# Did Shan-Thai twice marry Indochina and then India?: A Review

*Sangad Bunopas[1] and Sombon Khositanont[2]*

*1. 39/4 Soi 75, Moo. 13, Chokchai 4, Ladphrao Road, Bangkok, 10230*
*2. Geological Survey Division, Department of Mineral Resources, Rama VI Road, Phayathai, Bangkok, 10400, Thailand*

**Abstract**

"Did Shan-Thai twice marry Indochina then India?" Field evidences in the north and northeast Thailand led to a clear vision of their late heritage of the Quaternary pushed-pulled Himalayan extrusional continuum to major vertical crustal uplifting Inthanon Epeirogenesis to extreme that also tilted Khorat Plateau northeastwards and diverting Mekong River from Tonle Sap, both of which occurred prior to Buntharik Event (0.8 Ma cometary impact), Buriram basalts, and Asian glacial age.

History of Gondwana-derived continental crusts in Southern Hemisphere, Shan-Thai and Indochina microcontinents, North China and South China subcontinents migrated from west Australia since very latest Devonian (some preferred most unlikely lower Permian) to settled in late Norian, for the first time above the ocean, in Pangea in Northern Hemisphere. During late Triassic both microcontinents drifted up the latitude and stayed in the Northern Hemisphere after the 1st continent-continent collision. Pre-first continent-continent collision between Shan-Thai and Indochina occurred just under the Equator as early as Lower Triassic. Since the breakup of Pangea in late Cretaceous time, and very much later India continent drifting northwards and effect southwest margin of South East Asia (northern extension of early Shan-Thai, previously amalgamated to Indochina and South China) but not until 45 Ma that the Himalayan Extrusion, caused by the 2nd continent-continent collision, began and have its paroxysm in Mid-Miocene. Second continent-continent collision is known to be started at latest Cretaceous to Paleogene in west Myanmar. The rise of the Himalayan, the opening of the Gulf of Thailand, the opening of the South and North China seas and the forming of some country lands like Japan, the Philippines and New Zealand, etc. occurred during the Himalayan Extrusion especially during the Miocene. The all headed-down Shan-Thai, Indochina, North China, South China moved up to Northern Hemisphere with clockwise rotation over a half round (more than 180°) until the present day position.

New discovery in northern Thailand suggests the Himalayan extrusional continuum from late Pliocene to lower Quaternary Inthanon Epeirogeny and uplifted from 200 m to 1,000 m, or even to 2,600 m in the western mountains of Thailand, or from few thousands to nearly ten thousand meters in the Himalayan. The Khorat Plateau's early Quaternary vertically uplifting, after long Cenozoic cratonization of the Mesozoic Khorat Group, its northeast tilting eastwards diverted Mae Khong River before the 0.8 ma cometary impact catastroleoss and the overflowing Mid-Pleistocene Buriram and Indochina basalts. The incident was identified from real-time sequence with firmly known by many consistent absolute age results obtained from around the world laboratories from bedded tektites and splashed tektites in Thailand and Indochina. Paleomagnetic reversal polarity results from catastroleoss ensemble the real-time catastroleoss from the Buntharik Event of 0.8Ma cometary impact are absolutely well constrained. Quaternary uplifting and the following cometary impact became the most important principle of the paper links to southward sudden extension of younger Pleistocene sudden full glacial intervals in Asia now are better understood. Precision of research and good clear vision are needed in understanding terrestrial and extraterrestrial mix-up processes through the whole Quaternary Neotectonics of Thailand.

**Key words:** Shan-Thai, Indochina, India, Inthanon, Khorat Plateau, Mekong River, cometary impact, glaciation

## Introduction

Several successful IGCP projects (124, 321 and lately 411) have helped establishing the view that much of mainland Asia was formed by the progressive accretion of terranes derived from Gondwana culminating with the collision of India to form the Himalayas.

The Siluro-Devonian paleomagnetic data of Bunopas (1981) was the first to show that Shan-Thai was inverted and was at about 30S adjacent to NW Australia. This was confirmed by Bhongsuwan (1993). The palaeontological work of the joint Thai-Australian team confirmed very close similarities between western Australia and Shan-Thai during the Cambro-Ordovician which continued into the Siluro-Devonian (Burrett and Stait, 1985; Burrett et al., 1990; Cantrill, 2002).

Ancestry of Indochina, Shan-Thai, North China and South China were all upside-down off west coast of Australia. Fig. 1 shows Gondwana continent during Paleozoic period and Fig. 2 illustrates eastern Gondwana with paleogeographic reconstruction during the Late Cambrian time. It is interesting that the significant base metal deposit – the Baldwin deposit in central Myanmar occurred in this period (Zaw and Burrett, 1997). Paleo-North direction was -45° or 135° (see Bunopas, 1981) and NW Australia was about latitude 35-53° S. Ordovician position of Shan-Thai Australia must be a little adjusted to the Canning Basin, while the former location of Indochina was at off Bonaparte Gulf. In Middle Ordovician Australia had already rotated counterclockwise and moved down and met Shan-Thai and Indochina most appropriated with the Paleolatitudes of the Canning Basin and the Bonaparte Gulf, respectively.

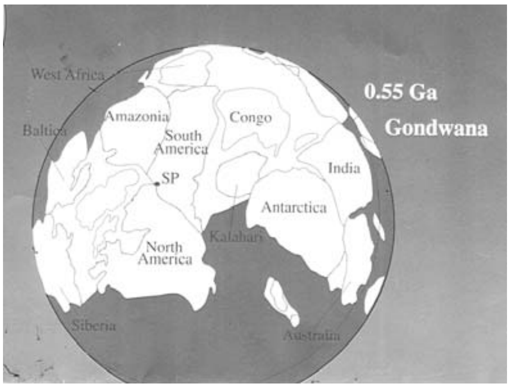


*Fig.1. Lower Paleozoic Gondwana in the Southern Hemisphere from 0.55 Ga, or 550 Ma, based on map for ISRGA Symposium in Osaka, Univ. of Osaka, Japan, October, 2001, Gondwana Supercontinent, the Paleozoic Southern World, the ancestry of Shan-Thai and Indochina in NW Australia.*

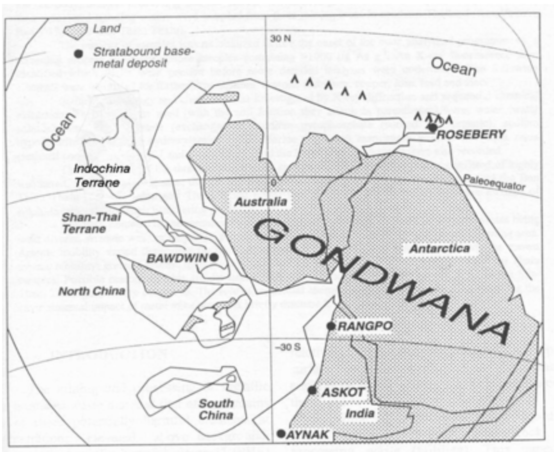


*Fig. 2. Paleogeographic reconstruction with orthographic projection of eastern Gondwana during the Late Cambrian time. Note the important base metal deposit, the Bawdwin deposits in Myanmar (from Zaw and Burrett, 1997).*

## Mid Paleozoic-Triassic drifting northward with 170° clockwise rotation in the southern hemisphere before entering northern hemisphere for the first continent-continent collision

The Early Permian Phuket-Khaeng Krachan Groups of southern Thailand are typical Gondwana glacimarine deposits and suggest adjoining of Shan-Thai and Australia in the Permian (Bunopas and Vella, 1983b, 1984, 1990).

## Mesozoic:
## The first Norian continent-continent collision of Shan-Thai, Indochina and South China in southern and northern hemispheres.

The assembling of Mesozoic Pangea commenced during the Early Triassic, but the growth of Pangea in the northern hemisphere due to continent-continent collisions occurred in Late Norian (Fig. 4.), 218 Ma or 198 Ma on new and current time scales, respectively. Early Triassic continent collisions comprise of Shan-Thai collision onto the Sukhothai Fold Belt,

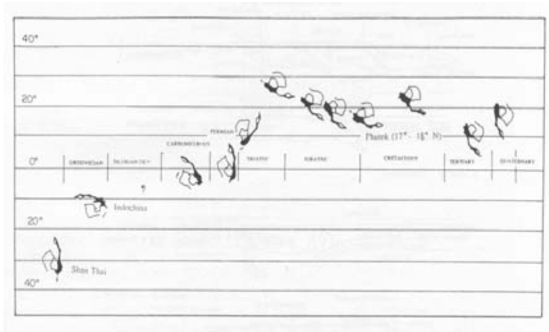


*Fig. 3. Tentative plots of the Shan-Thai (black) from measured given paleolatitude data on given time showing its clockwise rotation movement from South Latitude since 500 Ma in Lower Paleozoic (Cambrian) to Lower Mesozoic (late Norian, Upper Triassic) above the Equator. Indochina was attached to the Shan-Thai since the first continent-continent collision in Late Norian. Indochina (outlined) was shown diagrammatically to help in recognizing the appearance of Thailand and the neighboring Indochina. In Middle Permian the Indochina was 1,000 km away from the Shan-Thai (Achache and Courtillot, 1985).*

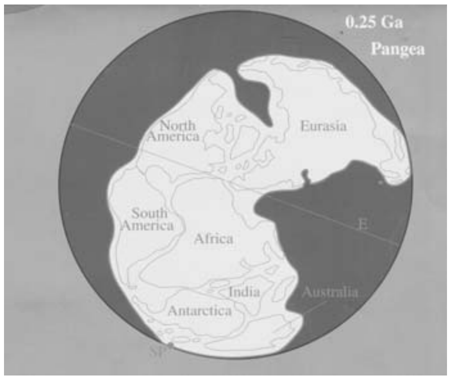


*Fig. 4. Mesozoic Pangea Supercontinent (250 Ma or 0.25 Ga) Thailand (in Shan-Thai) and Indochina amalgamated with Eurasia in South East Asia apex during 215 Ma (Norian). The paired microcontinent moved up from latitude 30º-40º S in NW Australia since Middle Paleozoic to 0º – 33º N, above the Equator near present. 1 Ga = 1000 Ma; and 1 Ma = 1000 Ka.*

occurred at the Shan-Thai active eastern margin, and collision of Indochina active westernmargin onto the Loei Fold Belt. The Norian continent-continent collision of Shan-Thai and Indochina added enormous volumes of igneous rocks along with important mineral deposits.

Intra-continent collisions were also widespread in Myanmar and west Yunnan especially along the Lancangjiang and Shaning Menglian Sutures in Baoshan, Changning Menglian blocks in northern Shan-Thai, and in Loei in Thailand, northern Laos and Sam Nua in central Vietnam in the Indochina. The intra-continental collisional intrusives represent ancient intra-continental sutures often mistaken for inter-continental sutures or often formally called geosuture. The latest geosuture between Shan-Thai and Indochina was Jinshajiang Suture-Ailaoshan Suture-Luang Prabang Suture-Nan-Uttaradit Suture-Sra Khaeo

Suture-Raub-Bentong line. East and west of the Norian geosuture were intra-continental sutures.

## The configuration of Shan-Thai and Indochina

The first proposed configuration of the paired microcontinents, Shan-Thai and Indochina, was made in 1981 by Bunopas (Fig. 5.) when geologic information was sparse and very few geologic maps were available. However, the configuration appears to be broadly consistent with modern information. The northward extension of Shan-Thai into Myanmar and west Yunnan are now becoming clearer (Bach, 1985; Jin, 1994; Jin et al., 2000; 2001; Hutchison, 1996; Shi et al., 1995; Wang et al., 2001). A much later, 1995, satellite imagery (Fig. 6.) matched well with the proposed configuration.

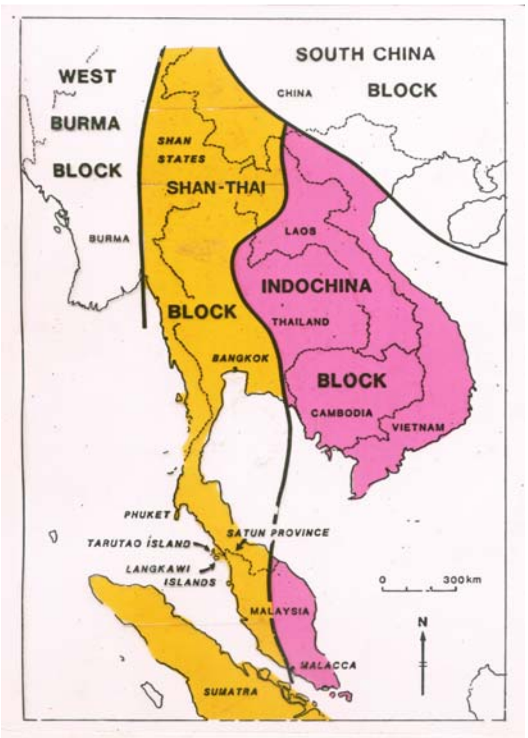


*Fig. 5. Shan-Thai and Indochina, a paired Lower Paleozoic Gondwana derived microcontinents or informally known as couple composite blocks, or terranes, finally formed continental SE Asia after the continent-continent collision in the Northern Hemisphere (Bunopas, 1981). Since then no configuration of the microcontinents has been modified, only more internal details are added, especially in west Yunnan. The extension of Shan-Thai to Lhaza Gandise block, and Tanggula- Quantang blocks with Jingshajiang-Longmuco Yushu sutures (along RRFZ) to Ailaoshan-Luang Prabang-Nan-Uttaradit-Sra Khaeo- Raub-Bentong sutures was noted. Along and on the west and east of this major suture are the Sukhothai Fold-Belt and the Loei Fold-Belt which are on the active margins since the middle Paleozoic. The geosuture represents mid-ocean ridge between the facing east Shan-Thai and the facing west Indochina. The ocean was part of Pre-Jurassic Paleo-Tethys which started to close in this part when the Norian continent-continent collision commenced (after Bunopas, 1981).*

*Fig. 6. Sattlelite image shows hysiographic settings of Thailand in Southeast Asia. Huge impressive subcircular or large oval shape is the extension of the Khorat Plateau into Laos, Vietnam and Kampuche. There are more widespread Jurassic-Cretaceous red-beds (Khorat Group) east of the western mountains, into southern China and east Malaysia Peninsular from the first continental-continental collision, which is analogous to those alluvial plain formations from the second continental-continental collision in the Gangise Plain. East of the Khorat Plateau contains thin and less quartzitic red-beds on the back slope (Non-Khorat Group) of upthrusted cratonic platform of Shan-Thai.*

## Shan-Thai and Indochina microcontinents regional boundary (after 20th century), currently defined boundaries were more precisely outstanding configuration.

**Shan-Thai Microcontinent consists of:**

a) Craton, or cratonic platform:
Myanmar: Eastern Highland or the Shan States
Western Yunnan: Tengchong block,
Baoshan block, (Jin, Xiaochi, 1994)
Changning-Menglian belt, (Jin, Xiaochi et al., 2000; Wang, Xiang-Dong et al., 2001 )
Thailand: MaeHong Son-Kanchananuri,
West of Eastern Gulf of Thailand (Chonburi, Rayong)
Peninsular Thailand,
Malaysia: West Peninsular Malaysia, (Hutchison, 1996)
Sumatra

b) Active Margin, Sukhothai Fold Belt:
Western Yunnan : Lanping-Simao block,
Laos: Luang Prabang belt,
Thailand : Sukhothai-Lumpang-Chiangrai-Nan,
Eastern part of West of Eastern Gulf of Thailand (Chanthaburi-Trad)
Eastern Lower peninsular Thailand,
Malaysia: East of Western Peninsular Malaysia (before Raub-Bentong Suture)
Sumatra

------- *Jinshajiang-Ailaoshan-Luang Prabang-Nan-Uttaradit-Sra Kaeo-Yala-Raub-Bentong sutures*--------

**Indochina Microcontinent consists**

a) Craton or massif, Kontum Platform:
Indochina countries: Kontum Massif (Laos, Vietnam, Kampuchea, under Khroat Plateau)
Central Vietnam: Song Da Precambrian Complexes
Kamphuchea: Kampot Ophiolites (Permian-Triassic, Le Dzuy Bach 1985)
Malaysia: (Raub-Bentong suture) Central and Eatern Belt (older granites,)

b) Phetchabun-Loei Fold Belt:
Loei – Phechabun-Pak lay-Luang Prabang- Dian Bien Phu –Song Ma- Song Da Fold

------------------------*Song Da Suture*------*RRFZ*------------------------------------------------------------

**South China Subcontinent: (not defined here)**

Yangtze Platform : Yunnan ,west Yunnan
South China Fold belt : southern China, northern Vietnam

***Fig. 7.*** *Shan-Thai and Indochina current boundary tentatively redefined after new investigations in UGS/IGCP 224, 321 and 441 Projects from 1985 to 2002.*

## The Khorat Group: One of the major global tectonic intra-cratonic sedimentary products of the first Norian continent-continent collision and volcaniclastics, basal volcanics and limestone conglomerates and Jurassic-Cretaceous continental red-beds

The Shan-Thai-Indochina collision is well dated, paleontologically, radiometrically, paleomagnetically and stratigraphically in Phayao, Nan, Nam Phrom Dam in Khon Kaen and numerous other sites as latest Triassic (Bunopas, 1967; 1971; 1981; Fontaine et al., 2001; Haile, 1973; Hahn, 1976; Hahn et al., 1986; Hinthong et al., 1999; Kobayashi, 1973; 1975; Maranate and Vella, 1986).

The Pha Daeng Formation, the topmost formation in central north Thailand, is part of a thick Triassic shallow marine ramp carbonate sequence that grades into the shallow through deep marine siliciclastic sequence of the Lampang Group (Chaodamrong and Burrett, 1997). Hada et al. (1997; 2000) recovered Middle-Late Triassic radiolarians from the accretionary complex of the Chanthaburi chert-clastic sequence. All of the rocks of both the Chanthaburi chert-clastic sequence and the Thung Kabin melange are unconformably overlain by the possibly Upper Triassic greywacke and andesitic tuffaceous sequences (Pong Nam Ron Formation), which are then unconformably overlain by the uppermost Triassic or Lower Jurassic Khorat Group red-beds.

The continent-continent collision resulted in two spectacular accumulations areas of siliciclastics in Southeast Asia, in:

(1) *the former Eastern fold zones and parts of previous Indochina Craton areas* in the environs of the great Indochina trough; and

(2) *the Western former Shan-Thai Cratonic basin areas*, in the narrower marine Jurassic, and restricted continental Cretaceous.

The latter of which retained shallow marine while the former area was mainly continental with greater thickness in paralic conditions, in a tectonically sinking mega-trough (Bunopas, 1981). The continent-continent collision terminated marine environment from the areas between Shan-Thai- Indochina and South China. From Jurassic to Eocene the South China region in west and southwest Yunnan subsided continuously leading to deposition of thick and extensive red-beds with occasional salt beds.

Mesozoic lands after the continent-continent collision became largely stable for a long time but their margins became seriously disrupted during the late Cretaceous-Cenozoic collision. Mesozoic paleomagnetism information greatly helps in the reconstruction, as well as solving on the stratigraphy of these widespread continental red-beds.

