's study (1988) were found in both the upper lateritic horizon as well as at the modern lateritic surface in situations where it had not been disturbed by agriculture. Ford (1988) developed an earlier hypothesis of Adam and Huffaker (1964) and proposed that tektites originated in an impact site in Cambodia, with dispersal occurring as far as Tasmania. Contributions by Wasson et al. (Wasson, 1987, 1989, 1991; Wasson and Heins, 1993; McHone et al., 1994; Fiske et al., 1996; Bunopas, Kositanont and Wasson, 1997; Bunopas et al., 1998) have also excited interest in the scientific community.

Apart from Laos (Lacroix, 1935), there has been some development of this research in other Indochinese countries. In Vietnam, Fontaine (1966) made note of medium Muong

Fig. 10: Department of Mineral Resources 12.8 kg - largest described layered tektite from Ubon Ratchathani Province, Thailand. It was contributed by Mr. Kaset Pitakpaivan. From Buriram to Ubon Ratchatani and approximately from Mukdahan to Nakhon Phanom all tektites are essentially layered tektites (Muong Nong) tektites, fragmented to small size. We can differentiate fragmented layered tektite, usually with experience, from splashed tektite by air bubbles and skin of the latter.

Nong tektites near Ho Chi Minh City, though there was little analysis of the discovery. In a more recent comprehensive study of Vietnamese tektites, Izokh and Le Dyk An (1983, 1988) explored 39 localities throughout Vietnam and subdivided the area into various sub-parallel belts. Tektites were found at variable levels of Quaternary deposits consisting of loess, conglomeratic sands, and laterites; though in a few instances tektites occurred at the bottom of the basement covered by loess and burnt wood/charcoal. They proposed that their tektites represented a sample from an Australo-Asiatic zone extending as a narrow 11,000 km belt from Vietnam to Tasmania. The Australo-Asiatic Belt was characterised as showing zonation in tektite size, morphology, as well as in certain aspects of fine internal structure. Izokh and Le Dyk An (1983, 1988) concluded that the belt was the result of a single tektite shower of extraterrestrial origin. Such a view is however inconsistent with views of others (e.g. Fiske et al., 1996) in which the terrestrial impact of a meteor or comet was believed responsible. Other significant papers on Cambodian tektites include Hildebrand et al. (1994); Hartung et al. (1994); Hartung (1990); Hartung and Rivolo (1979); and Ford (1988). This paper also deals primarily with the latest investigation of tektites and associated phenomena in the Khorat Plateau and elsewhere in Thailand. Research was conducted with the participation of the University of Tasmania's Geology Department in 1984 – 2004 (Ford, 1988; Howard, 1999, 2011; Howard et al., 2003; Haines et al., 2004) and with UCLA (University of California, Los Angeles) in 1989, 1990 and 1994 (Wasson, 1987, 1989, 1991; Wasson and Heins, 1993; Fiske et al., 1996).

2.5 Layered tektites had a limited concentration in NE Thailand and in Laos, Hainan Island, south China and Vietnam - Layered Tektites formed in pools of melt

Layered tektites (Figs. 11-12) have outstanding fine to very fine layering characteristics, some wavy or contorted since they solidified in situ, or were considered so, or remained nearby, or at a short distant away. The sizes range from a half kg to as heavy as 24 kg from Buntharik in Ubon Ratchathani (Fiske et al., 1996; Bunopas et al., 1999a). Ubon Ratchathani is at a similar latitude between 15°N-16°N comparing with Muong Nong in Laos and Danang in Vietnam, all are rich in layered tektites. The largest layered tektite of more than 24 kg was assumed to come from either Ubon Ratchathani Province, NE Thailand or from Laos (Fig. 11).

“Layered tektites first described by Lacroix (1935) as ‘’tectites sang formes figurées” i.e. as unshaped tektites. The first of these were found near the village of Muong Nong in the Laotian highlands, and Barnes (1963) used the designations “layered tektites’’ and ‘’Muong-Nong -type tektite” synonymously. The descriptor “layered” derives from the presence of subparallel layers defined by colour and/or bubble contents (Barnes and Pitakpaivan, 1962). Layered and splash-form tektites have very similar chemical compositions. The traditional view is that each of the tektite fields was formed as ejecta from a single crater. In fact, it appears impossible that ejecta from a single crater could form most pools stretching across an area with linear dimensions of 1200 km from Kampong Speu, Cambodia (Barnes and Pitakpaivan, 1962) to Hainan, China. There are several major problems associated with the deposition of melt at great distances: (1) the melt would be dispersed into small masses by atmospheric shear, and these would be unable to penetrate large distances through the atmosphere; (2) during the long flight time globules of melt would lose much of their heat and solidify; (3) if (by some miracle) the atmosphere were temporarily removed’ from the entire 1200-km region such that large,

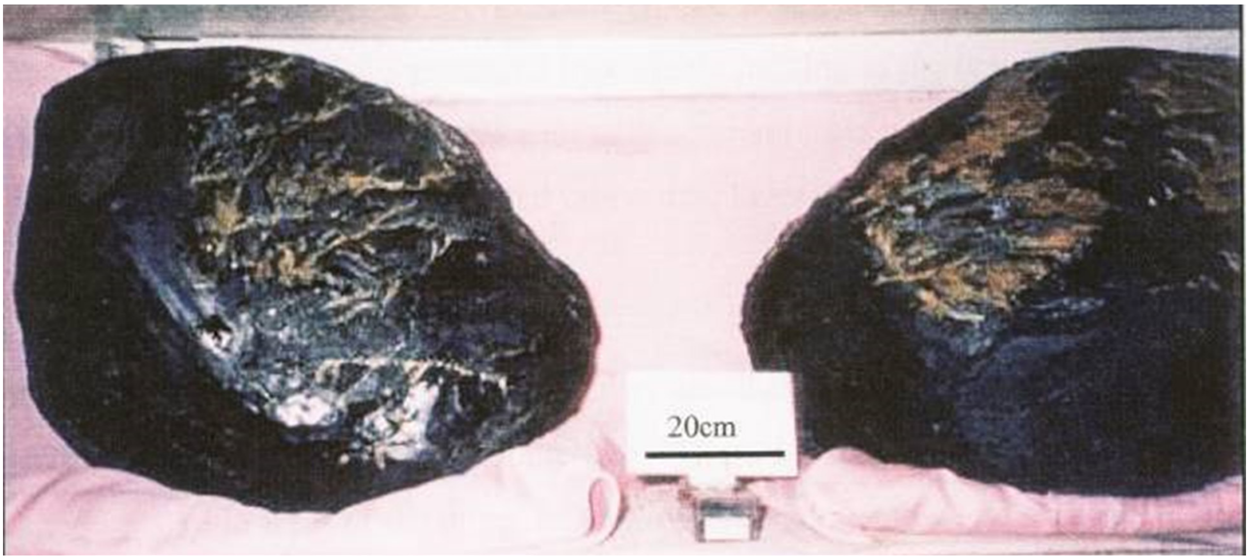


Fig. 11: Two c. 24 kg layered tektites at House of Gems in Bangkok courtesy of Boonmun Poonyathiro (photo by Howard, 1999). They are either from Ubon Ratchathani Province or from Laos.

m-size globules could complete their trajectory intact, their impact velocities would be so great that they would make hypervelocity craters and be dispersively mixed with unmelted ejecta".

"Our study of the stratigraphic occurrence of layered tektites exposed in situ near the Huai Om reservoir shows that tektites are found along a disconformable paleo-erosion surface covered by recent aeolian sand, similar to other occurrences throughout Southeast Asia. Based on our study at Huai Om the present-day surface density of layered tektites < 10 g in this area is 2 g/m^2 to 20 g/m^2 Our study of the stratigraphic occurrence of layered tektites exposed in situ near the Huai Om reservoir shows that tektites are found along a disconformable paleo-erosion surface covered by recent aeolian sand, similar to other occurrences throughout South¬east Asia. Based on our study at Huai Om the present-day surface density of layered tektites < 10 g in this area is 2 g/m^2 to 20 g/m^2."

"Layered tektites formed as pools of SiO_2-rich melt on the Earth's surface. In Southeast Asia layered tektites having thicknesses of 3-20 cm are found throughout a region 800 x 1200 km in extent. Pools of impact melt cannot be deposited at great distances (>l00 km) from a crater, instead, they are probably confined to the area (extending 2-3 crater radii) covered by continuous ejecta. The layered tektites of Southeast Asia probably formed in a myriad of small craters produced by fragments from a comet that disintegrated several months before accretion" (Wasson, 1991).

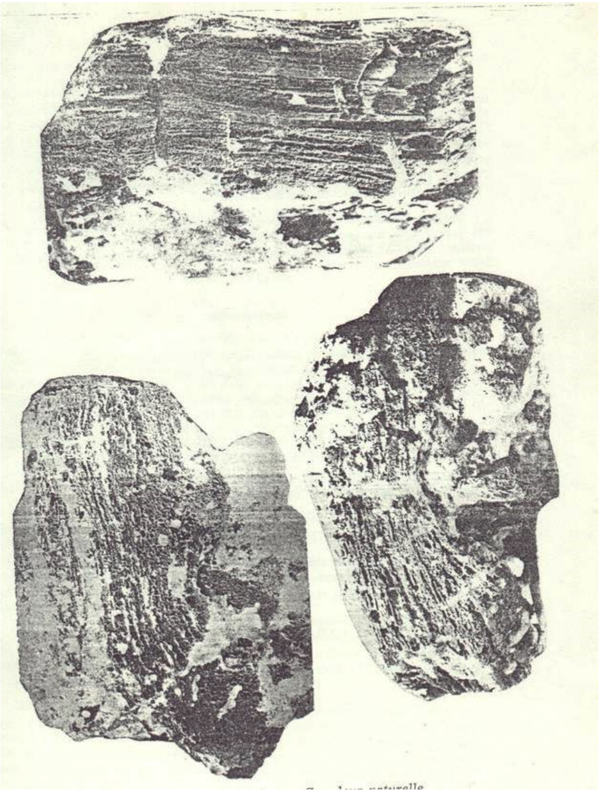


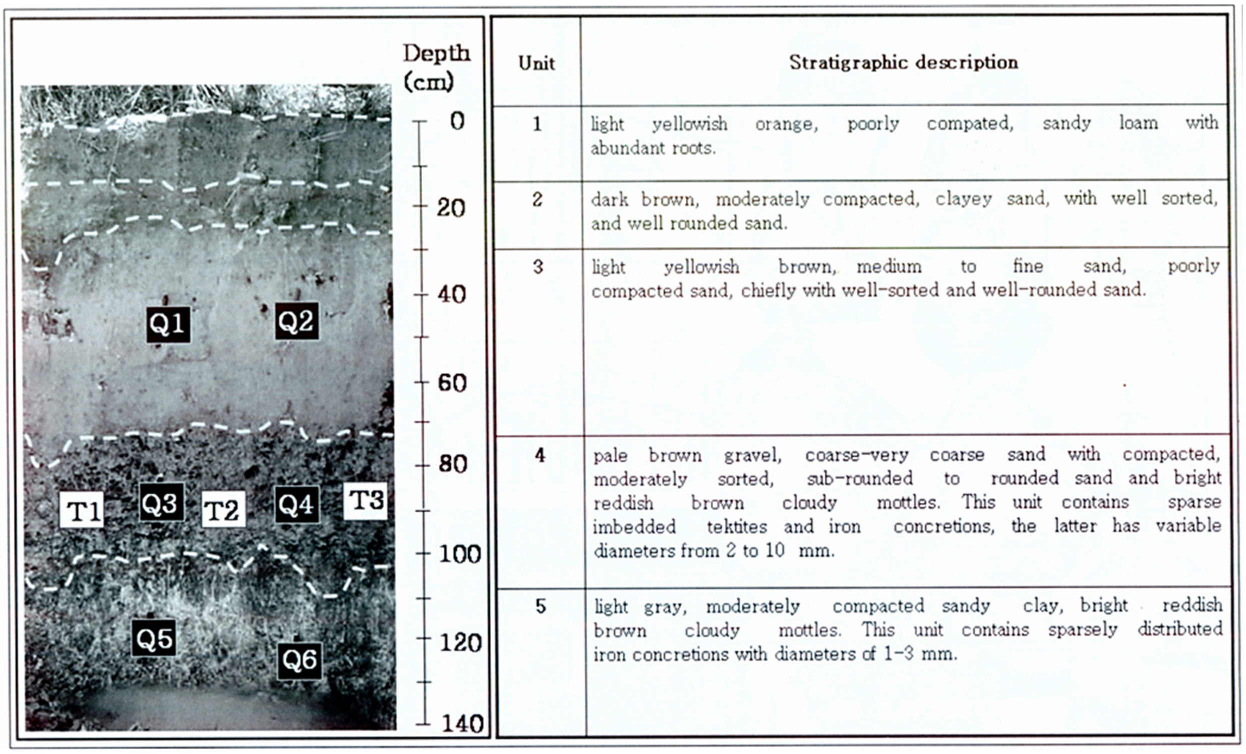
Fig. 12: Layered Tektite from Danang 0.5 kg from H. Fontaine, 1966.

"Glass (1970) described silt-size and size sorted zircon and chromite crystals, in addition to quartz and possibly coesite, in a Muong Nong-type indochinite. Glass (1970; 1972) believed that most of the mineral grains were relict detrital grains and that the mineral assemblage suggested a sedimentary parent material. Glass also pointed out that the mineral grains all showed evidence of shock damage consistent with the presence of coesite as reported by Walter (1965)" [Ed: and Glass et al. (2020)].

"The presence of lechatelierite indicates a high temperature of formation for tektites (> 1700 °C) and the presence of cristobalite associated with quartz, could be due to conversion of coesite and/or stishovite due to high residual temperatures". Data support a high temperature of formation for the Muong Nong-type Australasian tektites and that the minimum temperature must have been in excess of about 1,850° C."

Punpate et al. (2005) collected five samples of bedded or layered tektite and tektite-bearing sediments from an excavated trench and were selected for thermoluminescence dating from the Buntharik area, Ubon Ratchathani in the easternmost part of the Khorat Plateau, northeast Thailand. "Five sedimentary units of semi- to un-consolidated alluvial deposits were described stratigraphically in a descending order (Fig. 13). Unit 1 (av. 0.14-m thick) is characterized by light yellowish orange, poorly compacted, sandy loam (catastroloess) with abundant roots. Unit 2 (av. 0.1-m thick) is dark brown, moderately compacted, clayey sand, with well-sorted, and well-rounded sand. Unit 3 (~av. 0.38-m thick) comprises mainly light yellowish brown, poorly- compacted, medium to fine sand, chiefly with well-sorted and well-rounded sand. Unit 4 (av. 0.3-m thick) is composed mainly of pale brown, clayey to sandy compacted gravel with moderately sorted, sub-rounded to rounded coarse-very coarse sand and bright reddish brown cloudy mottles. This unit contains sparse embedded tektites and iron concretions, the latter has variable diameters ranging from 2 to 10 mm. Unit 5 (av. 0.5-m thick) is defined by light gray, moderately compacted sandy clay, bright reddish brown cloudy mottles. This unit contains sparsely distributed iron concretions with diameters of 1-3 mm. All the tektites were observed only in Unit 4 and are regarded as "layered "tektite. The tektites ranging in size from 1 cm up to 5 cm (Fig. 14) were discovered in a pebble bed at about 0.7 meter from a topsoil surface".

"Average Tl. age obtained from unit 3 is about 27.5 ka, that of Unit 4 is about 143 ka, and that of Unit 5 is about 370 ka. The average TL age of the layered tektites from Unit 4 is about 850 ka. The discrepancy in TL ages of tektites and tektite-bearing sediments are ascribed to the reworking of layered tektites from high



Unit	Stratigraphic description
1	light yellowish orange, poorly compated, sandy loam with abundant roots.
2	dark brown, moderately compacted, clayey sand, with well sorted, and well rounded sand.
3	light yellowish brown, medium to fine sand, poorly compacted sand, chiefly with well-sorted and well-rounded sand.
4	pale brown gravel, coarse-very coarse sand with compacted, moderately sorted, sub-rounded to rounded sand and bright reddish brown cloudy mottles. This unit contains sparse imbedded tektites and iron concretions, the latter has variable diameters from 2 to 10 mm.
5	light gray, moderately compacted sandy clay, bright reddish brown cloudy mottles. This unit contains sparsely distributed iron concretions with diameters of 1-3 mm.

Fig. 13: Detailed stratigraphy of the semi to unconsolidated alluvial deposits in Buntharik area, T1, T2, and T3 are sampling points of tektite, and Q1 to Q6 are tektite bearing sediments for thermoluminescence dating (From Punpate et al., 2005)

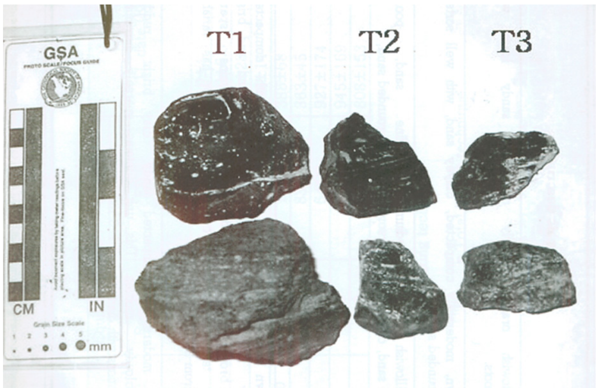


Fig. 14: Various bedded tektite varying from 1 to 5 cm from Unit 4. (From Punpate et al., 2005).

elevation to the low land and low alluvial plain. Additionally the TL ages of tektites from this study conform quite well with earlier TL ages of splashed tektites at the Ban Tha Chang sandpit in Nakhon Ratchasima, located 400 km in the western most part of the Khorat Plateau, suggesting a widespread occurrence of approximate 0.8 Ma catastrophic event (Charusiri et al, 2002). We consider that such the event may have taken place in response to the meteorite impact in Buntharik area over the clastic beds of the Khorat Group as earlier described by Bunopas et al. (2002)." Punpate et al. (2005).

"There seems to be only one plausible explanation of the layering of Muong Nong tektites, viz., that it was formed by small amounts of differential (probably down-slope) flow in a pool or sheet of melt (Barnes and Pitakpaivan, 1962). Key supporting evidence is provided by the magnetic remanence studies of De Gasparis et al. (1975). The inclinations of the measured paleofields are inclined by about 20° relative to the layering, roughly the same as the present -day inclination of the field in Southeast Asia: since the inclination was probably similar 780 ka ago, this observation strongly supports the interpretation that the layering was produced by processes occurring after the melt was deposited on the Earth's surface. It seems irrefutable that the layered tektites formed as pools or sheets of melt." Wasson (1991).

"Although the layered tektites seem to require formation as melt ejected at low velocity from a multitude of local craters, the microtektites and the ablated Australian tektites were almost certainly launched into trajectories that took them above the atmosphere. The evidence in support of this conclusion is the ablation features found on many australites and the great distance that microtektites have traveled; according to Glass (1982) the microtektite field extends from Madagascar to Taiwan, a distance > 6000 km. Because a 100-gm. microtektite will fall out of the stratosphere in days but large-scale lateral stratospheric transport requires months or years (except eastward in the jet stream), the observed wide distribution can only be achieved by ballistic transport above the atmosphere." Wasson (1991).

2.6 Multiple small (0.2-2 km) crater model of Wasson

"An important and possibly telling observation is that investigations of the tektite -bearing laterite layer in numerous locations in Ubon Ratchathani yielded many fragments of layered but no splash tektites, in contrast, most tektites found near Khon Kaen, 250 km to the northwest, are splash form. This observation is consistent with formation of craters near the Ubon Ratchathani area, and deposition of melt sheets over this region. Splash tektites are not expected under such conditions because the shapes of splash tektites that fell into the melt would have been degraded. Discovery of additional regions covered by melt >100 km from Ubon Ratchathani would confirm the necessity of multiple craters."

"If this constraint on the distance that melt can be transported and collected into pools is correct, a multitude of craters across Southeast Asia are required to explain the layered tektites. Most of these craters must have been small perhaps 0.2-2 km in radius roughly corresponding to 20-200 m in projectile radius. During most 1-Ma time intervals the largest object accreted to the Earth has a radius of 500 m, and a mass of about 1,012 kg (Wetherill and Shoemaker, 1982, Kyte and Wasson, 1986). The formation of many craters spanning a region > 1000 km long requires that such an interplanetary object broke up at great distances from the Earth and rained down as 20-200 m projectiles. Melt ejected from the resulting craters fell out locally and formed the layered tektites. Some melt escaped these fireballs and solidified in flight to produce the splash tektites." Wasson, (1991).

"Tektites of the early Quaternary are only distributed in the extreme south of mainland

China: the Leizhou Peninsula, the coastal area of Guangxi and Hainan Island. Xu Daoyi et al. (1989) included all of them to the Australasian tektite strewn-field. Original tektites can only be recognized in the section of (Q1-Q2) with continuous sedimentation of lacustrine facies, which can be easily traced in South China. Tektites have been discovered between the Zhanjiang Formation of the Lower Pleistocene and the Beihai Formation of the Middle Pleistocene. These two formations, whose ages may be determined by fossils, are widespread in Hainan Island and the southern part of Guangdong Province. They are characterized by mostly continental facies with interbedded layers of marine strata of various extent. The tektites occur precisely at the boundary between (Q1-Q2) which has an isotopic age of approximately 0.7 Ma; this coincides with the transition from the older Matuyama Magnetic Reversed Chron to the younger Brunhes Magnetic Normal Chron. The distribution of tektites is concentrated at the upper surface of the stratigraphic unit of the Zhanjiang Formation and the autochthonous tektites which were discovered in the boundary section at Wenchang Middle School, Hainan Island, have never been found at any other stratigraphic position" (Xu DaoYi et al., 1989).

More destructive and constructive impact materials (DCIMs) on terraces and in old rivers, were the environmental effects of the impact: The newly discovery of the extinction evidences of abundant buried, ancient felled trees (Xu et al., 1989) large tree trunks, numerously burnt or/and petrified plant material, burying under subsequently widespread mudflows, landslides, earth flows and avalanches with embedded tektites found on these previous terraces stratigraphically covered with the newly recognized 20 - 40 m thick catastroloess in Khorat in ancient river flooded deposits at Tha Chang, 300 km west of Ubon Ratchathani.

2.7 Tektites in Vietnam, The Problem of the Ground Transport and Scattering of Tektites in Vietnam

We know tektites from Vietnam from Izokh and An (1988) expedition for position of them mainly for a Quaternary stratigraphy but rather limited as the following outlines, and modern concept on tektites.

This problem seems to be an artificial one for Izokh and An (1988), since it arose exclusively because the investigators who concerned themselves with tektites tried to solve the age paradox that arose by assuming that the tektites were eroded out of the more ancient deposits into the subsequently earlier ones along the surface of the Earth. The authors of this article suggest taking this problem away from serious discussion because there are no factual bases for its establishment. More than 30 test pits in all Vietnam by Izokh and An, (1988) were proved to be similarly in Thailand with tektites immediately above the basement, or thought to be an old surface. In many pits to more than 10 m depth each contained also frequent burnt woods and charcoals. Dating of charcoals and dating by fission tracts of tektites from these pits and obtained many absolute ages confused the investigators. The age of charcoal that could be obtained was only less than 1.3 % of a maximum age of associated tektite in the same pit in similar catastroloess. There is no sense in searching for them in regions where the relief is strongly broken and where the remnants of the terraces or the ancient flat surfaces have not been preserved. This means that the tektites essentially vanish in the mass of redeposited material of the bedrocks. And they only remain in the "erosion-proofed" situation--on relatively flat leveling surfaces under a layer of loess. They remain in many practically the same place where they fell to the Earth. Thus, there also can be no discussion about the erosion of tektites from many other (later) source, or-still more about the strict selective (without the accompanying by fragments of other rocks) transport and scattering over extensive areas.

The tektites of Vietnam in most cases are devoid of signs of redeposition or transport, i.e., lie where they fell-in situ (Izokh and An, 1983). They are non-uniformly distributed in the area in the form of isolated areas or bands and are found in any planes of leveling, beginning with the 10-15 in flood terraces and ending with the highest levels (over 2.5 km). They are absent on the surface of the contemporary floodplain and on the coastal plain. This means that the tektites fell to the Earth at a time when the level of today's terraces above the floodplain, i.e., when they were the basis erosion surface. Nevertheless, they earlier concluded that the tektites fell to the Earth very recently (Izokh and An, 1983), which are now known for one age ~0.8 Ma (Glass, 1989, 1991; Wasson, 1991, Ford, 1988, Bunopas et al., 1999; Howard, 2000). The age paradox (Izokh and An, 1983) is now no more existed. Carbon dating of coal and charcoal, associated with tektites, is only a partial age (or a minimal age) because C dating has its limitation does not exceed fifty thousand years.

Izokh and An (1988) give the characteristics of the most typical sections where tektites have been found by the authors directly in the diggings. Where it is not stated otherwise, the descriptions belong to E. P. Izokh. Many loess mentioned by them should read catastroloess, similarly but are more widespread and are more completely studied, in Thailand as catastroloess (not the wind-blown sands).

"Open pit mines 18 km north of Ho Chi Minh City near the highway running in the direction of Ben Hua, 10 separate fragmented tektites of the Muong-Nong type were found at the base of the loess layer. There were the same number of fragments of droplets and spheres, as well as one intact disc. They were all devoid of even traces of roundness. Fine details of the primary structure as well as sharp edges of fragments were preserved. Bits of woody coal which were particularly copious near the foot were found in the loess throughout the entire section of the layer."

"Here pocket accumulations up to 10-15 cm in diameter consisting of separated bits of coal ranging in size up to 3-4 cm which preserve the structure of the ancient tubes are found. The coal undoubtedly lies in situ, and in this regard the coal, loess, and tektites are equivalent. The presence of the coal verifies namely the subaerial nature of the examined layer, i.e., the absence of subsequent washing out and redeposition".

"Tektites were collected by Izokh and the geomorphologist, Le Duc An from more than 120 places all over the territory of Vietnam. Tektites occurred in wide belts like those in Australia (Izokh and Le Duc An, 1983). Tektites are found on various planes of denudation, from 10-15 - meter terraces to 2-2.5 km high highland plateaus. There are no tektites on the flood-plain level, on slopes and in the recent alluvium. That means that tektites fell at the time when 10-15 meter terraces served as flood plains. i.e. the lowest (basic) level of erosion. Tektites belong to the one sole stratigraphic level which can be found throughout the Vietnam territory. It is at the bottom of the sandy loams varying in composition from place to place from clay-bearing to more sand-bearing, but ever having loess-like appearance. They are apparently subaerial sediments covering like a blanket the uneveness of the relief".

