EXCURSION MÉTALLOGÉNIQUE

Thaïlande 2014

Chiang Mai – Khon Kaen – Bangkok

12 au 26 mai

Organisé par le chapitre étudiant de la *Society of Economic Geologist* de l'Université du Québec à Chicoutimi

Responsables :

Sophie Maltais
Christophe P.-Doucet

Co-responsable :

Denis Côté

MERCI À TOUS NOS GÉNÉREUX PARTENAIRES

LOJIQ Les Offices jeunesse internationaux du Québec
OFQJ • OQAJ • OQMJ • OQWBJ

ARIANNE Phosphate

ICM Section Saguenay

VEOLIA ENVIRONNEMENT

MAGE UQAC
Mouvement des Associations Générales Étudiantes de l'Université du Québec à Chicoutimi

ITINÉRAIRE

12 mai : **8h15 Départ de l'aéroport Jean Lesage de Québec (YQB)**

13 mai : **22h55 Arrivée à l'aéroport Suvarnabhumi de Bangkok (BKK)**

14 mai : **13h10 Transfert Bangkok/Chiang Mai en avion**

15 mai : **A.M. Université Chiang Mai**
P.M. Temple de Suthep
Diner typique en soirée

16 mai : **A.M. Tour d'éléphant**
P.M. Site pétrole Fang

17 mai : **A.M. Transport vers Lampang et arrêts géologiques**
P.M. Mine de charbon Mae Moh

18 mai : **A.M. Transport vers Tak et arrêts géologiques**
P.M. Géologie de Tak Mae Sot
Marché Moei (Thaïlande-Birmanie) en soirée

19 mai : **A.M. Mine de Zinc de Pha Daeng**
P.M. Site historique de Sukhothai

20 mai : **A.M Mine d'or Chatree à Pichit**
P.M. Visite de la ville Phitsanulok
Transfert vers Nakhon Thai

21 mai : **A.M. Parc National Phu Hin Rong Kla**
P.M. Barrage Ubolratana
Transfert vers Khon Kaen

22 mai : **A.M. Musée de dinausaures Phu Kum Khao**
P.M. Université de Khon Kaen
20h00 Transfert Khon Kaen/Bangkok

23 mai : **A.M. Université Chulalonkorn**
P.M. Conclusion de l'excursion
Temple de Pra Kaw et le Grand Palais

24 mai : **Libre**

25 mai : **Libre**

26 mai : **6h50 Départ de Bangkok**

INFORMATIONS VOLS INTERNATIONAUX

Vols Québec–Chicago : United Airlines
Vols Chicago-Tokyo-Bangkok : Nippon Airways

# Vol	Date	Départ	Heure	Arrivée	Heure	Durée
UA5927	12 mai	Québec	08h15	Chicago	09h50	02h35
UA881	12 mai	Chicago	13h15	Tokyo+1J	16h10	12h55
UA9711	13 mai	Tokyo	18h15	Bangkok	22h55	06h40
UA9710	26 mai	Bangkok	06h50	Tokyo	15h00	06h10
UA9662	26 mai	Tokyo	17h15	Chicago	14h50	11h35
UA5926	26 mai	Chicago	19h00	Québec	22h21	02h21

BAGAGES UNITED AIRLINES

✖ 1 bagage de moins de 23kg, dimension maximale cumulée de 158cm (longueur+largeur+hauteur)

✖ 1 bagage à main de moins de 8kg, dimension maximale de 35cm*22cm*56cm

✖ 1 article personnel de moins de 8kg, dimension maximale de 22cm*25cm*43cm

BAGAGES NIPPON AIRWAYS

✖ 1 bagage de moins de 23kg, dimension maximale cumulée de 158cm (longueur+largeur+hauteur)

✖ 1 bagage à main de moins de 8kg, dimension maximale cumulée de 114cm ou de 40cm*25cm*55cm

INFORMATIONS VOLS INTERNES

Vol Bangkok-Chiang Mai: Thaï Airways
Vol Khon Kaen-Bangkok : Thaï Airways

# Vol	Date	Départ	Heure	Arrivée	Heure
TG110	14 mai	Bangkok	13h10	Chiang Mai	14h20
TG47	22 mai	Khon Kaen	20h00	Bangkok	21h00

BAGAGES THAÏ AIRWAYS

✖ 1 bagage de moins de 20kg, dimension maximale cumulée de 158cm (longueur+largeur+hauteur)