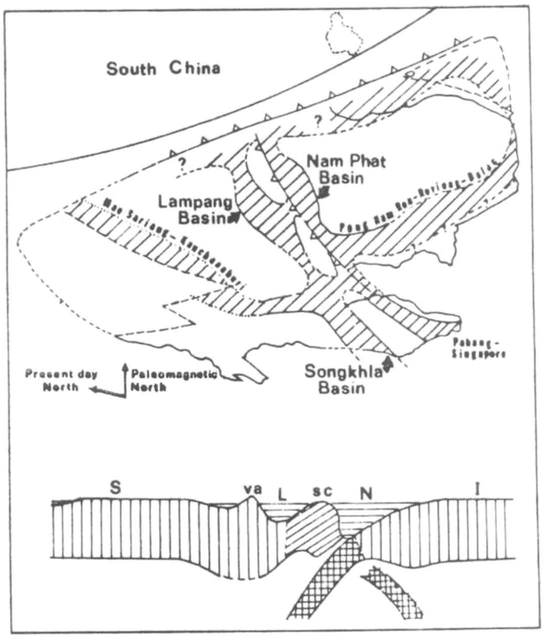


*Fig. 8. Paleogeographic sketch-map showing areas of late Middle to early Upper Triassic marine basins in Southeast Asia based on a palinspastic map prior to a middle-late Norian continent-continent collision, and generalized cross-section (present E-W), across the Lampang and Nam Pat basins; S, Shan-Thai; I, Indochina; va, volcanic arc; L, Lampang Basin; sc, subduction zone complex; N, Nam Pat Basin (after Bunopas, 1981).*

## Basal Khorat Group
## Upper Triassic (Norian)

**Nam Pha Formation at Nam Phrom Dam (Hahn's Unit ms1):** The ms1 consists of red, sandy claystone and fine-grained sandstone of red, light red, reddish brown, purple, gray-brown, gray and beige colours. Ms1 unit rested conformably on the marine Triassic strata in the central part or the basin. However, at the flanks of the basin it formed an angular unconformity. Based on fossils found in the underlying marine strata, the 300 m thick ms1 was considered to be younger than Late Carnian. At Nam Phrom Dam, Bunopas (1967; 1971; 1976) reported the grey shale with *Estheria*, which was later dated as late Norian (Kobayashi, 1975), under rocks similar to the Huai Hin Lat Formation. Erroneous later studies included this formation in the Huai Hin Lat Group. Nam Pha Formation (Bunopas, 1971), with type locality in the range near the Nam Phrom Dam, west of Chumphae, contains strata more than 500m thick with very similar lithologies and sequence to those in the Huai Hin Lat Formation except no thick conglomerate. The name has been mistakenly treated as a synonym of Huai Hin Lat Formation (Chonglakmani and Sattayarak, 1978). *Euestheria* is present and is restricted to fresh-water facies. *Euestheria mansuyi*, and other conchostracans were identified by Kobayashi (1975): *Euestheria thailandica* Kobayashi, sp.nov; *Euestheria buravasi* Kobayashi, sp.nov; *Khoratestheria macroumbo* Kobayashi, *gen.et* sp.nov*; Cyclestherioides bunopasi* Kobayashi, sp.nov; *Metarhabdostics* (?) sp.; and *Asmussia synmetrica* Kobayashi, sp.nov. These fossils indicate a Norian age. Fossil leaves reported by Bunopas (1971) have not been identified, but fossil pollens were reported by Haile (1973). Some horizons of the Nam Pha Formation may have been deposited in a shallow marine environment. Nam Pha Formation represents the forerunner of the conglomerate bearing Huai Hin Lat Formation on the other side of the range.

**Rhyolitic flows, volcanic tuff and tuffaceous beds, agglomerates, volcanic and rock fragmented conglomerates:** (mapped as ms2 by Hahn (1976) in Chiang Rai and Bunopas (1967; 1971; 1981) in Phrae-Nan as stratified volcanic flows, agglomerates and rhyolites under Jurassic red-beds)

Both Hahn (1976) and Bunopas (1967; 1971; 1981) seemed to have analogous level of either ms2 and volcanic flows in Chiang Rai, Phrae-Nan and the late Triassic grey-shale beds that followed immediately by volcanic conglomerate (Huai Hin Lat Formation) and red-beds. The basal parts and Lower Khorat Group in previous Shan-Thai are complicated.

Abundant volcanic extrusive flows indicated excessive occurrence of volcanic activity in Shan-Thai towards Chiang Rai to Phrae and Nan. It is believed that there was less volcanic activity at the Indochina margin towards the west of the Khorat Plateau, where it was dominated by the Lom Sak Formation (Bunopas and Bunyajitradul, 1970) and the Haui Hin Lat brecciated conglomerate Formation (Chonglakmani and Sattayarak, 1978; Ward and Bunnag, 1964). This is consistent with the continent-continent collision of the Shan-Thai over the Indochina.

**The Lom Sak Formation** (Iwai et al., 1966) with a type locality at west Lom Sak on the Lom Sak-Phitsanulok Highway, is predominantly basic to intermediate grey tuff. The formation also includes some carbonaceous shale with poorly preserved plant fossils of: *Sequoia ambigua* Heer,–*Pterophyllum* sp. and a possible reptilian tooth (Iwai et al., 1966). A Cretaceous age has been suggested on the evidence of the possible *Sequoia ambigua*. On the contrary, the formation is now known to stratigraphically underlie the lower red-beds (Bunopas, 1971; 1981) and is above the volcanics and sedimentary red-beds equivalent of ms2 of Hahn (1976) from Chiang Rai.

The grey beds are overlain by a lower red-beds sequence, composed of the *Nam Phong Formation*, which was overlain by the ***Phu Kradung Formation.*** The Nam Phong Formation is composed of soft grey and red siltstone, 70% of the formation, interbedded resistant beds of cross-bedded red sandstone and conglomerate. At the formation's type locality, it is 1456m thick. The Phu Kradung Formation comprises inter-bedded pink sandstone, red siltstone and shale with occasional thin fine-grained conglomerates. The basal part is a pelletal micritic limestone of lacustrine origin (Iwai, 1973). A thickness of the Phu Kradung Formation is 1000m. Away from their type sections, the Phu Kradung and Nam Phong formations are not individually recognizable. Moreover, the complete lower red-beds section is informally referred to as the Phu Kradung Formation, following the original description of Brown et al. (1951). Fossils of fresh water bivalves indicate a Lower Jurassic age. The red clays of the Phu Kradung Formation contained Laurasian crocodile *Sunosuchus* (Buffetaut and Ingavat, 1980).

Basal part of the Khorat Group, formed since the continent-continent collision, include ms1, or acid or intermediate effusive; Nam Pha Formation; shallow Triassic shale (ms1) in Chiang Rai; Lom Sak Formation and Huai Hin Lat Formation (lowest part). The age was mainly late Norian. After Norian time, the Khorat Basin started to sink (Fig. 14). Inferred tectonic events from a study on paleomagnetic of the Khorat Group were proposed by Maranate and Vella (1986).

## Lower Khorat Group
## Jurassic
## Greatest surface changed and sediments on basal Khorat Nam Pha Formation in eastern fold zones and previous Indochina Craton area:

Consequece to the continent-continent collision, those pre-Triassic marine basins were largely reverted to paralic basin conditions and large alluvial plains possibly comparable with the Indogangetic Plain, when the continent-continent collision commenced.

The fast clockwise rotation of more than 80° from late Early Triassic to latest Triassic (Bunopas, 1981) of the Shan-Thai occurred as a consequence of the great continent-continent collision leading to the disappearance of the pre-Jurassic sea (Tethys). It is also resulted in the moderately stable, less than 10º clockwise rotation of amalgamated Shan-Thai-Indochina (Fig. 8), but growing Jurassic land during most of the Mesozoic. This was consistent with the fast polar wandering from South to North from Late Triassic to Early Jurassic (Bunopas, 1981; 1994; and Bunopas and Vella, 1980). It revealed a distance of 1650 ± 850 km (Achache and Courtillot, 1985) of SW-NE convergence of 15º-10º counterclockwise, with respect to the Eurasia (North China) pole, between 205-160 Ma.

This also reflected on the continuous deposition of over 4000 m to 5000 m thick Jurassic-Cretaceous Khorat red-beds. There are extensive volcanic chains and volcanoes. The eruptions were sub-aerial eruptions of mainly rhyolites and andesites. The chain extends from east Shan States, eastern North Thailand, west of the Khorat Plateau, Kho Chang in Trat Province, to East Malay Peninsula. Agglomerate, conglomerate and sedimentary products mapped as ms2 by Hahn (1976), volcanic flows at east Chiang Rai and Phrae were late equivalents of volcanics. The equivalent horizon is the limestone volcanic conglomerate beds at Doi Ka in Nan area including the Huai Hin Lat Formation (Iwai et al., 1966; 1968) in the adjacent Khorat Plateau. These Huai Hin Lat conglomerates, principally with volcanic fragments and Permian-Triassic limestone fragments, were considered to be the base of the Khorat Group (Iwai et al., 1966; 1968; and Ward and Bunnag, 1964), representing the continent-continent collision debris.

**1) Huai Hin Lat Formation, Volcanic Formation, (Unit ms2):** The ms2 is characterized by intermediate to acid effusive rocks (andesite, rhyodacite, and rhyolite) and associated tuff. The unit rested more or less conformably on the non-marine red-beds in the basin center, whereas at the flanks and in the upland areas, it overlies unconformably on the Triassic and/or Permian rocks. The thickness varies from 300 to 350 m.

**2) Nam Phong–Phu Kradung Formation (Unit ms3):** The ms 3 is the major transgressive unit covering the eastern part of northern Thailand completely. Where it directly overlies the ms2 unit, it begins mostly with conglomerates then gradually changes upward to sandstone and shale. The thickness is 300 to 400 m. Lithologically, it resembles ms1. Typical or the whole units are the conglomerate, which occur throughout the basin. Limestone beds are found locally and presumably indicated the marine transgressions over the uplifted areas. Limestone breccias are probably remnants or strata deposited during marine transgressions. Unidentified bone fragments, fish teeth and scales were found in this bed.

**3) Phra Wihan Formation (Unit ms4):** The ms4 is characterized by quartzitic, partly arkosic sandstones of white, white-gray, yellowish, gray, gray-green, light brown and subordinately, reddish and red-brown colour. Some conglomeratic beds and intercalations of gray, grayish green and red claystone were also reported. The formation is 400 to 500 m thick.

**4) Sao Khua Formation (Unit ms5):** The red sandstone and claystone which is typical of the nonmarine red sequence is also present in unit ms5. The sandstone is fine-grained, occasionally argillaceous, and has red, reddish grey, grayish brown and redish brown colour. Generally, this sandstone has good bedding and is intercalated with red, often sandy, claystone. Salt producing wells, especially the one at Bo Klua (headwater region of the Mae Nam Nan) in the northeastern part of Nan province, indicate rock salt intercalations in units ms3 - ms5 (Credner, 1935). This formation is the highest formation in the Sukhothai Fold Belt. In the Khorat Plateau, this formation is widespread and contains Jurassic dinosaur fossils. This Jurassic sequence is equivalent to the highly tilted sequences in Pak Lay fold zone caused by excessive compressional folding since the collision. A transect from Chiang Rai to Pak Lay fold belt represents the combined active folding in the central fold belt (along the Sukhothai-Loei Fold Belts). Lower beds of this late Upper Triassic-Jurassic are often found vertical to overturn and are related to easterly underthrusting along the Nan-Uttaradit Suture Zone, east of the Nan River.

Although the deposition was predominantly east of the Uttaradit-Luang Phrabang suture, the group was also deposited west of the suture in Indochina craton. Granites in northern Thailand, east of the Shan States, and Peninsula Malaya were also of comparable event.

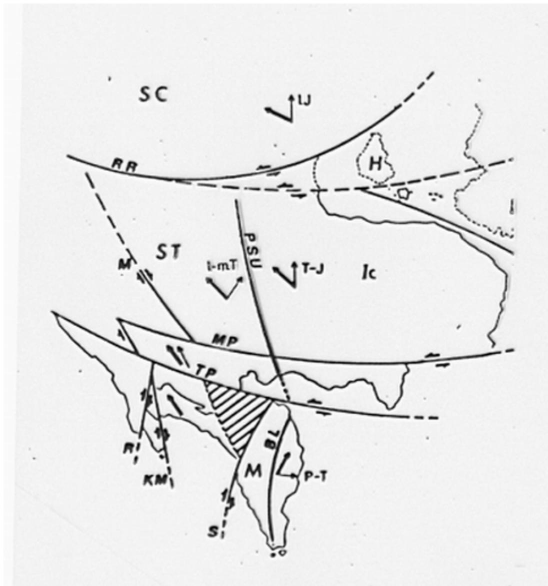


*Fig. 9. Late Triassic-Lower Jurassic palinspastic reconstruction of Shan-Thai and Indochina. Double shafted arrows show direction of present day north; single shafted arrows paleomagnetic north; P-T: Permian-Triassic; l-mT: lower to middle Triassic; T-J: late Triassic-early Jurassic; l.J: early Jurassic directions. PSU: Pha Som Ultramafic; BL: Bentong Ophiolite Line; TP: Three Pagoda Fault; MP: Mae Ping Fault; RR: Red River Fault; KM: Khlong Marui Fault; S: Songkhla-Penang Fault.*

In Chiang Rai, the ms3 unit of Hahn, consisting of shale, siltstone and minor sandstone, is equivalent to the red shale and siltstone at Nan, and to the lower Jurassic rocks of Nam Phong and Phu Kradung (Ward and Bunnag, 1964) formations in the Khorat Plateau. The ms4 consisting of white quartzitic sandstone and arkosic sandstone of green-grey and red brown color. They are correlated to similar horizon in Nan, and to the Phra Wihan Formation (Ward and Bunnag, 1964) in the Khorat Plateau. This horizon is mapped as a Middle Jurassic. Red siltstone, claystone and shale mapped in Chiang Rai as ms5 are similar to Nan upper red shale of upper Jurassic, and can be correlated with Sao Khua Formation in the Khorat Plateau. There is no known red-bed after the end of Jurassic in the north but sedimentation continued and was more limited on the Indochina Craton. Late Jurassic at Mae Sot to the western craton was also the uplifting time.

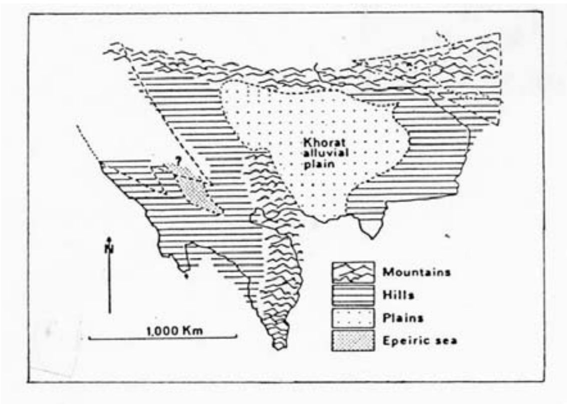


*Fig. 10. Paleogeographic sketch map of Jurassic of Southeast Asia, using Fig. 3. as the base, after the continent-continent collision but before late Jurassic uplifting.*

The Jurassic marine also developed on the east of Indochina basin at Dalat in southern Vietnam. The middle Jurassic Aalenian species of ammonites were previously known before in Dalat Basin. A new Bajocian molluscan in the middle of the formation in the Dalat Basin (Vu Khuc and Grant-Mackie, 1997) includes two species that were correlated to western Australia, western North America and eastern Europe of Bajocian to early Bathonian ages. The bivalves have Toarcian-Callovian ages and occurred with ammonites.

An unconformity between Jurassic and Cretaceous, based on paleomagnetic evidence of Sao Khrua and Phu Phan Formations in the Khorat Plateau, was suggested (Maranate and Vella, 1986).

### *Western former Shan-Thai cratonic areas*:

To the west of the cratonic areas adjoining Burma, in Mae Sot-Kanchanaburi, the Tethys was still opened (on the western inlets) to the end of Jurassic and deposited the marine Triassic-Jurassic Mae Moei Group, Triassic-Jurassic Sri Sawat Limestone, Jurassic Diso Limestone, older coarse-grained Jurassic limestone and conglomerate. The Kaeng Raboet Formation (Bunopas, 1981) probably formed at the begining of Jurassic. Shallow marine conditions (inner to middle shelf) existed over most of western and southern Thailand in the Toarcian-Bajocian, although the Mae Sot area was slightly deeper (outer shelf, perhaps upper slope). These conditions are indicated by: the abundance of faunas; the presence of oncolitic and oolitic limestones; and plant remains in sandstones. With the low Tethys sea levels of the Toarcian-Bajocian, the sea invaded only western Thailand. Toarcian and regression in the Bajocian (?) were represented by limestone conglomerates in most sequences. Upper Jurassic marine formation has been known only in Mae Sot with an Oxfordian faunules.

Jurassic of adjoining Burma further inland, the formation of platform carbonates (Namyau Limestone) continued in parts of the sedimentation area in East Burma. Locally, in the Northern Shan States evaporites continued to deposit (Namyau Group, Upper Triassic-Jurassic).

During the Upper Jurassic, the formation of coarse and fine red clastics as well as the pelites (Hsipaw Red Beds, approximately 1,200 m) started. The Hsipaw Red Beds begin with basal calcareous conglomerates in Northern Shan State. This formation was discordantly laid down on top of the Thigyit Beds (shale) of the upper Loi-An Series of the Southern Shan State (Kalaw Red Beds, approximately 2,000 m). Further to the South in the Karen-Tenasserim part of the Sino-Burman Ranges, similar clastic, mainly red sequences formed after a hiatus above the Upper Triassic Kamawkale Limestone (Bender 1982).

## Upper Khorat Group
## Cretaceous

***1) Eastern areas*** (north and northeastern Thailand, Laos, Cambodia, southern Vietnam)

The Cretaceous rocks were mainly continental in these cratonic areas in Peninsular Thailand and in Burma. However, these rocks are not existed on the emergent Shan-Thai active margin (in the Sukhothai Fold Belt).

The Cretaceous rocks distribute from the Indochina microcontinent in the frontal basin Nakhon Thai Geosynclinorium to the main Khorat Basin, as typical sinking continental trough. Found to continue its deposition in full steam, these rocks spread into Laos, southern Vietnam, Cambodia and eastern Malay Peninsula, and are well exposed in the Nakhon Thai synclinorium and the Khorat Plateau basin. In the Khorat Plateau basin, totally 1500 km of the Cretaceous Phu Phan Formation, as well as Phu Thok Formation (Bunopas et al., 1989; Imsamut, 1994), Khok Kruat Formation and Maha Sarakham Formation continuously developed (Ward and Bunnag, 1965; Iwai et al., 1966; 1968; 1975). The latter of which contains rock salt and potassium salt. Ban Na Yo Formation (Iwai et al., 1966; 1968) representing Cretaceous fossiliferous beds (Kobayashi, 1963) in northeast corner of the Khorat Plateau is probably correlated to Khok Kruat Formation (Ward and Bunnag, 1965) in most western parts of the plateau.

Phu Phan sandstone Formation and the equivalent Phu Thok Formation unconformably rested on Jurassic Sao Khua Formation that forms high ridges on the inner Khorat Plateau.

The Khok Kruat shales and siltstones, perhaps is similar to Cretaceous Na Yo Formation (Kobayashi, 1968) are disconformably (although questioned by Maranate and Vella, 1986) overlain by the salt bearing Maha Sarakham Formation. These Cretaceous Khorat Group are distributed only in the Khorat Plateau, Nakhonthai Plateau and in Laos.