"The underlying formations are distinguished by a great variety of age and composition. The youngest of them are alluvial pebbles of 10-15 metres high terraces dated as the nearly Pleistocene-Holocene boundary. Practically all bedrocks are lateritized, often completely. However, the tektites and loess-like layers are not affected by the process of lateritization, which provides one more evidence of their recent geological age. The loess-like layer contains abundant charcoal inclusions. The earliest ^{14}C-age (10,210 and 8,670 y.) was determined for the charcoals from the bottom of a loess-layer. The charcoals of different levels of loess-like sediments are of various ages: 3,855-1,840, 2,130, 1,435, 1,205, 1,060 and 385 years (analyst A. Panychev, Novosibirsk). It should be noted that the loess-layer is the uppermost stratum of the stratigraphic sequence of Vietnam, usually 0.2-1.5 m thick, but not more than 2- 3 m. In fact it is the main soil-forming layer, cultivated by man; charcoal's often associated with old pottery fragments. Among the Mekong-delta sediments, in the alluvial pebbles of the Saigon river, a geologist found some debris of trees dated at 27 + 0.5 thousand years at a depth of 16 m, and some others 3± 2 ka. at a depth of 63 m. Much earlier tektites were found in the same pebbles by Saurin (1935) at a depth of 40 m, i.e. on a stratigraphically higher level" Izokh and An (1988).

The valuable investigation on the position of tektites of Izokh and An (1988) in Vietnam reflect the consistent fact found in Hainan Island (Zu Dao Yi et al., 1989) in the north and recently in northeast Thailand, in the south-west (Wasson, 1995; Fiske, 1995; Bunopas et al., 1999, 2001, 2002, 2023, 2004) on the nearly NS trend of the Indochina Peninsula (Wasson, 1991; Wasson and Heins, 1993).

In Vietnam, tektites (in situ or intact tektites) are at bottom of the loess (in fact-catastroloess) on bedrock or gravel beds, as were found by Izokh and An (1988) in Vietnam in almost every test - pits from south to north, and in Hainan (Xu Dao-Yi et al., 1989). The handicap of dating of burned wood getting ages never beyond 50,000 years which has been limited by the method. Thus it was impossible for using the age for tektites. By this concept the paradoxical age of tektites is misleading.

2.8 Ablated tektite in the Indian Ocean

"A well-preserved ablated (button-shaped) tektite recovered from the surface sediments of the central Indian Ocean (Glass et al., 1996) lacks flow ridges and has apparently undergone ablation of 6.9 to 7.9 mm. The lack of flow ridges and amount of ablation indicate that, if it originated in Southeast Asia, it must have had a very shallow trajectory (only a few degrees) and a velocity on the order of 7 km/s as it re-entered the atmosphere.

"Prasad and Rao (1990) reported the discovery of a well-preserved ablated (button-shaped) tektite from the surface sediments of the central Indian Ocean (12°37'S; 78°30'E) in a water depth of 5,300 m. An ablated (button-shaped) tektite recovered from the central Indian Ocean basin is a unique specimen. It is the first tektite to be recovered from a deep ocean basin and it is the only ablated tektite recovered from the ocean floor. It is better preserved than tektite specimens found on land. There is a large (2.2 mm diameter) high-velocity impact pit on the anterior surface. The specimen lacks flow ridges on the anterior surface and appears to have undergone ablation in the range (1.9 to 7.9 mm as it came down through the Earth's atmosphere" Glass et al. (1996).

2.9 Microtektites coesite, stishovite and shocked quartz in ocean-core sediments

"Coesite and shocked quartz were found in seven out of 33 cores from the Australasian strewn field; however, no coesite or shocked quartz was found associated with the Ivory Coast rnicrotektite layer (Glass and Wu, 1993). Stishovite was also found at three of the Australasian sites. All of the Australasian cores containing coesite and shocked quartz were taken from within 2000 km of Indochina, which is believed by most to be the source area for the Australasian tektites and microtektites. Six of the seven cores have the highest concentrations of microtektites ever determined for Australasian microtektite-bearing cores. Australasian microtektites have been found in more than 40 cores throughout much of the Indian Ocean, the western equatorial Pacific, and the Sulu, Celebes, and Philippine seas: a total area covering ~10 % of Earth's surface (Glass, 1990; Smit et al., 1991; Schneider et al., 1992). Shocked quartz and coesite (>125 µm size fraction) were found in seven of the 33 cores from the Australasian strewn field. All seven cores were taken within 2000 km of Indochina, and six of the cores have the highest concentration of microtektites (>125 µm in diameter) of all the Australasian microtektite bearing cores (>300/cm^2). (i.e., close to the Brunhes-Matuyama reversal boundary). In three cores the shocked quartz and coesite were restricted to the microtektite-bearing layer, and their peak abundance occurred within 10cm of the peak abundance of the microtektites".

"The presence of coesite and shocked quartz in Australasian microtektite-bearing cores closest to the Indochina area and having the highest concentration of microtektites is consistent with previous suggestions that the source crater for the Australasian tektites and microtektites is in the Indochina region. The coesite and shocked quartz found near the Brunhes-Matuyama reversal boundary in a core that did not have an Australasian microtektite layer and taken from within the Australasian strewn field indicate that the distribution of microtektites within the strewn field is patchy and may represent a ray-like pattern". (Glass et al., 1996).

2.10 Iridium anomaly associated with the Australasian microtektite layer in ocean cores, the mass of the impacting body, the position and size of the Australasian crater and Antarctic microtektites

In their introduction (Schmidt, Zhou and Wasson, 1993), of their paper concerning iridium anomaly of the Australasian tektite, essentially all Cretaceous / Tertiary (K/T) boundary sediments (deposited 65 Ma ago) show anomalously high Ir concentrations that are widely accepted to constitute evidence of a major impact event (Alvarez et al., 1980; Kyte et al., 1980) at that time.

"Data on deep-sea cores show that the microtektite fluence falls exponentially away from southeast Asia, the fluence dropping a factor of 2 in ~400 km. In southeast Asia the trend merges with a roughly estimated mass fluence of ~1.1 g cm^{-2} inferred from evidence of a melt sheet in northeast Thailand. Integration of the inferred distribution yields a total mass of Australasian tektites of 3.2 x 10^{16} g, much higher than previous estimates. Assuming a similar fallout distribution for the impactor and a chondritic composition allows us to calculate its mass to be 1.5 x 10^{15} g, about 3 orders of magnitude smaller than the minimum mass of the impactor responsible for the extinctions at the end of the Cretaceous. The fluence of Ir can be used to estimate the mass of the projectile. This approach yielded a mass of ~10^{18} g for the end-Cretaceous projectile (Kyte and Wasson, 1982) and ~10^{14} g for the late-Pliocene impact in the southern Pacific (Kyte et al., 1988). To estimate the dependence of fluence on distance from southeast Asia we calculated the great- circle distances from Buntharik, Ubon Ratchathani Province, Thailand, near the center of a region where abundant layered tektites have been recovered in the southeastern corner of northeastern Thailand."

"Our integration of the total mass of tektitic material deposited across the field is 3.2 x 10^{16} g, 320 x greater than the Glass et al. (1979) value of 10^{14} g. Geochemical analyses of sediments from ODP site 758B and from ODP site 769A show small Ir enhancements at the depths where microtektites from the Australasian tektite event accumulated 0.77 Ma" (in here ~0.788 Ma). The microtektite abundances in these and other deep-sea cores confirm that the fluence of tektite matter decreases radially outwards from southeast Asia. Within 5,000 km the fluence falls in a roughly exponential fashion, decreasing by a factor of 2 in ~400 km. Extrapolation of the trend to southeast Asia yields a mass fluence in that region corresponding to a melt sheet 4 mm deep, consistent with the formation of layered tektites in this region. The model yields a total mass of tektitic glass of 3.2 x 10^{16} g for the Australasian field, with an estimated uncertainty of a factor of 2. In the absence of Ir fluence data at enough sites to determine a fallout pattern, we assumed a geographical distribution identical to that inferred for tektitic matter. This yields a total Ir deposition of 8.9 x 10^{8} g corresponding to a chondritic body (Ir concentration 600 ng/g) having a mass of 1.5 x 10^{15} g or a cometary body with a mass of 3 x 10^{15}g. These compare with an Ir-based estimated mass of the end-Cretaceous body of 7 x 10^{17}g. An Australasian impactor could have excavated a crater at least having a diameter of 15-19 km." (Schmidt et al., 1993)

M. Shyam Prasad, Vasudev P. Mahale, and V. N. Kodagali have identified 15 new Australasian microtektite sites along a roughly N-S transect in the central Indian Ocean. "These locations, in addition to the existing 46 sites, total to 61 microtektite sites in the oceans. We carried out regression analysis of a selected area between 12-26 °N and 98-112 °E, at 0.50° intervals using three microtektite data sets separately: 41 sites, 46 sies (number of sites known up to the years 1994 and 2006, respectively), and the entire data set of 61 sites. The 41 site data set defines an impact site at about 12°N and 106°E. Whereas the contours joining the highest values of the square of the correlation coefficient by using 46 site and 61 site data sets define an area located in NE Thailand-central Laos, the center of this site is at 18°N and 1 04°E. Therefore with progressive increase in microtektitic data the location of the impact site seems to get defined more rigorously. On the basis of the equations for the concentration of the ejecta and the distance from the source region, the calculated crater size has a diameter range between 33 and 120 km." Prasad et al. (2007)

"On the basis of the distribution of Muong Nong-type tektites, Barnes (1964, 1989) and Wasson (1991) suspected a cometary projectile, while the former suggested in situ melting of soil by a diffuse comet over the whole region of Muong Nong-type tektites, the latter felt that there could have been multiple local sites of impact, which generated the entire strewn field. However, the multiple impact origin has been disputed by the uniform composition of Muong Nong-type tektites (e.g., Blum et al., 1992) and the target stratigraphy inferred from the 10Be isotope data (Ma et al., 2004). Again on the basis of the geographical variation in composition and the distribution of Muong Nong-type and splash form tektites, backed up by intensive field study, Schnetzler (1992) proposed a site located in the southern part of Thailand-Laos border (16 °N; 105°E)."

"On the basis of evidence derived from chemical composition and isotope analysis, Chaussidon and Koeberl (1995) narrowed down to a location off the Vietnam coast, near the mouth of the Mekong River in the South China Sea (9°N 107°E). Ma et al. (2004) analyzed 10Be concentrations in tektites and on the basis of the isotope distribution pattern felt that a location in the Song Hong basin (off Vietnam, south of Gulf of Tonkin (17°N; 107°E) could be a possible impact site. Further, geochemical and Rb-Sr isotopic investigations by Lee et al. (2004) indicated the provenance of these tektites to be nonmarine: Jurassic sediments, which are found to occur in the southern part of Thailand-Laos. Including the 15 locations in this study, we find that there are 61 microtektite locations that contain the Australasian microtektite peak of abundance along with quantifiable estimates of microtektites (Prasad et al., 2007). Thus today we know 75 locations containing Australasian microtektites, which define the boundaries of this strewn field and the quantity of ejecta generated. For the total microtektite data set with 61 locations, the postulated crater location obtained from the algorithm developed to carry out rigorous analysis is 18°N and 104°E. Therefore the estimated diameter of the crater is approximately 120 km."

"Prasad et al., 2007 mention that there may occur some uncertainty in determination of the crater diameter based on the error present in the estimates of regression analysis. Thus the uncertainty in the diameter lies between 50 km to 360 km. if we consider the 46 location data from Glass and Koeberl (2006), having slope = -4.3 ± 0.27 and intercept = 24 ± 0.9, following the same procedure we get a diameter equal to 124 km. The uncertainty in the diameter of the crater diameter ~32 (± 14) km proposed by Glass and Pizzuto (1994) using the same equation. However, Glass and Koeberl (2006) considered solely the unmelted ejecta associated with the Australasian microtektite layer for which they obtained a higher R2 value, and defined a crater diameter of 43 ± 9 km by using the equations given by Stöffler et al. (1975). While the least square method shows much higher levels of uncertainty, calculation according to Stöffler et al.'s (1975) equation gives a crater size much closer to reality as ascertained by Glass and Pizzuto (1994). The estimate lies between 50 km to 350 km. However, by using Stöffler et al. (1975) equation using the concentration of ejecta and the distance from the source, the crater size considering the entire microtektite data is 33 ± 8 km." Glass and Pizzuto (1994).

Folco, Rochette. Perchiazzi, D'Orazio, Laurenzi and Tiepolo (2008) report on the discovery of a microtektite (microscopic impact glass particles) strewn field from the Transantarctic Mountains, Antarctica. Microtektites were found trapped in the local detritus accumulated in weathering pits and in joints of several glacially eroded summits (~2600 m above sea level) and distributed latitudinally for 520 km. Their physical and chemical properties define a coherent population with a geochemical affinity to Australasian microtektites and a broad but compatible Quaternary ^{40}Ar/^{39}Ar formation age. The margin of the Australasian strewn field is thus shifted southward by ~3,000 km and the maximum distance from the possible parent impact site or sites in Indochina by ~2,000 km.

2.11 Noble gases in Thailand tektites

Studies on gas compositions and their isotopes within bubbles in tektites show a mainly terrestrial origin and confirm their terrestrial origin (Hennecke et al.,1975; Hennecke and Manuel,1980). "The abundance pattern of noble gases in Thailand tektites shows an anomalous spike of neon, apparently from the diffusion of atmospheric neon through the glass. The isotopic compositions of non-radiogenic Ne, Ar, Kr, and Xe are atmospheric, but the Ar /Xe and Kr/Xe ratios in the tektites arc each about an order of magnitude lower than the values in air. The isotopic abundances of Ne, Ar, Kr, and Xe trapped in Thailand tektites are atmospheric in composition, except for an excess of radiogenic ^{40}Ar. The ^{36}Ar/Xe and Kr/Xe ratios are about an order of magnitude lower than those in the atmosphere, suggesting that most of the Xe may be from the tektite parent material." (Hennecke et al., 1975).

3. Loess in SE Asia

3.1 Loess

Loess is a windblown sand-silt that is widespread in areas close to Pleistocene ice caps and glaciers. It constitutes very thick deposits (up to 350 m with a mean of 106 m) in northern China and widespread deposits in Europe. It is a yellowish colour and is known in China as the yellow earth and its eroded sediment has given its name to the Yellow River or Huang He. Loess is widespread in

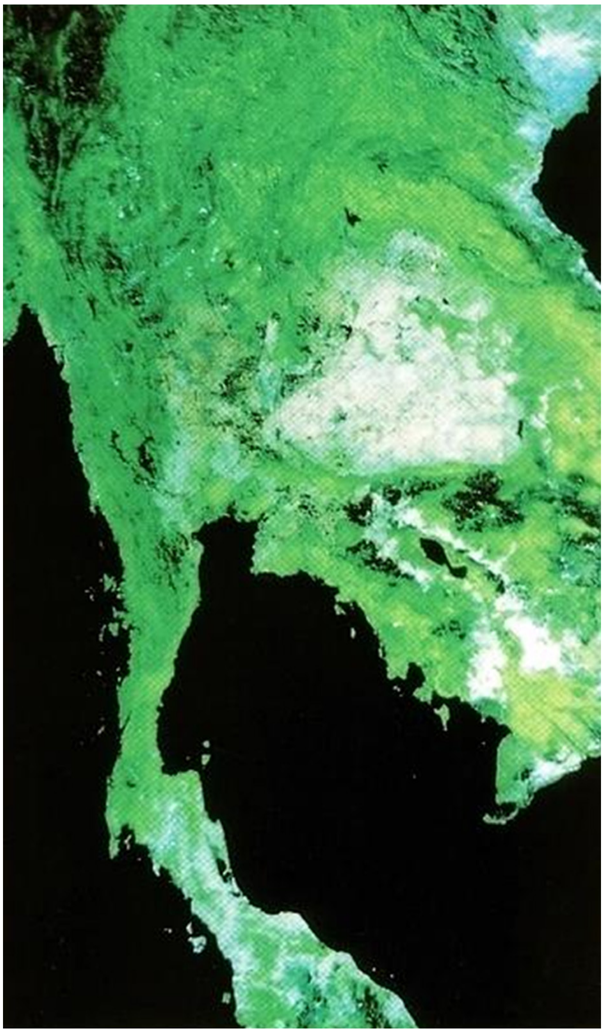


Fig. 15: Mainland SE Asia as seen from satellite reproduced by NRCT showing the catastroloess sheet showing light colour (high albedo) when some reworked as surface windblown sands. In mountainous forestry areas and in river valleys, the loess became disintegrated to soil and obscured.

Thailand, in north Vietnam and Cambodia and the bright yellow to buff deposits have a high albedo and show-up well on satellite imagery (Fig. 15). In NE Thailand, on the Khorat Plateau, loess ranges from about 3m thickness near Khon Kaen, to about 1.5 m near the Thai-Lao border and <1m in much of Laos. Loess rests on a laterite surface that contains tektites (Ford, 1988; Wasson et al., 1995; Fiske et al., 1999). Although it a dominant surficial sediment and is very important as the basis for farming, as an engineering material and as a landfill throughout NE Thailand it has received little scientific attention except for a few publications (e.g. Nutalaya et al., 1987, Udomchoke 1989, Nichol and Nichol, 2015). The grain size distribution of Thai loess is, in detail, different to that of the typical aeolian loess (yellow earth) in North China and Europe which were deposited close to glaciated areas in the Pleistocene. The Thai and Vietnamese loess may be regarded as anomalous in tropical Thailand (Nichol and Nichol, 2015).

Loesses in Vietnam and Thailand are substantially different, particularly with regard to their contents of sand and clay, the absence of $CaCO_3$ or of any effect of wind abrasion. Analysis of the Thu Duc loess horizon (Hoang Ngoc Ky, 1986) shows its sand content in the northeast area to be 46.53 percent, and on islands along the Vietnam coast up to 48.45 percent. The only exception occurs on the Danang Plateau with a sand component of 11.46 percent. The clay content varies from 31.56 to 33.56 percent. Udomchoke (1989) describes up to 70 percent sand and 30 percent silt and clay in the "yellow" loess of the Khon Kaen area in northeastern Thailand. Nutalaya et al. (1986) report that "so called sand sheet deposits near Khon Kaen show characteristics of loess". We consider this reworked surficial catastroloess, and some were previously called wind-blown sands.

"New analyses of samples taken during the IGCP 296 meeting (October 1990) in Mukdahan Province in northeastern Thailand, which were analysed in the laboratories of the Geological Survey in Bratislava and Prague, Czechoslovakia (Minariková, pers. com.) contain about 60 percent sand, 10 to 15 percent silt and 25 percent clay (Fig.16). Graphic parameters (according to Folk and Ward, 1957) indicate the following values: mean size Mz varies from 5.33 to 5.48 (e.g. 0.22-0.24 mm), inclusive graphic standard deviation 3.08 reflecting a very weakly sorted material, with graphic skewness around 0.60 showing a very positive asymmetry and graphic kurtosis Ko that varies from 0.47 to 0.71, corresponding to a very platykurtic distribution. The median Md oscillates between 3.60 and 3.87 (0.07 to 0.08 mm) and is thus substantially coarser than the mean size Mz." (Sibrava, 1993).

All these values differ from the grain composition as known from the loess sediments in China as well from European loess. As shown above, the main difference lies in the high content of sandy and clay components and the low content of silt in loess from Vietnam and Thailand, contrary to Chinese and European loess covers. Additionally, no substantial surface

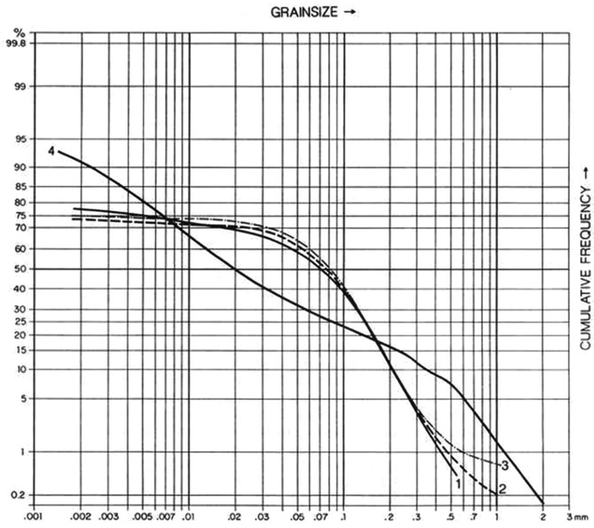


Fig. 16: Comparison grain size of loessic sediments on the Khorat Plateau, Thailand (curves 1-3) with typical loess curve from Central European loess (4) (from Sibrava, 1993). Also see Nichol and Nichol (2015).

markings on the quartz grains caused by wind abrasion has been observed in loess of Vietnam and Thailand. Sediments there are totally decalcified.

Loess occurs in several other areas outside of the Khorat Plateau. Loess extends to northern Thailand and covers some river terrace deposits (Vella et al., 1987). As it is easily erodible, when capped by more resistant sediments it erodes into pillars known as 'sao din' (earth pillars) in northern Thailand and in eastern Thailand at Sra Kaeo. These widespread deposits remain undated directly but 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 which are closely associated with unreworked 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 based on similarity to those in Yunnan.

Catastroloess erosional feature is very common in catastroloess outcrops; as Pha Wingchoo (Cliff climbing for lover) at Hod; sao din (earth pillars) at Nanoi in the north, Pae Muang Pi (ghost town) in Phrae, Thoeng, Pai; a castle-like wall in south-west Chiangmai, Lampang, east Lom Sak, Sinking holes or land of erosion at west Ratchaburi, Burirum are outcrops of 0.8 Ma loess deposition during wet and humid and dry yearly. The outcrops are almost readily recognized for numerous, small and even gully erosion, which is not a common feature in stream and alluvial sediments.

Catastroloess is the impact product from continental sediments and gravel beds as unmelted ejecta blown up into the atmosphere, fallen down and form layered beds (very fine stratification), and some hung up in the atmosphere for possibly years. Tektites are melted impact terrestrial rocks, the process was immediately solidified and some splashed to solidify in the atmosphere. The extraterrestrial bodies (comet) that brought in elements from far outer space including Iridium. They usually started the boundary clay that formed a layer immediately ahead of extraterrestrial body or bodies as is known from the K/T boundary. In the catastroloess, or unmelted ejecta, minute fractions contain microtektites, microglasses, PDF's of microglasses or minute quartz crystals, usually known as spherules. These categories are not expected in 'normal' aeolian origin loess. Laboratory procedures are sufficient to separate normal aeolian loess from catastroloess.

Australasian tektites and North China loess have closely related compositions. Wasson and Heins plot compositions of tektites (Chapman and Scheiber, 19691) and loess data from Liu (1985b) with the latter from the classic site at Luochuan, Shaanxi Province. The loess data are corrected for $CaCO_3$ prototektitic material and that the CO_2 lost during the heating event; to minimize the effects of $CaCO_3$, we have excluded samples with CaO contents >38 mg/g. again choosing the cutoff to correspond to a hiatus in CaO.

The clearest trends in the tektite data are the negative correlations between Al or Fe and Si; similar trends are observed in the loess (in disagreement with the statement by Blum et al. (1992) that loess is an unsuitable source because samples of each deposit contain uniform major element compositions). Although ranges in the loess are lower by a factor of roughly 3, the fields overlap. If tektites were produced from loess deposits in SE Asia, these must have contained appreciable amounts of a high-Al and -Fe component such as laterite and of an Si-rich component such as a high-SiO_2 sandstones; sources of such components are widely available in SE Asia. Wasson (1991) conclude that presently available bulk compositional data are consistent with Australasian tektites having been produced by the melting of loess, spiced by minor amounts of lateritic soils, quartz-rich materials, and even ultramafic (Wasson, 1991) materials. Loess is unmelted product or unmelted ejecta, (together the melted products-tektites), here called catastroloess.

Field evidence in the Khorat Plateau which contains catastrophic loess with more powerful middle size fraction different property from European loess (Fig. 16), such loess are found within the Australasian strewn-field area in the Gobi Desert area in China, and elsewhere in north China including the Luachuan Loess which contain common spherules (Wasson and Heins, 1993; Salyapongse and Pitakpaivan, 1999). The most important fact is they buried tektites and other DCIMs from the impact in Thailand indicating they were immediately syn- and mainly post-tektites in origin in the same event. Thus they cannot be the impact rocks/sediments, but the un-melted ejecta layer from the impact rocks which were soils, gravels and chiefly underlying Jurassic-Cretaceous redbeds in the Indochina impact field, possibly at Buntharik in Ubon Ratchatani a suspected impact crater.

3.2 Catastroloess and sao din in Thailand

Loess-like sediments (herein catastroloess) are found beyond the Khorat Plateau in hilly areas in northern Thailand, western and eastern Thailand (Figs. 17-30). They are often capped by gravels and once these gravel-bed caps are eroded the catastroloess erodes into earth pillars known as sao din and by other local names. The catastroloess is difficult to date definitely, though thorough studies may yield results in the future. At the sao din area at Nanoi south of Nan city in Nan Province, stone tools have been found associated with the catastroloess and are comparable with those found in Yunnan and may range in age from 1 Ma - 0.5 Ma, (Zeitoun et al., 2012).

3.3 Catastroloess earth pillars newly recognised in Kunming (SW China)

Catastroloess in Kunming (Fig. 31) formed among the track of the Australian Cometary Impact and should have an 0.8Ma age. Loess in North China mentioned above is normal loess associated with glaciations.

Catastroloess originated only when impacted, bursting dusting debris and fine sands including nearby ejecta, and largely, in very remote areas, the glacial outwashes were drawn in and sent to a high or very high atmosphere, many hundreds kms above the earth's surface. Catastroloess caused darkness and starting glaciation in northern Asia, China, Australia. These were soon after or almost contemporaneously with the great wildfires of massive felled trees down below were becoming the greatest killing

Fig. 17: Mae Cho, Chiangmai above the western ranges

Fig. 18: Pha Wing Choo, Hod, Chiangmai. Typical rill effect of catastroloess covered by 2 m of medium to large, well rounded pebbly gravels, possibly river gravels raised 70 m above present river.