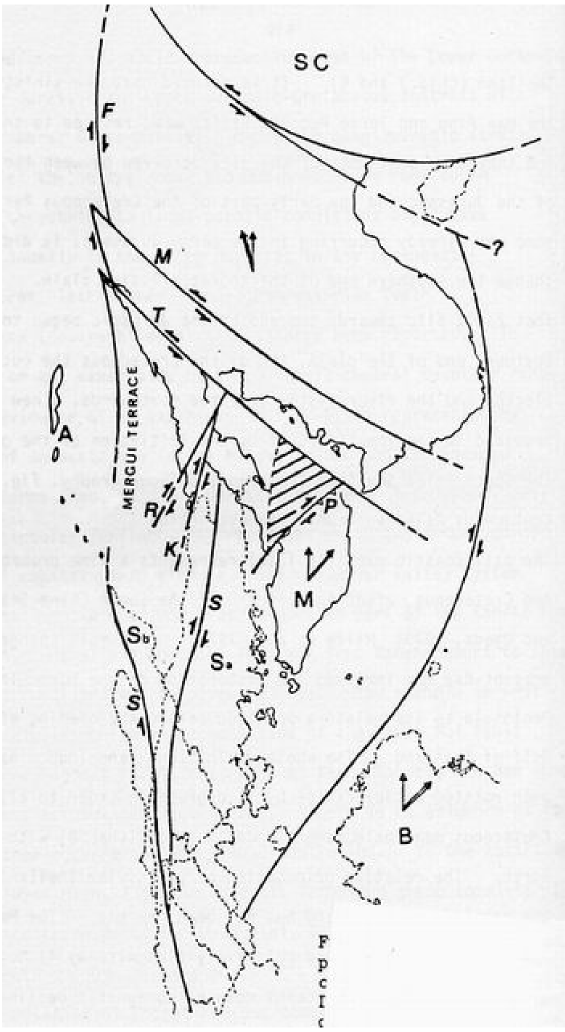


*Fig. 11. Early Late Cretaceous palinspastic reconstruction of continental Southeast Asia. Double shafted arrows represent present-day north, single shafted arrows represent Cretaceous paleomagnetic north. SC: South China; M: Malay Peninsula; B: Borneo; Sa and Sb: Sumatra in two alternative positions; A: Andaman volcanic arc. F: Mandalay Fault; M: Mae Ping Fault; T: Three Pagoda Fault; R: Ranong Fault; K: Klong Marui Fault; P: Songkhla-Penang Fault; S: Samangko Fault.*

Two paleomagnetic ages of the Phu Phan Formation at Phu Thok, Nong Khai, based on two different sample collections determined at two separated laboratories, i.e. in Bangkok and in Kunming, yielded l55 and l43 Ma, respectively. These results conform to the latest Jurassic and mainly lower Cretaceous age at the base of the formation (Bunopas et al., 1989; Imsamut, 1995). The plateau was emergent to a massive land, after a maximum age of the Maha Sarakham Formation around 80 Ma (Bunopas, 1981; 1982; Maranate, 1982; Maranate and Vella; 1984).

Although results of inclination measurements in Maha Sarakham salt specimens from the Nakhon Phanom drillhole are less reliable, they suggest correlation with any part of the paleomagnetic time-scale after 85 Ma. The Maha Sarakham Formation overlies Khok Kruat and could be late Cretaceous or Tertiary in age. Angular unconformity between the Maha Sarakham and underlying Khok Kruat Formation was reported verbally at a seminar given by Esso Petroleum at the Department of Mineral Resources (DMR), Bangkok, on February 2, 1983 (Maranate, 1984).

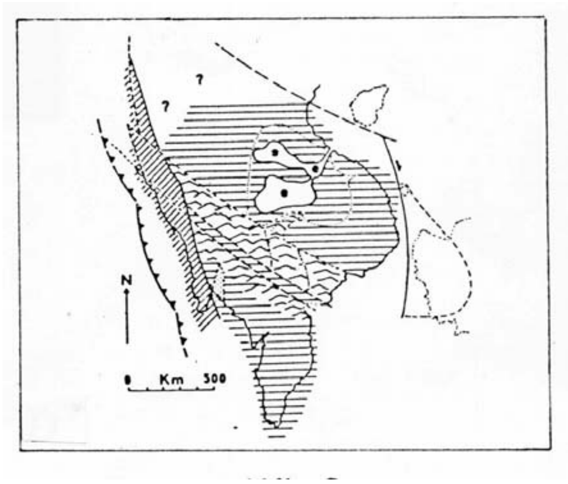


*Fig. 12. Early to Middle Cretaceous paleogeographic sketch map using Fig. 10. as a base map. Mountains and hills are shown by same hatching as on Fig. 4. Small dotted area in southwest represents alluvial plain.e: marine evaporite basins; diagonal hatching on left, zone of Cretaceous granites; barbed line to left, trench, barbs showing direction of underthrusting.*

However, so far no precise age of these strata can be given since macrofossils and pollen are absent. A Late Cretaceous to Early Tertiary age would not only correlate with the strata below, but also fit into the world-wide observed period of transgression. An upper age limit of the formation is given as Miocene by pollen found in the upper clastic unit. Harris (1977) previously carried out palynological studies of core samples from DMR potash wells and gave the age of mid-Cretaceous for the Maha Sarakham Formation. This study concluded that the age of the formation should range from Mid-Late Albian to Cenomanian. Sulphur and oxygen isotope studies on the Maha Sarakham evaporitic anhydrite from the Bamnet Narong area also yielded the age of Neocomian to Cenomanian, preferably Cenomanian (Pisutha-Arnond et al., 1986).

Hansen et al. (2002) have collected samples along a 1,200 m long profile in the shaft at Bamnet Narong Asian Potash Mine. The collected samples vary from halite and anhydrite to carnallite as well as one clay sample representing middle elastic layers. Multiple isotopic approaches (K/Ar, K/Ca and $^{87}Sr/^{86}Sr$-composition) have been made to date the salt formation. The obtained data point to a deposition age of some 93 Ma. The age of the Maha Sarakham Formation salt is therefore considered by Hansen et al. (2002) to be Cenomanian, which is in good agreement with the ages (Aptian-Albian) obtained from vertebrate fossils from the underlying Khok Kruat Formation (Buffetaut and Ingavat, 1986). Nevertheless, an age of the salt up to Santonian was suggested by Maranate and Vella (1986) as quiet normal interval dated from Santonian to upper Hauterivian (80 - 115 Ma) or mid-Upper Cretaceous from magnetic horizons nearby.

Recent single sedimentologic analysis of the potash-bearing Maha Sarakham Formation (Upper Cretaceous) shows that it was not of marine origin as previously thought (Utha-Aroon, 1993). The main reason is a lack of evidence suggesting transgression onto the underlying red-beds of the Khok Kruat Formation, which was of desert stream deposits. Similar lack of evidence also holds for the salt/red clastic contacts within the evaporites. Sedimentary features preserved in cores also point toward the nonmarine origin. Algal lamination, palmate and swallow-tail fabrics in anhydrite (formerly gypsum) suggest shallow gypsum pan environment, while truncation and dissolution of the primary halite crystals suggest ephemeral salt pan conditions. Clastic units alternating in the formation contain features, such as desiccation cracks, caliche, and displacive anhydrite nodules that characterize saline and dry mudflat environments. In the potash zone, neither carnallite nor sylvite shows structures that may indicate sedimentation in a standing brine body or growing upward from the pan floor. Moreover, it is discernible at places that carnallite and sylvite were formed interstitially in the salt pan halite host, which implies their diagenetic origin.

Considering the information gained so far, it is apparent that there was no restricted sea in northeastern Thailand during Late Cretaceous time. The Maha Sarakham Formation was in fact deposited in arid desert, probably deep in the continent. The new interpretation raises several questions, i.e. basin history, stratigraphic subdivision of the Khorat Group, and relationship among the formations within. It may also affect the economic aspects of the formation, i.e. continuity of the potash horizons and occurrence and migration of subsurface brines.

The Lom Sak Formation previously given Cretaceous age from the fossil grass (Iwai et al., 1966; 1968) is now proved to be Late Triassic based on magnetic stratigraphy and vertebrates (Bunopas, 1981; 1982; Buffetaut et al., 1984) and also on stratigraphic relation (Bunopas et al., 1971).

Footprints are found in the Cretaceous sandstone of Phu Rua and Khao Yai. Dinosaur bones are found in younger Cretaceous siltstones at Ban Khok Kruat, Khorat. The first discovery of dinosaur footprints and new discoveries of dinosaur bones in the Lower Cretaceous of the Savannakhet Province, Laos, was made in the thirties. A French geologist, Josue Heilmann Hoffet, was surveying the sedimentary formations of lower Laos when he discovered dinosaur remains, which he attributed to a hadrosaur, *Mandschurosaurus Iaosensis* and sauropod bones, described as *Titanosaurus falloti.* The description of these specimens, which were associated to a bivalve fauna, led him to suppose the dinosaur bearing formation was Senonian in age.

From 1990 to 1994, several franco-lao expeditions in the Savannakhet Province discovered new dinosaur remains in the vicinity of the village of Tang Vay. Two localities have yielded parts of sauropod skeletons (30 caudal vertebrae, a complete hind limb, pelvic bones, etc.). At another locality, bones of a small iguanodontid, teeth of a theropod, fragmentary bones of crocodiles, turtles and fishes were recovered with freshwater bivalves and plant remains.

A preliminary study showed that Hoffet's interpretations had to be corrected. What had been described as a hadrosaur is an iguanodontid, and the sauropod does not belong to the genus *Titanosaurus.* The fossiliferous beds are not Senonian but Early Cretaceous in age.

In the same geological formations, the first dinosaur footprints in Laos have been discovered in 1993 and 1994. Their tracks are printed on siltstone slabs along the bank of the Se Sang Soi River near the village of Pha Lane. Forty six footprints of ornithopods and 13 of a theropod give complementary information about this Lower Cretaceous dinosaur fauna.

Further studies should provide a better knowledge of this fauna and its associated flora and help in stratigraphic correlation with a better understanding of the biogeography of Southeast Asia during Early Cretaceous time.

***2) Western areas*** (East Burma, west and Peninsular Thailand and west Peninsular Malaya)

In west Peninsular Thailand, the Trang Group continues into two Cretaceous formations in the folded structure. The lower formation consists predominantly of conglomerates, conglomeratic sandstone and poorly sorted coarse-grained sandstone of alluvial fan origin. The upper formation consists of fine-grained sandstone of fanglomerates origins with trough and planar cross-bedding reflecting braided stream and debris flow origins. This formation are paucity in fossil but was given an age of Upper Cretaceous.

## Non-Khorat Group Shallow Marine: Restricted Shallow Marine Upper Triassic-Jurassic in Mae Sot and East Myanmar

The Late Triassic depositions cover the welded microcontinent. There are marine Jurassic rocks in Shan-Thai cratonic platform in western Thailand, while in other areas sediments are continental in origin.

In western Thailand, the Late Triassic Kamawkale Limestone grades up through a limestone-shale intercalation to a shale or sand sequence, named the *Upper Mae Moei Group* (Von Braun and Jordan, 1976). While marine biostromal limestone continued locally, detrital marine sedimentation continued to a Late Jurassic time (Von Braun and Jordan, 1976; Bunopas, 1981).

At Umphang, south of Mae Sot, continuing shallow marine, Jurassic Paleo-Tethys in Thailand, in cratonic platform basins as the *Upper Mae Moei Group* (Braun and Jordan, 1976) was studied biostratigaphically in detail by Asanee Meesook. The Jurassic sedimentary rocks of Thailand consist of both marine and non-marine which are widespread in the western and northeastern parts of the country respectively. The marine Jurassic is well exposed in the Mae Sot and Umphang areas where bivalves and ammonites are abundant and diverse. Based on these faunas, the Thai Jurassic ranges in age from Toarcian to Early Bajocian and biostratigraphic correlations within Thailand and Southeast Asia are summarized.

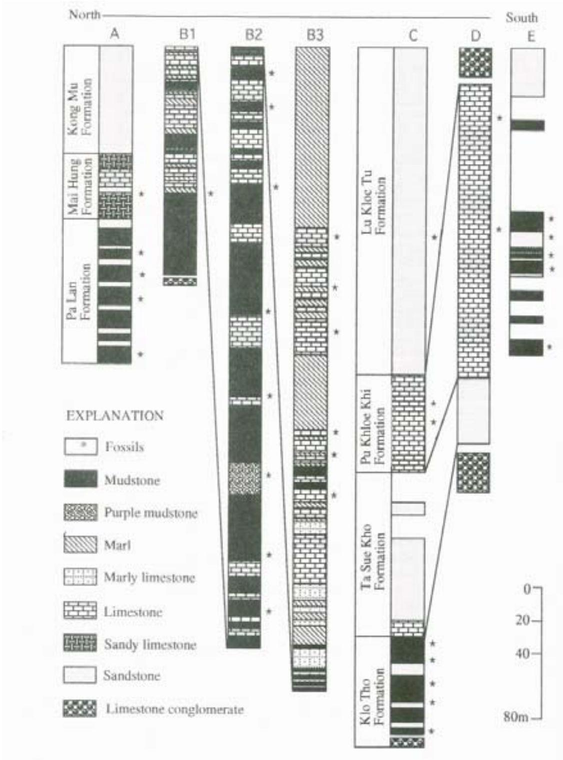


*Fig. 13. Stratigraphic correlation of restricted shallow marine Upper Triassic-Jurassic in Mae Sot and East Myanmar (after Meesook and Grant-Mackie, 1994).*

Toarcian-Early Bajocian marine Jurassic strata of Thailand (Meesook and Grant-Mackie, 1994) are widespread from Mae Hong Son in the north to the southern peninsula, and are thickest and best exposed in the Mae Sot and Umphang areas. Biostratigraphic correlation within Thailand is based on ammonites with some bivalves and foraminifera. The Umphang Jurassic unit is similar to that of Mae Hong Son by its bivalve content and a few ammonites, but differs significantly from that of the intervening Mae Sot area. The Jurassic of Umphang and Mae Sot can be correlated with that of Kanchanaburi from foraminifera and algae. The Jurassic rocks of Nakhon Si Thammarat district can be dated and related to the Umphang sequence by the sole bivalve *Modiolus.* The marine Jurassic rocks can also be correlated with the non-marine Phu Kradung and Phra Wihan Formations in the northeastern Thailand. In Southeast Asia, the Thai Jurassic rocks belong to the eastern Tethyan and most closely similar to that of Vietnam and Myanmar, with some relationships with other regions in the vicinity.

## Non-Khorat Group red-beds

**The Trang Group** in the peninsula overlaid unconformably on Upper Triassic coral-bearing limestone of Chai Prakarn Formation, formerly mapped as Permian limestones, at Patthalung province east of Trang province (Teerarangsigul et al., 1999). In the south and central parts of the eastern edge of the Indo-Burman Ranges, Cenomanian limestone, siliceous and bituminous limestones and calcareous sandstone (Bender, 1983) formed above the Upper Triassic *Halobia* beds or above chocolate-coloured shale of unknown age.

The paleogeographical interpretation of the sedimentation during the Cretaceous is made difficult by the fact that strata of this age occur in a continuous stratigraphic sequence. Further to the west, exclusively at the east edge of the Indo-Burman Ranges, Cretaceous sediments occur only as allochthonous rock masses and blocks in Tertiary flysch type sediments. The allochthonous rocks originated in the area at the east edge of the Indo-Burman Ranges and in the Inner-Burman Tertiary Basin that adjoins to the East.

Cretaceous deposits are of very limited extent. Their main occurrence is east of the suture lines. There is no evidence of extension of the red-bed facies beyond the Early Cretaceous.

The deposition of post-collision continental rocks up to the Jurassic is consistent with the Khorat Group, from volcanic sediments and conglomerates, on the youngest marine Triassic greywacke and shalet. Although the deposition was predominantly in east of the Uttaradit-Luang Phrabang suture, in Indochina the group was also deposited west of the suture to Cretaceous.

## Age Determination of Mesozoic Continental Khorat Group and Paleomagnetic Stratigraphy

Dating of the regional wide Mesozoic continental red-beds from the significantly important cratonic basin, which are normally barren of fossils, helps stratigraphic dating. Correlating the Jurassic and red-beds from the western platform to the now better control Khorat Group also helped understanding tectonic settings (such as Buffetaut et al., 1981; Bunopas, 1981; Bunopas and Vella, 1983b; 1992; Chaodumrong and Burrett, 1997; Haile and Tarling, 1975; Hansen et al., 2002; Imsamut, 1983; Iwai, 1973; Iwai et al., 1966; 1968; Kobayashi, 1964; 1968; 1980; 1983; Maranate, 1982; 1983; 1984; Maranate and Vella, 1986; Meesook and Grant-Mackie, 1993; Ward and Bunnag, 1964). However, it is now, in the beginning of the 21st century that the multilithologies and tectonic assemblages part of the Khorat Group, from Huai Hin Lat and lower formations since the collision, are understood.

Paleomagnetic data had been reported by Maranate (1982) and Maranate and Vella (1986). Other data from northeast Thailand (Haile and Tarling, 1975; Barr et at., 1978; Bunopas et al., 1978; Bunopas, 1981; Achache and Courtillot, 1985) were mentioned also. There are now a substantial number of paleomagnetic measurements from the region. These measurements were made in various laboratories, but generally in good agreement, lending some confidence to tectonic inferences based on them.

## Subsidence of Northeast Thailand during the Khorat group: Inferred Tectonic Events from a Study on Paleomagnetic of the Khorat Group

The Khorat Group is a post-orogenic molasse facies (Bunopas (1981), and see next section below). Most of it was deposited on a large alluvial plain, probably similar to the present Indogangetic Plain, while some parts were deposited in paralic conditions (Bunopas, 1981). The estimated maximum thickness is approximately 5,000 m which indicates progressive subsidence of Northeast Thailand during late Triassic and Cretaceous times. If vertical crustal movement were the only factor, Phu Phan-Sao Khua unconformity would indicate that the subsidence was interrupted by still-stand or uplift between late Jurassic and early Cretaceous periods. However, if allowance is made for eustatic sea level changes during the Jurassic (Hallam, 1978) and Cretaceous (Sliter, 1976; Hancock and Kaufman, 1979) the subsidence appears to have been continuous from late Triassic to Cretaceous times and decreasing in rate exponentially (Fig. 14C). Hancock and Kaufman (1979) estimated a net eustatic sea level rise of 600 m between 105 and 70 Ma (beginning of the Albian to Maastrichtian). We consider it reasonable to assume a net rise of 1000 m between the beginning of the Jurassic and the Maastrichtian (Fig. 14B). The points that define the subsidence curve (Fig. 14C) were derived by subtracting sea level (above basal Jurassic sea level) at the appropriate time from each point defining the 4 cumulative thickness curves (Fig. 14A). Using values of 800 and 1200 m for the Jurassic to Maastrichtian net sea level rise gives essentially exponential subsidence curves, but using a value of 600 m fails to remove the effect of the Phu Phan-Sao Khua unconformity.

Data points of Maranate and Vella (1986) are too widely spaced in time to show effects of short term sea level changes on the subsidence curve, which shows significant smoothing of irregularities on the cumulative thickness curve at only two places. The larger one is between 150 and 125 Ma where the effect of the Phu Phan-Sao Khua unconformity disappears, suggesting that the unconformity was formed as a result of the fall of sea level (Hallam, 1978) during late Jurassic (Kimmeridgian-Tithonian) time. The lesser smoothing effect is the reduction of the dip in the cumulative thickness curve caused by the thinness of the Phra Wihan (pw) Formation relative to the subjacent and superjacent Phu Kradung (pk) and Sao Khua (sk) formations. The Phra Wihan is not only thinner, but also coarser-grained. It is a prominent ridge-former. It probably owes its distinctive lithology to the l60-110 Ma (Bathonian) low sea level (Hallam, 1978).

Errors in age, thickness and sea level estimates are sufficient to account for the scatter of the datum points on Fig. 14C. The subsidence shown is possibly exaggerated because it is based on the maximum measured thickness of formations, and the true maximum thickness of the Khorat Group at any single location may be nearer to 4,000 m than 5,000 m. However, unpublished petroleum exploration results may soon yield more accurate thickness.

Lom Sak Tuff Formation was not included in the plots in Fig. 14 because it is probably older than an Indosinian Orogeny. It is localized in distribution and, in our opinion, probably should not be treated as a part of the Khorat Group.

The exponential decay of the subsidence rate of Northeast Thailand is similar to that of ocean lithosphere which gradually sinks isostatically because of cooling and thermal contraction (Sclater et al., 1971). Average subsidence rates estimated from individual formation thickness and age ranges in the Khorat Group decrease from 4 in/Ma in the early Jurassic to 0.7 in/Ma in the middle Cretaceous. The fastest rate is ten times slower than the average subsidence rate of ocean lithosphere younger than 60 Ma (Sclater and Tapscott, 1979). However, the eventual amount of subsidence is similar. We postulate that the lithosphere of Northeast Thailand gradually cooled down after the mid- to late-Triassic Indosinian Orogeny (Bunopas, 1981) and sank isostatically because of thermal contraction combined with the load of Khorat Group sediments.

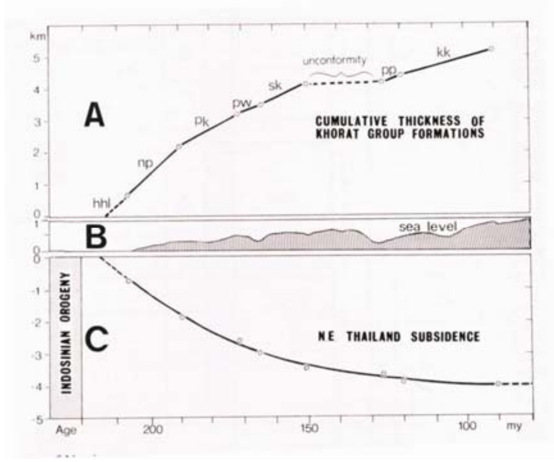


*Fig. 14. Subsidence of Northeast Thailand at exponentially decreasing rate during Jurassic and Cretaceous, **A**: Cumulative thicknesses at inferred ages of formation tops (Lom Sak Tuff is not included, see text for detail); **B**: Jurassic-Cretaceous sea level changes. **C**: Jurassic-Cretaceous subsidence of Northeast Thailand derived by subtracting B with A (after Maranate and Vella, 1986).*

## Lateral displacement relative to Eurasia during the Mesozoic

The Huai Hin Lat (Norian) pole (the position determined by Achache and Courtillot, 1985), combined with younger Khorat Group pole (the position determined by other authors), with respect to the Eurasian Mesozoic pole positions (Irving, 1977), show the convergence of Indochina and Eurasia occurred between late Triassic and middle Jurassic times (Achache and Courtillot, 1985). According to Achache and Courtillot, initial contact of the continental domains occurred before Norian and resettled in anticlockwise differential rotation of Indochina relative to Eurasia. The main differential movement is shown by paleolatitude differences. While Indochina remained at nearly the same latitude as present, Eurasia moved southward by 1600 ± 750 km (Achache and Courtillot, 1985).

Paleobiogeographic and paleomagnetic evidences (Achache and Courtillot, 1985) and lithostratigraphic evidence (as discussed in previous section) leave little doubt that Indochina was sutured to Shan-Thai and South China by late Triassic time. Achache and Courtillot considered that the convergence of the Indochina–Shan–Thai-South China collage with Eurasia between late Triassic and middle Jurassic was centred on the Songpan Ganzai (Bakan Hai Range), which lies between North China (southern edge of Eurasia Plate), the South China and Tibet paleoplates. They were, however, uncertain whether the convergence was resulted from subduction of a remnant of the Paleothethys Ocean or from shortening of continental crust, by either overthrusting or strike-slip faulting.

The clockwise rotation of Northeast Thailand, indicated by all Mesozoic declinations, happened after middle Cretaceous time (Maranate, 1982). The rotation was considered by Achache and Courtillot (1985) to have been caused by the collision of peninsula India against Asia in the Cenozoic Era and to have been associated with the suggested propagating extrusion tectonics of Tapponnier et al. (1982). We have previously inferred from the paleomagnetism that major dextral displacement has occurred along the Red River Fault in Mesozoic and Cenozoic times, which is contrary to the sinistral displacement suggested by the propagating extrusion hypothesis (Tapponnier et al., 1982).

## Cenozoic: Breakups of Pangea
## Second continent-continent collision of India to northern extended of Shan-Thai to Tibet (Northern Shan-Thai)

Second continent-continent collision of India to East Asia mainland (Archaryya, 1999; Bunopas, 1981; Molnar and Tapponnier, 1975) or northern extended of Shan-Thai to Tibet (Northern Shan-Thai) (Bunopas et al., 2003) started sometimes in latest Cretaceous. The extrusion of India and Asia was during Early Tertiary (see below).

## The Extrusion of Indochina during the India/Eurasia Collision: Early Tertiary

Yang et al. (2001) carried out paleomagnetic study from Tertiary sections located in both the eastern (Dayao area) and western (Jinggu, Jiangcheng and Mengla areas) sides of the Red River fault (RRF). The characteristic remnant magnetization (ChRM) is isolated using stepwise thermal demagnetization. The primary nature of the ChRM directions is ascertained through positive fold or reversal tests. Differential rotations of sampling sections in the northern part of Indochina block are related to the faulting of the Red River shear zone and its conjugate faults during the Early Tertiary and Miocene. These results further confirm the post-Cretaceous clockwise rotations and sinistral motion of the Indochina block relative to the South China block. Comparison of the latitudes from both sides of the RRF indicates the extrusion of 1,000 km of Indochina along the Red River fault relative to the Southern China Block (SCB) during the Paleocene. The convergence between India and Eurasia was, not only accommodated by huge crustal shortening in the Tibet plateau, but also the lateral extrusion involving the extensional tectonics in the Gulf of Beibu and opening of the South China Sea. These results show that extrusion is one of the main mechanisms, which accommodates crustal shortening during the India-Asia collision. The Himalayan foreland basin and around the Gongha syntaxis in the SCB were also discussed by Archaryya (1999), while the effect in South China Seas was discussed by Bochu (1999), Ishikawa et al. (1990) and Lui et al. (1999).

Modern theory where collisions are resulting in immediate concomitant orogenesis are readily observable (Aitchison and Davis, 2001). Although the early stages of collision between two major fragments of continental lithosphere are nowhere observable at present, we are able to observe smaller scale collisions between accreting island arcs and continents in locations such as Taiwan, Timor, Japan and Papua New Guinea. All of these areas have experienced orogenesis with juvenile topographic relief on the order of 4,000 meters. Uplift has been synchronous with collision and in each of these locations there has been a geologically immediate response to the entry of continental lithosphere into the subduction system. Collision of a relatively minor intra-oceanic island arc, the Luzon arc, with the continental margin of Asia has given rise to nearly 4 km of topographic relief in Taiwan over the past 5 Ma. The deformation front is propagating across the leading edge of the continental margin of eastern China just as the last of the remaining oceanic lithosphere is being subducted and arc magmatism is ceasing. In northern part of Taiwan where collision has finished, orogenic collapse with attendant extrusion parallel to the axis of the collision belt is now well advanced and topographic relief is actively being reduced.

Prevailing models for the India-Asia collision, the greatest on-going collision event in existence, suggest that collision between two major continental fragments at 55 Ma was not followed by mountain-building orogenesis for at least 20 million years. One might ask why this has not previously been thought to be highly anomalous. Either existing models that invoke India-Asia collision at 55 Ma are wrong, i.e. collision occurred at a different time, and/or a different collisional event is recorded. We suggest that two different tectonic events are recognizable. Features related to each event need to be interpreted separately and no collisional continuum should be assumed. One event occurred at around 55 Ma, another at around 30 - 25 Ma.

Collision of India with an intra-oceanic island arc at the end of the Cretaceous, removed a south-facing convergent plate boundary from within Tethys (Aitchison and Davis, 2001). Recognition of this event provides an explanation for the slowdown in convergence between India and Asia at 55 Ma. This intra-oceanic island arc is now preserved within the India-Asia suture zone. Continent-continent collision between India and Asia did not occur until the end of the Oligocene and was met by an immediate response in the form of orogenesis.

## Lansang, Tak, isotopic mineral dating

To evaluate Bunopas (1981) on the Cenozoic N-S extensional regime and the opening of the Gulf of Thailand, the DMR team cooperated in the French-Chinese Neotectonics Expedition in Lansang as part of the Wang Chao Fault Zone, the Three Pagoda Fault Zone in relation to the Red River Fault Zone (RRFZ) and collect rock samples from Pre-Cambrian gneisses. Details are in Lacassin et al. (1997) and only some are reviewed here as Cenozoic Diachronism of strike-slip movements and deformations along the east side of India related to tectonic regime in Thailand since early Eocene (50 Ma). The clockwise rotation continued into Miocene (20 Ma). The Miocene movement was at the maximum and was also the last recorded available.

## Diachronism of Strike-Slip Movements and Deformations along the East Side of India to East Asia (Himalayan Extrusion)

The southern part of Indochina (or Sundaland) appears to have been pushed towards the SE along the Wang Chao and Three Pagoda Fault Zones (WCTP) from ~24 to ~30 Ma (Lacassin et al., 1997). Such motion may have started prior to that of the whole Indochina block along the Red River fault zone (Fig.15c). Rifting and extension in pull-apart and mismatch basins at the southeastern end of these left-lateral strike-slip faults appear to have been the case with the Thai and Malay basins (T and Ma on Fig. 15c), with the mouth of Mekong basins in southern Vietnam (Me, Figs. 15b and 15c), and with the South China Sea (Figure 15b). Coevally, towards the north, shortening and thrusting with south-vergence seem to have occurred in the Eocene (~36 Ma), either in northern Tibet or in northern Indochina (Figure 15b), and large part coeval with regional motion (Tapponnier et al., 1986; Peltzer and Tapponnier, 1988; Briais, 1989; Briais et al., 1993; Leloup et al., 1995). This N-S folding in the Simao basin and in northern Thailand as well as related conjugate striking faulting (Figure 15b), may have absorbed shortening on the west side of Indochina during extrusion (Fig. 15c) (Lacassin et al., 1996). The location of

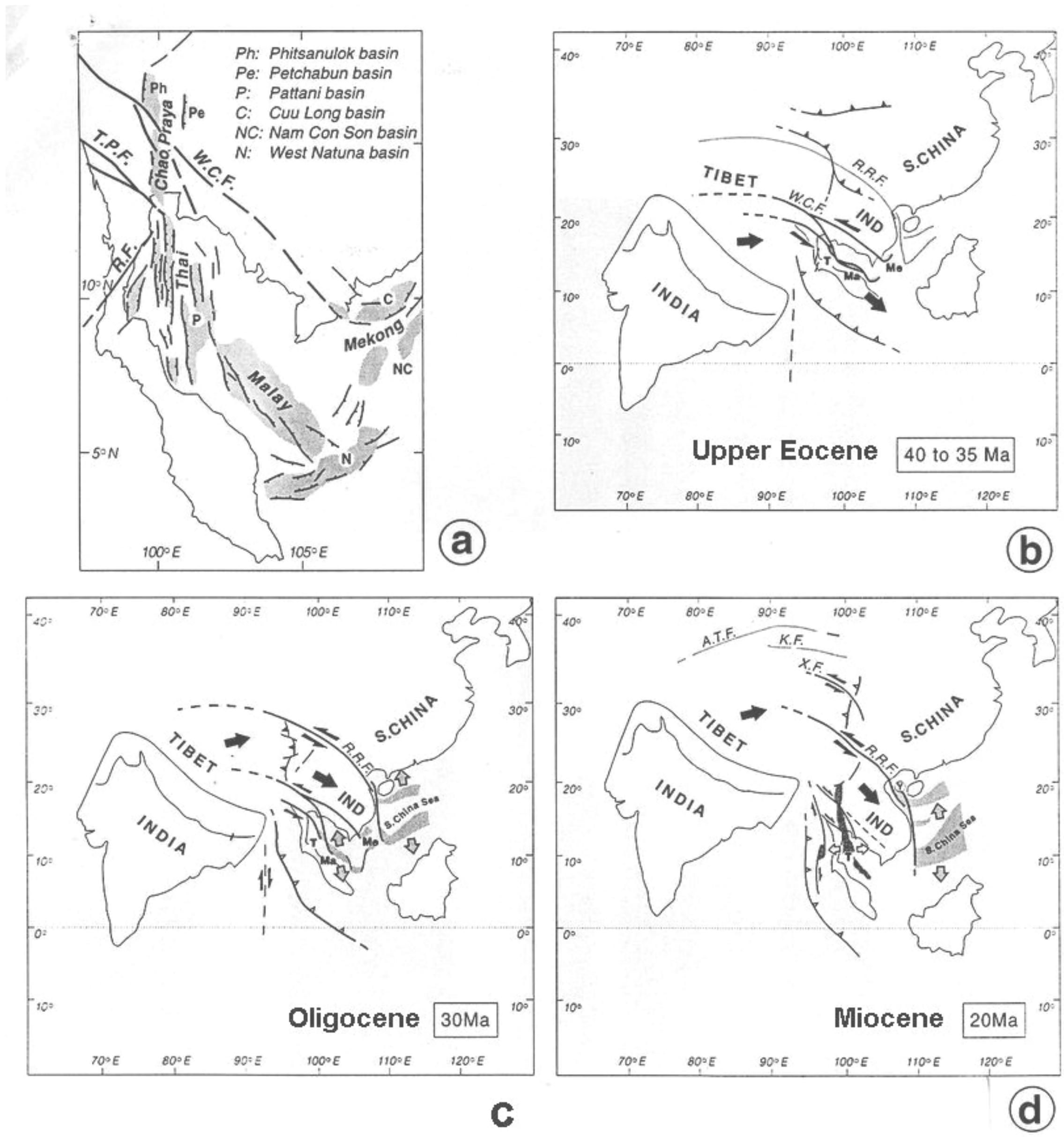


*Figure 15. Speculative sketches of successive extrusive phases from Late Eocene to lower Miocene, and relation with basin opening at southeastern tip of major faults.*

*(a) Structural sketch of main Cenozoic basins after (ASCOPE, 1981; Hutchinson, 1989; Tan, 1995). W.C.F., T.P.F., R.F. are Wang Chao, Three Pagodas, and Ranong faults, respectively.*

*(b) Plate and continental blocks situation in Upper Eocene (40 to 35 Ma). Beginning of sinistral motion on Three Pagodas-Wang Chao fault zone (W.C.F.), extrusion of southwestern Indochina, and correlative opening of Malay (Ma), Mekong delta (Me) and parts of Gulf of Thailand (T) basins. At the same time, south directed thrusts were probably active in NE of Tibet and in northern Indochina (Lacassin et al., 1996).*

*(c) Lower Oligocene (~30 Ma). Major extrusion of Indochina (IND), with sinistral motion along Red River Fault (R.R.F.) and opening of South China Sea. This occurred coevally with latest shear increments along Three Pagodas-Wang Chao Fault Zone.*

*(d) Lower Miocene (~20 Ma), sinistral motion continued along Red River Fault together with opening of South China Sea and Yinghehai (Y) pull-apart basin (Leloup et al., 1995).*

regions affected by shortening at that time is reminiscent of that of regions now undergoing shortening north and east of Tibet. N-S and E-W shortening, respectively, indeed characterize the contemporaneous tectonics of the Qilian Shan, along the north edge of the Tibet (Tapponnier et al., 1990; Meyer, 1991), and of the Lungmen Shan, along the western edge of South China. Early shortening and extrusion and shortening of the southernmost slice of Indochina apparently stopped somewhat after 30 Ma. At the Oligo-Miocene boundary, as rapid left-lateral shear was occurring along the Ailao Shan-Red River shear zone (Scharer et al., 1990; Tapponnier et al., 1990; Scharer et al., 1994; Leloup et al., 1995), E-W extension, which was possibly linked with right-lateral reactivation of the WCTP faults, began to affect the southwestern part of Indochina (Fig. 15d).

At this time, southern Indochina was already located SE of the northeastern corner of the Indian indenter.

The maximum horizontal stress, due to the Indian push, might thus have veered to nearly N-S in this region, allowing for E-W extension (Tapponnier and Molnar, 1976; Tapponnier et al., 1982; Le Dam et al., 1984; Peltzer and Tapponnier, 1988; Huchon et al., 1994). The uplift and cooling of the N-S metamorphic belt, that we document around 23 Ma, may have been related to such E-W extension and to normal faulting along the Sam Ngao fault. Note, however, that E-W shortening and N-S folding between 29 and 24 Ma could have caused significant part of the uplift of this belt (Ahrendt et al., 1993).

Whatever the case, it seems clear that, as the Indian indenter kept penetrating northwards into Asia (Fig. 15b and 15c), Indochina suffered several, radically different, deformation phases in a rapidly changing kinematic framework and stress field (Tapponnier and Molnar, 1976; Tapponnier et al., 1982; Le Dam et al., 1984; Tapponnier et al., 1986; Peltzer and Tapponnier, 1988; Huchon et al., 1994; Leloup et al., 1995). At the scale of the whole collision zone, India appears to have successively pushed towards the east or southeast several continent-size blocks along left-lateral strike-slip faults located farther and farther northwards (Tapponnier et al., 1982; Tapponnier et al., 1986; Peltzer and Tapponnier, 1988). The locus of major sinistral movement, as well as of the areas affected by shortening or extension, kept jumping towards the North (Fig. 15b to 15c). Our detailed work on the faults of western Thailand supports the inference of northward diachronism in the onset and cessation of strike-slip movements on the east side of the collision zone. Left-lateral motion occurred from at least ~36 to ~33 Ma along the Three Pagodas Fault Zone (Fig. 15) and ~33 to ~30 Ma along Wang Chao Fault Zone (Fig. 15). Extrusion of Indochina occurred at least between ~26 and ~17 Ma (possibly as early as 35 Ma) along the Ailao Shan-Red River shear zone (Scharer et al., 1990; Scharer et al., 1994; Leloup et al., 1995; Harrison et al., 1996). Farther north, left-lateral motion still in progress began at least 15 Ma ago on the Xianshuihe fault (Roger et al., 1995), and yet later, possibly as early as ~7 Ma ago (Gaudemer et al., 1995) or as late as ~1.8 Ma (Burchfiel et al., 1991) along the Haiyuan fault east of the Qilian Shan. Accurate age constraints still lack for the onset of motion on the Kunlun fault. The onset of E-W extension follows a comparable S-N diachronism. It occurred in the upper Oligocene in the Gulf of Thailand, in the Miocene in northern Thailand and probably in the Pliocene in Yunnan near the Red River Fault (e.g., Leloup et al., 1995).

In southwestern Indochina, onset of E-W extension in Gulf of Thailand (T) possibly driven by dextral reactivation of Three Pagodas-Wang Chao fault zone. X.F., K.F., A.T.F. are future traces of Late Cenozoic Xianshuihe, Kunlun and Altyn Tagh sinistral faults.

Motion of India relative to Asia is after Patriat and Achache (1984) and Besse and Courtillot (1988). Poles and rotation rates for Indochinese blocks are those of Briais et al. (1993) adapted by Leloup et al. (1995) (From Lacassin, 1997).

Plotting such ages as a function of distance measured north of $5^{\circ}$N, shows that the approximate timing of left-lateral motion on the different faults follows and lies roughly parallel to the path of Indian indenter northeastern corner in a reference frame fixed to Eurasia. This gives quantitative support to diachronic activation of sinistral faults located farther and farther north of the Indian indenter northeastern corner. Left-lateral motion appears to have started on the Three Pagoda, Lansang-Wang Chao, Xianshuihe, Kunlun, and Haiyuan faults, when the N-S distance between that corner and the Cenozoic.

## Thailand Stratigraphy during the Cenozoic and the Opening of the Gulf of Thailand (Out of the Khorat Plateau Region)

The Gulf of Thailand was formed by rifting during the Cenozoic (fig 16; Bunopas, 1981). It is floored by very thick (up to 5 km) mainly fresh-water sediments that include beds at least as old as Oligocene, and probably considerably older. High heat flow in the sediments suggests a basement of young mantle-derived rocks. Seismic prospecting data indicate many north-south trending normal faults that have moved progressively during deposition of the sediments. Rifting was east-west, at right angles to the trend of the normal faults, and the northwest trend of the Gulf of Thailand is not related to the rifting trend, but is inherited from a line of weakness along the Mesozoic northwest trending sinistral Three Pagoda Fault Zone.

Approximately northeast trending dextral faults in peninsular Thailand lie roughly at 45° to the east-west sense of extension of the Gulf, and accommodate increasing separation towards the south, of peninsular Thailand from Indochina (the eastern Gulf coast). From paleomagnetic evidence, the Malay Peninsula has rotated anticlockwise away from Indochina with a pole of rotation near or in western Borneo, and its northern end may be overthrusting southern peninsular Thailand.