Fig. 19: Pha Wing Choo, Hod, Chiangmai, southern end

Fig. 20: Pha Wing Choo from south looking north

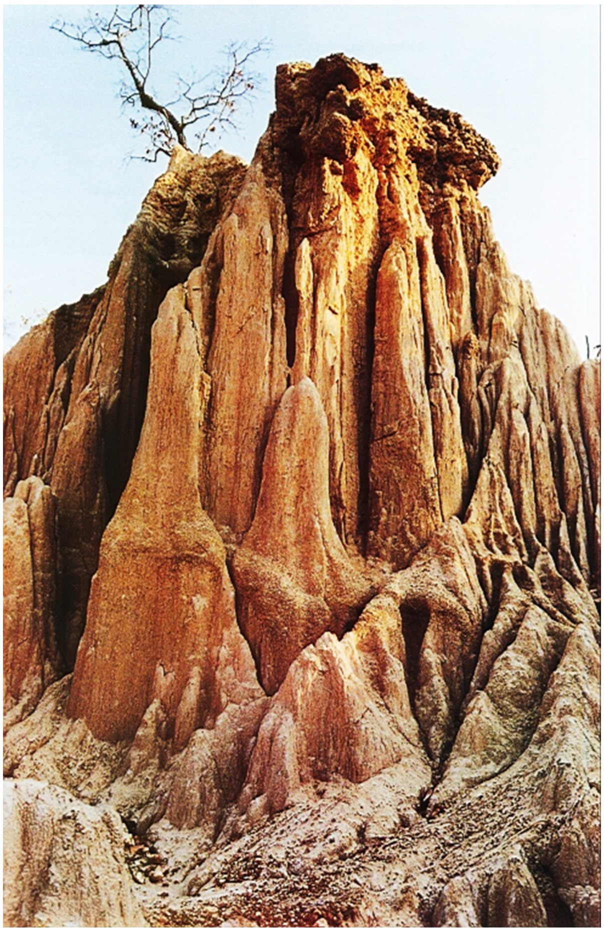


Fig. 22: Sao Din (earth pillar), Na Noi, Nan Province

Fig. 21: Pha Wing Choo from Mae Ping, south of Chiangmai

Fig. 23: Sao Din (earth pillar), Na Noi, Nan Province

Fig. 24: Sao Din (earth pillar), Na Noi, Nan Province

Fig. 25: Sao Din (earth pillar), Na Noi, Nan Province

Fig. 26: Sao Din (earth pillar), Na Noi, Nan Province

Fig. 27: Phae Muang Pi (ghost town bush) at Phrae, catastroloess column on terrace capped by 1-2 m gravel beds (kindly supplied by Paveena Kitbutrawat)

Fig. 28: Phae Muang Pi (ghost town bush) at Phrae, catastroloess column on terrace capped by 1-2 m gravel beds (kindly supplied by Paveena Kitbutrawat)

Fig. 29: Phae Muang Pi (ghost town bush) at Phrae, catastroloess column on terrace capped by 1-2 m gravel beds

fields along the trail to NNE, from south Kazakhstan to China, NE Thailand, Australia and disappeared in Mt, Darwin with crater. This was seriously wrongly understood, the tektite event originated by a cometary impact event, a terrestrial catastrophe from an extraterrestrial body from the deep space in the solar system (Wasson, 1985), apart from tektites, the most important was the catastroloess or was known also as ejecta. Chinese loesses are common above 35°N, above Huang Hue River, and around Beijing, not Kunming, which is newly recognised catastroloess in SW China.

We now know Chinese loess had little original connection with the impact although there may be some interbedding of catastroloess

Fig. 30: A-D. Sra Kaeo, eastern Thailand new discovered sao din (earth column) similar to those at Na Noi, 1000 km to the north. Lalu is its local name (kindly supplied by Paveena Kitbutrawat).

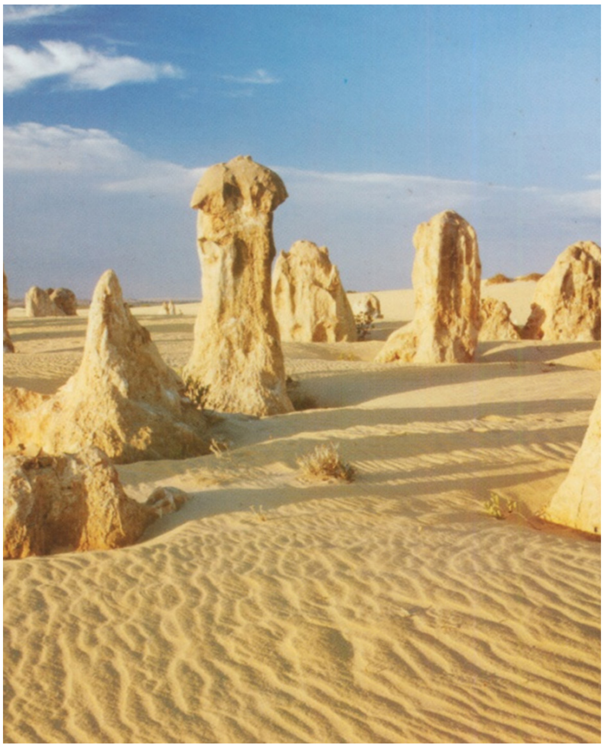


Fig. 31: Catastroloess in Kunming – similarly eroded to sao din in Thailand (from Discover the World, Royal Orchid Holidays-a tour guide 2008).

at L8 to L9. With microspherules reported (contamination), but later when related glaciation being developed after the impact, and regenerated as normal loess from glaciation in the whole columns (Li, C.; Ouyang, Z.; Liu, D. and An, Z., 1991). Hence, the Chinese columns. contain mainly atmospheric or normal loesses and thin interval in L8 or L9? Contain catastroloess from 0.8 Ma impact with Microtektites and glass microspherules in loess (Li, C.; Ouyang, Z.; Liu, D. and An, Z., 1991).

The known Chinese loesses from “Yellow Mountain” washed into the Yellow River Huanghue River are the atmospheric loesses (‘normal’ loesses) from Pleistocene debris while the real ~0.8Ma Australasian catastroloess is found in Kunming to the southwest.

3.4 Other areas of Thailand with possible catastroloess

Other areas in Thailand with loess include thick sections at Mae Tha in Lampang Province (Fig. 32) and along the Lomsak-Chumphae road (Fig. 33-34). At Mae Tha (Fig. 32), the widespread


Fig. 32: Km 26 to Mae Tha, Lampang, on opposite side young basalt flows on top gravels.

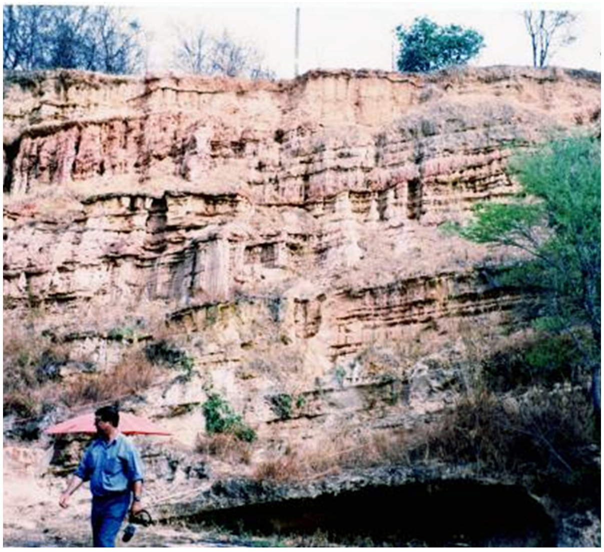


Fig. 33: Km 16, Lom Sak-Chumphae Road.

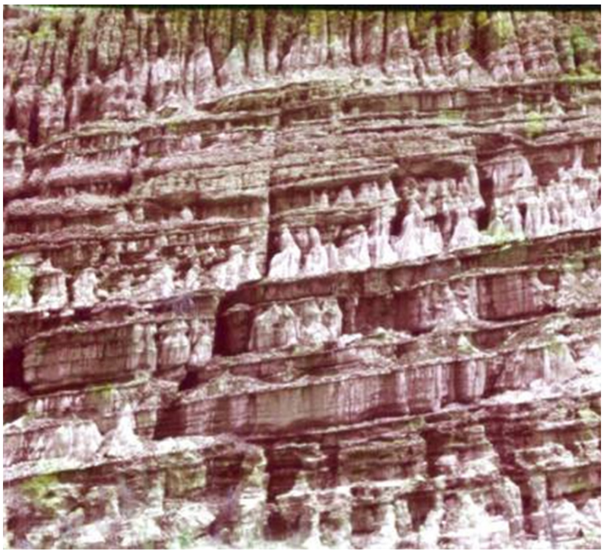


Fig. 34: Very fine sandy beds at higher levels of Fig. 33.

Lampang basalt is dated in part to about 0.8 Ma, has a reversed magnetism and lies above river gravels which contain an important collection of Acheulian (Homo erectus) artifacts (Barr and Macdonald, 1981).

3.5 The youngest Pliocene age for Tertiary deposits in Thailand, 1 km deep lake in Lampang tectonically immediately older than Pleistocene

Three diatomite samples from Lampang were brought to New Zealand (Bunopas, 1981) and the diatoms were kindly photographed by scanning electron microphotography and identified by Dr. Margaret Harper at Victoria University of Wellington. Dr. Harper (written comm.) stated that 99% or more of the frustules present are Melosira granulata (Ehrenberg) Rafts in Pritchard. Both spined terminal frustules and toothed terminal frustules of the coarse pored form are present. The predominance of this planktonic diatom suggests a deep lake with a silica concentration between 5 and 25 mg/l which is a high concentration (Kilham, 1971) and alkalinity between 10 and 1 meq/l which is relatively dilute. Although M. granulata is found in a wide range of climates the very thick walled forms with very coarse pores appear to be characteristic of warm climates (especially sub-tropical to tropical). Also they are better known in older deposits (early Holocene or older) but this may be an artefact of preservation and found only M. granulata and two closely related species in some Tertiary deposits in Canada.

A few volcanic glass shards are found with some sponge spicules, some smooth and some with rippled surfaces. The absence of species other than M. granulata is strange in terms of present day flora, but is likely to be due to solution of other more delicate frustules during deposition or diagenesis, coupled with a strong initial dominance of M. granulata.

A change from fine-grained facies to rudaceous facies marks the base of what is regarded as Quaternary, but the change is not well dated and could be above or below the real Tertiary-Quaternary boundary. It indicates the beginning of the rapid uplift of the present mountains.

The now Phaholyothin road at Km 2 from Lampang to Chiangrai (Fig. 35) exposed excellent outcrop of 3 diatomite beds 1 to 2 m thick each with no conglomerate overlying on

Fig. 35: Neogene diatomaceous beds formed before the catastroloess and uplifted before the impact, Lampang.

top but catastrophic loess indicating they were 1 km uplifted.

3.6 Miocene or younger fish fauna at Lomsak, Phetchabun Province, Thailand

Well preserved freshwater fish are well known and well described from shallow excavations near Lom Sak, Phetchabun Province (Figs. 36-37) and have been ascribed a Miocene age (Roberts and Jumnongthai, 1999). The abundant and diverse fish fauna is found in mudstones and siltstones and is overlain by sands here interpreted as loess (or catastroloess). We suggest the possibility that the fish fauna is actually Pleistocene in age and suffered a mass mortality due to the 0.78 Ma impact event.

4. Nakhon Ratchasima Province (Khorat) sandpits-evidence of the 08 Ma impact event

4.1 Ban Tha Chang (Khorat) sandpits

The sandpits or sand pumping mines at Tha Chang (Figs. 38-46) serve as the most perfect global classroom for the global impact which we have long searched for. These pits were later studied in detail by (Howard, 1999; Howard et al., 1999 and Howard et al., in 2000). The pit in late 1997, on the west side of River Mun south of Ban Tha Chang contains DCIMs reported by Bunopas et al. (1999) are as follows:

1) Numerous extensive burnt felled trees, all roots up, lower levels contain abundant charcoal and sulfides. Uprooted tree trunks up to 1 metre in diameter are often shattered, branchless, snapped, and burnt to the core. Their presence in deposits throughout Thailand is evidence of widespread burning. These suggested extensive wild-forest-fire which were reported burnt trees or woods the whole of Southeast Asia.

2) Ancient Animals such as Mastodon, ancient species elephant, turtle, crocodiles and etc. suggesting a mass extinction event.

3) Tektites rare splash-form tektites from the pits.

4) Impact crater in Buntharik - though it is still dubious.

5) Catastrophic sands represent debris and ejecta that formed widespread sheet enclosed other DCIMs. This name is proposed “Catastroloess”, for this impact sands washed and catastrophic flooded as sands at Ban Tha Chang, Howard (1999) added,

6) Microtektites, glasses, impact quartz and impact glasses etc. and,

7) Isotopic elements from INAA, ICP-MS measurements in tektites from Thailand, China and recent study from Ban Tha Chang sands .

Howard (1999) found the 7 DCIMs and a little later, Howard et al. (1999) emphasized many fluvial facies, microtektites and spherules.

The impact consistent with one from the Buntharik Impact Event at Ubon Ratchatani,

Fig. 36: Lom Sak, Phetchabun Province fish pond, the man stands on the previous bank of the pond where the pond was filled by catastroloess and buried fishes.

Fig. 37: A villager is hunting for the most beautiful fossil fishes. Same location as Fig.36.

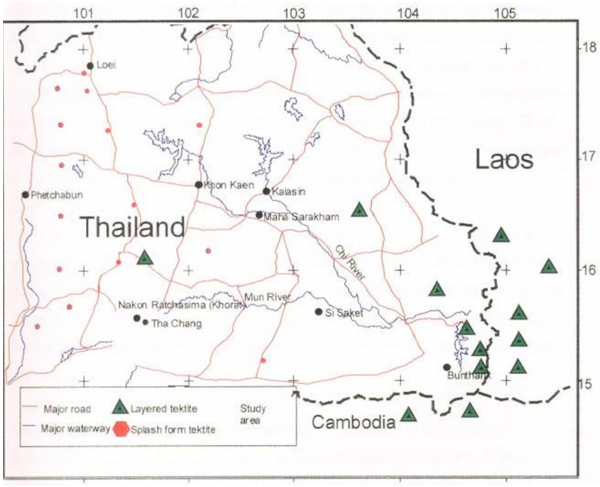


Fig. 38: Map of NE Thailand (Khorat Plateau) showing sites and roads, Ford, (1988) and recorded tektite finds. Triangle showing sites of layered tektites around Buntharik area. (From Howard, 1999).

Thailand and catastrophic products enclosed in their findings and noted that Glass and Pizzutto (1994) and Glass and Wu (1993) had their record of the Australasian field microtektites in the seas.

Geochemical analyses of the sediments of the lower section of pit 1, Ban Tha Chang, reveal that the sediments possess a major oxide distribution that consists of two distinct components. SiO_2 is the dominant component comprising on average 95.03 wt% of the analysed samples, this is reflected in the dominance of quartz revealed in petrographic analysis. The second component of the samples is a clay component that holds the remaining major oxides and the majority of trace elements. This second and minor component was revealed effectively by the use of Cs and Rb as analogues for clay content.

The sands of Ban Tha Chang possess a trace element geochemical signal that is similar to that typical of the upper crust of Earth (no enrichment in Ir, Ni or Co). However, these sediments are depleted in the elements Ba and Sr relative to most upper crustal sediments. Despite this depletion, barium (mean l08ppm) remains the most abundant element in the analysed samples followed by Zr (mean 60.2ppm), Ce (36.88ppm) and Rb (30.66ppm).

The REE present within the samples show minor light REE enrichment in the stratigraphically lowest portion of the section (sample 1). Generally, however, the samples possess REE patterns typical of the upper crust. The REE geochemistry of the Ban Tha Chang sands exhibit typical features of the REE in that they appear to behave in a uniform manner as indicated by a high degree of inter-correlation. This strongly suggests that these REE are distributed relatively pervasively throughout the mineral phases present in the Ban Tha Chang sands. The use of Cs as an analogue for clay content within the samples analysed reveals that Cs and clay content exhibits a general increase up-section. As may be expected, the abundances of other trace elements correlate well with increases in Cs content; implying that the fine clay component of the sample hosts most trace elements. However, Cs is not a perfect analogue for clay content and despite correlating with Cs, components of many trace elements abundances are not related to Cs. These

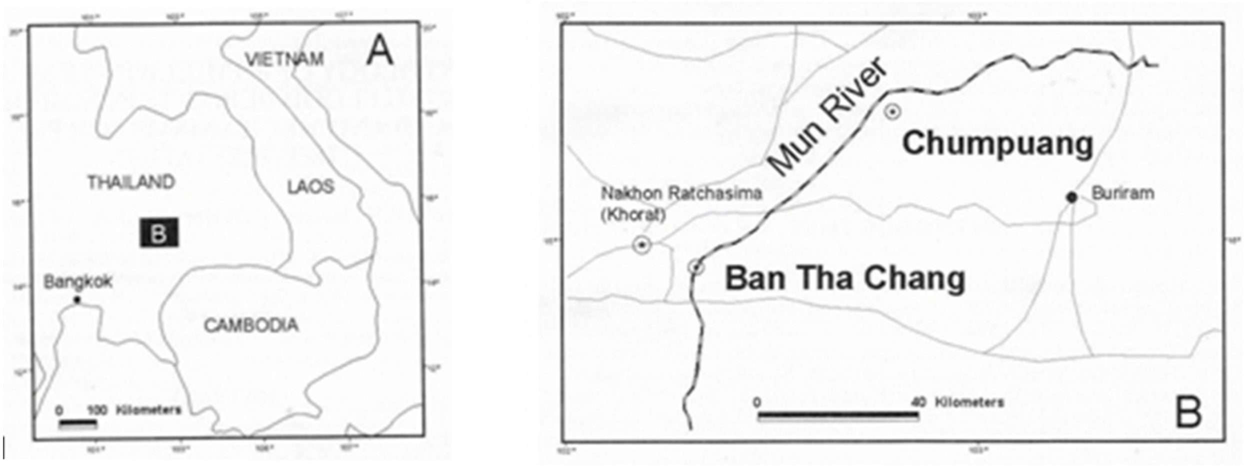


Fig. 39: Location of Ban Tha Chang and Chum Phuang sandpits

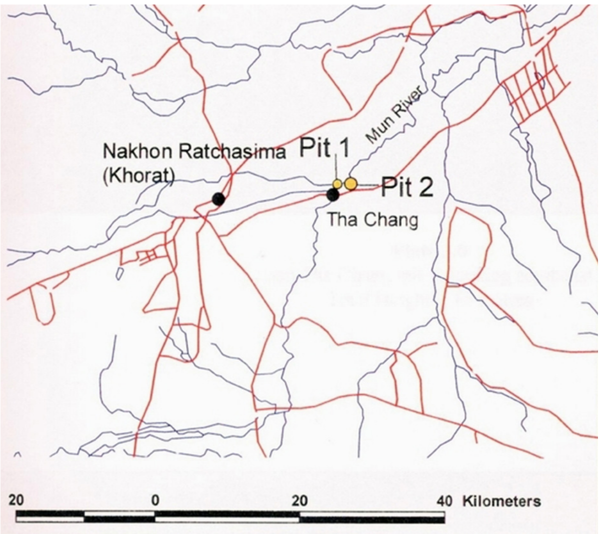


Fig. 40: Map showing location of sampled Ban Tha Chang sandpits 1 and 2, near Khorat City

Fig. 41: Looking into the southern pit at Ban Tha Chang Clive Burrett and the late Somboon Khositanont in 1997. (Flooded a year later, no stratigraphic measurement).

Fig. 42: Pit 1 east Nam Mun, south of Pit 2

Fig. 43: Pit 2, after being worked for a long time, east Nam Mun

Fig. 44: Pit 3 west Nam Mun (later flooded, not available for stratigraphic measurement).

Fig. 45 A and B: A Pit 2 left . B right. Panorama view of Pit 2L upper and 2R under.

Fig. 46: Sandpit or sand pumping mine at Tha Chang as the most perfect global impact long searching for. Later studied in detailed by Howard et al., 1999, Howard et al., in 2000; Haines et al., 2004).

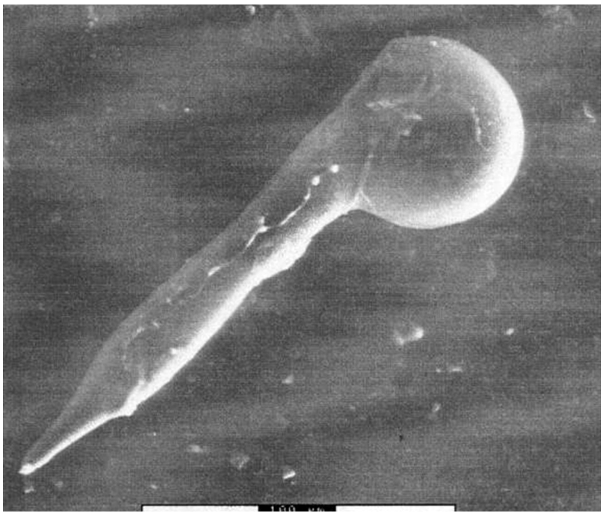


Fig. 47: Microtektite or microglass at Ban Tha Chang, Pit 2 (Howard, 1999).

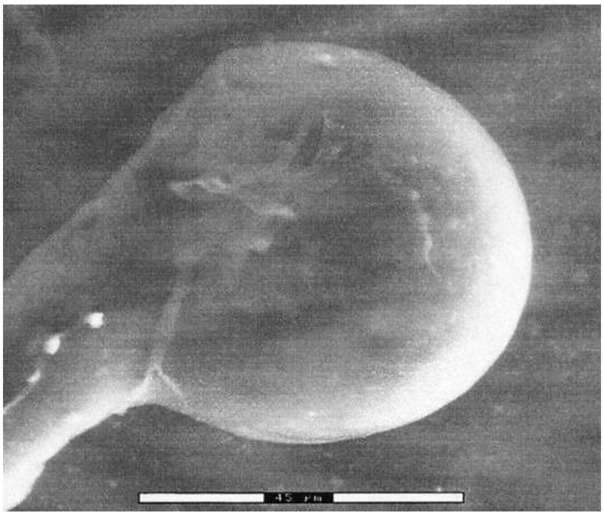


Fig. 48: Enlargedmelted impact dust particle on to the molten glass particle (Howard, 1999).

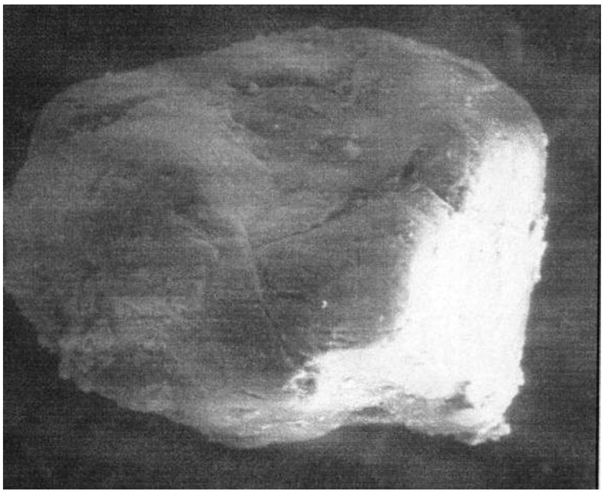


Fig. 49: Sub-spherical non-tektite micro-impact glasses showing also numerous cracks. The glass shows some fracture plane on its surface, related to post-deformation transport. (Howard, 1999).

Fig. 50: Close up of above pit. (Howard, 1999).

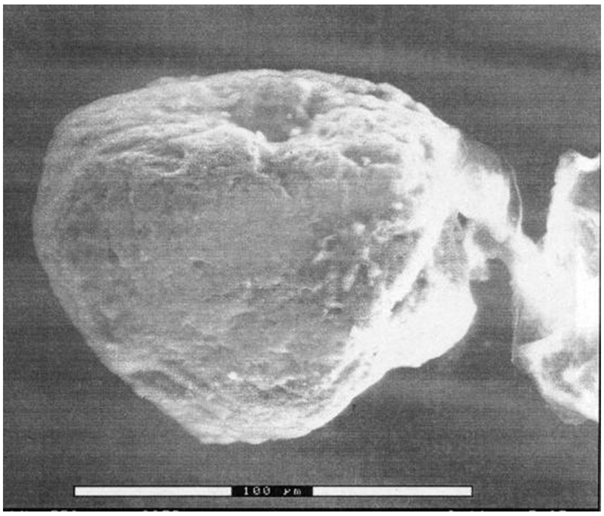


Fig. 51: Non-tektite micro-impact glasses with pronounced pit structure at the top. (Howard, 1999).

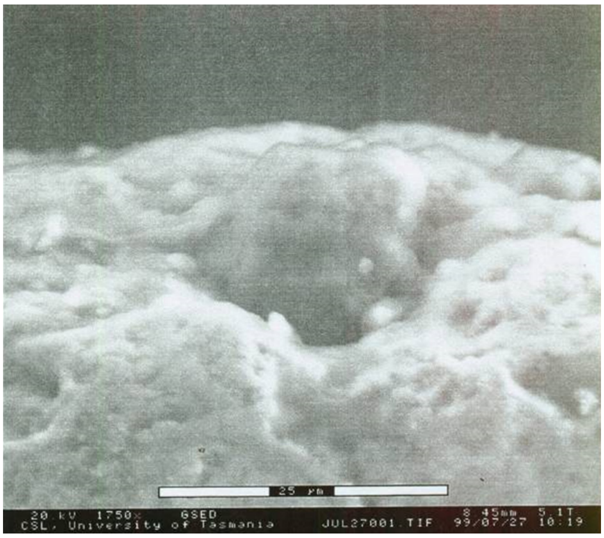


Fig. 52 : Microglass at Ban Tha Chang. (Howard, 1999)

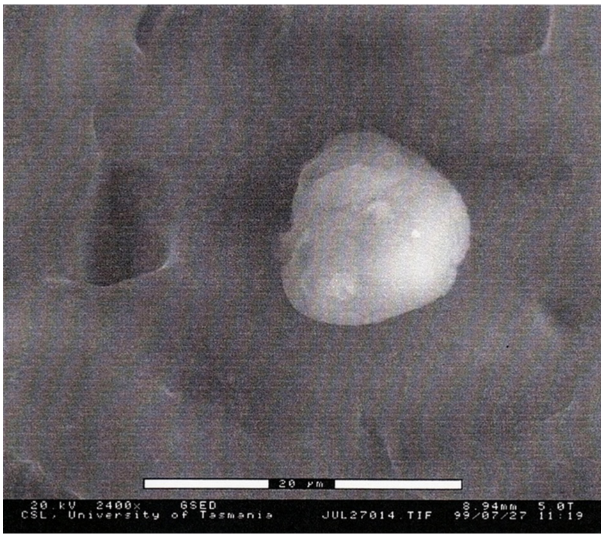


Fig. 53: Very small sub-spherical glass. (Howard, 1999).