Intracratonic spreading in the Gulf of Thailand and extensional tectonics in western, central and northern Thailand are probably related to the current subduction of the Indian Plate under Southeast Asia along the Java trench and the Andaman-Nicobar Island

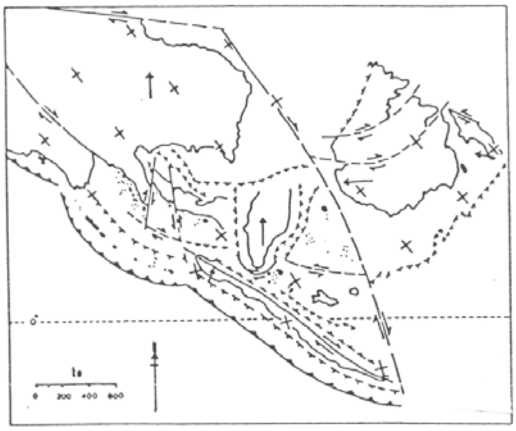

*Fig. 16. Map showing configuration of continental Southeast Asia in late Cretaceous and early Tertiary times. The opening of the Gulf of Thailand was about to start during early Cenozoic by rifting generated from continent-continent collision increasingly more intensified. Arrows show Mesozoic magnetism declinations, half arrows, sense of strike slip displacements. Notice a brief anticlockwise off the margin.*

Fine-grained detrital and organic-rich Lower and Middle Cenozoic fresh-water sediments in central, western and northern Thailand indicate continuing low relief of these areas. Late Cenozoic rudaceous deposits reflect the rise of the present mountains, probably during

Pliocene and early Quaternary. The present mountains are horsts and tilted blocks bounded by normal faults that generally trend north-south. The normal faulting coincided with the extrusion of high alumina alkaline basalts represented by many small basalt fields in eastern and northern Thailand, and in Indochina.

## Tertiary basins in ridges and basins areas, the opening of the Gulf of Thailand and the non-depositional period in the Khorat Plateau region

Nearly all of the forementioned activities, in the western and peninsular Thailand were outside of Khorat Plateau, but with serious uplifting and rotational affect to it. Cenozoic evolution of Thailand, precisely known to be involving in the tectonically busiest period, including was the second, to the first in late Triassic (in the Mesozoic), continent-continent collision from Gondwana India to Asia causing the Himalayan Extrusion and subsequent diachronism and related extensional tectonics regime, i.e. opening of the Gulf of Thailand and NS fault extensional Neogene basins on mainland. The phenomena were known more intensified towards the Miocene and Pliocene for the period of more cultivation of energy resources in Thailand and South East Asia, both onshore and offshore. Above all, during the Cenozoic Thailand had been greatly spatially changed to 20 Ma and shortly after, to 5 Ma before present with still submerged Peninsula and low intermontane basins. Paleomagnetically it included the dominantly clockwise rotation, and changing generally of smaller latitudes. Continental fragment long traveling on the continental margin through the Gulf of Thailand during the maximum N-S extension and the opening of the Gulf is being investigated. Latest inversion of Neogene basins was commonly recorded as abundant highly tilted rudaceous sequences, and common Quaternary basalts indicated new immediate uplifting.

## The Transition from Pliocene to Pleistocene: Pliocene-Pleistocene boundary in Thailand and in Africa as a type and in general

The Olduvai Paleomagnetic Event from Olduvai Gorge in Tanzania regards as the beginning of Pleistocene contains some volcanic rocks interbedded with 1.75 Ma fauna indicated the Pleistocene began more than 1.74 Ma ago. Pliocene-Lower Pleistocene basalts were 90 % widely distributed and were well dated by K/Ar (see Sutthirat et al., 1994; 1999). The volcanism of Afghanistan is placed at Plio/Pleistocene boundary (Vikhter, 1978). The Olduvial Event is not recognized in Thailand but thought to be the basal part of P1eistocene terraces older basalts and alluvial covering in morphological troughs and basins.

Basaltic flow bands at Mae Thah and Buriram (Barr and Macdonald, 1976; Sutthirat et al., 1994) gave a Pleistocene compilation age range from 0.95 – 0.69 Ma, with individual ages 0.8 ± 0.3 Ma, 0.6 ± 0.2 Ma, 0.59 ± 0.05 Ma. Fig. 22 shows basalt flow bed melted an upper part of the underlain catastrophic loess, melted and attached on.

While volcanic basalt flowing on the catastro-loess, appeared as a half golf ball at the hill south of Buriram town, melted the underlying catastro-loess quickly. This material suggests that most of basaltic flows in Buriram were well younger than catastrophic loess. These basaltic flows are also widespread on rice farms. Dating of Khao Kradong Basalt revealed the timing of 0.92 ± 0.3 Ma by K/Ar age (Sutthirat et al., 1994). Dating result of the basalts must be younger than ~0.8 Ma (by $^{40}Ar/^{39}Ar$ age from tektites at Ubon Ratchathani Province which was a contemporary event age of catastrophic loess). Ninety percent of Pliocene-Lower Pleistocene basalts were widely distributed and were well dated by K/Ar (see Sutthirat et al., 1994). The volcanism of Afghanistan is placed at Plio/Pleistocene boundary (Vikhter, 1978). Late Pliocene to early Pleistocene basalts with age ranging over 1 to 3 Ma, a few at little higher than 4 Ma, and rarely up to 9 Ma are reported at Lamnarai and Ko Krut, in front of the Khorat plateau region. Cores of Pleistocene basalts from Huai Rak Mai near Mae Moh Basin in were said to be similar to Kenya continental rift alkali basalts (Boonsoong and Panjasawatwong, 2003). The Nam Ma fault of Myanmar and Laos, and the Mae Chan fault of Thailand show geomorphic expression similar to Early Quaternary sapphire-bearing basalt field at Houei Sai, Laos suggesting a result of extension along a north-south opening, and clearly related to the Mae Chan fault (Woods, 2003). This basalt lies in the bed of the Mekong River at Chiang Khong where it is K-Ar dated by Barr and McDonald (1981) to be 1.7 Ma. New road cuts north of Houei Sai, along the Mekong River exposed the base of a north-flowing paleostream canyon filled with basalt, 30 m above low water level.

## Quaternary: Quaternary extension tectonics in southern Tibet (implication of vertical uplifting?)

Evidence for Quaternary and active faulting were collected in the field (Armijo et al., 1986) during three Sino-French expeditions to southeastern Tibet (1980-1982). Detailed mapping of Quaternary and active faults as well as microtectonic measurements indicate that normal faulting has been a dominant tectonic regime north of the Himalayas in the last 2 ± 0.5 Ma. Maximum horizontal principal stress in south Tibet appears to be only the intermediate principal stress δ2 (δ1 being vertical). South of the “chord” joining the eastern and western syntaxes of the Himalayan arc, extensional strains are principally localized within seven regularly spaced rift zones, three of which have been studied in some detail. The extension direction is determined to be N96ºE ± ρ mainly from statistical averaging of strikes of newly formed normal faults. Throw rates on normal faults are evaluated for different time spans (2 ± 0.5 Ma, 50 ± 40 Ka, and 10 ± 2 Ka B.P.), using structural and topographic relieves, as well as synglacial and postglacial vertical offsets. The rate of Quaternary extension is about 1% per Ma along a 1100-km-long ESE traverse across south Tibet. This rate corresponds to a 'spreading' rate of 1 ± 0.5 cm/yr. This rate and the divergent horizontal projections of slip vectors of earthquakes along the Himalayan front constrain the state at which rigid India underthrusts southern Tibet to be 2 ± 1 cm/yr. Although most of the normal faults appear to be independent of, and nearly orthogonal to, the E-W Mesozoic-Tertiary tectonic fabric, the Yadong-Gulu rift appears to he guided for over 130 km by the older, oblique (NE-SW) Nyainqentariglha range and fault zones along it. This reactivated zone is the most prominent left-lateral strike-slip fault system in SE Tibet. Excepting this zone, and the vicinity of the SE extremity of the Karakorum fault, Quaternary strike-slip faulting is rare in south Tibet, i.e., south of the chord between syntaxes of the Himalayan arc. North of the chord, however, the tectonic style is different. Minor conjugate strike-slip faulting is widespread and appears to control Quaternary norma1 faulting, which is more diffused and subdued than in south Tibet. Along the chord, the presence of a major zone of active right-lateral, en échelon strike-slip fault (Karakorum-Jiali fault zone) probably reflects the better facilitating of eastward extrusion in north central Tibet, in response to the northward push of India. The eastern Himalayan syntaxis may be an obstacle to such extrusion movements south of the chord.

### Lower Pleistocene gravels and basalts, and new tentative Quaternary stratigraphy in Thailand and South East Asia

Fig. 19 is a tentative stratigraphic chart related to the rapid vertical uplift and is proved to be new understanding of the Quaternary in Southeast Asia. This is perfectly consistent with a new discovery instead of using only tektites previously known at 0.73 Ma as a key for the correlation (Sibrava, 1993). Lower Pleistocene terraces of the lower Pleistocene in Thailand from 1,800 Ka (Pliocene/Q boundary) to 790 Ka (new Australasian Tektites age), and beyond mid-Middle Pleistocene to 600 Ka (last basalts age), indicated continue uplifting, but with decreasing uplifting intensity. The western mountains of Thailand were uplifted to this present level during the Early to Middle Pleistocene with last basalt activity at Mae Thah and Buriram (Sutthirat et al., 1994). Some Lower Pleistocene gravels were uplifted to several hundreds of meters. Upper Pleistocene and the Recent were the recovering and degradational stages with little thickness of normal sedimentation.

### Inthanon Epeirogenesis: Rapid Uplifting in Western Mountains of Thailand, and the Himalayan

Miocene Himalayan Extrusion had been mainly vigorous tectonics, deficit of, or not necessary responsible for the extreme heights of present Himalayan (Fig. 15) and clockwise rotation in Thailand. Until the last 5 Ma (seafloor anomaly 3), large parts of Peninsular Malaysia and lower Indochina Peninsula were still under the sea (Rangin et al., 1990a; 1990b). The 1,000 m altitude of lignite measures at the Suan Son prospect, Hot, south of Chiang Mai, with thin unconformity catastroloess (Bunopas et al., 1999; 2002, 2003) must be suddenly vertical uplifted to the present level. This assumption was based on the previously low, possibly close to sea level, as the sulphur isotope indicated some influence of marine incursion (Silaratana et al., 2003). This ultimately implied the non-existent of the western ranges in Neogene time. Deposition of lignite in the western mountains during that period, therefore, was not possible. The unconformity was time equivalent to the commonly, and widespread rudaceous sequence. At this moment we seem to agree that at early Pliocene the western mountains was affected by the rifting judging from the rather common Pliocene basalts (Barr and Macdonald, 1981; Sutthirat et al., 1994; Boonsoong and Panjasawatwong, 2003; Ratanasthien, 1997), the western ranges and the directly connected Himalayan and Qinghai-Tibetan plateau were some kilometers from its maximum heights. The unconformity interpreted from known age catastroloess on lignite beds indicated that during 0.80 Ma, while the vertical uplifting of the mountain was almost at the maximum level, the impact catastroloess settled. This was also reported in Qinghai- Tibetan plateau. This assumption is consistent with the 2.0 to 0.5 mm./yr uplift of the Himalayan (Armijo et al., 1986).

During Lower to Middle Pleistocene uplifting were much greater as the numbers were estimated to be much greater than 100 mm/yr (from the basis of vertical uplifting at 1- 2.6 km in 1-1.2 Ma and much more in the Himalayan area and the peripherals), comparing 0.6 to 0.8 mm/yr in east of the mountains at present (Fenton et al., 1997).

*Fig. 17. Photograph of a new prospecting lignite excavation site. The photo was taken in January 2000 at the site located immediately to the south of Hot to Mae Sariang Road (at the beginning of the road from Suan Son to Omkoi) in Precambrian terrain. According to Uttamo et al. (1999) scattered lignite mines are found north to northwest of Chiang Rai (Wiang Haeng), many hundred kilometers to the north.*

*Fig. 18. Neogene diatomaceous beds formed and were uplifted before the catastroloess at Km 2. This photograph was taken in 1999 on the New Phaholyothin Road, northeast of Lampang. The diatomaceous beds were uplifted 1000 m from the bottom of the lake before they were covered by the catastrophic loess.*

### Gravel beds on the Khorat Plateau

An integrated geographic model was proposed by Parry in 1996 for the high terrace gravels in the Khorat Plateau, northeast Thailand. In this model, which is proposed for the deposition of the high terrace gravels and their “preservation” as a landscape feature, the high terrace is controlled by both tectonic and climatic processes connecting with the uplifting of the Qinghai-Tibetan plateau. Gravels were washed into the Khorat and Sakhon Nakon basins from the Phetchabun ranges with common pebbles or clasts of Permian fusulinacean limestone with common red and green chert and volcanic rocks gravels. Burnt tree trunk at Wat Krok Duan Ha was buried under these gravels (Fig. 20). The gravel beds probably overlie the Khok Kruat Formation of Mesozoic Khorat Group (Chonglakmani and Malila, 2003) formerly established as Phu Khao Thong Formation (Udomchoke,

1989) with petrified trees, and terrace gravels (also at Khon Kaen province) with petrified trees near the top (Boonsener, 1986; Wannakao, 1999), both indicating pre- and 0.8 Ma surfaces. The buried trees are only a few meter under the surface (Galong and Kuttikul, 1999). There are abundant petrified woods in the mudflow layers (Wannakao, 1999) similar to our observation in Nakhon Ratchasima Province. Nachuak Formation (Suwanich, 1997), known from the top of a drill hole at Maha Sarakham province and its probably correlative to outcrops near Roi Et province, was possibly lower Quaternary local lake sediments deposited during the uplifting and tilting, locally formed in depositional basins, below the catastroloess previously known as windblown sands. The depositional products in Nakhon Ratchasima and Khon Kaen provinces were high terrace gravels containing wood fragments, which were subsequently petrified under catastrophic surface.

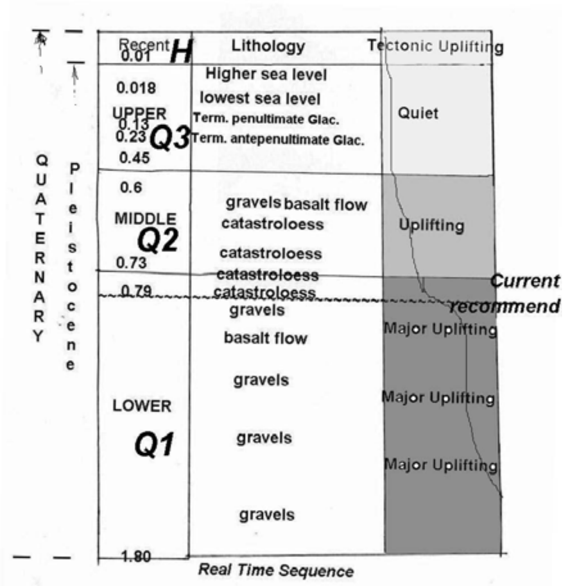


*Fig. 19. Provisional tectonic and volcanic activities related the real-time Pleistocene sequence. Tentative Quaternary divisions, $Q_1$ (1.8-0.79 Ma), $Q_2$ (0.79-0.45 Ma), $Q_3$ (0.45-0.01Ma) and Recent (0.01-0 Ma). Current date of $Q_1/Q_2$ is 0.73 Ma., and 0.60 Ma obtained from basalts dates from Mae Thah and Burirum, respectively. This is possibly the end and the youngest date of catastrophic loess (or catastroloess). The duration of deposition of these catastrophic loess was therefore assume to be between 0.79 and 0.60 Ma, or 19,000,000 years (from early Middle to late Middle Quaternary) of dust covering the global atmosphere (from 100 to 0 %).*

The Quaternary major uplifting tectonics would be in the Lower Quaternary and rate of uplift became slower until approximately after 0.6 Ma, or late Middle Quaternary. The age accuracy depends much on the good dating of Middle Pleistocene basalts. Position and age of the catastroloess in the Quaternary stratigraphic scale are on late $Q_1$-early to middle $Q_2$. From late $Q_2$ and younger, mainly reworked catastroloess as windblown sands and those affected by last glacial age, lower and rising sea level up to the Recent (provisional), are reported. Remark of CCOP practices: Pliocene/$Q_1$ 1.9 ma, $Q_1/Q_2$ 730 ka, $Q_2/Q_3$ 127 ka, $Q_3$/Holocene 0.010 ka (Yang et al., 1990).

## Catastroloess, Australasian tektites, trees burnt in wildfires, mass extinction of ancient elephants and other animals and plants

Bunopas et al. (1999; 2001; 2002), Howard (1999) and Howard et al. (2000), Haines et al. (2003) described the assemblages in ancient channel at Ban Tha Chang, Khorat as the products of ancient mega-flood from catastrophic flood dated 0.8 Ma by tektites and reversed paleomagnetic direction. These were interpreted by Bunopas et al. (1999; 2001) as the result of a 0.80 Ma cometary terrestrial impact. When the comet impacted, there were blasting and fire splashing and dust blowing up high into the atmosphere, melting the bedded rocks, which were then quickly solidified, and distributed as tektites. Dust and éjecta hanging in the atmosphere for some 100 Ka, deposited in layers all over Southeast Asia and later found as attractive badlands around the country. All destructive and constructive materials (DCMs) from the impact were catastrophic loess or, in short, "catastroloess". The catastroloess is found overlying conglomerates in many places. The DCMs in catastroloess was washed into every channel or river as in Ban Tha Chang, Nakhon Ratchasima province.

Catastroloess is related to Neogene deposits because of its widespread distribution and known age by tektites. New discovered ground, that is, solidified intact and bedded tektites at an elevation of 1,000 m in Hot district, can be interpreted as having involved in the uplift during 0.8 Ma (Bunopas et al., 2001; 2003). Thus, this is one application of a real-time sequence (catastroloess layer) on neotectonics.

## Khorat Plateau Uplifting in the Inthanon Epeirogenesis from early Quaternary Himalayan Extrusion Continuum, Northeastwards Tilting of Mekong River

The uplifting and eastward tilting (pushed and pulled/and raised, Bunopas et al., in press) of the Khorat Plateau, the central plain and the adjacent eastern gulf and the peninsula were also largely affected from the latest Himalayan extrusion against the Indochina Kontum Massif during early to late Middle Pleistocene time.

Northeast tilting of the Mesozoic Tembelling Group at the Jenka Pass (Ibrahim et al., 1998) in Malaysia Peninsula was consistent with the Khorat northeast tilting. The waning may be resulted from further underthrusting that caused the new extrusional continuum, during late Pliocene - early Pleistocene, reflected the uplift and eastward tilting of the Indochina block. Peninsular Thailand and Malaysia must have been uplifted several meters as evident by common conglomerate beds in Satun, and different geodynamic situations of the peninsula from 5 Ma (anomaly 3) to present (anomaly 0) by Ragin et al. (1990), and also easterly tilted during lower Pleistocene.

In the Khorat Plateau, the uplifting must be in at least 2 successive stages of pushed and pulled action (Bunopas et al., in press), where initial stage uplifting of the highlands that supplied abundant coarse conglomerate for some thickness, and later raised escarpments and mesas up to more than 1,300m above mean sea level.. This later stage included the northeastwards tilting and the diverting of Mekong, deserted behind the Tonle Sap in Kamphuchea, some thousand years before the impact at 0.80 Ma with tektites and the mass extinction of most lives and catastroloess (Bunopas et al., 1999). Burirum basalts extruded around 0.65 Ma (Sutthirat et al, 1994) and flew over (Jumphol Vichiansilp, per comm.) fresh, in place, catastroloess. This answers the inconsistent of Hartung (1990) and Ford (1988) speculation for the occurrence of Tonle Sap in Kamphuchea and Indochina basalts, respectively.