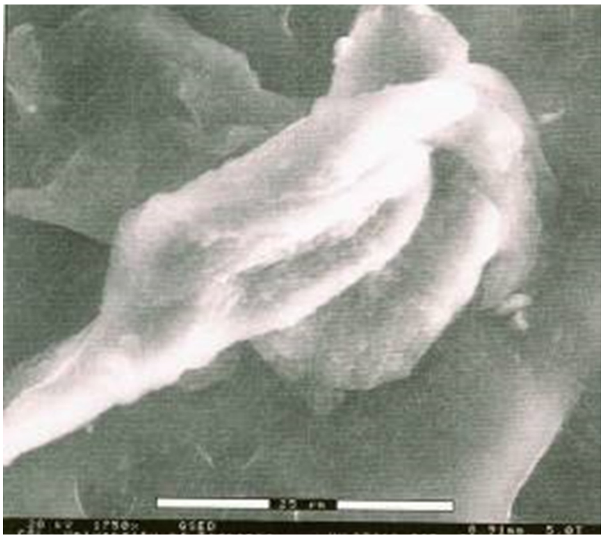


Fig. 54: Irregular shape micro-glasses from Ban Tha Chang sands (Howard, 1999).

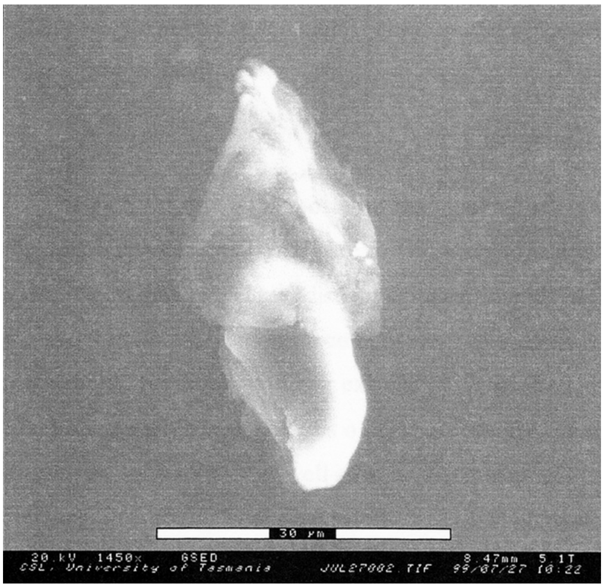


Fig. 55: Another irregular shaped glass, such extremely irregular morphologies are less common. These are the first terrestrial non-tektite impact glasses to be found in Thailand and are the only onshore non-tektite impact glasses (other than Darwin glass) to be directly associated, by stratigraphic position and geography, with the Australasian tektite strewn field. The analyses by XRD reinforce the overwhelming abundance of quartz in the sands. as well as the minor presence of the minerals rutile, baryte and several other, very minor, minerals. Baryte may itself represent a secondary product formed within the treatment process through reaction with H2S04 (Howard,1999).

components strongly suggest that minerals such as K-feldspar, zircon and the mica family of minerals are present, in minor amounts, within the sands and are hosting these trace elements.

4.2 Microspherules, microtektites, microglasses, pdf in quartz crystals, shocked quartz at Ban Tha Chang

Sandpits at Ban Tha Chang, south of Khorat, northeast Thailand, provide an ideal locality to study the environmental effects of the 0.788 Ma event. Based on the distribution of layered tektites that are believed to form close to the site of an impact, Ban Tha Chang is possibly 400km west or more of inferred impact centres. The sands exist above one of the regionally extensive tektite bearing layers of 788 ka and consist of six interbedded facies outcropping in two active sandpits. Facies 1-4 in the sands have chaotic grainsize distributions and were rapidly transported and deposited in flood events.

The sands contain abundant partially or wholly petrified and/or burnt trees, these were deposited during flood events and are confined to two distinct stratigraphic horizons. The trees

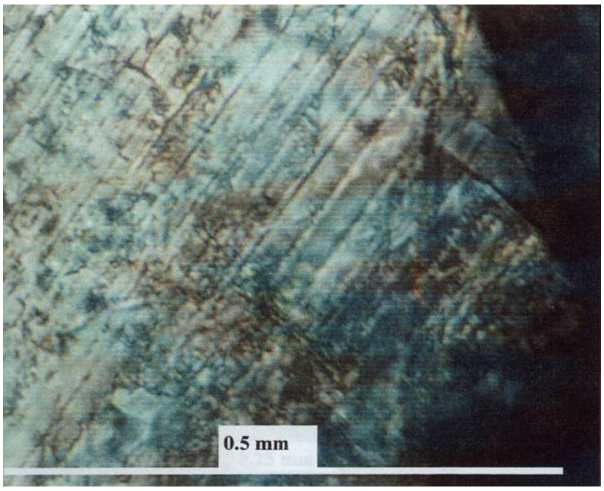


Fig. 56: PDF's in quartz close-up. (Howard, 1999).

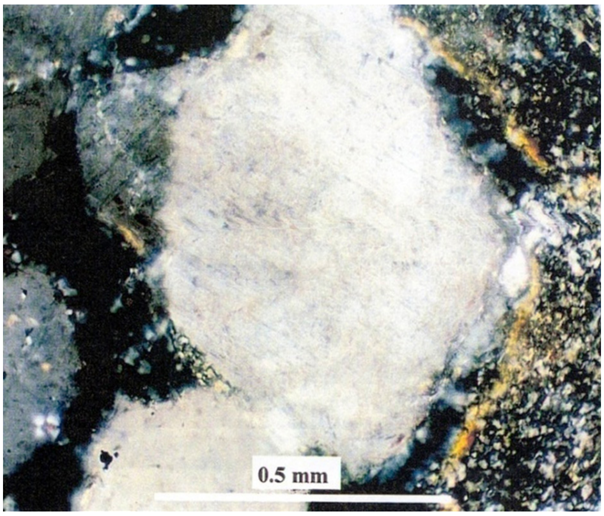


Fig. 57: NW-SE orientated PDF's in quartz. Note: there is a second set of NW-NE planar fractures (PF's or PDF's ?) visible in the top left corner of this quartz grain (Howard, 1999).

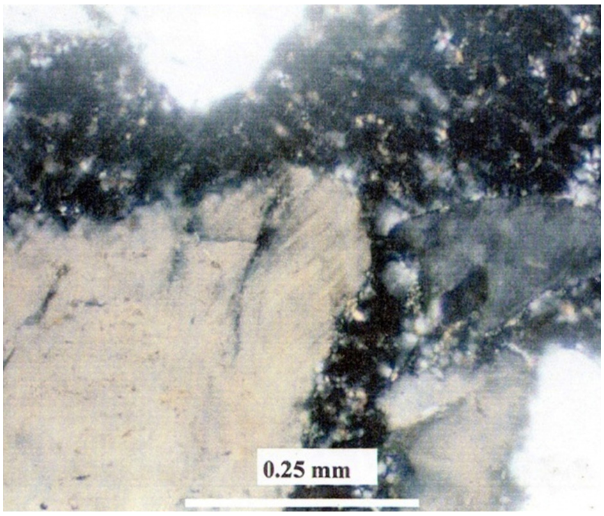


Fig. 58: PDF's in quartz. (Howard, 1999)

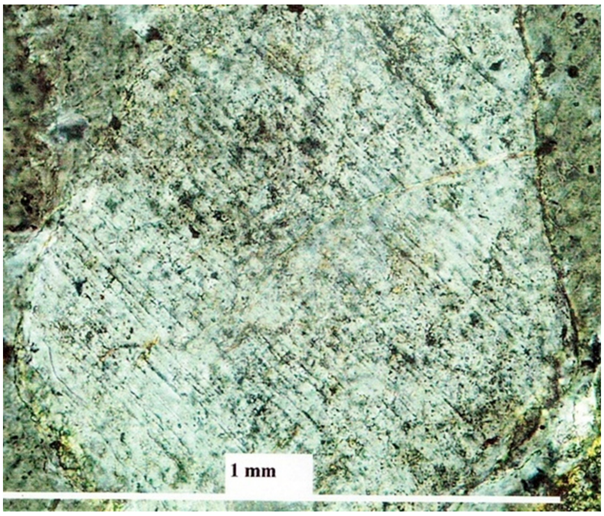


Fig. 59: PDF's in quartz. (Howard, 1999).

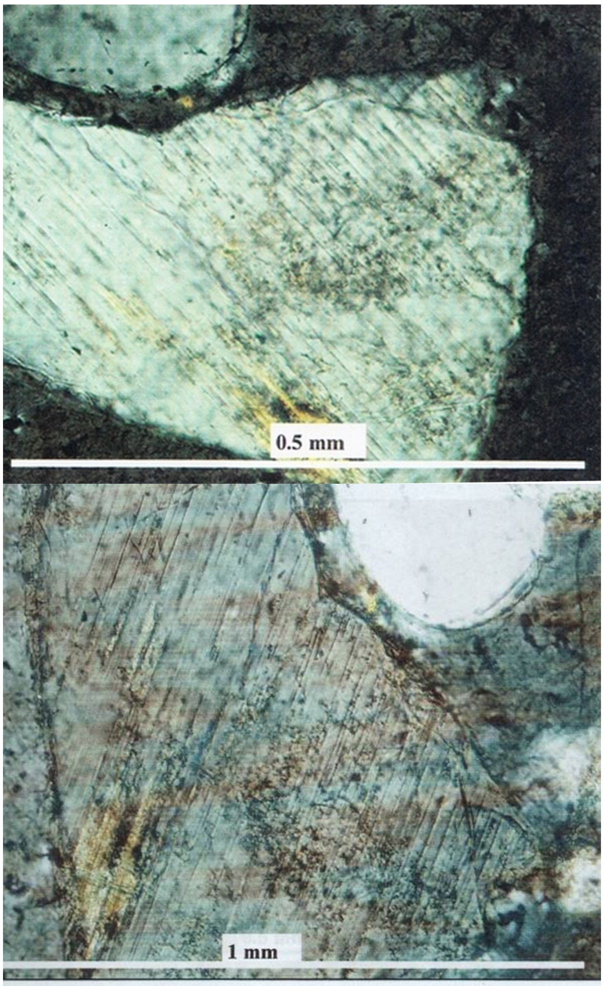


Fig. 60: PDF's in quartz Ban Tha Chang, Scale of A) 0.5 mm and B) 1 mm (Howard, 1999)

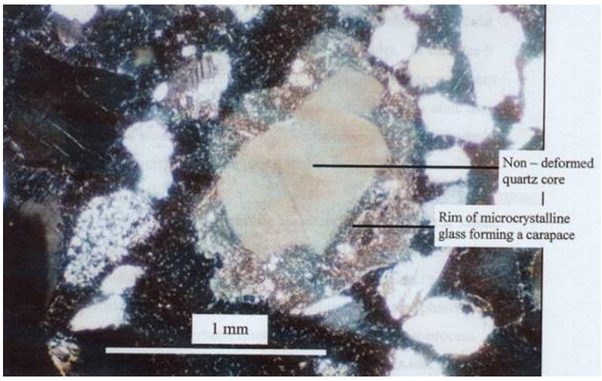


Fig. 61: 'Cored grain' showing quartz grain with quenched margin. Note: deformation features are absent from the quartz grain. (Howard, 1999).

are branchless, snapped, uprooted, burnt to the core and are very similar to those at Tunguska, Siberia, site of a small impact event in 1908. The destruction of the trees at Ban Tha Chang is related to processes of impact induced shock and forest fires.

Microspherules (typically l00μm) glasses in sands at Ban Tha Chang and also Ratchaburi (west Thailand) are suspected to be of impact origin on the basis of their compositions and morphologies (Figs. 47-55). These glasses are typically sub-spherical to more irregular in form, to rarely teardrop shaped. The glasses may be divided into two distinct groups. Group A impact glasses are composed almost exclusively of SiO_2 (97.7%), while group B impact glasses possess low SiO_2 (37%), high Al_2O_3 (28%) and anomalous fluorine (6.6%) contents. Group A impact glasses are believed to have formed from a quartz rich photolithography. If a primary chemical signature, the composition of group B impact glasses suggests that these formed from target material rich in fluorine, most likely implying a fluorite rich target e.g. granites. Quartz grains in sands at Ban Tha Chang contain planar fractures and in some grains these are spaced at less than 10 microns and resemble Planar Deformation Features (PDFs) that form at the lower end of impact induced shock pressures, from around 10 to greater than 30 GPa (Figs. 56-60). Also present in the Ban Tha Chang sands are partially melted grains of quartz that are surrounded by a glassy carapace up to 0.1 mm in width. The quartz grains contained within this carapace do not show deformation features but rather a relatively homogenous surface that grades into the outer, glassy carapace surrounding crystalline quartz (Fig. 61). This texture is characteristic of 'cored grains' (French 1998).

Australasian tektites have been dated at 770 ± 20 ka (Izett and Obradovich, 1992; Bollinger, 1993) and 786 ± 12 ka (Kunz et al., 1995) and 788 ± 3 ka (Jourdan et al., 2019) using ^{40}Ar-^{39}Ar methods. Independent age evidence comes from a deep sea microtektite horizon widely believed to be associated with the tektites on land, which is situated just below the Brunhes-Matuyama magnetic reversal (Schneider et al., 1992). Ages of 793 ka (Lee and Wei, 2000) and 803 ± 3 ka (Hou et al., 2000) have recently been suggested on this basis. Because of the minor variations in these published ages, we have referred to the event herein as the ca. 800 ka impact event. This is equivalent to latest Early Pleistocene extending to earliest Middle Pleistocene.

The main aims of the report are about the DCIMs from the impact which are known, though impact in a very substantial percentage of the World, all DCIMs were found only in Thailand. The DCIMs that formed by the Cometary Impact are mainly 95 % from Ban Tha Chang and Chum Phuang, described by Bunopas et al., 1999; Howard (1999), Howard et al., 2000, 2003; Haines et al. (2004).

4.3 Sedimentology of ~0.8Million-Year Old Log-Bearing Flood Deposits in Northeast Thailand and Mechanisms for pre-flood Deforestation

Pleistocene alluvial sands within the palaeochannels of major rivers in Northeast Thailand contain a very unusual abundance of large, burnt tree trunks (Figs. 62-67, 70, 82-83). Detailed studies in active sandpits near Khorat reveal 6 sedimentary facies (Figs. 71-81) with tree trunks confined to 2 stratigraphic horizons. Stratigraphy, unabraded tektites and vertebrates, including the pygmy elephant Stegodon, suggest a Pleistocene age for the upper sections of the pits with the burnt trees. Facies 1-4 were deposited in catastrophic mega-flood events. These are overlain by 2 facies characteristic of normal fluvial processes. The flood deposits may be associated with the formation of residual topographic features seen on Landsat images, which are similar to those of the channeled scabland of the USA.

Fig. 62: Devastation of a vast area of Siberia due to the 1908 Tunguska airblast leading to an estimated 80 million trees being demolished arranged in a radial pattern. Hundreds of reindeer were killed. Trees near ground-zero were still upright in 1927 but their limbs and bark had been stripped away (cf. Ban Tha Chang). Public domain photograph from the Kulik expedition of 1927. Wikipedia, Tunguska Event.

Fig. 63: Ban Tha Chang pit 3 studied by Haines et al. (2004). Note abundance of burnt logs. Photograph kindly supplied by Dr Peter Haines (Australia).

Fig. 64: Tree log, here pyrite appears as the grey colour to the right of the pencil. Note the crust of sulphosalt around the outside, calcite veins in centre.

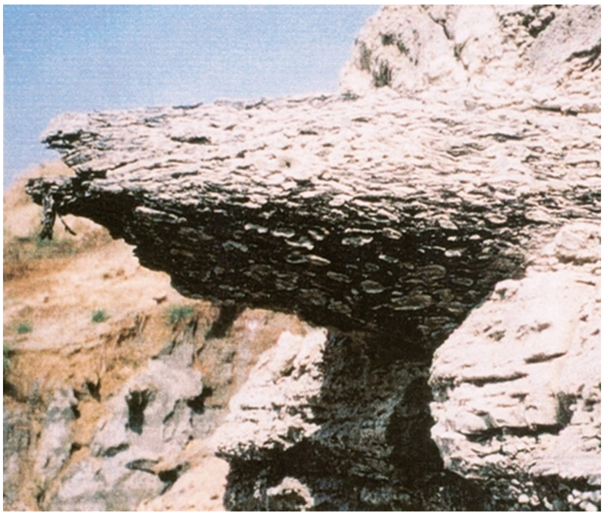
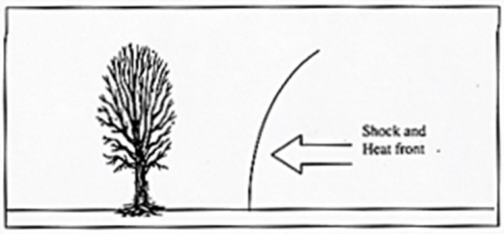


Fig. 65: Snapped and splintered tree end at Ban Tha Chang (Howard, 1999).

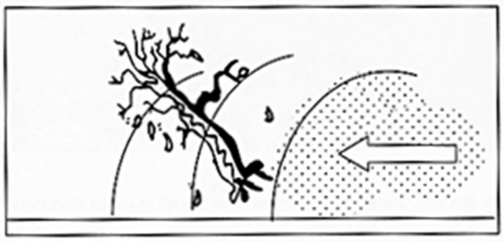
Fig. 66: Assemblage of felled and deposition of trees at Ban Tha Chang Pit 1. (Howard, 1999).

Fig. 67: Burnt and shattered tree. (Howard,1999).

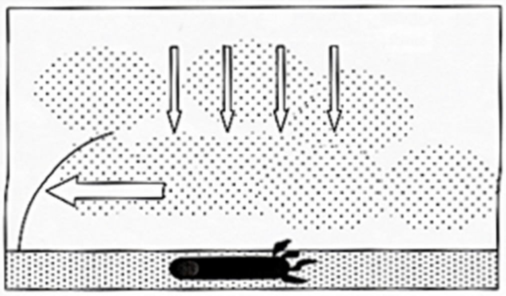
Model of tree destruction in event of impact or atmospheric explosion



A) Shock front from impact advances toward tree



B) Shock energy uproots tree, stripping branches. Heat from shock destroys branches and ignites uprooted tree.



C) Uprooted, burning tree falls to ground as shock front advances. Fall out of ejected sand, dust,ash and impact glasses in the shock fronts wake buries the burning tree. This burial depletes oxygen and causes smoldering of the remaining tree trunk and root clump, leading to the development of charcoal throughout entire trunk. NB: non- burnt trees are envisaged to simply be uprooted and snapped by shock front without burning or with only initial burning prior to burial and extinguishment of fire.

Fig. 68: Model for effects of initial shock front and thermal pulse on trees from impact. (Howard et al., 2003).

Uprooted tree trunks to > 1 metre in diameter are often shattered, branchless, snapped, and burnt to the core. Their presence in deposits throughout Thailand is evidence of widespread burning and are reminiscent of the huge forest devastation of the Tunguska, Siberia aerial blast in 1908 (Fig. 62).

We suggest a genetic relationship between the mega-flood and deposits, forest burning and the ca. 800 ka impact event (Figs. 68 and 69).

This forest destruction would have greatly accelerated the erosion regime in the area and increased sediment and wood supply to drainage channels including the palaeo-Mun River. Floods ultimately overwhelmed the drainage networks and led to breaching of existing banks and log-jam induced dams in a series of mega-flood events that represent major topographic modification of the environment (Fig. 69).

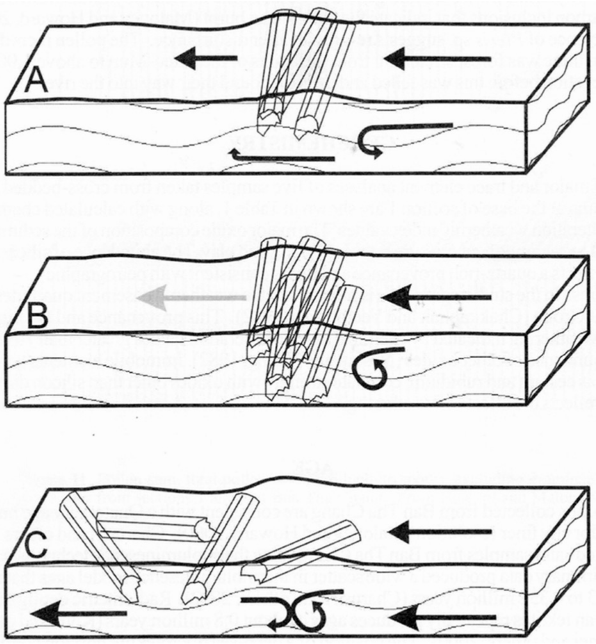


Fig. 69: Depositional model for log bearing flood deposits.
A. Early stage log jam.
B. Log-jam density increase, reduced flow and deposition of mud lenses during this low energy period.
C. Pressure builds up behind log jam until the point of failure. On failure, a high energy flow resulted and deposits the sand, gravel, and logs in distinct stratigraphic horizons. (Howard et al., 2003)

Some logs have longitudinal fractures and snapped ends. Such logs show evidence of insect burrowing (Fig. 84) (Howard et al., 2003).

4.4 Tektites in Khorat sandpits

Completely unabraded tektites were found throughout unit A (Fig. 85). These tektites show little evidence of having been transported. And are comparable, if not better, in their preservation than those from famous locality near Port Campbell, Victoria, Australia (Shoemaker and Uhlherr, 1999). Tektites were also found in unit B but these are abraded and have spent considerable time being reworked and transported. Geochemical analyses of tektites from Ban Tha Chang and Chum Phuang show that they belong to the Australasian strewn field. Haines et al. (2004) found one very fragile tektite at Chum Phuang that is extremely unlikely to have been reworked (Fig. 85).

4.5 Palynology at Ban Tha Chang sandpits

Pollen sequences for two pits at Ban Tha

Fig. 70: Ban Tha Chang sands, Pit 2, with abundant burnt wood near bottom removed by sediment hosing.

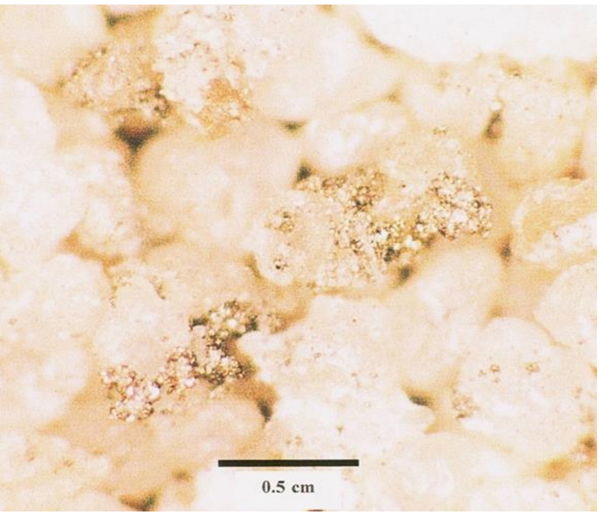


Fig. 72 B: Pyrite on quartz grains. (Howard, 1999)

Fig. 71: Facies 1, cross bedded sands (Howard,1999).

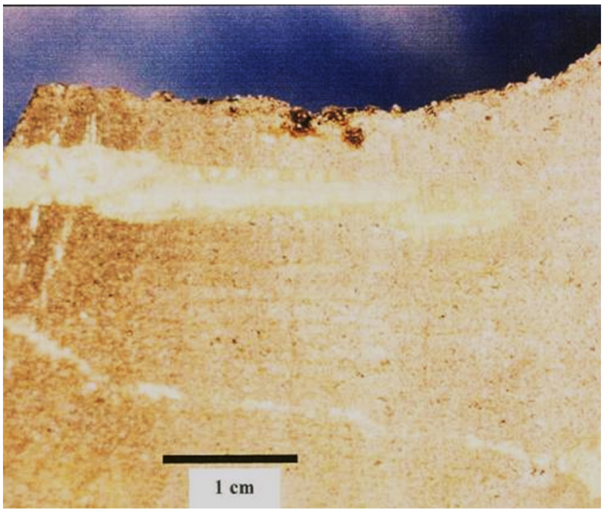


Fig. 73: Pyrite in burnt trees. Pyrite occur as 'veinlets' in fracture within the trees fragment. Pyrite also forms a disseminated grains throughout charcoal in petrified trees at Ban Tha Chang sands. (Howard, 1999).

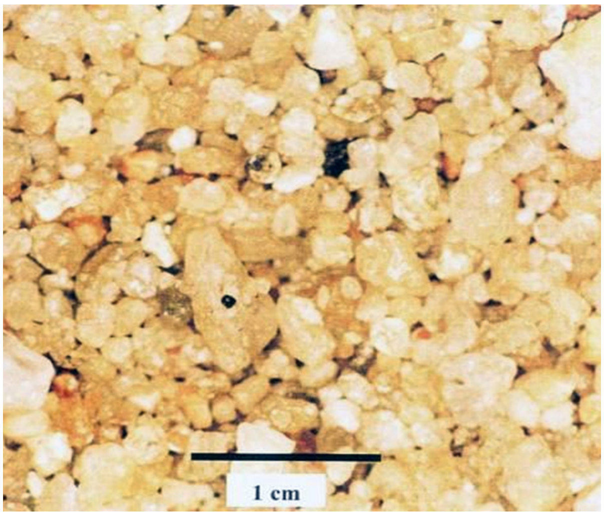


Fig. 72A: Facies 1 under binocular microscope, note the poor sorting in this facies (Howard, 1999).

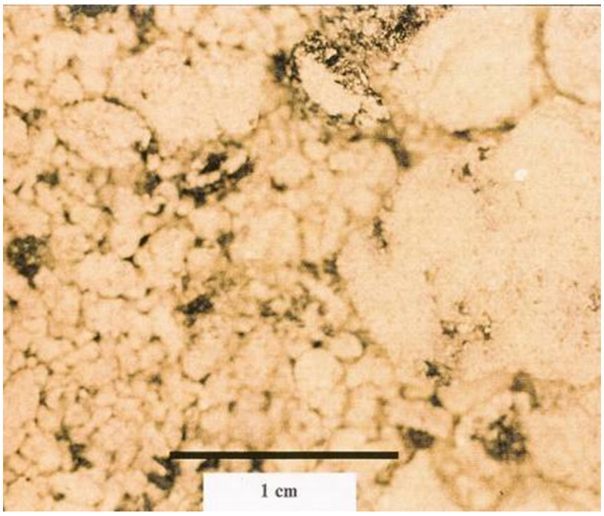


Fig. 74: Charcoal in facies 1 (Howard, 1999).

Fig. 75: Facies 2: structure-less sands (Howard,1999).

Fig. 76: Ban Tha Chang. Facies 3: silt. (Howard, 1999).