Many abandoned oxbow lakes, terminated channels (soke) and lakes (bueng, nong), and the shifting of Mekong (Mae Khong) River from the central plain to the present cause must have had taken place while the uplifting, tilting and shifting 90° east near Nongkhai during the Inthanon Epeirogenesis.

The cometary impact in the Buntharik Event which spreaded the Australasian tektites, huge forest fires and led to extinction of many ancient elephants and trees, etc. deposited more than 10 m of catastroloess above the gravel beds (Bunopas et al., 1999). Many thousand years worth of falling catastroloess would be washed simultaneousy to ancient channels (Howard, 1999; Howard et al., 2000; 2003). Many instructive answers to previous questions in the Khorat Plateau are now possible.

The base of the impact in the Buntharik Event is now absolutely certain at the level of ancient fallen burnt trees, covering by earth and mudflows (Galong and Kuttikul, 1999). Blasting and heat wave followed shortly by storms and the heaviest rains on earth resulting in burying of all trees. Avalanche debris at Ban Krok Duen Ha (Fig. 21) contains pioneer splash-form tektites. This level on ancient high and medium terraces in Khorat is only a few meters below lateritic sands in Ubon Ratchathani Province, known by Fiske et al. (1996), near the Chulaphorn Dam, which filled with splash tektite in a low catastroloess.

*Fig. 20. A photograph showing an uprooted and burnt hard wood tree trunk that was buried under terrifying earth flows, later formed gravel beds near Wat Krok Duan Ha, at Khorat Petrified Trees Museum site in Nakhon Ratchasima province on the Khorat Plateau. At time of comet impact all trees grown on older gravel terraces were suddenly uprooted fallen flat and almost all of these catastrophic burnt trunks pointing their roots ends toward the blasting impact on Ubon Ratchathani Province. Some of these trees are covered by surface slump, landslide and earth flows. The gravels were mixed with atmospheric fallen catastrophic loess and splashed tektites until none but only catastrophic loess for more than 10 m thick. We nominate the place as the Q1/Q2 boundary, the new and advance dating of ~800 Ka.*

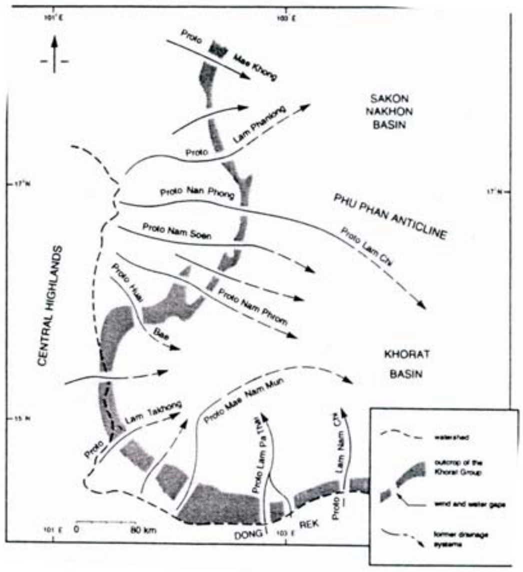


*Fig. 21. A schematic plan by Parry (1996) showing the uplifting of Paleozoic limestone, cherts and quartzitic sandstones of Chaibadan in the central highlands supplied conglomerates and sandstones beds deep into the plateau basins. Late stage of the uplifting raised the escarpments and mesas higher than the former highlands. Parry believed the uplifting of the plateau was the connection to the uplift of the Qinghai-Tibetan plateau. The western mountains, the central plain and the Khorat Plateau were all connected to the Himalayan Extrusion Continuum, the very East Asia continental-wide vertical uplifting, and Lower Quaternary Inthanon Epeirogenesis (2.0-0.6 Ma).*

Quarries situated in ancient channel deposits of the Mun River, in Nakhon Ratchasima province, northeast Thailand, expose sand and gravel deposited during high-energy flood pulses. These sediments contain abundant organic matters including horizons of large logs, fossil bones and Australasian tektites. Some logs and twigs showed evidence of variable degrees of burning, a few composed entirely of charcoal. From a combination of palaeontological, palaeomagnetic and tektite evidences we infer that deposition occurred close to 0.8 Ma (Howard et al., 2003). Above this horizon are massive clayey sands, called catastroloess, for some meters before disappearance of gravel beds.

## Uplifting and easterly tilting of the Central Plain

The Chao Phraya Central Plain shows thick alluvial fans in Suphanburi, Uthai Thani (Thiramongkol, 1987), Suphanburi, Kamphaeng Phet, Tak and Phitsanulok provinces on western side (Bunopas, 1976a; 1976b; 1976c) indicating the western regional uplifting. Consequently, the Ping River migrated eastward, the Wang River initiated eastwards tilting resulted in eastwards migration of the Yom River cutting on gravels affecting land use change at Srisatchanalai district (Saykawlard et al., 2003).

## 650 Ka Buriram Basalt overflew 800 Ka impact catastroloess

Buriram Basalt overflew the 800 Ka catastroloess at ~650 Ka in Buriram province (Fig. 22.). The age implied that the impact catastroloess finally ceased settling from the atmosphere, because there is no report of younger catastroloess. Up to 5 m thick of the atmospheric catastroloess deposited from 800 to 670 Ka, which was far many years of settling after the cometary impact, and longer duration than previously assumed and calculated by specialists (e.g., Glass, 1990; Wassan, 1991; Wassan and Heins, 1993).

*Fig. 22. A very rare photo specimen of 650 Ka Buriram Basalt. The rock had overflown and melted 800 Ka catastroloess (lighter coloured half ball) on the foot-hill south of Buriram province.*

Most of Quaternary basalt swamps in southern China, Myanmar and northern Laos were attributed to many strike-slip faults (Woods, 2003). This may also be the case for basalts in southern Indochina including southern Northeast Thailand.

## Late Middle to Upper Quaternary

After the activity of vast areas of basalts on the plateau (also in Indochina) ceased, during Late Middle to Upper Quaternary, indicating the regional uplifting also ceased, the transitional aggradation and deposition continued from early Quaternary into young alluvium. This tectonically stable part of Quaternary in Thailand may be acquainted to us and will not discuss further here.

Thailand has late Quaternary sequences that can be determined by standard stratigraphic methods and dated by inferring correlations with climatic changes (Nutalaya et al., 1986). The marine terrace they have mentioned is only the lowest, youngest and best defined one. The highest of which are at altitudes greater than 100 m in north of Pattaya district, Chonburi province, and Rayong province. Their elevations would provide perfectly confident ages and uplift rates when compared with high sea level times elsewhere in the world, as long as the uplift rate has been constant or varying in some regular way, as would be expected for tectonic movement.

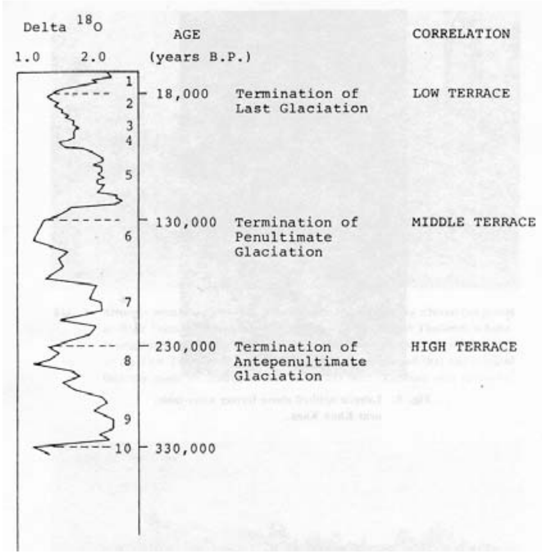


*Fig. 23. Proposed correlation of low, middle and high terraces with Quaternary oxygen isotope stages (Vella et al, 1983). Uplift rates are calculated from low, middle and high terraces heights in Ban Luang Muang Kong and Ban Muang Kud basins, North Thailand, given by Thiramongkol (1983). Correlation of each terrace (fan) aggradation with a full glacial interval, as shown, indicates a maximum uplift rate of 0.25 mm per year, consistent with the weak seismic activity in Thailand. Correlation of the fan gravels with stadials of the last glaciation would indicate a maximum uplift rate of 1.0 mm per year which should be accompanied by stronger seismicity. (From Nutalaya et al., 1986)*

Alluvial fan gravels also form terraces. However, their terrace heights are not constrained to a nearly uniform worldwide initial elevation, and cannot be analysed to show quantitative ages in the same way as those of marine terraces. The pollen record at Lynch's Crater in Queensland (Coventry et al., 1980) suggests little difference in climate between stadials and interstadials of the last glaciation, and rainfall being nearly uniformly low (less than 1,000 mm) throughout the last glaciation (ca. 80,000 to 10,000 years B.P.). Consequently, Vella et al. (1983) have inferred that each alluvial fan terrace in Thailand represents one full glacial stage. Some independent method of dating is needed to confirm the inference. Furthermore, the present differentiation of alluvial fan gravels into Low, Middle and High Terraces is probably over-simplified. It can be expected that more levels of terraces will be recognised in the future. At present eight full glacial intervals are considered to have occurred in the last 800,000 years (Nutalaya et al., 1986, Fig. 9) and possibly numerous ones in the early Pleistocene and late Pliocene (Shackleton and Opdyke, 1976).

## Extended Origin of Pleistocene into Asian Glacial Age

The glacial age existence was much later in Asia than that of North America and Europe since Lower Pleistocene. We started to link the 0.8 Ma cometary impacts with, in parts increasing of the last 800,000 years long Pleistocene glacial intervals and the many thousand years long of darkness from dense and dusty atmosphere, or impact catastroloess, and heavily torrential storms in Asia and Europe. The event might involve a quick drop of temperature from 20ºC to much below 0ºC. The

Buntharik Event on the 0.8 Ma cometary impacts must undoubtedly be the only source for the extended origin of the long sustained glacial age during Pleistocene in Asia and Europe. The Buntharik Event represented the cometary impact in Kazakhstan, Indochina, SE Australia-Tasmania tektite-strewn fields that originated larger catastroloess (Bunopas et al., 1999; Peter W. Haines, personal comm.). The glasses at the Darwin crater (Ford, 1988) at Mt. Darwin, Tasmania represent extremely high temperature in-situ tektites from the direct impact of the coma (head) to the terrestrial basement of the Southeast Australia-Tasmania tektite-strewn fields.

It has been known that the Pleistocene glacial and the Holocene constituted the Quaternary Period. Louise Agassiz demonstrated that continental glaciers at one time covered much of America. He also suggested that glaciation in both Europe and North America caused by a Great ice period". Evidences of multiple glaciations are reported in North America, Europe and Asia. The concentration on causes of the multiglaciation has surprisingly been contributed to astronomical, atmospheric and oceanic controls.

We are not hesitated to suggest an important role of regional major vertical crustal uplifting, worldwide and the 0.8 Ma cometary impact of the Buntharik Event, one-third global-wide of darkness, unusually high atmospheric catastrophic loess covering several thousand years in Asia as an origin of glacial age. Later the Buriram and Indochina basalts overflew on the loess.

## Conclusion

The Mesozoic continental Khorat Group was formed as the late and post-continent-collision that created the largest tectono-intracratonic basin mainly on the Indochina microcontinent. After the salt bearing accumulation was completed, the basin became emerged and cratonized through the whole Cenozoic era.

Even though the Cenozoic Era was the busiest time on tectonics and deposition around this region (Chaodamrong and Chaimanee, 2002; Sinsakul et al., 2002), not much were known in the Khorat Plateau of Thailand and throughout Southeast Asia.

The uplifting of the Khorat Plateau and the adjacent Eastern Gulf and the Peninsula were largely affected by the latest Himalayan extrusion against the Indochina Kontum Massif during Early to late Middle Pleistocene time. The northeastwards tilting of the plateau diverted also Mekong (Mae Khong) eastwards, at west of Nong Khai, and abandoned the Tonle Sap leaving only short watershed and many more inlets. Basaltic flows around the Khorat Plateau were connected with the vertical uplifting and tilting northeastwards of the plateau. Most of which occurred before the impact and only in Buriram province and inside the plateau had lastly regenerated the flows and overflown the impact catastroloess (Bunopas et al., 2001; 2002). The Khorat Plateau was the result of the Inthanon Epeirogenesis on the pushed-pulled theory action of the Himalayan Extrusional Continuum to the termination (Bunopas et al., in preparation). We now concluded that in the northeast Khorat Plateau, the upper gravels underneath the catastroloess was the first level of the Australian Tektites of both forms and the level also marked $Q_1/Q_2$ boundary. This is probably the first continental $Q_1/Q_2$ global boundary. The gravels were products of the Khorat Plateau vertical uplifting.

The western mountains of Thailand came into existed as the same time of the Khorat Plateau's uplifting during the Lower to Middle Pleistocene at the rate of much greater than 100 mm/yr based from very low ground that possibly had marine incursion to 1.0 - 2.6 km in 1.0 - 1.2 Ma. The uplifting would be much more in the Himalayan area and the peripherals, comparing to 0.6 to 0.8 mm/yr in east of the mountains at present (Fenton et al., 1997) would be almost negligible. The vertical uplifting of the western mountains was referred from the known extraterrestrial tectonics of a new discovery in Hot of the 0.8 Ma real-time stratigraphic unconformity.

This pushed-pulled theory for the young major crustal vertical uplifting movement should be merit, for a simple ideology, to young petroleum flowing as young as 2.0-6.0 Ma along the crust also. However, this preliminarily investigated paper may answers most questions pertaining geology of the region. The vertical crustal uplifting is emphasized by the very famous pushed-pulled output theory. This discovery also answers the question of the Pleistocene expansion of younger glaciation into lower latitudes in Asia. The impact created widespread and prolonged dust (catastroloess) and permanent darkness obstructed the light and heat from the sun, for more than 1/3 of the Earth over the Australasian for many thousand years since 0.8 Ma, could also initiate Pleistocene climatically low, ice age, interglacial intervals (opp. Wassan and Heins, 1993, p. 3050). The writers wish also to suggest, and urge to all, the newly known Thailand incident to be a precious type and to appreciate the greatest effect to the globe during the previous cometary impacts in geological history.

## Acknowledgement

The writers were grateful for the very helpful cooperative instruction on Buriram basalts and the catastroloess in the fields at Khorat of Drs. Jumpol Vichiansilp and Prathoeng Jintaskul from Rajabat Buriram and Rajabat Nakhon Ratchasima, respectively. Previous neotectonics team from France, paleomagnetic and tektites studies by Prof. J. T. Wassan, UCLA and Prof. B. P. Glass, Univ. of Delaware, Newark U.S.A., and the University of Tasmania, Australia were greatly acknowledged for their work lead to our discovery impact 10 DCMs. We are not hesitated to urge for the conservation of the World First Cometary Impact of the Indochina Field Museum at Nakhon Ratchasima to boosting geological tourisms.

## References


Achache, J. and Courtillot, V., 1985, A preliminary Upper Triassic paleomagnetic pole for the Khorat Plateau (Thailand): consequences for the accretion of Indochina against Eurasia, Earth and Planetary Science Letters **73**, 147-157.

Acharyya, S.K., 1999, The role of India-Asia collision in the amalgamation of the Gondwana-derived blocks and deep-seated magmatism during the Paleogene at the Himalayan foreland basin and around the Gongha Syntaxis in the South China block, Gondwana Research **2 (4)**, 510-512.

Ahrendt, H., Chonglakmani, C., Hansen, B. and Helmcke, D., 1993, Geochronological cross section through Northern Thailand, Journal of Southeast Asian Earth Science **8 (1-4)**, 207-217.

Ahrendt, H., Hansen, B.T., Lumjuan, A., Mickein, A. and Wemmer, K., 1997, Tectono-metamorphic evolution of Northwest Thailand dehjduced from U/Pb-, Rb/Sr-, Sm/Nd- and K/Ar-isotope investigations, *In*: P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien, C. Utha-aroon, N. Sattayarak, T. Nuchanong and S. Techawan (eds.), Proceedings of the International Conference on Stratigraphy and Tectonic Evolution of Southeast Asia and the South Pacific, Bangkok, Thailand, 314-319.

Aitchison, J. C. and Davis, A. M., 2001, How did the India-Asia collision really happen?, Gondwana Research **4 (4)**, 560-561

Armijo, R., Tapponnier, P., Mereier, J.L. and Tonglin, H., 1986, Quaternary extension in southern Tibet: field observations and tectonic implications, Journal of Geophysical Research **91**, 13,803-13,872.

Armijo, R., Tapponnier, P. and Tonglin, H., 1989, Late Cenozoic right-lateral strike-slip faulting in southern Tibet, Journal of Geophysical Research **94**, 2,787-2,838.

ASCOPE, 1981, Tertiary sedimentary basins of the Gulf of Thailand and South China Sea: stratigraphy, structure and hydrocarbon occurrences, Report of ASEAN Council on Petroleum (ASCOPE).

Barr, S.M. and McDonald, A.S., 1979, Paleomagnetism and geochemistry of the Denchai Basalt, Northern Thailand, Earth and Planetary Science Letters **46**, 113-124.

Batchelor, D. A .F., 1986, The age of Malaysian fluvial tin placers, *In:* N. Thiramongkol (ed.), Economic Geology, Tectonics, Sedimentary Processes and Environment of Quaternary in Southeast Asia, Haad Yai, Thailand, 103-124.

Baum, F., Bhaun, E. Von, Hahn, L., Hess, A., Koch, K. E., Khuse, G., Quarch, H. and Siebenhiner, M., 1970, On the geology of Northern Thailand. - Beih. geol. Jb., 102: 23 p.; Hannover.

Bender, F., 1983, Geology of Burma, Gebrüder Borntraeger, Berlin, Stuttgart.

Bhongsuwan, T., 1993, Paleomagnetic investigation in Thailand, Ph.D. Thesis, Lulea University of Technology, Lulea, Sweden.

Bignell, J.D., 1972, The Geochronology of the Malayan Granites, Ph.D. Thesis, University of Oxford, Oxford, England.

Bochu, Y., 1999, The Geotectonic character of Southeast Asia and Cenotectonic history of South China Sea, Gondwana Research **2 (4)**, 512-515.

Bolinger, K., 1993, $^{40}$Ar-$^{39}$Ar Datierun von Tektites, Diploma Thesis, Max Planck Institute, Heidelberg.

Boonsener, M., 1986, Quaternary of Khon Kaen Province, Northeastern Thailand, *In:* N. Thiramongkol (ed.), Economic Geology, Tectonics, Sedimentary Processes and Environment of Quaternary in Southeast Asia, Haad Yai, Thailand, 75-86.

Boonsoong, A. and Panjasawatwong, Y., 2003, Basalt stratigraphy in the drill holes at Huat Rak Mai Village, Mae Moh District, Lampang Province, *In*: B. Rattanasathien, S. L. Rieb and S. Chantraprasert (eds.), RCPNS 46 - 8th International Congress on Pacific Neogene Stratigraphy Chiang Mai, Thailand, 375-391.

Braun, E. von and Hahn, L., 1976, Geological map of northern Thailand 1:250000, Sheet (Chiang Rai) 2, (Fed, Inst Geosciences Natural Resources), Hannover.

Braun, E. von and Hahn, L. and Maronde, H.D., 1981, Geological map of northern Thailand 1:250000, Sheet (Amphoe Li) 6, (Fed, Inst Geosciences Natural Resources), Hannover.

Braun, E. von and Jordan, R., 1976, The Stratigraphy and paleontology of the Mesozoic sequence in the Mae Sot area in Western Thailand, Geol. Jb., B 21:5-51, Hannover.

Briais, A., P. Patriat. and Tapponnier, P., 1993, Updated interpretation of magnetic anomalies and seafloor spreading stages in the South China Sea, implications for the Tertiary tectonics of Southeast Asia, Journal of Geophysical Research **98**, 6,299-6,328.