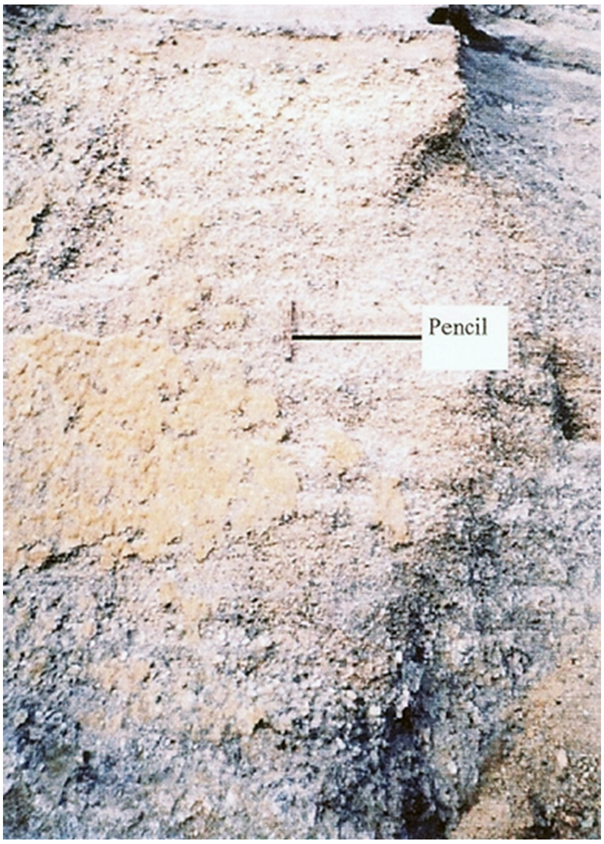


Fig. 77: Ban Tha Chang. Facies 4: Pebble/gravels. (Howard, 1999).

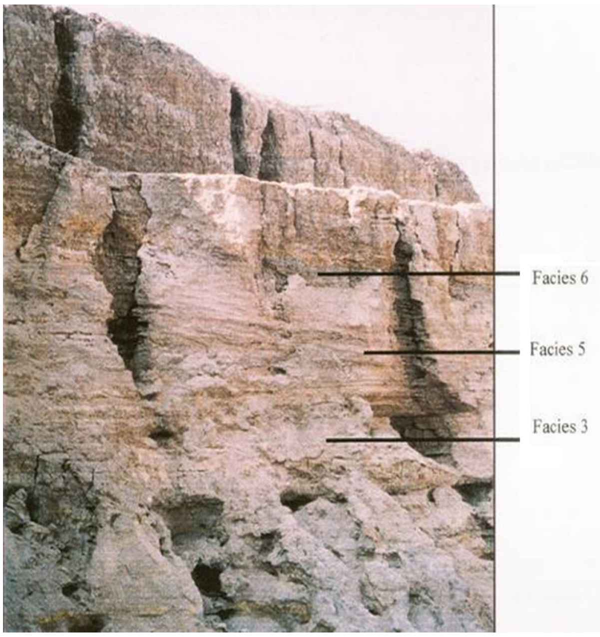


Fig. 78: Facies 5 and 6 on the upper part of Ban Tha Chang Pit 2. The distinct beds are of facies 5. Total thickness of facies 5 = 3m. (Howard, 1999).

Fig. 79: Type section at Pit 1, left 14 m high; Pit 2 right 15 m high. (Howard, 1999).

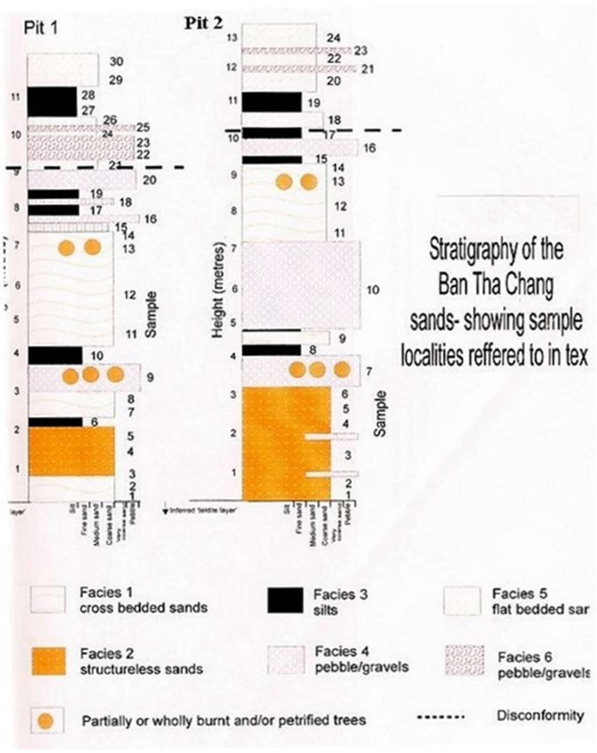


Fig. 80: Lithofacies on the Ban Tha Chang sands stratigraphy of Pit 1, left and Pit 2, right. (Howard, 1999).

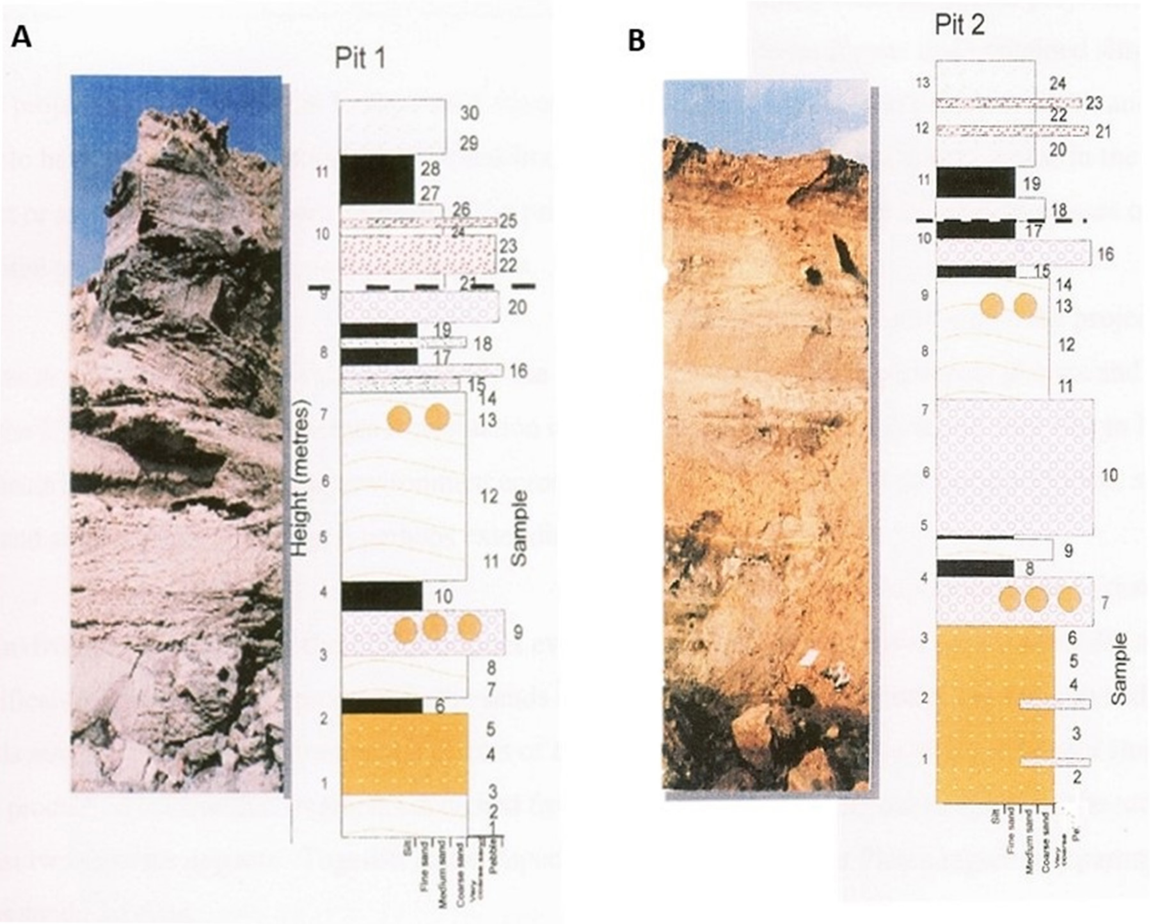


Fig. 81 A: Ban Tha Chang. Pit 1 B: Ban Tha Chang. Pit 2 (Howard, 1999).

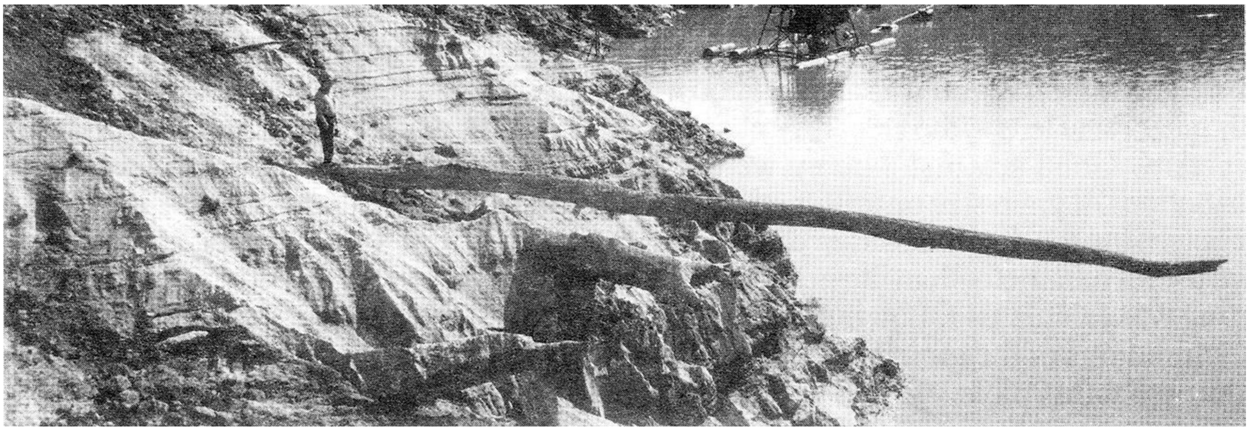


Fig. 82: Large limbless logs in flood deposits at Chum Phuang. Note man standing on log (1.87 m tall) for scale

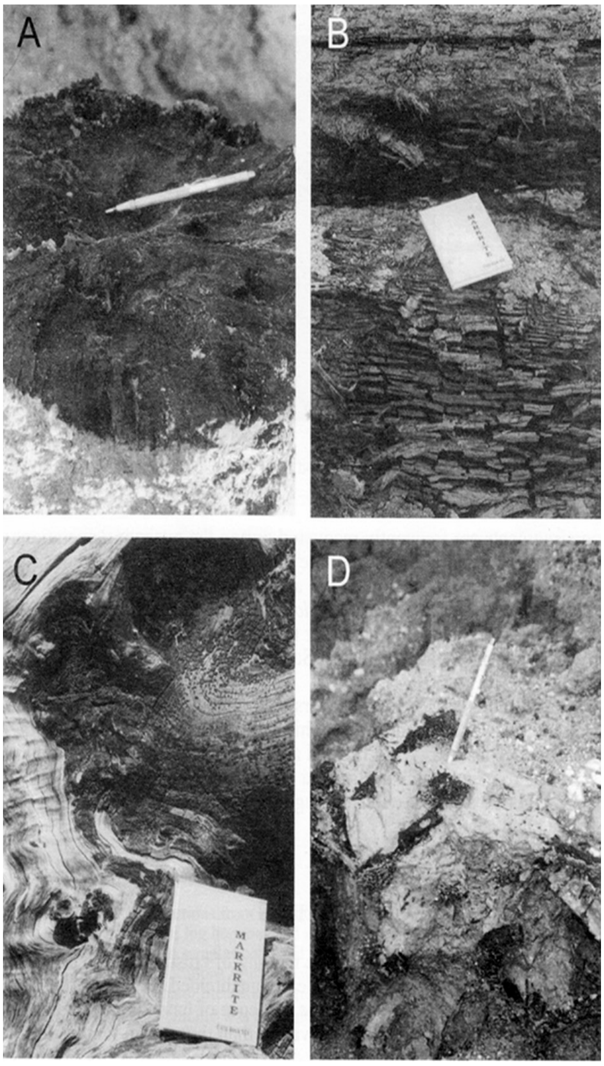


Fig. 83: Variably burnt woody material in the flood deposits.

A. Log that is completely composed of charcoal.

B. Partially burnt log. The burnt outer margins are crumbling away from the non-burnt core.

C. Partially scorched log. The surface of this log has been variably singed by intense heat before the flames were extinguished.

D. Small burnt pieces of wood in sand at Ban Tha Chang, logs are more evenly distributed throughout the profiles.

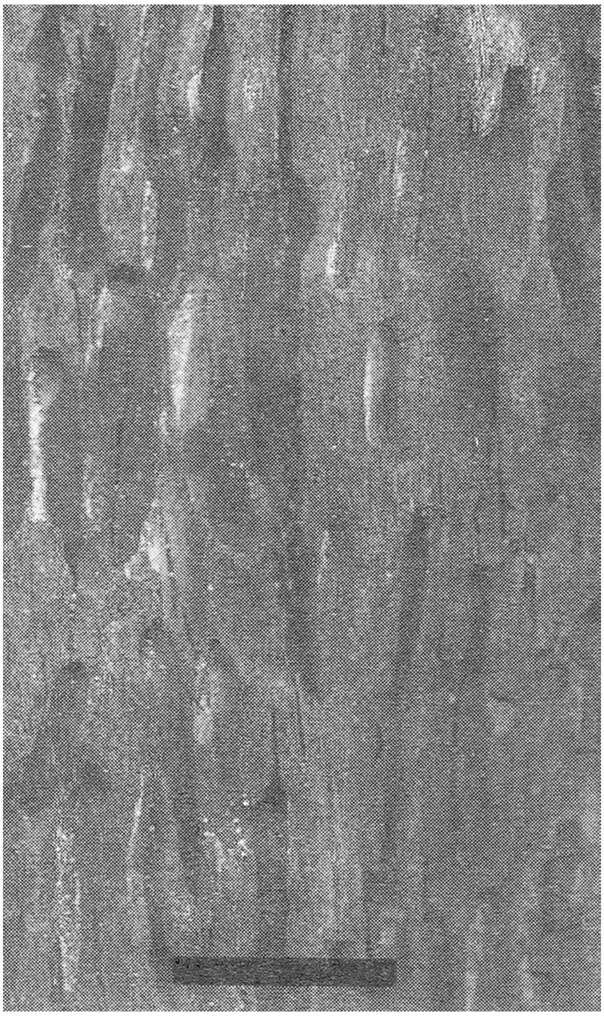


Fig. 84: Insect burrows in non-burnt wood from Ban Tha Chang. (Howard et al., 2003) (Bar scale = 1 cm)

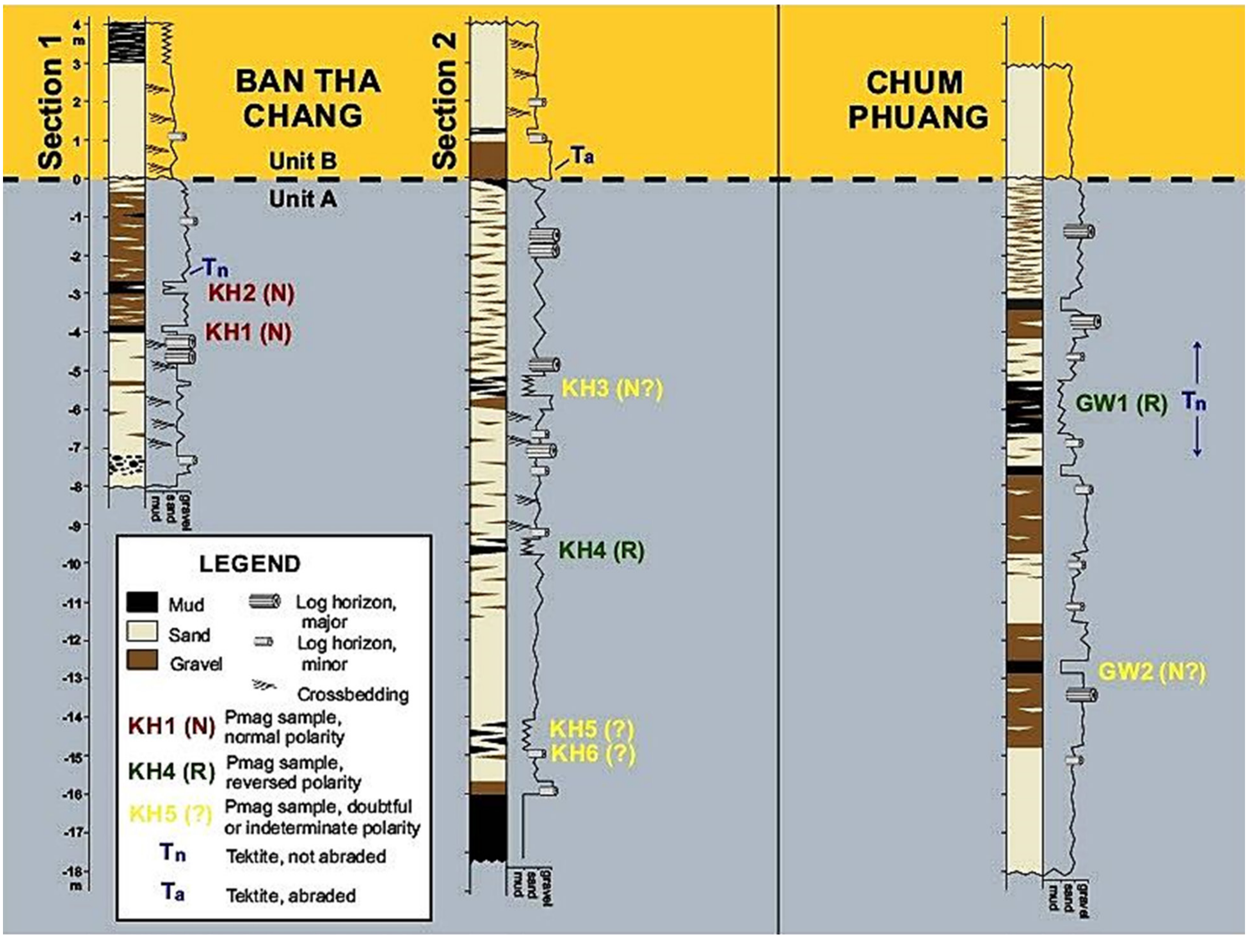


Fig. 85: Measured section from sand quarries at Ban Tha Chang and Chum Phuang showing the position of the main log horizon. The polarity of magnetic remanence in samples collected and analysed by Haines et al. (2004). Measured sections were terminated at the top when material disturbed by mining was encountered. Unpublished colour Fig. kindly provided by Dr Peter Haines (Australia).

Chang by Maloney and Howard (2000) are presented in Fig.86. These data are percentage -based and the Pinus pollen data should be ignored when characterising the past local vegetation because pine pollen are widely dispersed and may have been distantly sourced. Podocarpus, Castanopsis / Lithocarpus, and Quercus are likely to be from forests above 1,000 meters elevation. Salix tetrasperma and Elaeocarpus species are common along river courses.

Both sections show an upward decrease in pollen diversity and a simultaneous proportional increase in grasses. Gramineae pollen dominates all samples and this suggests that vegetation was open. Most Thai trees are pollinated by insects and animals and do not produce much pollen and maybe are significantly under-represented. Samples P2-7 and S3-13 contain phytoliths from Panicoid genera grasses. Some of these phytoliths from S3-13 contain carbon inclusions that indicate they have been burnt (Maloney and Howard, 2000).

The occurrence of the fern Pteris sp. suggests re-growth after disturbance. The pollen record shows that there was forest stretching from the banks of the paleo-Mun to above 1,000 meters elevation before this was felled and the trees found their way into the river.

4.6 Geochemistry of Ban Tha Chang sands

Results of major and trace element analyses of five samples taken from cross-bedded and sand at the base of section 1 are shown in Fig. 87, along with calculated chemical index of alteration weathering index values. The major oxide composition of the sediments indicates at two-component mixture between quartz and clay. The abundance of silica dioxide reflects a quartz-rich provenance and this is consistent with petrographic observations. In the study region, this is most likely the weathered basement sandstones of the Khorat Group. This provenance

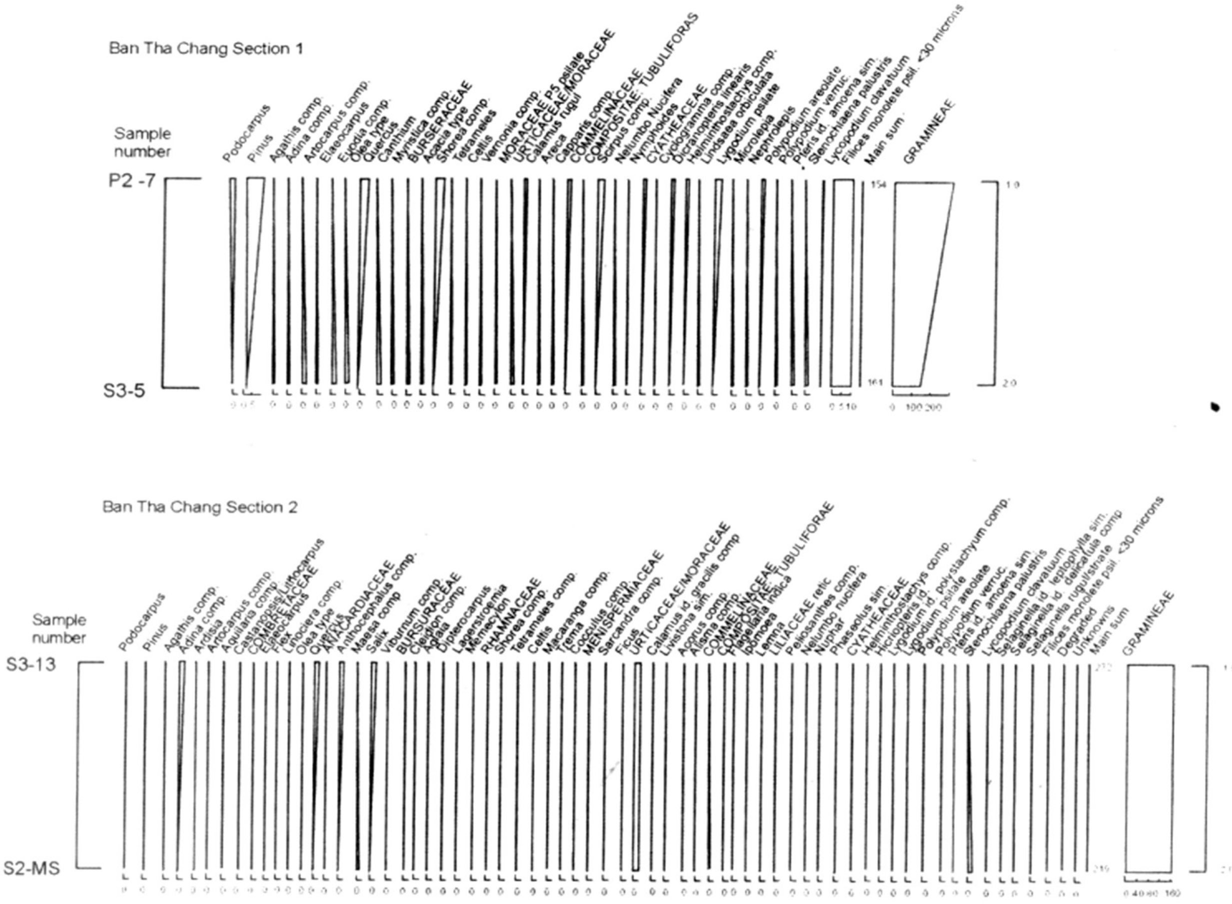


Fig. 86: Pollen sum, total pollen , and pteridophyte spore Gramineae. Sample from Ban Tha Chang. Many are present-day Khao Yai species. (Maloney and Howard, 2000)

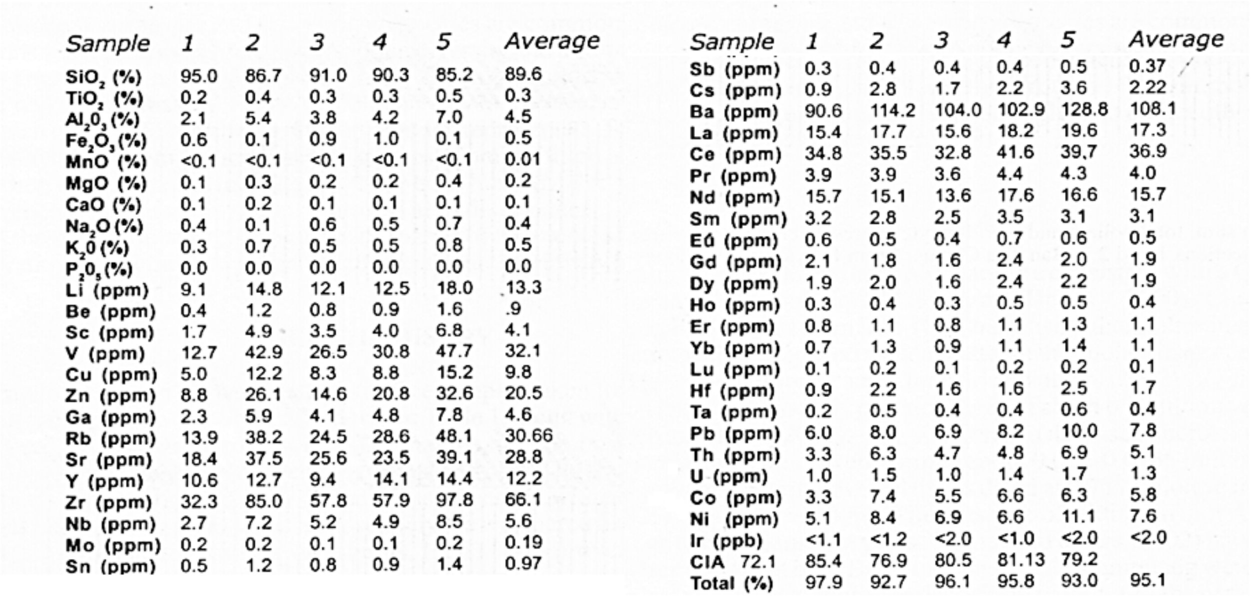
and the high degree of weathering indicated by chemical index of alteration values greater than 70 explain the low abundance of other oxides (Nesbitt and Young, 1982). Immobile elements typical of clay, such as cesium and rubidium, correlate strongly with oxides other than silicon dioxide. This also reflects the effects of weathering.

4.7 Ages of sediments, palaeomagnrism and fossil mammals at Ban Tha Chang and Chum Phuang.

4.7.1 Ages of sediments at Ban Tha Chang

Palynomorphs collected from Ban Tha Chang are consistent with a Quaternary age but do not allow for any finer resolution (Maloney and Howard, 2000). Charusiri et al. (2002) dated sand samples from Ban Tha Chang using thermoluminescence (TL) techniques. Their preliminary data produced a wide scatter in thermoluminescence model ages that range from 0.623 to 4.338 million years (Charusiri et al., 2002). However, the level with burnt tree trunks and tektites gave a TL age of 0. 748 Ma. along with a similar age for tektites.

“Radiometric dating of Australasian tektites repeatedly produces ages of about 0.8 million years (Kunz et al., 1995 ; Hou et al., 2000; Jourdan et al., 2019). The position of a deep-sea microtektite horizon confirms that the Australasian tektites were formed about 0.012-0.0165 million years prior to the Brunhes/Matuyama polarity reversal that is dated at 0.78 million years (Schneider et al., l992; Lee and Wei, 2000). The presence of tektites in unit A constrains the maximum age to ca. 0.8 million years. Haines et al. (2004) have demonstrated that mud layers from unit A at both Ban Tha Chang and Chum Phuang were deposited under reversed polarity. This constrains the deposition of unit A to the period between the time of the tektite fall and the Brunhes/Matuyama polarity reversal. This is between about 0. 8 million years and 0.78 million years. The completely unabraded nature of tektites in unit A suggests rapid deposition after the tektite-forming impact event.” (Haines et al., 2004).



Sample	1	2	3	4	5	Average
SiO_2 (%)	95.0	86.7	91.0	90.3	85.2	89.6
TiO_2 (%)	0.2	0.4	0.3	0.3	0.5	0.3
Al_20_3 (%)	2.1	5.4	3.8	4.2	7.0	4.5
Fe_2O_3 (%)	0.6	0.1	0.9	1.0	0.1	0.5
MnO (%)	<0.1	<0.1	<0.1	<0.1	<0.1	0.01
MgO (%)	0.1	0.3	0.2	0.2	0.4	0.2
CaO (%)	0.1	0.2	0.1	0.1	0.1	0.1
Na_2O (%)	0.4	0.1	0.6	0.5	0.7	0.4
K_20 (%)	0.3	0.7	0.5	0.5	0.8	0.5
P_20_5 (%)	0.0	0.0	0.0	0.0	0.0	0.0
Li (ppm)	9.1	14.8	12.1	12.5	18.0	13.3
Be (ppm)	0.4	1.2	0.8	0.9	1.6	.9
Sc (ppm)	1.7	4.9	3.5	4.0	6.8	4.1
V (ppm)	12.7	42.9	26.5	30.8	47.7	32.1
Cu (ppm)	5.0	12.2	8.3	8.8	15.2	9.8
Zn (ppm)	8.8	26.1	14.6	20.8	32.6	20.5
Ga (ppm)	2.3	5.9	4.1	4.8	7.8	4.6
Rb (ppm)	13.9	38.2	24.5	28.6	48.1	30.66
Sr (ppm)	18.4	37.5	25.6	23.5	39.1	28.8
Y (ppm)	10.6	12.7	9.4	14.1	14.4	12.2
Zr (ppm)	32.3	85.0	57.8	57.9	97.8	66.1
Nb (ppm)	2.7	7.2	5.2	4.9	8.5	5.6
Mo (ppm)	0.2	0.2	0.1	0.1	0.2	0.19
Sn (ppm)	0.5	1.2	0.8	0.9	1.4	0.97

Sample	1	2	3	4	5	Average
Sb (ppm)	0.3	0.4	0.4	0.4	0.5	0.37
Cs (ppm)	0.9	2.8	1.7	2.2	3.6	2.22
Ba (ppm)	90.6	114.2	104.0	102.9	128.8	108.1
La (ppm)	15.4	17.7	15.6	18.2	19.6	17.3
Ce (ppm)	34.8	35.5	32.8	41.6	39,7	36.9
Pr (ppm)	3.9	3.9	3.6	4.4	4.3	4.0
Nd (ppm)	15.7	15.1	13.6	17.6	16.6	15.7
Sm (ppm)	3.2	2.8	2.5	3.5	3.1	3.1
Eû (ppm)	0.6	0.5	0.4	0.7	0.6	0.5
Gd (ppm)	2.1	1.8	1.6	2.4	2.0	1.9
Dy (ppm)	1.9	2.0	1.6	2.4	2.2	1.9
Ho (ppm)	0.3	0.4	0.3	0.5	0.5	0.4
Er (ppm)	0.8	1.1	0.8	1.1	1.3	1.1
Yb (ppm)	0.7	1.3	0.9	1.1	1.4	1.1
Lu (ppm)	0.1	0.2	0.1	0.2	0.2	0.1
Hf (ppm)	0.9	2.2	1.6	1.6	2.5	1.7
Ta (ppm)	0.2	0.5	0.4	0.4	0.6	0.4
Pb (ppm)	6.0	8.0	6.9	8.2	10.0	7.8
Th (ppm)	3.3	6.3	4.7	4.8	6.9	5.1
U (ppm)	1.0	1.5	1.0	1.4	1.7	1.3
Co (ppm)	3.3	7.4	5.5	6.6	6.3	5.8
Ni (ppm)	5.1	8.4	6.9	6.6	11.1	7.6
Ir (ppb)	<1.1	<1.2	<2.0	<1.0	<2.0	<2.0
CIA 72.1	85.4	76.9	80.5	81.13	79.2	
Total (%)	97.9	92.7	96.1	95.8	93.0	95.1

Fig. 87: Analytical results for five samples, TC1 to TC5, from the base of section 1 at Ban Tha Chang. Major elements by X-ray fluorescence and trace elements, excluding Ni, Co, and Ir, by solution inductively coupled plasma mass spectrometry at the University of Tasmania. Ni, Co, and Ir by ignition neutron activation analysis at NASA Johnson Space Center. Chemical index of alteration values calculated using equation of Nesbitt and Young (1982) suggest a high degree of weathering in these sand samples. (Howard et al., 2003)

Fig. 88: Field photograph of log and tektite bearing deposits in a gravel and sand quarry near Chum Phuang (15.381° N. 102.728ºE). Unit B is overlain by material transported during excavation. (Haines et al., 2004). Photograph kindly supplied by Dr Peter Haines (Australia).

Fig. 89: Field photograph of a major log-bearing horizon at Chum Phuang. Some of the logs have been washed out of the enclosing sediments by water cannon operations. (Haines et al., 2004). Photograph kindly supplied by Dr Peter Haines (Australia).

4.7.2 Palaeomagnetism of sediments at Ban Tha Chang and Chum Phuang

"Palaeomagnetic evidence including reversed polarity in mud lenses closely associated with unabraded tektites suggests that tektite-bearing flood deposits near Ban Ta Chang and Chum Phuang are penecontemporaneous with the impact event. The deposits include abundant organic debris, including whole tree trunks (Figs. 88-89) and mammal bones that were preserved due to reducing conditions, which are also responsible for the presence of abundant iron sulphides. Sedimentological observations suggest a series of major flood events that are out of character with the modern meandering river system to which they are related. The deposits are consistent with the effects of regional deforestation, increased run off and erosion, and other environmental disruptions expected in the aftermath of a major impact event". Haines et al. (2004).

Tektites by themselves only provide a oldest age limit for the deposits in which they occur, and claims of tektites embedded in sediments dating from the time of fall (e.g. Hou et al., 2000) have been criticized for lacking independent age constraints (e.g. Koeberl and Glass, 2000). Previous authors (e.g. Howard et al., 2000) have suggested that some ancient flood deposits in Thailand may be related to the ~ 0.8 Ma impact event. Haines et al. (2004) confirmed the presence of in situ Australasian tektites within these deposits and used palaeomagnetic and other evidence to provide independent minimum-age constraints.

"The sand-pit deposits are very similar at both locations, comprising distinct lower and upper units, separated by a marked discontinuity (Fig. 85). The upper unit (unit B), is typically about 5 m in thickness and continuing to the surface, comprises sand, fine gravel and silt considered to represent normal channel and floodplain deposition produced by the migrating meander belts of the Mun River. This unit is oxidized, has a brown-yellow color, and contains minimum organic matter, limited to minor isolated fragments and logs of wood, the latter possibly reworked from the underlying unit. The lower unit (unit A) is markedly different, comprising crudely stratified and cross-bedded sands and gravels, with minor lenticular mud horizons. Logs of wood, including entire limbless tree trunks, some in excess of 10 m in length and complete with tap roots are common throughout the unit, but are particularly abundant in discrete horizons. Some of the wood is partly or wholly replaced by silica and pyrite, but most is preserved as original woody tissue. The local presence of charcoal on the same logs is confirmed by Environmental Scanning Electron Microscope (ESEM) studies (Howard et al., 2003). Fragmentary mammal bones are also present. The entire lower unit is chemically reduced, with a grey color and ubiquitous pyrite/marcasite present as disseminated material and as encrustations around wood and bone." Haines et al. (2004).

Several previous workers have reported tektites in the sand quarries at Ban Tha Chang e.g. (Charusiri et al., 2002; Sato, 2002). "We searched all measured stratigraphic sections and adjacent exposures for tektites and were successful in locating four tektites in situ; one from unit A and two from unit B at Ban Tha Chang, and one from unit A at Chum Phuang. The specimens from unit A have sharp broken edges and no signs of fluvial abrasion while both from unit B have clearly been abraded by prolonged fluvial action. In the former, the sharp delicate broken edges show evidence of light chemical etching indicating that breakage preceded burial and is not of modern origin." Haines et al. (2004).

4.7.3 Palaeomagnetic studies of sand section from the pit

Palaeomagnetic studies were carried out on oriented mud samples collected from unit A along three measured quarry sections; two at Ban Tha Chang and one at Chum Phuang. "Available sedimentological evidence strongly suggests that at least the upper well exposed section of unit A was deposited rapidly, but probably in several discrete pulses as indicated by the lenticular mud interbeds. Two independent lines of age evidence are broadly supportive of our age interpretations. Bones that we collected within unit A at Ban Tha Chang include common Stegodon sp. (J. de Vos, personal communication, 2002) indicating a mid-Pleistocene or older age, although it is possible that some bones could be reworked from a lower horizon. Thermoluminescence dating of quartz grains from tektite-bearing sands at Ban Tha Chang gives a reported age of 0.75 ± 0.13 Ma (Charusiri et al., 2002; Howard et al., 2003). Unit A is interpreted as a series of high-energy flood deposits. They are unusual in their preservation of abundant organic debris, most notably large complete tree trunks. Fast flowing river channels and sheet floods are normally oxidized environments. The reduced nature of these high-energy deposits is thus somewhat paradoxical, unless the large amounts of entrained organic matter were buried and sealed rapidly, before significant aerobic decay was possible. Under such sealed conditions, oxygen is quickly exhausted during incomplete aerobic decay leading to reducing conditions and development of iron sulfides by the sulfate reduction activity of anaerobic bacteria (Saunders et al., 1997). The lack of oxidized, rooted or bioturbated surfaces, suggests that the flood pulses were closely spaced in time, rapidly infilling the pre-existing incised river channel or valley, probably with the aid of frequent debris-induced stream damming."

"Large impact events will be accompanied by regional environmental destruction, including regional deforestation and other changes to the landscape (Toon et al., 1997). Inevitably this will lead to greatly increased erosion and runoff

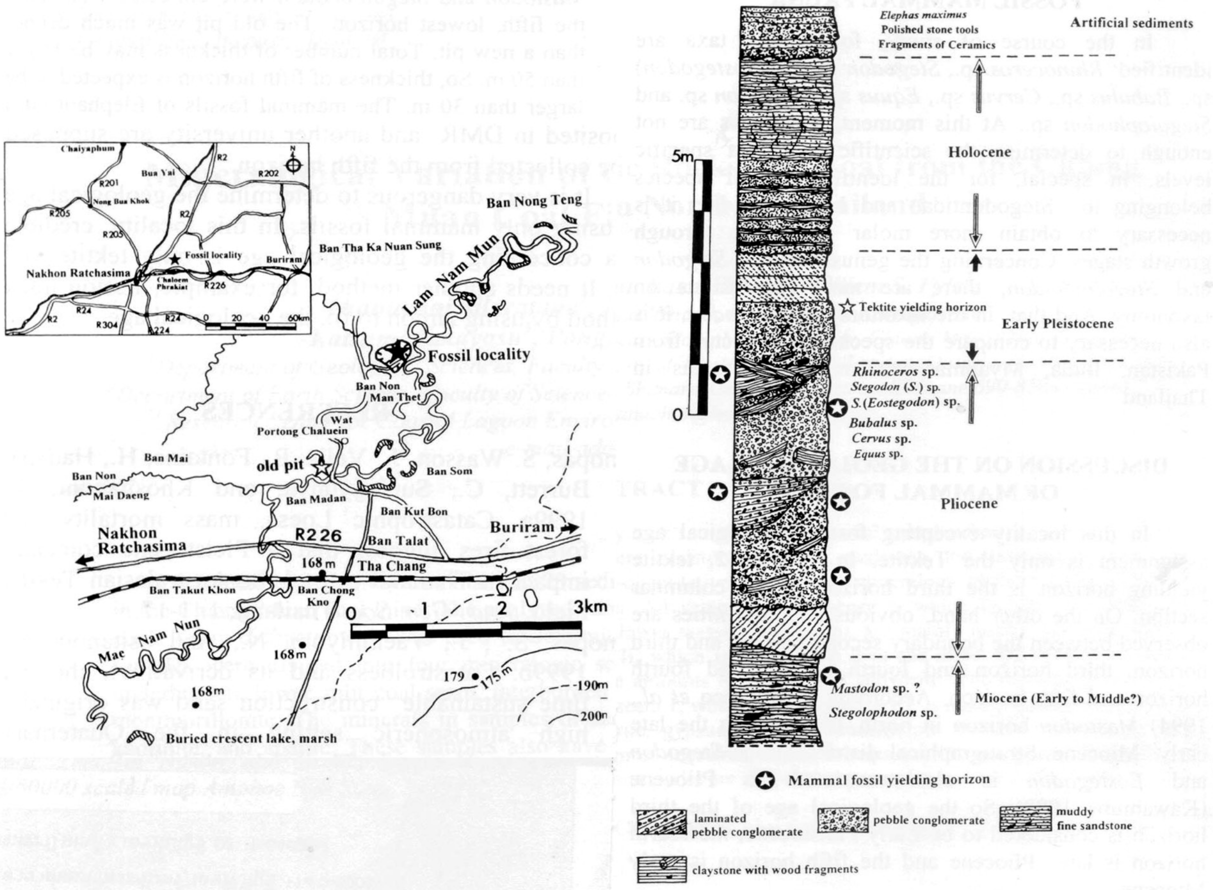


Fig. 90: Location of fossil locality (sand pit), Ban Non Man Thet, in Nakon Ratchasima. (Reproduced from 1/50000 scale map Amphoe Non Sung, 5439/U (Left) and columnar section of fossil locality, new pit (right). (Sato, 2002).

resulting in floods of unusual magnitude, carrying higher than normal sediment loads and plant debris resultant from the deforestation. Such floods would be most likely in the years immediately following the event, before significant recovery of soil binding vegetation. Combining palaeomagnetic evidence with the presence of tektites leads to the conclusion that some or all of unit A was most likely deposited very soon after the ~ 0.8 Ma tektite producing impact event in Southeast Asia. As such, flooding may have been a direct result of increased runoff following catastrophic deforestation, as can be predicted for any large impact event on or near land." Haines et al. (2004).

[Editor's note: These palaeomagnetic, age and palaeoenvironmental conclusions are markedly different from those 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 in the Ban Tha Chang sandpits as the study by Haines et al. (2004). From palynological studies, Yang and Grote (2018 b) suggest major vegetational and palaeoclimatic changes from cool to warm to cool, and correlation of the sediments to parts of two glacial periods (Riss and Wurm) during the deposition of 3.25 m of sediments which Howard et al. (2003) and Haines et al. (2004) argue were deposited within, at most, a few years.]

4.7.4 Fossil mammals at Ban Tha Chang by Sato

"At Ban Non Man Thet, west of Ban Tha Chang, Khorat an extraordinary rich fauna of fossil mammals have been found in the eastern part of Nakhon Ratchasima. A tektite is also found in an upper horizon in the same locality (Fig. 90). The occurrences of fossils are allochthonous. Molars and bones are scattered in the sediments, but they are not derived fossils. Mammal fossils consist of bones and teeth. Lower than the tektite horizon, every horizon yields fossils. Almost of bones are scattered in the beds and thin bones like scapula, ilium and ribs, are deposited parallel to bedding plane. Though the fragmentation of bones is frequent, serious abrasions of the bone surfaces are not observed. Vertebrate hones also are not articulated, but all the processes are nearly preserved. Skulls have not been discovered in this new pit. In the course of study, the following taxa are identified: *Rhinoceros* sp., *Stegodon* sp., *S. (Eostegodon)* sp., *Bubalus* sp., *Cervus* sp., *Equus* sp. *Mastodon* sp. and *Stegolophodon* sp.. At this moment, specimens are not enough to determine species. In species, for the identification of species belonging to Stegodontidae and Mastodontidae, it is necessary to obtain more molar specimens through growth stages.

“In this locality excepting fossils, geological age assignment is only the tektite. In Fig. 90 (below), tektite yielding horizon is the third horizon in the columnar section. On the other hand, obvious unconformities are observed between the boundary second horizon and third horizon, third horizon and fourth horizon and fourth horizon and fifth horizon. According to Ducrocq et al. 1994) the Mastodon horizon in north Thailand is the late early Miocene. The stratigraphical distribution of Stegodon and Eostegodon is also restricted to Pliocene (Kawamura, 1998). So the geological age of the third horizon is considered to be Early Pleistocene, the fourth horizon is late Pliocene and the fifth horizon is early Miocene” Sato (2002).

“Most part of this formation is Miocene. In the present course of study, only a few molars of Mastodon and Stegolophodon were collected from only the fifth, lowest horizon.”

“The old pit was much deeper than a new pit. Total number of thickness may be larger than 50 m. So, thickness of fifth horizon is expected to be larger than 30 m. The mammal fossils of Elephantoidea deposited in DMR and universities are supposed to be collected from the fifth horizon.”

“It is very dangerous to determine the geological age by using only mammal fossils. In this locality, credible data concerning the geological age is only tektite, 0.7 Ma. It needs another method, for example, fission track method by using zircon to fix the geological age.” (Sato 2002)

4.8 Neogene mammalian fauna and reptiles in other areas in Thailand and neighbors – mass mortality in ~0.8 ma impact

Neogene mammalian fauna in Thailand are started researches, and found interesting results that could be relevant to the later ~0.8 Ma impact.

The Japan-Thailand Fossil Expedition Team, reported their paleontological survey in the Late Cenozoic basins of Thailand during the 1996 to 2002 field seasons, and re-examined the geology and mammalian faunas of the following fossil sites: Mae Soi, Chiang Muan, and Sop Mae Tham Northern Thailand); and Tha Chang (Northeastern Thailand). From the sand pits in Tha Chang they found three new Late Cenozoic mammalian faunas at least: the middle Miocene fauna consists of amebelodontid gomphothere and Prodeinotlurium: the latest Miocene to early Pliocene fauna yields Hipparion, Stegolophodon, and Merycopotarnus; and the early Pleistocene fauna yields advanced Stegodon (Figs. 96-98). The discoveries of Pliocene and Pleistocene (in Tha Chang) mammalian faunas are the first reports of mammalian faunas of these ages in Thailand. (Nayake et al., 2003)

4.9 Khok Sung locality, Nakhon Ratchasima Province

“Khok Sung sand pit is situated in Nakorn Ratchasima Province, Northeastern Thailand. Concerning the Pleistocene, a rich and diversified Middle Pleistocene mammalian fauna has been excavated from ancient river deposits at Khok Sung sandpit in Nakon Ratchasima Province which has delivered outstanding fossils like a complete skull of a spotted hyaena which is extinct in Asia (Chaimanee, 2006), several complete skulls of a long snouted gavial, a fish eating crocodile which is also extinct in Thailand. Associated is an extinct elephant, Stegodon and deer, buffalos, gaur and banteng remains, it represents the best preserved Middle Pleistocene fossil assemblage from Thailand. (Fig. 99). Usually these animal remains are only documented from caves where their remains have been fragmented by predators and by porcupines. Therefore mostly isolated teeth are left in cave sediments. From such caves we have also discovered spotted hyaena in the Peninsular Thailand near Nakhon Si Thammarat Province and in several other places in Northern Thailand. Where they are associated with remains of giant

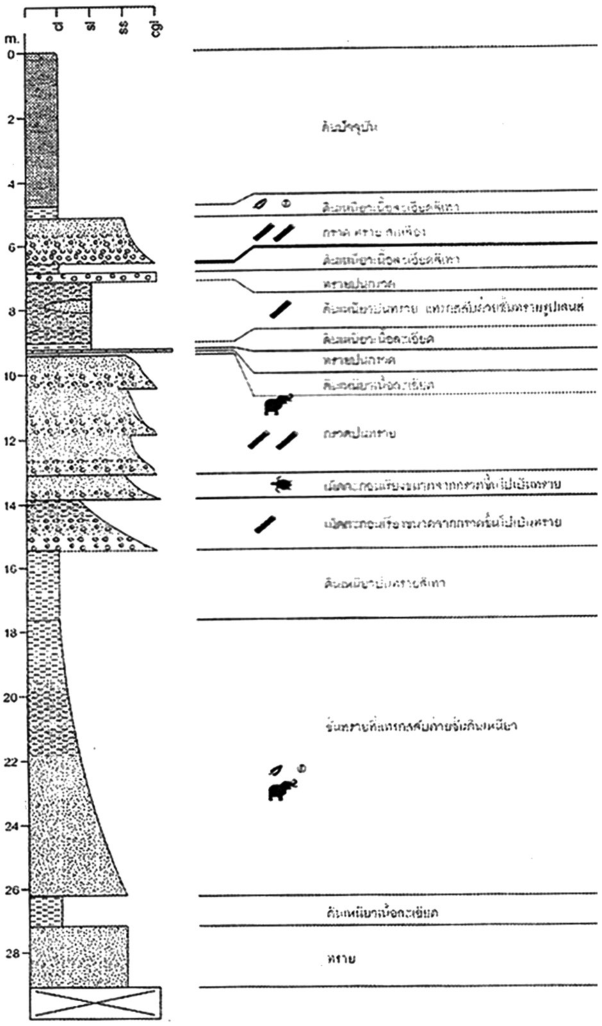


Fig. 91: Strata of the sands at Siam sands mine, Ban Tha Chang (BTC), A. Chalerm Prakiat, Nakorn Ratchasima, Thailand with Upper Miocene elephants (level 10 to 25m), turtle at 15m, and other mammals and other reptiles. Petrified burnt trees and un-burnt, woods are found at many levels. Horse remains are also found in some other sand pits by Chaimanee et al. (2003).

panda, orangutans and many micromammals (Chaimanee, 1998). These fossils indicate that the climate and vegetation was rather different from today, with heavier rain fall and more extended grassland areas at some periods. This interpretation has been recently confirmed by the carbon stables isotopes extracted from the teeth.” Chaimanee, 2006.

“Fossil mammals are well represented for their biochronological and palaeoenvironmental contributions. Several Tertiary basins in Thailand have been precisely dated by combining biochronological data and magnetostratigraphic studies. There are two Paleogene basins rich in mammalian fauna that have been discovered, Krabi basin of late Eocene age located in the Peninsular Thailand and Nong Ya Plong basin of late Oligocene age in Central Thailand. There are several Neogene basins in Northern Thailand that have yielded rich mammalian fauna, most of them being of middle Miocene age. Concerning the Paleoenvironments, Thailand has always remained in the tropical domain during the Tertiary. But the tropical environments have considerably varied through time from rain forests to dry open grassland. Swamp and lake

Fig. 92: Rhinoceros teeth and bones from Somsak sandpit, Khorat.

Fig. 93: Horse teeth in Somsak sandpit Khorat.

Fig. 94: Large turtle from Siam sandpit Khorat. Note hammer for scale.

Fig. 95: Turtle as Fig. 94. Siam sandpit Khorat.

deposits are over represented due to the numerous Tertiary basins. Climate dramatically changed during the ice ages in the Pleistocene (Figs. 91-95), where important latitudinal shifts occurred, some taxa of northern areas such as the giant panda and Hadromys humei (an Assam rat) moved southwards to the Thai-Malay border (Chaimanee & Jaeger, 2000).” (Chaimanee, 2007).

(Ed: More recent work at Khok Sung by Duangkrayom et al. (2014), Duval et al. (2019) and Suraprasit et al. (2015, 2016) have conducted

Fig. 96: Tusk of an elephant in a sandpit in Khorat.

Fig. 97: Stegodon reconstruction fibre-glass models of Sivalik Hills, Nepal specimens. Tusks are 5m long. From: I, Vjdchauhan, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2449818).

Fig. 98: Stegodon teeth, Khorat sand-pit.

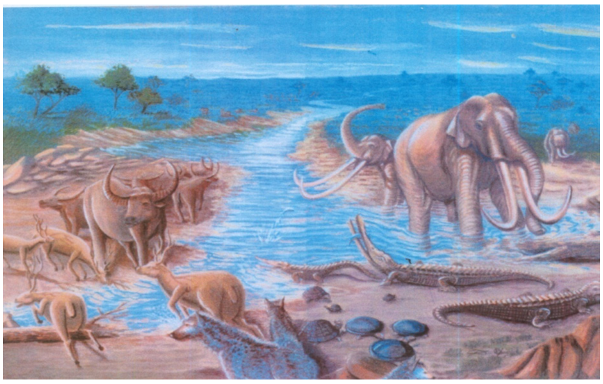


Fig. 99: Reconstruction of the environs of savannah forest of Ban Khok Sung along the palaeo-Mun River, in Khorat (Nakhon Ratchasima), NE Thailand at c. 217 ka or 130 ka (reconstruction from Chaimanee, 2004). A broadly similar reconstruction is possible for the probably older Pleistocene deposits c.788 ka at Ban Tha Chang.

Fig. 100: Early operation of open pit Bo Phloi gem mine western Thailand with yellow sands (loess) on top and numerous burnt felled trees on gravels with sapphire grains.