Bristow, C. S., 1991, Sedimentology of the Phra Wihan Formation, Khorat Group, Thailand, GEOSEA VII Conference, Bangkok, abstract 23.

Bromley, A., 1993, The sedimentology and reservoir potential of the Khorat Group, the Phitsanulok Basin, Central Thailand, *In:* T. Thanasuthipitak (ed.), Proceedings of International Symposium on Biostratigraphy of Mainland Southeast Asia: Facies and Paleontology (BIOSEA), Chiang Mai University, Chiang Mai, vol. 1, Abstract, 1

Brown, G.E., Buravas, S., Javanaphet, J., Jalichandra, N., Johnston, W.D. Jr., Sethaput, V. and Taylor, G.C. Jr., 1951, Geologic Reconnaissance of the mineral deposits of Thailand, U.S. Geological Survey Bulletin **984**, 183.

Buffetaut, F., Ginsburg, L., Ingavat, R., Janvier, P., Martin, M. and Suteetorn, V., 1981, A new continental vertebrate fauna from the Upper Triassic of Thailand, Terra Cognita, special issue, 116.

Bunopas, S., 1994, Regional stratigraphy, paleogeography and tectonic events of Thailand and continental Southeast Asia, *In*: P. Angsuwathana, T. Wongwanich, W. Tansathien, S. Wongsomsak and J. Tulyatid (eds.), Proceeding of International Symposium on Stratigraphic Correlation of Southeast Asia, Bangkok, Thailand, 2-24.

Bunopas, S., 1981, Paleogeographic history of western Thailand and adjacent parts of Southeast Asia - a plate tectonics interpretation, Ph.D. Thesis, Victoria University of Wellington, New Zealand.

Bunopas, S., 1976, On the stratigraphic successions in Thailand-a preliminary summary, Journal of Geological Society of Thailand **2 (1-2)**, 31-58.

Bunopas, S., 1976a, Geology and Mineral Resources of Phitsanulok, Sheet NE 47-15, Report of Investigation No.16 (Pt.1 and 2), Department of

Mineral Resources, Bangkok, 217.
Bunopas, S., 1976b, Geological map of Thailand 1:250000, Sheet Nakhon Sawan ND47-3, Geological Survey Division, Department of Mineral Resources, Bangkok.
Bunopas, S., 1976c, Geological map of Thailand 1:250000, Sheet Suphan Buri ND 47-7, Geological Survey Division, Department of Mineral Resources, Bangkok.
Bunopas, S., 1971, On the geology and stratigraphy of the Nam Phrom Dam and its vicinities, Geological Society of Thailand Newsletter **4**, 17-40.
Bunopas, S., 1967, Report on the investigation of Amphoe Song - Rong Khwang, Phrae Province, 47Q/EC10, 47Q/EC14, Department of Mineral Resources, Bangkok.
Bunopas, S. and Bunyajitradul S., 1970, Stratigraphy and structure of Khorat Group along the Phitsanulok, Mineral Research Gazette **15 (7)**, 9-12.
Bunopas. S., Hada, S. and Yoshikura, S., 1992, The Late Triassic to Early Jurassic accretion of terranes in Thailand, Abstracts of the IGCP Project 321, 2nd International Symposium on Gondwana Dispersion and Asian Accretion, Osaka. Japan**.** 2-7.
Bunopas, S., Pitakpaivan, K., Sukroo, J. and Vella, P., 1978, Preliminary paleomagnetic results from Thailand sedimentary rocks, *In:* P. Nutalaya (ed.), Proceedings of the 3rd Regional Conference on Geology and Mineral Resources of Southeast Asia, Bangkok, 24-32.
Bunopas, S. and Vella, P., 1992, Geotectonics and geologic resources of Thailand, *In:* C. Piancharoen (ed.), Proceedings of Geologic Resources of Thailand: Potential for Future Development, Bangkok, 209-228.
Bunopas, S. and Vella, P., 1989, "Pebbly mudstones", A composite assemblages of ice-rafted sediments on the western rifted marginal basin of Shan - Thai while drifting away from Gondwana during the Upper Paleozoic, Proceedings of the 4th Internation Symposium on Pre-Jurassic East Asia, IGCP Project 224. Hat Yai and Langkawi Island, Thailand and Malaysia.
Bunopas, S. and Vella, P., 1984, Phuket - Kaeng Krachan Group, A rifted continental margin deposit with effect of ice-rafting from Gondwana. Abstr. paper presented at GEOSEA V., Kuala Lumpur.
Bunopas, S. and Vella, P. 1983a, Opening of the Gulf of Thailand - rifting of continental Southeast Asia and late Cenozoic Tectonics, Journal of Geological Society of Thailand **6 (1)**, 1-12.
Bunopas, S. and Vella, P., 1983b, Tectonic and geologic evolution of Thailand, Workshop on Stratigraphic Correlation of Thailand and Malaysia, Haad Yai, Thailand.
Bunopas, S. and Vella, P., 1980, Upper Paleozoic-Mesozoic polar wander curves from Thailand rocks (abstract), Proceedings of the.4th Gondwana Symposium, Wellington, New Zealand.
Bunopas, S. and Vella, P., 1978, Late Paleozoic and Mesozoic structural evolution of Northern Thailand, *In:* P. Nutalaya (ed.), Proceedings of Regional Conference on Geology and Mineral Resources of Southeast Asia, Bangkok, Thailand, 133-140.
Bunopas, S., Vella, P. Fontaine, H., Hada, S., Burrett, C., Haines, P. Howard, K. T. and Khositanont, S., 2003, The Pleistocene epeirogenesis, rapid vertical uplifting of the western mountains of Thailand in the late active himalayan extrusional continuum at 0.8 Ma impact, Journal of Geological Society of Thailand.
Bunopas, S., Vella, P. Hada, S., Fontaine, H., Burrett, C., Haines, P., Khositanont, S. and Howard, K. T., 2002, Australasian tektites and catastrophic products enclosed in impact ejecta horizon from the Buntharik Impact Event in Thailand on old surface gravel beds marked real-time Asian Quaternary correlation, *In*: N. Mantajit (ed.), The Symposium on Geology of Thailand (GEOTHAI 2002), Bangkok, Thailand, 181-187.
Bunopas, S., Vella, P., Hada, S., Fontaine, H., Burrett, C., Haines, P., Khositanont, S. and Howard, K.T., 2001, Australasian tektites and catastrophic products enclosed in impact ejecta horizon from the Buntharik Impact Event in Thailand. Symposium on Rodinia, Gondwana and Asia, Osaka, Japan, Gondwana Research **4 (4)**, 586.
Bunopas, S., Vella, P., Hada, S, Fontaine, H., Haines, P.W., Burrett, C., Potisat, S. Wongwanich, T., Chaodamrong, P., Khositanont, S. and Howard, K.T., 2003, The Khorat Plateau early Quaternary vertically uplifting after long Cenozoic cratonization of the Mesozoic Khorat Group, its northeast tilting diverted Mae Khong River before the 0.8 Ma cometary impact catastroloess and the overflowing Mid-Pleistocene Burirum Basalt. 1st International Conference on Paleontology of Southeast Asia, Mahasarakham University Journal 22, Special Issue.
Bunopas, S., Wasson, J. T., Vella, P., Fontaine, H., Hada, S., Burrett, C., Suphajanya, T. and Khositanont, S., 1999, catastrophic loess, mass mortality and forest fires suggest that a Pleistocene cometary impact in Thailand caused the Australasian tektite field, Journal of Geological Society of Thailand **1**, 1-17.
Burchfiel, B. C., Zhang, P., Wang, Y., Zhang, W., Jiao, D., Song, F., Deng, Q., Molnar, P. and Royden, L.H., 1991, Geology of the Haiyuan fault zone, Ningxia-Hui autonomous region, China, and its relation to the evolution of the northeastern margin of the Tibetan Plateau, Tectonics **10**, 1,091-1,110.
Burrett, C. and Stait, B., 1985, Southeast Asia as a part of Ordovician Gondwanaland - a paleobiogeographic test of a tectonic hypothesis, Earth and Planetary Science Letters **75**, 184-190.
Burrett, C. F., Long, A. and Stait, B.A., 1990, Early-Middle Paleozoic biogeography of Asian terranes derived from Gondwana, Memoir of Geological Society of London **12**, 16-173.
Cantrill, R. C., 2002, Aspects of Ordovician conodonts and the stratigraphy of Thailand, Malaysia and Tasmania. Ph. D Thesis, School of Earth Sciences, University of Tasmania, Australia.
Carter, A., Bristow, C. and Hurford, A., 1995, Constraints on the thermal history and provenance of the Khorat Group in Thailand using fission track analysis, Proceedings of the IGCP Symposium on Geology of SE Asia XI/1, Hanoi, 995
Chantaramee, S., 1978, Tectonic synthesis of the Lansang area and discussion of regional tectonic evolution, Department of Geological Science, Chiang Mai University Report 7, 355-380.
Chaodumrong, P. and Burrett, C., 1997, Early Late Triassic colliding between Shan-Thai and Indochina Terranes as indicated by occurrence of

fan delta red beds of Pha Daeng Formation, central north Thailand, *In*: P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien, C. Utha-aroon, N. Sattayarak, T. Nuchanong and S. Techawan (eds.), Proceedings of the International Conference on Stratigraphy and Tectonics Evolution of Southeast Asia and the South Pacific, Bangkok, Thailand, 143-157.

Chaodumrong, P. and Chaimanee, Y., 2002, Tertiary sedimentary basins in Thailand, *In:* N. Mantajit (ed.), The Symposium on Geology of Thailand (GEOTHAI 2002), Bangkok, Thailand, 156- 16.

Charusiri, P., Pongsapich, W. and Khantaprab, C., 1991, Granite belts in Thailand: new evidences from $^{40}Ar/^{39}Ar$, Mineral Resources Gazette **1**, 43-62..

Chen. Z., Wang, C. and Deng, X., 1965, Some results of paleomagnetic research in China (in Chinese). Auto Geol. Sin. **43**, 241—246

Chonglakmani, C. and Sattayarak, N., 1978, Stratigraphy of the Huai Hin Lat Formation (Upper Triassic) in northeastern Thailand, *In:* P. Nutalaya (ed.), Proceedings of the 3rd Regional Conference on Geology and Mineral Resources of Southeast. Asia, Asian Institute of Technology, Bangkok, 739-762.

Chonglakmani, C., Gabel, J., Helmcke, D., Lamchuan, A. and Meischner, D., 1991, Geodynamic interpretation of marine Triassic basins of Northern Thailand (Abstract), *In:* P. Nutalaya (ed.), Proceedings of the 3rd Regional Conference on Geology and Mineral Resources of Southeast.Asia, Asian Institute of Technology, Bangkok, 13.

Coventry, R.J., Hopley, D., Campbell, J. B., Douglas, I., Harvey, N., Kershaw, A.P., Oliver, J., Phipps, C.V.G. and Pye, K., 1980, The Quaternary of northeastern Australia, *In:* R.A. Henderson and P.J. Stephenson (eds.), The Geology and Geophysics of Northeastern Australia, Geological. Society of Australia, Queensland Division, 375-417.

Creer, K. M., 1971, Mesozoic paleomagnetic reversal column, Nature **233**, 545 - 546.

Darbyshire, D.P.F., 1988, Geochronology of Thai granites, NERC Isotope Geology Centre Report No. 88/5.

Ducrocq, S., Buffetaut, E., Buffetaut-Tong, H., Chaimanee, Y., Jaeger, J. J. and Suteethorn, V., 1991, Age and correlations of the Neogene continental basins from Thailand, 7th Regional Conference on Geology, Mineral and Energy Resources of Southeast Asia (GEOSEA VII), Bangkok, Thailand.

Fenton, C. H., Charusiri, P., Hinthong, C., Lumjuan, A. and Mangkonkarn, B., 1997, Late Quaternary faulting in northern Thailand, *In*: P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien, C. Utha-aroon, N. Sattayarak, T. Nuchanong and S. Techawan (eds.), Proceedings of the International Conference on Stratigraphy and Tectonic Evolution of Southeast Asia and the South Pacific, Bangkok, Thailand, 436-452.

Fiske, P.S., Putthapiban, P. and Wasson, J.T., 1996, Excavation and analysis of layered tektites from Northeast Thailand: Results of 1994 field expedition, Meteoritics and Planetary Science **31**, 36-41.

Ford, R. J., 1988, An empirical model for the Australasian tektite field, Australian Journal of Earth Sciences **35**, 483-490.

Galong, V. and Kuttikul, P., 1999, The application of ground penetrating radar (GPR) for petrified wood mapping, *In:* C. Khantaprab and S. Sarapirome (eds.), Proceedings of the Symposium on Mineral, Energy and Water Resources of Thailand: Towards the year 2000, Bangkok, Thailand, 135-141.

Gatinsky, Y. G., Mischina, A. V., Vinogradov, I. V. and Kovalev, A. A., 1978, The main metallogenic belts of Southeast Asia as the result of different geodynamic conditions and inferences, *In*: P. Nutalaya (ed.), Proceedings of the 3rd Regional Conference on Geology and Natural Resources of Southeast Asia, Bangkok, 313-318.

Gaudemer, Y., Tapponnier, P., Meyer, B., Peltzer, G., Guo, S., Chen, Z, Dai, H. and Cifuentes, I., 1995, Partitioning of crustal slip between linked, active faults in the eastern Qilian Shan, and evidence for a major seismic gap, the "Tianzhu gap', on the western Haiyuan Fault, Gansu (China), Geophysics **120**, 599-645.

Glass, B. P., 1990, Tektites and microtektites: key fact and interferences, *In:* L. O. Nicolysen and W. U. Reimold (eds.), Cryptoexplosions and catastrophes in the geological record with a special focus on the Vredefort Structure, Tectonophysics **171**, 393-404.

Hada, S., Bunopas, S., Ishii, K. and Yoshikura, S., 1999, Gondwana accretion and Asian accretion, IGCP 321 Final Results Volume. 67-87. A. A. Balkema/Rotterdam/Brookfield /1999.

Hada, S., Bunopas, S., Ishii, K. and Yoshikura, S., 1997, Rift-drift history and the amalgamation of Shan-Thai and Indochina/East Malaya Blocks, *In*: P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien, C. Utha-aroon, N. Sattayarak, T. Nuchanong and S. Techawan (eds.), Proceedings of the International Conference on Stratigraphy and Tectonics Evolution of Southeast Asia and the South Pacific, Bangkok, Thailand, 273-286.

Hada, S., Bunopas, S., Thitisawan, V., Salyapongse, S., Panjasawatwong, Y., Yaonoiyothin, W. Ishii, K. and Yoshikura, S., 1994, Accretion tectonics in Thailand along the Nan-Uttaradit suture, AAPG 1994 International Conference and Exhibition, Kuala Lumpur, Southeast Asian basins: oil and gas for the 21st Century, Official program, abstract, 41.

Hahn, L., 1976, The stratigraphy and palaeogeography outline of the non-marine Mesozoic deposits in Northern Thailand, Geol. Jb., B., Hannover **21**, l55-169.

Hahn L K., Koch, E., Wittekindt, H., Adelhardt, W. and Hess, A., 1986, Outline of the Geology and the mineral potential of Thailand, Geol. Jb., B., Hannover **59**, 3-59.

Haile, N. H., 1973, Note on Triassic fossil pollen from the Nam Pha Formation, Chulaporn (Nam Prom), Thailand. Geological Society of Thailand Newsletter **6 (1)**, 15-16.

Haile, N. S. and Tarling. D. H., 1975, Note on reconnaissance paleomagnetic measurements on Jurassic red-beds from Thailand, Pacific Geology **10**, 101-103.

Hailing, L., Yan, S., Lingshi, G., Liangshu, S., Shukang, Y. Di, Z. and Yixiang, A., 1999, On the kinematic characteristics and dynamic process of boundary faults of the Nansha Ultra-crust Layer-Block, Acta Geologica Siinica **73 (4)**, 452-463.

Hallam, A., 1978, Eustatic cycles in the Jurassic, Paleogeography Paleoclimate Paleoecology **23**, 1-32.

Hancock, J. M. and Kaufman, F. G., 1979, The great transgression of the Cretaceous, Journal of Geological Society of Thailand **136**, 175-186.

Hansen, B. T., Klaus Wemmer, Sabine Pawlig , Janina Klaus, S. Assavapatchara, M. Nontaso 2, Ch. Chairangsee and Putthapiban, P., 2002, Isotopic evidence for a Late Cretaceous age of the potash and rock salt deposit at Bamnet Narong, Northeast Thailand, *In*: N. Matajit (ed.), The Symposium on Geology of Thailand, Bangkok, Thailand.

Harder, S. H., 1991, Extensional tectonics in the Gulf of Thailand and South China Sea, 7th Regional Conference on Geology, Mineral and Energy Resources of Southeast Asia. (GEOSEA VII), Bangkok, Thailand,

Harris, Jr, R. W., 1977, Palynological analysis of outcrop well samples from the Khorat Basin, Mineral Fuel Division, Bangkok.

Harrison, T. M., Leloup, P.H., Ryerson, F. J., Tapponnier, P., Lacassin, R. and Chen, W., 1996, Diachronous initiation of Transtension along the Ailao Shan-Red River Shear zone, Yunnan and Vietnam, *In:* T. M Harrison and A. Yin (eds.), The Tectonics of Asia, Cambridge University Press, New York..

Harrison, T. M., Wenji, C., Leloup, P. H., Ryerson, F. J. and Tapponnier, P., 1992, An Early Miocene transition in deformation regime within the Red River fault zone, Yunnan, and its significance for Indo-Asian tectonics, Journal of Geophysical Research **97**, 7,159-7,182.

Hartung, J. B., 1990, Australasian tektite source crater? Tonle Sap, Cambodia, Meteoritics **25 (4)**, 369-370.

Heggemann, H., 1994, Sedimentare Entwicklung der KhoratGruppe (Ober-Trias bis Palaogen) in Northeast und North Thailand. Goutinger Arb. Geol. Paleont. **63**, 146

Helmcke, D. and Lindenberg, H. G., 1983, New Data on the "Indosinian' Orogeny from central Thailand. Geol. Rundschau, **72**, 317-328.

Howard, K.T., 1999, Distal environmental effects of the 770 ka impact event, Northeast Thailand, Honours Thesis, University of Tasmania, Australia.

Howard, K.T., Bunopas, S., Burrett, C.F., Haines, P.W. and Norman, M.D., 2000, The 770 ka tektite producing impact event: evidence for distal environmental effects in Northeast Thailand, Papers and Proceedings of the 31st Lunar and Planetary Science Conference abstract no. 1308.

Howard, K. T., Haines, P.W., Burrett, C.F., Ali, J.R. and Bunopas, S., 2003, Sedimentology of 0.8 million-year old log-bearing flood deposits in northeast Thailand and mechanisms for pre-flood deforestation, *In*: B. Rattanasathien, S. L. Rieb and S. Chantraprasert (eds.), RCPNS 46- 8th International Congress on Pacific Neogene Stratigraphy, Chiang Mai, 46 -67.

Huchon, P., Le Pichon, X. and Rangin, C., 1994, Indochina peninsula and the collision of India and Eurasia, Geology **22**, 27-30.

Hutchison, C. S., 1996, Geological evolution of South-East Asia, Geological Society of Malaysia, 368.

Hutchinson, C. S., 1989, Geological evolution of SE Asia, Oxford monographs on geology and geophysics, Clarendon Press, Oxford **13**, 368.

Ibrahim, A. I., Jantan, A. and Hamzah, S.M., 1998, Deposition of the Tembeling Group: an eastward tilted grabe model, 9th Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia, GEOSEA '98, Kuala Lumpur, Malaysia, 198.

Imsamut, S., 1996, Magnetostratigraphy of the Phu Thok Formation at Phu Thok and Phu Wua areas, Changwat Nong Khai, M.Sc. Thesis, Department of Geology, Chulalongkom University, Bangkok, Thailand.

Irving, F., 1977, Drift of the major continental blocks since the Devonian, Nature **270**, 309-304.