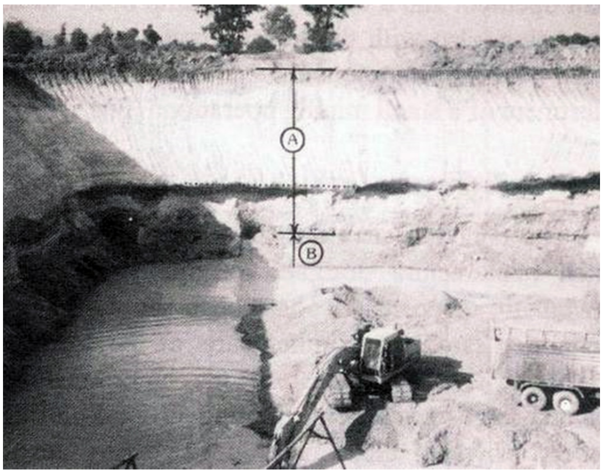


Fig. 101: Bo Phloi gem mine, western Thailand upper (A) sands (loess), lower (A) weathered gravels, (B) gravels with weathered basalt with sapphire. Burnt trees are underlying sands on top of gravels.

Fig. 102: Basaltic flow sheet melted underlying catastroloess as many rolling tennis balls stick to sheet in the lower sheets of basalt hills south of Buriram town (sample by courtesy of Dr. Chumpol Vichiansilp of Buriram Rajabhat University).

magnetostratigraphy, updated the taxonomic composition of the fauna, provided a good sedimentological analysis and have suggested two possible dates at about 217 ± 36 ka or 130± 29 ka based on ESR dating and magnetostratigraphy).

4.10 Bo Phloi sapphire quarries, Kanchanaburi Province, western Thailand.

The sapphire bearing sand-pits at Bo Phloi in Kanchanaburi Province, western Thailand have long been known to contain abundant apparently burnt trees but these deposits have not yet been dated. The upper horizon above the abundant burnt trees (Figs. 100 -101) is probably loess and may, also be

4.11 Buriram basalt enclosed by the catastroloess to form rolling balls.

An interesting sample of basaltic sample with firmly fused by a half golf size sandy loess (catastroloess to be more accurately) was given to us, during Buriram basalt, among many varied sizes of rolling balls of semi-melted loess. All of these samples indicated flowing bands of high heated basaltic flows flown over catastroloess horizon and were meted by basaltic flows flown across. Some loess stick under the flows and some appeared as many rolling balls.

Fall from the impact ended, and were over flowed by later basaltic flows. The sample indicates that parts of Buriram basalt must be younger than 0.8 Ma, which was the age of the catastroloess (Fig.102). Older ^{40}K/^{39}Ar dates by Barr and Macdonald (in Suthirat, 1999) was 0.92± 0.3 Ma and 0.43 Ma. More recent Ar/Ar work by Chualaowanich et al. (2008) also give dates of 0.49-0.43 Ma. If these dates and

Fig. 103 A: Mudflow gravels that buried petrified burnt felled trees in contemporaneous mudflows and avalanches with gravels at south Khorat at a terrace at Ban Krok Duen Ha. The gravels represent previous vegetation surface on common terraces when impact arrived. B: A splashed tektite specimen was found embedded in the mudflow covering the tree. The terrace gravels seen under, nearby catastroloess to east and west.

Fig. 104: Petrified tree within river terrace gravels at Ban Krok Duen Ha, Khorat. Note man for scale.

Fig. 105: Tree (73 m long) found in river terrace gravel at Ban Tak District,Tak, NW Thailand. Pleistocene - exact age unknown. Ban Tak District west of Tak, Afzelia xylocarpa (Kurz) (Photo kindly supplied by Cherdchan Pothichaiya)

Fig. 106: Same as Fig. 105. Tree found in terrace gravel at Tak, NW Thailand. Pleistocene (Photo kindly supplied by Cherdchan Pothichaiya)

conclusions are correct, an age constraint on the loess is provided of >0.43 Ma.

4.12 Ban Krok Duen Ha, Khorat. Tree and tektite in terrace deposit. Huge tree in terrace deposit in Tak, northwest Thailand

Buried petrified burnt tree are found in the contemporaneous mudflows and avalanches with gravels at south Khorat at a terrace at Ban Krok Duen Ha (Fig. 103). A splash form tektite specimen was found embedded in the mudflow covering the tree (Fig. 104). The terrace gravels marked the impact surface, seen under nearby catastroloess, uprooted hard wood tree trunk, burned, was buried under terrifying earthflows, later formed gravel beds at near Wat Krok Duan

Fig. 107: Photo of a new lignite excavation prospecting taken in January 2000 at immediately south of the road from Hod to Mae Sariang at the beginning of the road from Suan Son to Omkoi in inferred Precambrian terrain.

Ha, at Khorat Petrified trees Museum site in Khorat on the Khorat Plateau. When impact all trees grown on older gravel terraces were suddenly uprooted fallen flat and almost all of the catastrophic burned or burnt trunks pointing their roots ends to the blasting impact on Ubon Ratchatani etc., and some are entrained by surface slump, landslide and earthflows. The gravels were mixed with atmospheric falls of catastrophic loess, splashed tektites until none but catastrophic loess or the catastroloess for more than 10m. We nominate the as this Q1/Q2 boundary the new and more advanced datings ~800 ka.

4.13 Suan Son Lignite Quarry (Bo Luang Prospect), Hod, 90 km south of Chiangmai

Suan Son Lignite Quarry (Bo Luang Prospect, now Lam Thong Mining in 2002) is recently known (later than 1990, after the Geological Mapping Program of Baum et al., 1970; and Hahn et al.,1986) in the previous Tertiary basins in the Precambrian terrain of the Western Mountains described and the study above by Uttamo et al. (1999). Tertiary beds were truncated by grey muddy sands (Fig.107) while uplifting to more than 1000 m above sea level and were finally overlain by brownish red catastroloess sands dating to 790 ka. This was indicated that the general uplifting of this area was active before and during 790 ka, as similar to the uplifting of diatomaceous beds that was uplifted, in Fig. 107, before the catastroloess was falling in. This also implied that the uplifting of the Western Mountains were uplifting during Lower Pleistocene as was real-time correlated dating from the catastroloess. Almost everywhere catastroloess were over the high to medium terraces excepting floodplain. See Uttamo et al. (1999) for more new information on Tertiary sequence on the Western Mountains.

At Bo Luang, Suan Son (Pine trees forest) in the "former western mountains and the peninsular parts", tilted and slightly folded Tertiary with the unconformably overlying 2 meters dark grey muddy-sandy soil is conformable with the grey beds by three meters of reddish yellow catastrophic sands (catastroloess) and topsoil found in early 2000. There is not any conglomerate between folded lignite beds or the grey topsoil and the reddish yellow catastrophic sands (catastroloess). It is most likely means when the lignite beds folded the measures soon covered by topsoil and was relatively uplifting while the nearby areas deposited gravel beds (Bunopas,

Fig. 108: Sand beds at sand quarry west of Na Thawi, southern Thailand also showing a little more than 6 m (top parts above distinctive fault). Lower parts are faulted sandy gravel beds of pre~0.8Ma impact.

1981).

Probable loess or catastroloess is also found in southern Thailand as at Na Thawi (Fig.108).

THE INTHANON EPEIROGENY IN THAILAND

Another effect of the immediately pre-catastroloess was shifting of courses of rivers such as the Mun and Chi. Mekong River that was already moved eastwards from the Grand Lake in Cambodia towards southern Laos and northeast Cambodia. The Grand Lake (Tonle Sap) itself became overfilled and deserted. Hartung (1990) and Stauffer (1978) suggested a tektite source crater in the Tonle Sap, but this is considered very unlikely.

The Khorat Plateau Early Quatemary Vertical Uplifting was after Long Cenozoic Cratonization of the Mesozoic Khorat Group. Its Northeast Tilting Diverted the Mae Khong River before the 0.8 Ma Cometary Impact Catastroloess and the verflowing Mid-Pleistocene Buriram Basalt. New discoveries in northern Thailand suggest the late Pliocene to lower Quaternary Inthanon Epeirogeny and uplift from 200 m to 1,000 m, or even to 2,600 m in the western mountains of Thailand (Bunopas et al., 2004). The Khorat Plateau early Quaternary vertical uplift, after the long Cenozoic cratonization of the Mesozoic Khorat Group, its northeast tilting eastwards diverted the Mae Khong River before the 0.8 ma cometary impact catastroleoss and the overflowing Mid-Pleistocene Buriram and Indochina basalts. Palaeomagnetic reversal polarity results from the catastroloess ensemble show the real-time catastroloess from the Buntharik Event of ~0.8Ma cometary impact are absolutely well chronologically constrained.

The base of the impact in the Buntharik Event is now absolutely certain at the level of ancient felled burnt trees, covering by earth and mudflows on the blasting and heat wave followed shortly by thunder storms and heaviest rains on earth resulting in the buryial of trees. In the avalanche debris at Ban Krok Duen Ha contain pioneer splash tektites, and this level on ancient high and medium terraces in Khorat is only few m. below lateritic sands in Ubon Ratchatani known by Fiske et al. (1996) near the Chulaphorn Dam filled with splash tektite in a row of catastroloess. Above the horizon are massive clayey sands here called catastroloess for some meters.

Settling of enormous debris and fine sands in the later stage given rise to the accumulation

Fig. 109: *Homo erectus skull* (Peking Man also Java Man in Indonesia). Photograph by Yan Li of specimen in Paleozoological Museum of China (https://en.wikipedia.org/wiki/Homo_erectus).

of catastroloess field, of considerable thickness, accumulated evenly in a sheet to all earth surface in differ local environments from tops of mountains to bottoms of the seas as constructive material burying most of the "Old World" surface. The catastroloess did varied from places to places concerning chiefly upon local environs where it rested on. Catastrophically, when it falls it was globally fallen down to differ qualitatively and quantitatively devastated and disaster surfaces. The process on the formation of the catastroloess needed to have precisely studied dynamically. Since it was previously globally known and was seriously interpreted with the strong conception for normal local geological windblown sands or flooded river sands, or ordinary loess, for more than a century in Thailand or abroad.

In fact, catastroloess was the accumulation of ejecta, impactites and previous erosion debris, but there were unknown of such considerable thickness from previous geological record. Ordinary loess does not quantitatively contains such products of ejecta, impactites, impact sands, impact glasses, microtektites and dust, but local or exotic erosion debris with/or without minor local glacial outwashes blown, traditionally in Europe, by lateral low atmospheric windblown or gusty storm.

4.14 Tektites in Southeast Asia and Homo erectus

[Editor's note: The predecessor species to our species Homo sapiens - Homo erectus in Java is now well studied and the tektites found in the H.erectus beds and associated volcanic horizons are well dated. There can be little doubt that Homo erectus (a.k.a. Pithecanthropus, Java Man, Peking Man (Fig. 109)) witnessed the Australasian tektite event both in Yunnan and Java and would have been strongly affected by the event. Hou et al. (2000) have studied the convincingly unreworked tektites and also the stone tools from the Bose Basin in Yunnan which were almost certainly made by Homo erectus and conclude "..the presence of abundant charcoal and silicified wood fragments, detected during excavation and laboratory study, {are} in precisely the same sediments containing the tektites and stone artifacts. On the basis of the co-occurrence of these remains, we suggest that the Paleolithic artifacts of Bose signal a behavioral adaptation to an episode of woody plant burning and widespread forest destruction initiated by the tektite event, which exposed cobble outcrops throughout the basin." and subsequent use of the cobbles by incoming H.erectus populations.

The following is a discussion of the stratigraphic position of Homo erectus in Java from Sibava (1993). "The Jetis fauna containing early Javanese Homo erectus is Early Middle Pleistocene according to Hooijer, Kurten and Kahlke (in Nilsson, 1983). Beds following the Trinil fauna possess a rich faunal assemblage with 440,000 to 600,000 years for basalt layers interbedded with marine deposits containing the Trinil fauna. Tektite dated about 700,000 years have been found some The late Cenozoic strata in the Sangiran area have been divided into an Upper and Lower Kalibeng Formation, followed by the Early Pleistocene Pucangan Formation, and the Early to Middle Pleistocene Kabuh and Notopuro Formations (Watanabe and Kadar, editors, 1985). Tektites represent another marker horizon, suitable for wider regional correlation. The tektites found in situ in the middle part of the Kabuh Formation in the Sangiran area of Java have been dated by the fission track method at 0.71 ± 0.09 million years and 0.71 million years respectively (Itihara et al., 1985; Suzuki et al., 1985). The tektite horizon in the Sangiran area of Java is close to the base of the Middle Pleistocene, as the underlying Middle Tuff has also been dated at 0.78 million years. The position of stratigraphic horizons of hominid finds in the Sangiran area based on the fluorine method has been discussed by Matsu'ura (1985). This method confirms the stratigraphic assignment of Homo erectus finds to a horizon between the Middle and Lower Tuff of the Kabuh Formation (Homo erectus VII and VIII). Homo erectus corresponds to the base of the Kabuh Formation. Following this concept, Homo erectus modjokertensis together with Homo erectus are accompanied by the Early Pleistocene Jetis fauna." (Sibava, 1993).

5. Impact craters, glasses and tektites possibly the same age as the Australasian strewn field impact(s).

The Australasian Tektite Strewn Field (Ford, 1988; Glass, 1990; Glass and Pizzutto, 1994; Wasson, 1991; Wasson et al., 1995) may speculatively be divided into 3 impact fields (see below): Kazakhstan, Indochina and Australia-Tasmania fields. After thorough field work on tektites, examined tektite expedition from Vietnam (Izokh and An, 1988) and tektites from southeast China and Hainan, it was found that that Muong Nong type tektite or layered tektites are characteristic of the Indochina field and restricted to a relatively small area. On the other hand glass in Tasmania exhibited greater temperature towards Darwin Glass an impactite glass scattered asymmetrically about Darwin crater, Tasmania (Fudali and Ford, 1979; Howard, 2004) possibly from the coma part and ended the long journey landing of the unnamed comet to the Earth.

5.1 Zhamanshin Crater and irghizites, Kazakhstan

Further evidence that tektites can be produced by an impact lies in the discovery of tektite-like glass (irghizites) around the 14 km diameter Zhamanshin impact crater in Kazakhstan (Florensky and Dabizha, 1980). They have compositions and ages similar to the Australasian tektites, but many have a composite form consisting of numerous droplets welded together. Microirghizites show a greater range in composition than the irghizites. O'Keefe (1987) suggested that the Zhamanshin crater was not the source of the irghizites, but that the crater was produced by the impact of a large mass of glass of irghizite composition and that the irghizites are merely fragments of the impacting body. However, most authors believe that the impacting body was a meteorite and that the irghizites are tektite-like glasses produced by impact melting of the surface deposits during the impact that produced the crater (e.g., Taylor and McLennan, 1979: Bouška et al., 1981: Glass et al., 1983. The glasses are not well dated but the Zhamanshin Crater was formed at 900 ka ± 100 ka.

5.2 Darwin Crater and Darwin Glass, Tasmania, Australia

Darwin Crater has been known for a long time since Ford (1988) but later little had been carried on and there was extremely limited information. Darwin Glass is an impact glass found In a strewn field near Mt Darwin, western Tasmania, and Australia. It has been dated at 816 ± 7 ka by Ar-Ar methods. A 1.2 km circular depression, named Darwin Crater (42°18.39'S, 145°39.41'E), has previously been suggested as the source crater for the glass. The structure sits in a remote valley in Siluro-Devonian (Eldon Group) quartzite and slate. Earlier geophysical investigations demonstrated that the structure is an almost circular sediment-filled basin.

Drill core intersected fine grained lacustrine sediments (-60m thick) overlying poorly sorted crater-fill deposits. The pre-lacustrine crater-fill stratigraphy comprises an uppermost polymict breccia (~40m thick) of angular quartz and country rock, which contains very rare (<<1%) glass fragments (Crater-fill Facies A). Beneath the polymict breccia facies, the drill core intersected monomict sandy breccias of angular quartz (Crater-fill Facies B), and a complicated package of deformed slates (Crater-fill Facies C). One core penetrated to a maximum depth of ~230m, at which point coherent slate was encountered. Quartz grains in the crater-fill samples contain abundant irregular fractures. In some of the most deformed quartz grains, sub-planar fractures define zones of alternating extinction. Kinked micas are also present. The deformation observed in the crater-fill facies is far greater than in rocks cropping out around the crater. However, diagnostic shock indicators (e.g. planar deformation features in quartz) are absent, preventing confirmation of an impact origin by petrographic analysis of crater-fill samples alone.

Geochemical analyses of the glass reveal two compositional groups. Group I is close to bulk average Darwin Glass and Is highly variable in composition. its major element compositional range is: SiO_2 (80.6-93.9%), Al_2O_3 (3.1-10.6%), TIO_2 (0.2-0.7%), FeO (0.8-4.2%), MgO (0.25-2.3%) and K_2O (0.7- 2.7%). Group I glass is predominantly light green to dark green or white. Group 2 glass is almost always black. Group 2 has a lower average 5102 (81.1%) content, and a decreased range in SiO_2 (76.4-84.4) concentrations. Average Al_2O_3 (8.2%) Is also greater than in Group 1. Group 2 glass is also significantly enriched in FeO (+1.5%), MgO (+1.3 %) and Ni, Co and Cr relative to Group 1. Average Ni (416 ppm), Co (31 ppm), and Cr (162 ppm) concentrations in Group 2 glass are beyond the range expected in average sedimentary rocks. The remaining trace element data show affinity with typical upper crustal sediments including pronounced negative Eu anomalies (Eu/Eu= 0.48 - 0.66) and LREE enrichment (La/Lu* = 5.8 - 8.87).

Sr and Nd isotope data indicate that a mixture of the Eldon Group lithologies (suspected target rocks) can form Darwin Glass. Mixing calculations using average Eldon Group compositions also successfully model the glass composition. Such models result in significant errors only for Ni, and to lesser extents CO, MgO, Cr and FeO in some Group 2 glass samples. Enrichments in these elements require an ultramafic contribution. However, mixing models using a component of Tasmanian dunite, pyroxenite. or lamprophyre fail to produce the required glass compositions, and can thus be ruled out as significant components of the target rock stratigraphy. The observed composition of Group 2 glass samples can only be explained by mixing with up to 9% of a chondrite or chondrite-like projectile. The distribution of projectile material in the glass is extremely heterogeneous, and the amount of this contribution is varied. Only the transition metals are enriched, with no simultaneous enrichment in the highly siderophile elements (HSE) that are present in crustal abundances.

Geochemical and isotopic data are considered to be consistent with Darwin Crater being the sole source of the glass. The crater-fill facies are also interpreted as consistent with impact processes. The argument for a genetic connection is strengthened by the observed trends in the distribution of glass relative to the crater. In the proposed model of the impact event, the polymict matrix supported breccia of Crater-fill Facies A is interpreted to have formed from non-melted angular quartz and country rock fragments that were blasted outwards and upward along the cavity floor, before collapsing

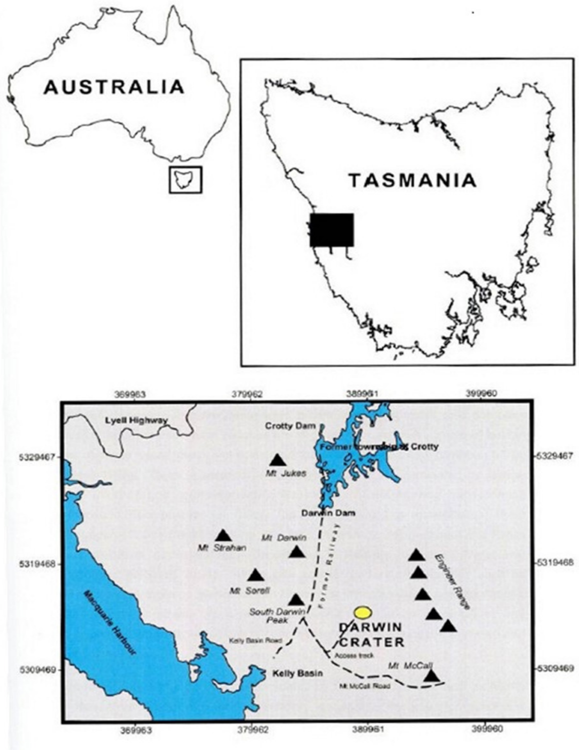


Fig. 110: Location of Darwin Crater in SW Tasmania, Australia. Historically glass was found in the state railway track to Kelly Basin. (Howard, 2004)

Fig. 111: Dense trees in the study area. (Howard, 2004)

Fig. 112: Darwin glass collected near Mt. McCall in 2002. Scale bar= 5 cm. (Howard, 2004).

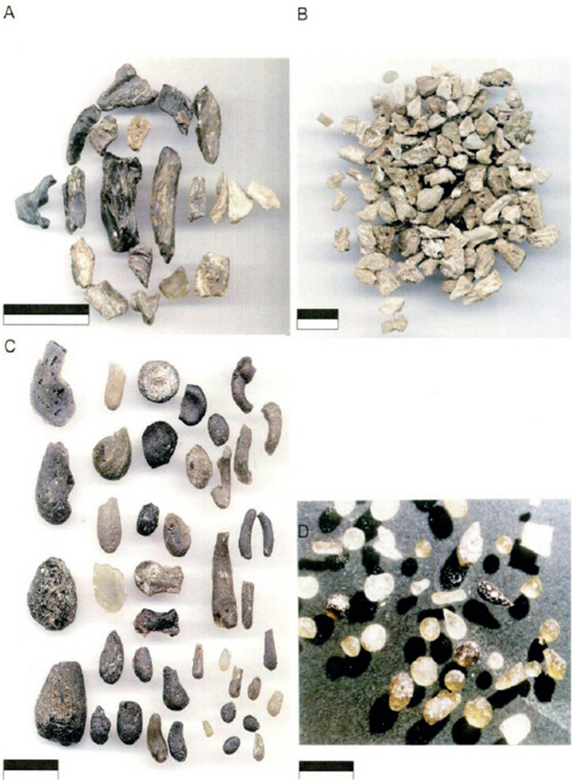


Fig. 113: Darwin Glass, A) Irregular and ropy glass fragments (scale bar 5 cm) size; B) Irregular white glass fragments (scale bar = 1 cm.); Splash-form Darwin Glass (scale bar = 2.5 cm.), Splash-form mini glasses (scale bar = 5 cm), (Howard, 2004)

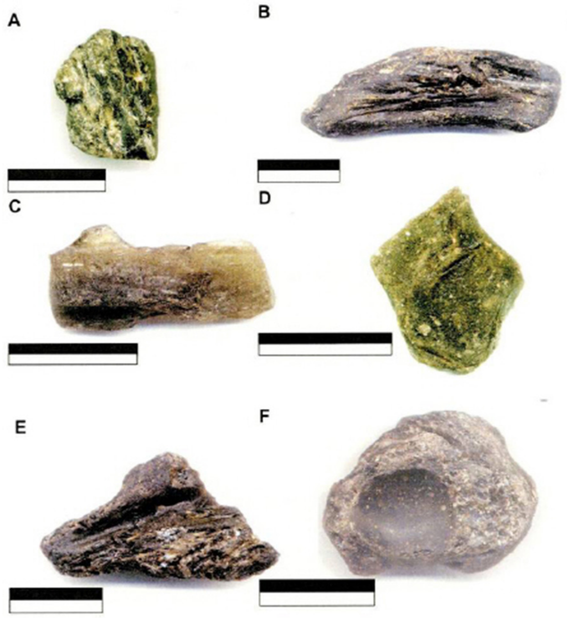


Fig. 114: Irregular Darwin Glass, A-F) scale bar = 2cm. Note the parallel layering that is predominantly planar and common presence of vesicles best illustrated in Fig. 13.9B. These specimens have a superficial resemblance to the Australasian Strewn field. (Howard, 2004)

inwards and mixing. Crater-fill Facies B and C are interpreted as representing shattered quartzite and plastically deformed slate (<5GPa), sourced from slumping of the cavity walls.

Physical trends in glass distribution relative to distance from the crater can also be used to test the genetic relationship between the strewn field, and show that the ejected melt cooled and rained down as glass fragments over more than 410km^2 of western Tasmania. In rare cases glass fragments exceeded 1 kg, but typically were only a few grams in size. In a 50 km^2 area surrounding the crater (~1/8th of the strewn field), and it is estimated that the total glass volume is at least 11,250 m^3 Therefore, relative to the size of the crater, Darwin Glass is the most abundant impact glass on Earth. The wide distribution and anomalously high abundance of glass in the strewn field is explained as relating to groundwater infiltration of the target rocks along fractures and faults prior to impact. Surface swamps are interpreted to have been present in the study area throughout the Pleistocene, and thus were a likely feature of the pre-impact environment. The abundance of water would have produced a highly volatile- charged target stratigraphy. This volatile enhancement is interpreted to have increased the explosiveness of the impact, and the efficiency of melt dispersal and ejection. Australian tektites are very different to Darwin Glass as the following Figs 110-123 show.

Analyses of more than 4000 fragments of glass recovered in situ around the crater show:

1) the largest recovered fragments are found closest to the crater;

2) a decrease in the proportion of fine glass fragments away from the crater;

3) size distribution data for the recovered glass specimens are strongly skewed towards outlying large fragments;

4) an increase in the proportion of black glass away from the crater;

5) an increase in the proportion of splash-form, relative to irregular or ropey shapes away from the crater: and

6) splash-form shapes are preferentially black.

In the impact model, impact glass size distribution data are considered to be consistent with ballistic ejection of melt. The poor size sorting is interpreted to indicate that the ballistic ejection of melt from the crater was as a highly turbulent plume and that large and small fragments were deposited together, on the breakdown of turbulent cells in the plume The increase in the proportion of black glass fragments with increasing distance from the crater is related to the depth of excavation. Black glass is interpreted to form from melting of pelitic layers in the Keel Quartzite, which is the uppermost target formation and it expected that the upper most target rocks that will ejected farthest during impact.

Splash-form shapes form during aerial transport, increasing the distance of melt ejection will promote development of such shapes, and this is in turn consistent with the preference for splash-form shapes to be black. The expected lower viscosity of the black melt (based on SiO_2 content) is also interpreted to have promoted the development of splash-form shapes. Deriving of black glass from the upper-most target rocks, close to the target-projectile interface, also aids in explaining the evidence for preferential projectile contamination of some black glass specimens.

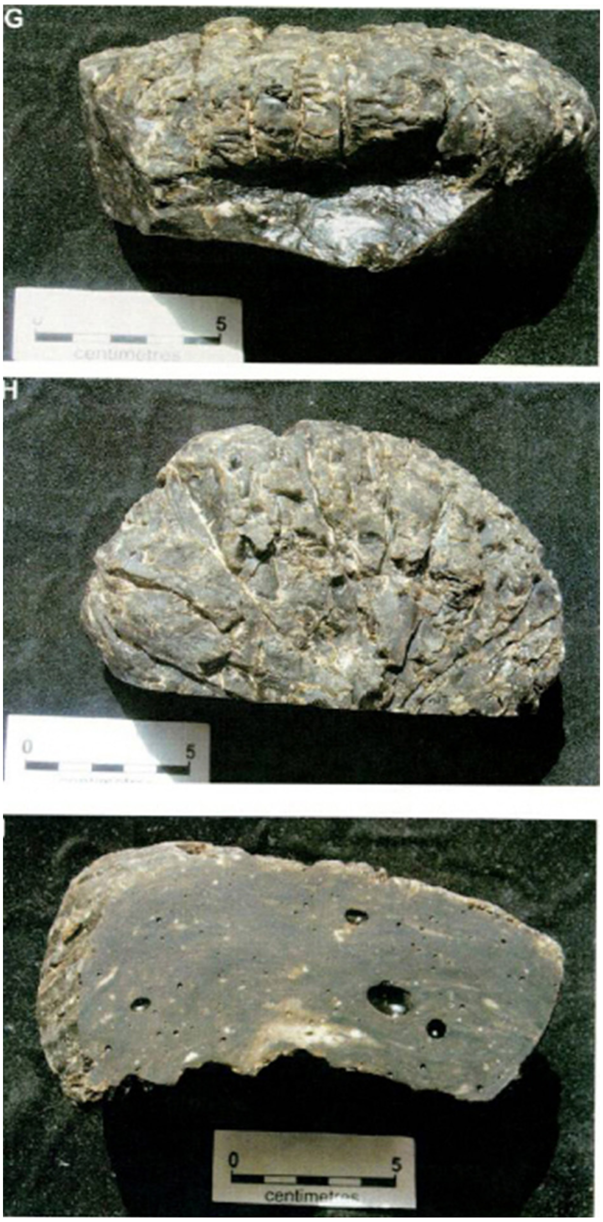


Fig. 115: Irregular Darwin Glass, G-I) The largest known fragment of Darwin glass that weighs 946g after a slice has been removed for sectioning. The fragment was collected by R. J. Ford. This specimen also has a superficial resemblance to layered tektites of the Australasian strewn field. (Howard, 2004)

6. CONCLUSIONS: Pleistocene cometary impact in Thailand or nearby caused the Australasian tektite field; as suggested by catastrophic loess, mass mortality and forest fires

New discoveries in 1997 (Bunopas, S.; J. T. Wasson, Vella, P., H. Fontaine; S. Hada; C. Burrett Th. Suphajunya and S. Khositanont, 1999) added to previous research on tektites and impact craters in Thailand, which suggested that common continental fires; mass mortality of

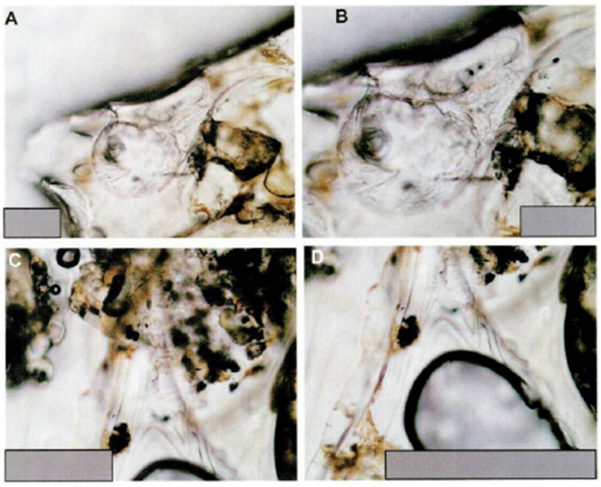


Fig. 116: Internal features of Darwin Glass, A) Schlieren defining a wave or droplet shape (scale bar = 100μm; B) Close up of A (scale bar = 100μm). These features reflect turbulent circulation in the melt jet. C) Tail of another droplet shape feature (scale bar = 100μm); D) Close up of C (scale bar = 100μm). (Howard, 2004)

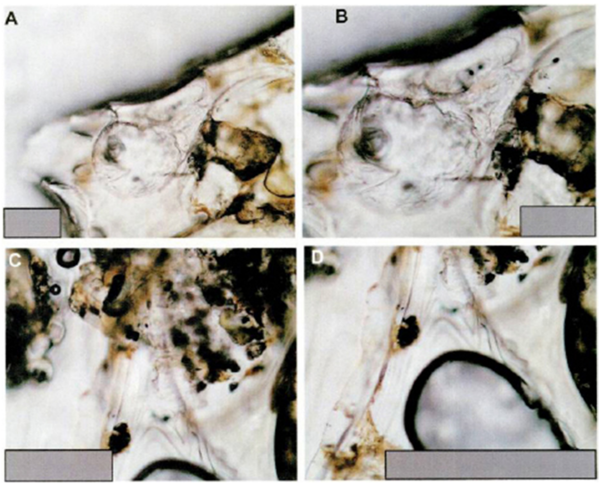


Fig. 117: Ropy Darwin Glass. A-F) scale bar = 2cm. Twisted ropy feature reflects the extreme topographic expression of the parallel layering characteristic of the irregular glasses. This texture reflects quenching from a rapidly stretching viscous melt. (Howard, 2004)

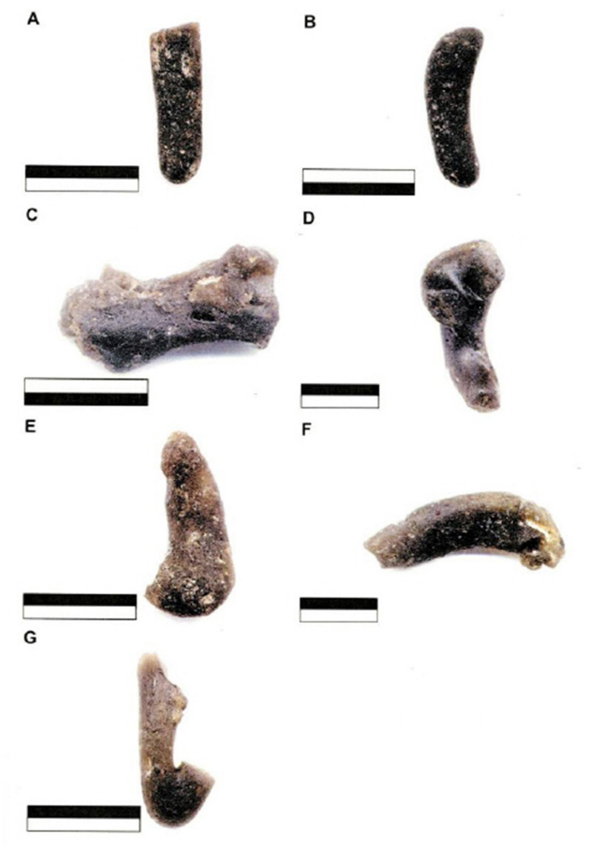


Fig. 118: Elongate Darwin Glass, A) scale bar = 1cm; B) scale bar =2cm; C) scale bar = 2cm; D) scale bar = 1 cm; E0 scale bar = 1 cm; F) scale bar = 1 cm; G) scale bar = 2cm. These are usually planar and rod-like but a= samples with bulbous end and also found along very rare and usually poorly developed dumbbells. Such elongate samples almost always have broken ends. (Howard, 2004)

trees, mammals, and reptiles, as well as the presence of thick catastrophic loess, are linked in an extraordinary global catastrophic event. Evidence from these new discoveries have been superimposed on an area larger than the region known as the Australasian tektite strewn-field. Radiometric dating by various methods of tektites from this field gave ages between 0.709 - 0.770 ± 0.020 Ma. [*788 ± 3 ka Jourdan et al., 2019*] This date is probably consistent with related evidence of an early Quaternary event and possibly correlated to a glacial stage at O-isotope stage 20.2 (~NN20). 300 km west of the probable impact center in Ubon Ratchatani, sand pumping pits were investigated in Tha Chang and Chum Phuang; respectively 16 km east and 100 km northeast of Khorat in northeast Thailand. Pits >12 m were sufficiently deep to reveal irregular piles of partially to completely burnt and petrified logs, trunks, and trees, apparently pushed and pulled down abruptly to the ground by tremendous force.

Nearby at Tha Chang, two newer sandpits produced complete ancient elephant teeth and Stegodon sp. fossils of Pleistocene age were also found, distributed among other mammal bones, crocodile teeth and bones, as well as burnt trees in the black reduced beds and in the bottom of the pits.

This evidence suggests sudden ground melting resulting from an extra-terrestrial impact, contemporaneous with the formation of tektites in the Australasian field, though geochemical analyses have not indicated the addition of any

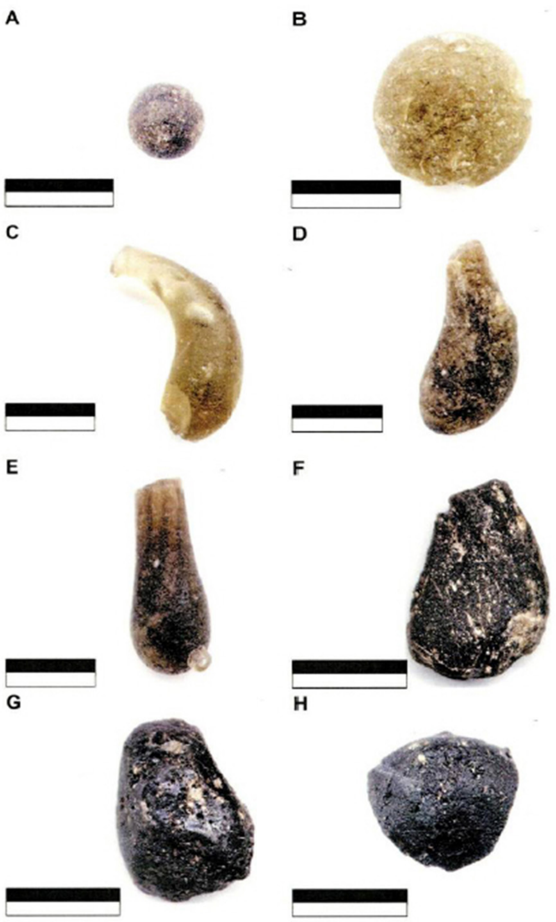


Fig. 119: Spheroid and droplet shaped Darwin Glass, A) scale bar = 1cm; B) scale bar = 1cm; C) scale bar = 0.5cm; D) scale bar = 0.5cm; E) scale bar = 1cm; F) scale bar = 2cm; G) scale = 2cm; H) scale bar = 2cm. These spherical glasses appear to have the most highly pitted surfaces of all of the glass shapes (e.g. B). These droplets are almost always asymmetric and typically have broken tails. Examples like F, G and H bear aver strong resemblance to splash-form tektites of the Australasian strewn field, particularly Thailandites. (Howard, 2004)

new elements or minerals. A rapid succession of enormous global explosions followed the proposed impact, causing global distribution of various tektites. Consequent continental forest fires and build-up of atmospheric sands (or dusty debris) caused great loss of life over a very large area.

Small, medium, and (rarely) large layered tektites are found near an impact centre, and less commonly outside. This evidence may substantiate the enormous terrestrial impact of a big comet, indicated by the considerable size on and large numbers of multiple craters in an 800 x 1140-km impact centre between Hainan and Cambodia.

The presence of microtektites and glass

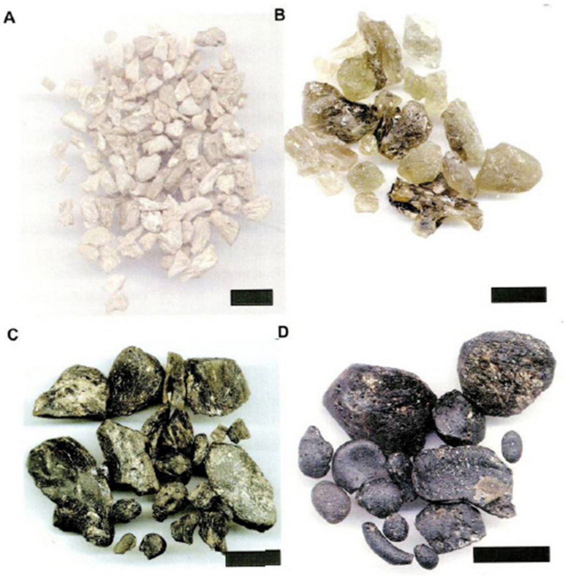


Fig. 120: Colour variation of Darwin Glass, A) Typical white glass (scale bar = 1cm); B) Typical light green glass (scale bar = 2cm); C) Typical dark green glass (scale bar = 2cm); D) Typical black glass (scale bar = 2cm) (Howard, 2004).

microspherules in north Chinese loess confirms that late generation of loess enabled the collection of minute material suspended in the atmosphere. The catastroloess is related to both an early Pleistocene mass mortality event, as well as to the addition of thick sediments to normal local geological processes.

Incorporating the 1997 evidence from Thailand allows a new Comet theory to be proposed: The Cometary Impact Theory encompasses the effects of a large comet disintegrating and impacting on Earth, causing great global shocks and quakes, disastrous continental fires, and a mass mortality that affected much of the extant flora and fauna. Numerous violent impact explosions caused rapid exhaustion of atmospheric oxygen, which, in turn resulted in vast quantities of debris and dust being sucked up into the atmosphere. Subsequent cooler conditions on Earth were accompanied by the late steady fallout of dry earth-sands settling and forming thick and extensive catastroloess. A modern analogy for this catastrophe would be a country impacted by many hundreds of nuclear bombs, allowing resident communities little chance of survival.

Tektites may be found at any level in the sands that cover the basement. We contend the variation in this level reflects repositioning either during the catastrophe or as a result of geological

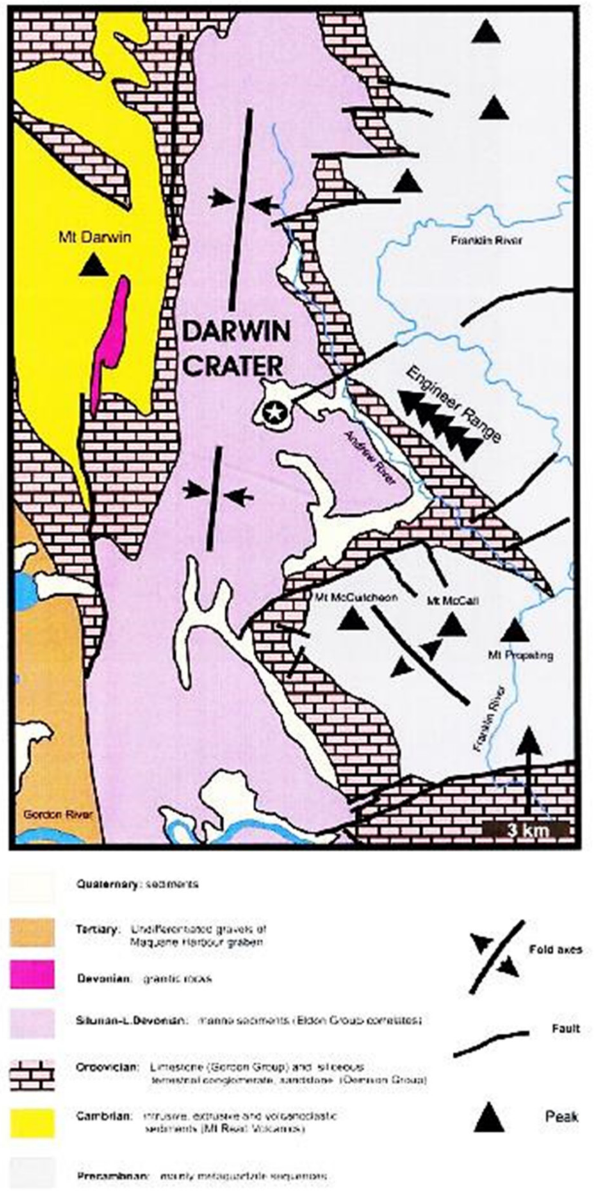


Fig. 121 : Geology of the Darwin Crater Strewn field. Based on Corbett and Brown (1975) and Corbett et al. (1993).

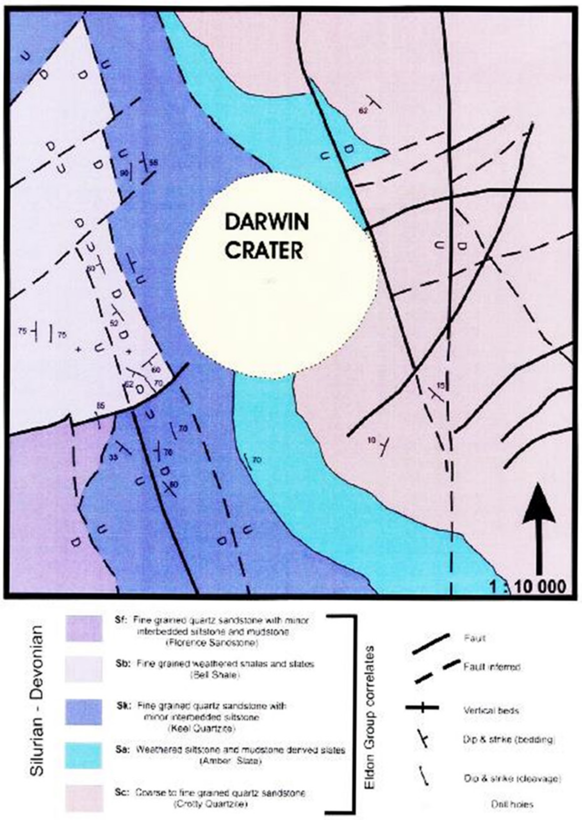


Fig. 122: Darwin Crater geology. Based on field mapping in this study and by R.J. Ford; 1: 25 000 aerial photographs; Corbett and Brown (1975) and Corbett et al. (1993).

Fig. 123: Physiography of Mount Darwin western Tasmania, Australia. (Howard, 2004).

processes at some stage between the time of catastrophic events and the present day. The catastrophe should be known as the Buntharik Event, name derived from a town south of Ubon Ratchathani, Thailand where all evidence outlined in this study can be examined in a few hours. The Buntharik Event which is responsible for the studied tektites, also caused the outbreak of global continental fires, mass extinction flora and fauna, and the development of a catastroloess that dramatically altered the lower Quaternary landscape. The impact may also have triggered vast basaltic volcanism nearby (Ford, 1988) and facilitates demarcation of the lower-middle Pleistocene boundary in Southeast Asia (Bunopas et al., I999a; Sibrava, 1993 etc.) and China (Han et al., I997; Wang et al., 1985). Dating of tektites reveals the age of the event between 0.709 - 0.770 ±0.020 Ma (Blum et al., 1992; Gentner et al., 1967; 1969; Izett an Obradovich, 1992 and Zahringer, 1963). [788 ± 3 ka Jourdan et al., 2019]. The global disaster contributes to the theory of extra-terrestrial tectonics and allows an understanding of the origin of earth's common exotic loess sands. We contend that such sands are not the normal weathering products in an arid region, but rather represent reworked catastroloess.

In final conclusion, such a catastrophe may comprise occurrences in the following categories:

1) **Numerous extensive burnt felled trees,** all root up and most are petrified, lower levels contain abundant soot and sulfides. Uprooted tree trunks up to 2 metres in diameter are often shattered, branchless, snapped, and burnt to the core. Their presence in deposits throughout Thailand is evidence of widespread burning. These suggested extensive wild-forest-fire which were reported bunt trees or woods the whole of Southeast Asia.

2) **Ancient animals** such as Stegodon turtles, crocodiles etc. (Chaimanee, 2004), all suggesting a mass mortality event.

3) **Tektites** are rare splashed tektites from the pits but many layered tektites in Ubon Ratchatani, 233 km east.

4) **Impact crater** in Buntharik though it is still dubious.

5) **Catastrophic dusty sands** represent debris and ejecta that formed widespread sheet enclosed other DCIMs. This name is proposed "Catastroloess", for this impact sands washed and catastrophic flooding as sands at Ban Tha Chang, Howard (1999) added.

6) **Microtektites, glasses, impact quartz and impact glasses etc.** (Howard, 1999)

7) **Isotopic elements from INAA, ICP-MS measurements**

in tektites from Thailand, China and recent study from Ban Tha Chang sands (Howard, 1999).

8) **Reversal paleomagnetism with fragile (unreworked) tektite** (Haines et al., 2004).

9) **Mass Mortality Event.** The great impact mass killed numerous ancient vertebrate and knocked down and burnt previous flourishing forest trees. Bunopas et al. (1999, 2007).

Evidence constituted by these criteria supports the theory of a cometary impact during the early Quaternary. We believe that evidence of the Buntharik Event, including phenomena of tektites, impact craters, burnt woody fossil material, and catastroloess all further our understanding of mass mortality events and possibly extinctions in general.

The impact occurred at almost the end of a Lower Pleistocene time (Q1). The impact surface is marked by ground forested layer gravels of latest Lower Pleistocene, continued by sandy impact debris belonging mainly to the early parts of Middle Pleistocene, consistent with the stratigraphic age and the age of the tektites (latest Q1 and mainly Q2). An analysis of the Quaternary stratigraphy indicates that all badlands that make a good touring place, and mega-flooded BTC sands at Khorat, and above the fish beds at Lomsak, Pha Wing Choo, south Chiangmai and faulted sand beds at Na Thawi in Songkhla, the Southern Peninsula etc., are marked as Middle Pleistocene age.

Continuation of the regional uplifting had resulted in considerable thickness of common covering or capping gravels and late raising of impact layer to a higher level. All gravels under the "muddy gravels" on the top of lower terrace gravels mark the 770 ka "avalanches and mudflows mixed with the earliest onset of catastroloess sands" surface. The gravels must be former impact forestry surface. These "muddy gravels" buried felled trees at Krok Duan Ha, Khorat and also at school yard, Ban Non Thung, Buntharik, containing rare splash and abundant un-oriented, small to medium layer tektites, respectively, and are correlated

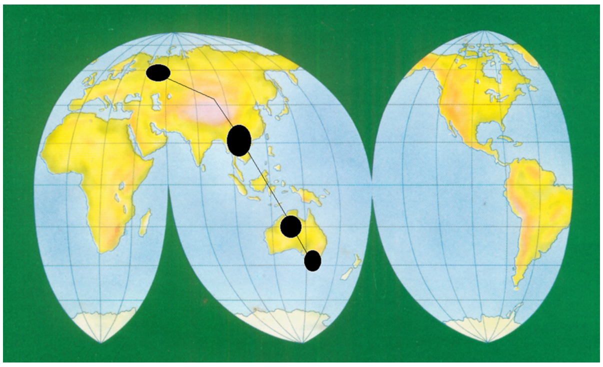


Fig. 124: Projection of Earth Showing Host Continents, Asia and Australia When they were Impacted by the Australasian Comet at Kazakhstan with irghizites at Zhamanshin structure, south China and Indochina (South-East Asia), and Australia with tektites, then collided, terrestrially to Mount Darwin making the Darwin Crater in Tasmania with Darwin glass. DCIMs, most are misinterpreted, and are newly known in Thailand, Vietnam, China, Australia and Antarctica etc.

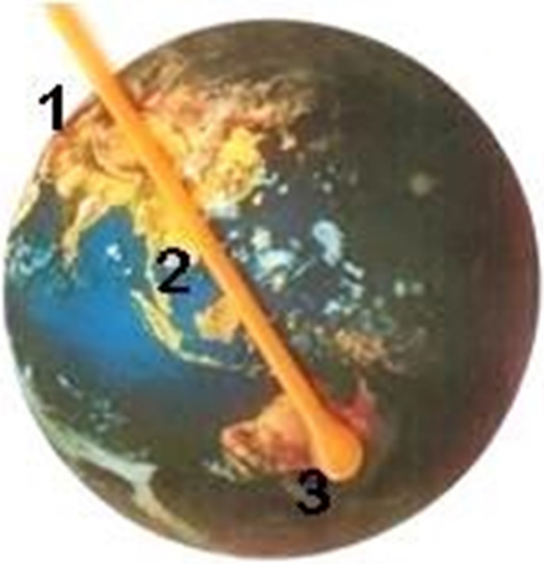


Fig. 125: Proposed track of the 0.788 Ma comet. 1. Zhamanshin (Kazakhstan), 2. Indochina, 3. Australia including Tasmania, Darwin Crater.

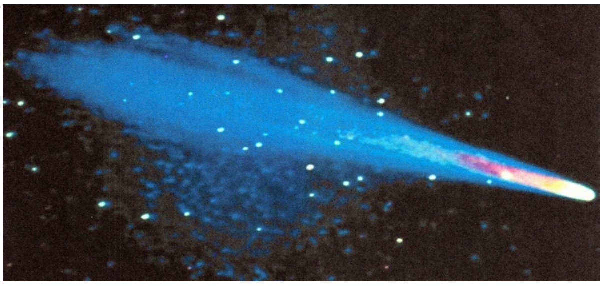


Fig. 126: The icy missiles with solid cores made fantastic Jupiter impact in 1994 (in this Fig. it is represented by Halley's Comet). The coma of the comet is the halo or nebulous envelope of gas, ice and rock bursting from the rocky-ice-gas nucleus at the head of the comet.

to Bo Phloi, Kanchanaburi, on 23m thick older gravels with sapphires.

All terrace gravels in most regions of Thailand are dated as Lower Pleistocene, the tectonic uplifting stage. Lower Pleistocene includes also high terrace and lower terrace gravels under Ban Tha Chang Sands (Howard et al., 1999) and river sands in the Mun and Chi rivers. In the Khorat plateau "old gravels" were thought to be below the tektites. The top of the gravel is represented by old tree growth and form the disastrous surfaces during the impact with original first generation tektites fine sandy-silty and lateritic layer with tektite in Ubon Ratchatani (Fiske et al., 1996) is only a few metres above the avalanche position in a locality few km to the south. Finally, the horizon produces high atmospheric explosion size frequency pattern and consistent REE pattern similar to those for tektites (Wasson, 1991) derived from siliceous sediments in previous impact surface.

The Buntharik Event is proposed for the event that produced tektites in the Australasian field covering 1/10, and the catastroloess covering much of the Earth's surface (Bunopas et al., 1998). The catastroloess admixed to those local vital normal conditions in mountainous valleys; rejuvenated the current physiography of all valley and flood plain areas; and made the extinction of many older plants and in lowlands or floodplain areas or paddy fields everywhere in Thailand contain some thickness of catastroloess or/and the secondary enriched equivalent sands several metres thick. This is applied also to the floors of the Gulf of Thailand that were filled with these sands.

The 0.788 Ma impact event was likely caused by the disintegration of a comet and the impact of its fragments, first in Kazakhstan to form the Zhamanshin Crater, then in Indochina perhaps forming numerous small craters and then in western Tasmania to form the Darwin Crater (Figs. 124-126). If this model is correct, then Thailand contains unique evidence for the terrestrial impact and the catastrophic effects of a large extraterrestrial object.

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