Irving, F. and Pullaiah, G., 1976, Reversals of the geomagnetic field, magnetostratigraphy, and relative magnitude of paleosecular variation in the Phanerozoic, Earth Science Review **12**, 35-64.

Iwai, J., Asama, K., Veeraburus, M. and Hongnusonthi, A., 1966, Stratigraphy of the so-called Khorat Series and a note on the fossil plants bearing Paleozoic strata in Thailand, Geology and Paleotology of Southeast Asia **2**, 179-196.

Iwai, J., Sakagami, S., Nakornsri, N. and Yuyen, W., 1968, Mesozoic Stratigraphy of the north-west part of the Khorat Plateau, Thailand, Geology and Palaeontology of Southeast Asia **5**, 151-165.

Izett, G.A. and Obradovich, J.D., 1992, Laser-fusion 40Ar/39Ar ages of Australasian tektites, In 23rd Lunar and Planetary Science Conference, 593-594.

Kobayashi, T., 1980, Notes on the Mesozoic history of Thailand and adjacent territories, Geology and Palaeontology of Southeast. Asia **21**, 27-32.

Kobayashi, T., 1975, Upper Triassic Estheriidae in Thailand and the Conchotracan development in Asia in Mesozoic Era, Geology and Palaeontology of Southeast Asia **16**, 57-90.

Kobayashi, T., 1968, The Cretaceous non-marine pelecypods from the Nam Phung dam site in the northeastern part of the Khorat Plateau, Thailand, with a note on the Trigonioididae, Geology and Palaeontology of Southeast Asia **4**, 109–138.

Kobayashi, T., 1964, Geology of Thailand, Geology and Paleonplogy of Southeast Asia, **1**, 1-15.

Kobayashi, T., 1963, On the Cretaceous Ban Na Yo fauna of East Thailand with a note on the distribution of Nippononaia, Trigonoides and Plicatounio, Japanese Journal of Geology and Geography, **34 (1)**, 35-43.

Lacassin, R., Maluski, H., Leloup, P.H., Tapponnier, P., Hinthong, C., Siribhakdi, K., Chuaviroj, S. and Charoenpravat, A., 1997, Tertiary extrusion and deformation of Indochina western margin: structural and $^{40}Ar/^{39}Ar$ evidence from Northwest Thailand, Journal of Geophysical Reseach **102(B5)**, 10013-10037.

Lacassin, R., Scharer, U., Leloup, P. H., Arnaud, N., Tapponnier, P., Liu, X. and Zhang L., 1996, Tertiary deformation and metamorphism Southeast of Tibet: the folded Tiger-leap d̂collement of Northwest Yunnan, China, Tectonics **15(3)**, 605-622.

Larson, R. L. and Hilde, T. W. C., 1975, A revised time-scale of magnetic reversals for the early Cretaceous and late Jurassic, Journal of Geophysical Research **80**, 2586–2594.

Le Dam, A. Y., Tapponnier, P. and Molnar, P., 1984, Active faults and tectonics of Burma and surrounding regions, Journal of Geophysical Research **89**, 453-472.

Lee, C., Lee, H., Liu, C. and Yeh, T., 1963, Preliminary study of paleomagnetism of some Mesozoic and Cenozoic red-beds of South China, Acta Geologica Sinica **43,** 241-246.

Lee, M.Y. and Wei, K.Y., 2000, Australasian microtektites in the South China Sea and the West Philippines Sea: implications for age, size and location of the impact crater, Meteoritics and Planetary Science **35**.

Leloup, P. H., Harrison, T. M., Ryerson, F. J., Chen, W., Qi, L., Tapponnier, P. and Lacassin, P., 1993, Structural, petrological and thermal evolution of a Tertiary ductile strike-slip shear zone, Diancang Shan, Yunnan, Journal Geophysical Research **98**, 6715-6743.

Leloup, P. H., Lacassin, R., Tapponnier, P., Zhong, D. Liu, X., Zhang, L., Ji, S. and Phan, T. T., 1995, The Ailao Shan-Red River shear zone (Yunnan, China), Tertiary transform boundary of Indochina, Tectonophysics **251(1-4)**, 3-10.

Limsuwan, R., 1999, Bore drilling" a new choice for deep sampling for placer deposit of gemstone, *In*: C. Khantraprab and S. Sarapirome (eds.), Symposium on Mineral, Energy and Water Resources of Thailand: Towards the year 2000, October 28-29, Bangkok, Thailand, 485-495.

Maranate, S., 1984, Magnetostratigraphic correlation for dating in the Khorat Group, Northeastern Thailand, *In*: N. Thiramongkol, S. Nakapadungrat and V. Pisutha-Arnond (eds.), Proceedings of the Conference on Applications of Geology and the National Development, Chulalongkorn University, Bangkok.

Maranate, S., 1983, Paleomagnetic core collection and field data of the Huai Hin Lat Formation in Northeast Thailand: GEOMAG Pub. no. 10, Geological Survey Division, Department of Mineral Resources, 25.

Maranate, S.,1982, Paleomagnetism of the Khorat Group in Northeast Thailand, M.Sc. Thesis, Victoria University of Wellington, New Zealand.

Maranate, S. and Vella, P., 1986, Paleomagnetism of the Khorat Group, Mesozoic, Northeast Thailand, Journal of Southeast Asia Earth Sciences **1**, 23-31.

McCabe, R., Harder, S., Paijitprapapon, V., Giang, N., and Lumadyo, E., 1991, Paleomagnetic evidence to define a stable East Asia and Sundaland, The 7th Regional Conference on Geology, Mineral and Energy Resources of Southeast Asia (GEOSEA VII), Bangkok, Thailand.

McElhinny, M. W. and Burek, P. J., 1971, Mesozoic paleomagnetic stratigraphy, Nature **232**, 98-102.

Meesook, A. and Grant-Mackie, J. A., 1994, Biostratigraphic correlation of the marine Jurassic rocks of Thailand and Southeast Asia, *In*: P. Angsuwathana, T. Wongwanich, W. Tansathien, S. Wongsomsak and J. Tulyatid (eds.), Proceeding of International Symposium on Stratigraphic Correlation of Southeast Asia, Bangkok, Thailand, 160-169.

Meesook, A. and Grant-Mackie, J. A., 1993, Facies, faunas and biostratigraphy of the marine Jurassic of Thailand, *In*: T. Thanasuthipitak (ed.), International Symposium on Paleontology of Mainland Southeast Asia: Facies and Paleontology. Vol III, Chiang Mai, Thailand (abstract).

Metcalfe, I., 1995, Gondwana dispersion and Asian accretion, Journal of Geology **5/6**, 223-266.

Metcalfe, I., 1993, Southeast Asian terranes: Gondwanaland origins and evolution, *In*: Finlay, Unrug, Banks and Veevers (eds.), Gondwana eight, 181-200.

Mickein, A., Ahrendt, H., Hansen, B.T., Lumjuan, A. and Wernmer, K., 1995, New age information of the history of the basement rocks of Thailand, *In*: L. Wannakao, W. Youngme, C. Buaphan, K. Srisuk and Lertsirivorakul (eds.), Proceeding of the International Conference on Geology, Geotechnology and Mineral Resources of Indochina, Khon Kaen, Thailand.

Molnar, P. and Tapponnier, P., 1975, Cenozoic tectonics of Asia: effects of a continental collision, Science **189**, 419 426.

Nutalaya, P., Vella, P., Bunopas. S. and Kaewyana, W., 1986, Quaternary Process in Thailand, *In*: N. Thiramongkol (ed.), Economic Geology, Tectonics, Sedimentary Processes and Environment of Quaternary in Southeast Asia, Haad Yai, Thailand, 23-34.

Parry, J. T., 1996, The high terrace gravels, Northeast Thailand- a revaluation and integrated theory of their origin, Zeitschrift Fur Geomorphologie **40 (2)**, 145-175.

Pechersky, D. M. and Kramov, A. N., 1973, Mesozoic paleomagnetic scale of USSR. Nature **244**, 499-501.

Peltzer, G. and Tapponnier, P., 1988, Formation and evolution of strike-slip faults, rifts, and basins during India-Asia collision an experimental approach, Journal of Geophysical Research **93**, 15,085-15,117.

Pitsutha-Arnold, V., Chiba, H. and Yumuang, S., 1986, A preliminary sulphur and oxygen isotope study of the Maha Sarakham evaporitic anhydrite from the Bamnet Narong Area of Northeastern Thailand, The Regional Conference on Geology, Mineral and Energy Resources of Southeast Asia,(GEOSEA V), Malaysia, 189-222.

Racey, A., Goodall, J.G.S., Love, M.A., Polachan, P. and Jones, P.D., 1994, New age data for the Mesozoic Khorat Group of NE Thailand, *In*: P. Angsuwathana, T. Wongwanich, W. Tansathien, S. Wongsomsak and J. Tulyatid (eds.), Stratigraphic Correlation of SE Asia. IGCP 306, Proceedings, Bangkok, Thailand, 245-252.

Rangin, C., 1990, Peleogeodynamic maps of the West Pacific, Bulletin de la Société Géologique de France, Paris.

Ratanasthien, B., 1983, The effect of Pleistocene volcanic activity to Mae Moh coal - bearing Formation, Proceedings of the Workshop on Economic Geology and Tectonics Sedimentary Processes and Environment of the Quaternary in Southeast Asia, Haad Yai, Thailand, 45-52.

Richter, B.; Fuller, M., Schmidtke, E., Tin Myint, U., Tin Ngwe, U., Mya Win, U. and Bunopas, S., 1993, Paleomagnetic results from Thailand and Myanmar: implications for the interpretation of tectonic rotations in Southeast Asia, Journal of Southeast Asian Earth Sciences **8 (1–4)**, 247-255.

Sawata, H., 1973, Note on a young deposit near Lan Sang Village, Tak Province, northern Thailand, Proceedings of Geological Conference, Chiang Mai University, Chiang Mai.

Saykawlard, S., Sithiyos, P. and Rodjanapo, S., 2003, Evolution of Yom River and land use change at Srisatchanalai, Sukhuthai Province, Lower Northern Thailand, *In*: B. Rattanasathien, S. L. Rieb and S. Chantraprasert (eds.), RCPNS 46 - 8th International Congress on Pacific Neogene Stratigraphy, Chiang Mai, 203-211.

Scharer, U., Tapponnier, P., Lacassin, R., Leloup, P. H., Zhong, D. and Ji, S., 1990, Intraplate tectonics in Asia: a precise age for large-scale Miocene movement along the Ailao Shan - Red River shear zone, China, Earth and Planetary Science Letters **97**, 65-77.

Schneider, D.A., Kent, D.V. and Mello, G.A., 1992, A detailed chronology of the Australasian impact event, the Brunhes - Matuyana geomagnetic polarity reversal, and global climate change, Earth and Planetary Science Letters **111**, 395-405.

Sclater, J. G. and Tapscott, C., 1979, The history of the Atlantic, Scientific American **240**, 156-174.

Shackleton, N. J. and Opdyke, N.D., 1976, Oxygen-isotope and paleomagnetic stratigraphy of Pacific core V28-239, late Pliocene to latest Pleistocene, Geological Society of America Memoir 145 , 449-464.

Sibrava, V., 1993, Quaternary sequences in Southeast Asia and their regional significance, stratigraphy of Asia and the Pacific IGCP 296, Mineral Resources Development Series. ESCAP Atlas of stratigraphy XII, United Nations, New York.

Silaratana, T., Ratanasthien, B., Takayasu, K., Asnachinda, P., Kandharosa, W. and Kusakabe, M., 2003, Sulfur isotope implication of Middle Miocene marine incursion in northern Thailand, *In*: B. Rattanasathien, S. L. Rieb and S. Chantraprasert (eds.), RCPNS 46 - 8th International Congress on Pacific Neogene Stratigraphy Chiang Mai, February 2003.

Sinsakul, S., Chaimanee, N. and Tiyapairach, S., 2002, Quaternary geology of Thailand, *In*: N. Mantajit (ed.), The Symposium on Geology of Thailand (GEOTHAI 2002), Bangkok, Thailand, 170-180.

Sutthirat, C., Charusiri, P., Farrar, E. and Clark, A. H., 1994, New $^{40}Ar/^{39}Ar$ Geochronology and characteristics of some Cenozoic basalt in Thailand, *In*: P. Angsuwathana, T. Wongwanich, W. Tansathien, S. Wongsomsak and J. Tulyatid (eds.), Proceeding of International Symposium on Stratigraphic Correlation of Southeast Asia, Bangkok, Thailand, 306-321.

Suwanich, P., 1997, Na Chauk Formation, the new topmost formation of the Khorat Plateau, *In*: P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien, C. Utha-aroon, N. Sattayarak, T. Nuchanong and S. Techawan (eds.), Proceedings of the National Conference on Stratigraphy and Tectonics Evolution of Southeast Asia and the South Pacific, Bangkok, Thailand,

Tamura, T., 1986, Geomorphological development of Northeast Thailand with reference to problem soil formation- an hypothesis based on preliminary observation.- Report of JICA expert Agricultural Development Research Centre, 11p; Khon Kaen.

Tan, M.T., 1995, Seismic-stratigraphic studies of the continental shelf of Southern Vietnam, Journal of Petroleum Geology **18**, 345-354.

Tapponnier, P., Lacassin, R., Leloup, P. H., Scharer, U., Zhong D., Xiaohan, L., Shaocheng, J., Lianshang, Z. and Zhong J., 1990, The Ailao Shan/Red River metamorphic belt: Tertiary left-lateral shear between Indochina and South China, Nature **343**, 431-437.

Tapponnier, P., Peltzer, G. and Armijo, R., 1986, On the mechanics of the collision between India and Asia, in collision tectonics, *In*: M. P. Coward and A. C. Ries (eds.), Geological Society Special Publication, 19, Geological Society, London, 115-157.

Tapponnier, P., Peltzer, G., Armijo, R., Le Dam, A.Y. and Cobbold P., 1982, Propagating extrusion tectonics in Asia: new insights from simple experiments with plasticine, Geology **10**, 611–616.

Teerarangsigul, N., Raksaskulwong, L. and Khanthaprap, C., 1999, Reconsideration of the lithostratigraphy of non-marine Mesozoic rocks in Thung Yai - Khong Thom area, Southern Thailand, *In*: C. Khantraprab and S. Sarapirome (eds.), Proceedings of the Symposium on Mineral, Energy and Water Resources of Thailand Towards the year 2000, Bangkok, Thailand, 98-114.

Thiramongkol, N., 1986, Neotectonism and rate of uplift in the eastern margin of the lower Central Plain of Thailand, *In*: N. Thiramongkol (ed.), Economic Geology, Tectonics, Sedimentary Processes and Environment of Quaternary in Southeast Asia, Haad Yai, Thailand, 35-44

Thiramongkol, N., 1983, Geomorphology of Ban Luang Muang Kong and Ban Muang Kud basins, Northern Thailand, Journal of Geological Society of Thailand **6 (1)**, 31-37.

Trinh D., 1995, Stratigraphic correlation of Neogene sequences of Vietnam and adjacent areas, Journal of Geology Series B, No. 5-6, 114-120, Proceeding of the International Symposium Geology of Southeast Asia and Adjacent Areas, Hanoi.

Udomchoke, V., 1989, Quaternary stratigraphy of the Khorat plateau area, Northeast Thailand, Proceedings of the Workshop on Correlation of Quaternary Successions in South, East and Southeast Asia, Bangkok, 69-94.

Upton, D. R., 1997, Tertiary tectonic denudation in Northwestern Thailand: provisional results from apatite-fission tract analysis, *In*: P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien, C. Utha-aroon, N. Sattayarak, T. Nuchanong and S. Techawan (eds.), Proceedings of the National conference on Stratigraphy and Tectonics Evolution of Southeast Asia and the South Pacific, Bangkok, 421-431.

Utha-Aroon, C., 1993, Continental origin of the Mahasarakham Evaporates, Northeastern Thailand, Journal of Southeast Asian Earth Sciences **8(1-4),** 193-203.

Uttamo, W., Nichols, G. I. and Elde, C.F., 1999, The Tertiary sedimentary basins of Northern Thailand, *In*: C. Khantraprab and S. Sarapirome (eds.), Proceedings of the Symposium on Mineral, Energy, and Water Resources of Thailand: Towards the year 2000, Bangkok, Thailand.

Van Hinte, J. F., 1976, A Jurassic and Cretaceous time scale, American Association of Petroleum Geologist Bulletin **60**, 489-516.

Vella, P., 1983, Tensional faults in Tertiary strata, Mae Moh, Thailand, Journal of the Geological Society of Thailand **6**, 13-15.

Vella, P., Bunopas. S., and Kaewyana, W., 1983, A loess covered alluvial gravel terrace near Chiang Mai, Northern Thailand, Geological Society of Thailand Newsletter **3**, 29-31.

Vikhter, B.Ya., 1978, Pliocene-Quaternary volcanism of Afghanistan, International Geology Review **20 (5)**, 525-536.

Vu Khuc, D. and Grant-Mackie, J. A., 1997, A new Bajocian fauna, Dalat Basin, Southern Vietnam. (Abstr.), *In*: P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien, C. Utha-aroon, N. Sattayarak, T. Nuchanong and S. Techawan (eds.), Proceedings of the National Conference on Stratigraphy and Tectonics Evolution of Southeast Asia and the South Pacific, Bangkok, Thailand.

Wan, T. and Zhu, H., 1991, Tectonic events of Late Paleozoic - Triassic in South China, Journal of Southeast Asia Earth Science **6 (2)**, 147-157.

Wannakao, P., 1999, The surficial deposition system in Khon Kaen Basin: a case study for understanding the neo-sedimentary deposits of the Khorat Basin, *In*: C. Khantraprab and S. Sarapirome (eds.), Proceedings of the Symposium on Mineral, Energy, and Water Resources of Thailand: Towards the year 2000, Bangkok, Thailand, 128-134.

Ward, D. E. and Bunnag, D., 1964, Stratigraphy of the Mesozoic Khorat Group in Northeast Thailand, Department of Mineral Resources, Bangkok, Report of Investigation, 6, 1-95.

Wasson, J. T., 1991, Layered tektites: a multiple impact origin for the Australasian tektites, Earth Planetary Science Letters **102**, 95-109

Wasson, J. T. and Heins, W. A., 1993, Tektites and climate, Journal of Geophysical Research **98**, 3043-3052.

Woods, S., 2003, Quaternary strike - slip faulting and basalt volcanism in northernmost Thailand and adjacent Laos, *In*: B. Rattanasathien, S. L. Rieb and S. Chantraprasert (eds.), RCPNS 46 - 8$^{th}$ International Congress on Pacific Neogene Stratigraphy, Chiang Mai, 428-429.

Wu, G., 1993, Late Paleozoic tectonic framework and Paleotethyan evolution in Western Yunnan, China, Scientia Geologica Sinica. **2 (2)**, 129-140.

Yamei, H., Potts, R., Baoyin, Y., Zhengtang, G., Deino, A., Wang, W., Clark, J., Guangmao, X. and Weiwen, H., 2000, Mid-Pleistocene Acheulean-like stone technology of the Bose Basin, South China, Science **287**, 1622-1626.

Yang, Z., Sun, Z., Ma, X., Yin, J. and Otofuji, Y., 2001, The extrusion of indochina during the India/Eurasia collision: early Tertiary paleomagnetic constraints, Gondwana Research **4 (4)**, 234.

Zaw, K. and Burrett, C. F., 1997, Cambrian volcanic hosted sulphide mineralization in Australia and Southeast Asia: are they related to rifting of Northern Gondwana?, *In*: P. Dheeradilok, C. Hinthong, P. Chaodumrong, P. Putthapiban, W. Tansathien, C. Utha-aroon, N. Sattayarak, T. Nuchanong and S. Techawan (eds.), Proceedings of the National Conference on Stratigraphy and Tectonics Evolution of Southeast Asia and the South Pacific, Bangkok, 690-692.