✖ 1 bagage à main de moins de 7kg, dimension maximale de 45cm*25cm*56cm

✖ 1 article personnel de moins de 1,5kg, dimension maximale cumulée de 75cm ou de 12,5cm*25cm*37,5cm

- **Excès environ 2$/kg**

THAÏLANDE - MAI 2014

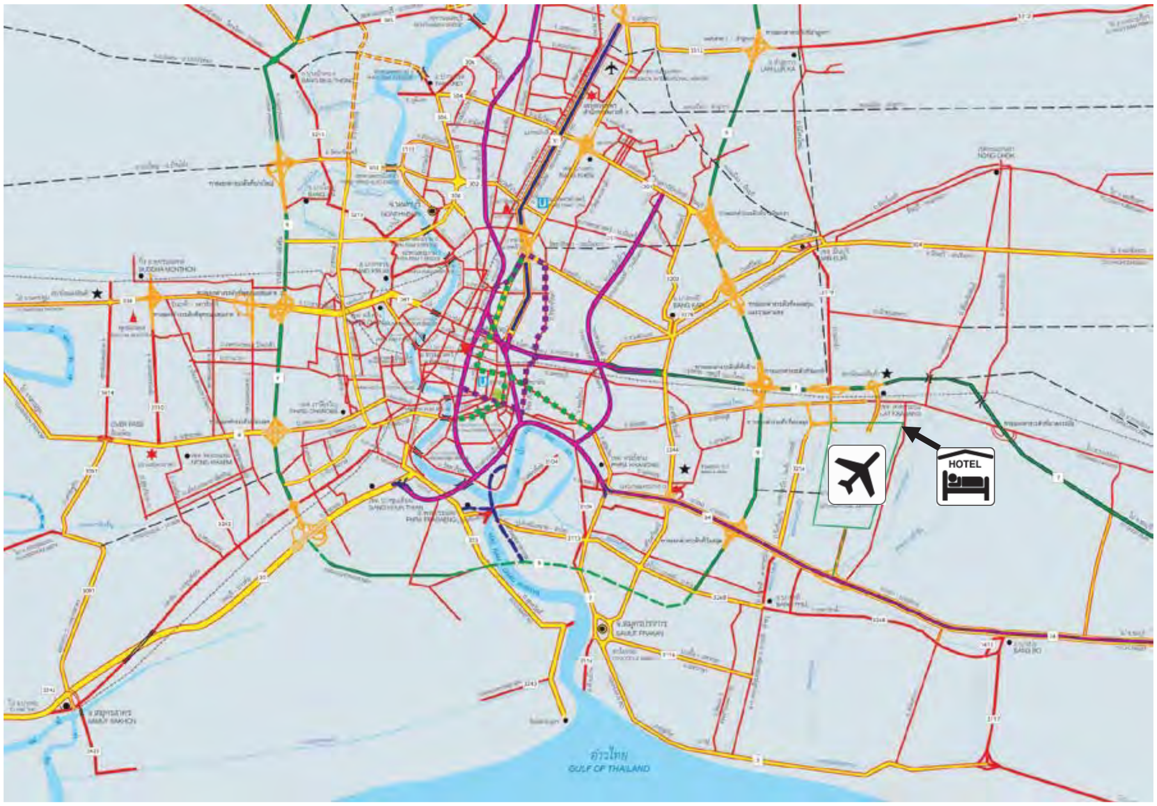
Dimanche	Lundi	Mardi	Mercredi	Jeudi	Vendredi	Samedi
11	12 8h15 Départ de Québec	13 22h10 +1J Arrivée à Bangkok	14 13h10 Transfert vers Chiang Mai	15 A.M. Université Chiang Mai P.M. Temple de Suthep	16 A.M. Tour d'éléphant P.M. Site de pétrole Fang	17 A.M. Transport vers Lampang P.M. Mine charbon Mae Moh
18 A.M. Transport vers Tak P.M. Géologie de Tak Mae Sot Soir Marché Moei	19 A.M. Mine de zinc Pha Daeng P.M. Site historique Sukhothai	20 A.M. Mine d'or Chatree P.M. Visite ville Phitsanulok Transfert vers Nakhon Thai	21 A.M. Parc National P.M. Barrage Ubolratna Transport vers Khon Kaen	22 A.M. Musée des dinosaures P.M. université Khonkaen 20h00 Transfert vers Bangkok	23 A.M. Université Chulalongkorn P.M. Temple Pra Kaw	24 Libre
25 Libre	26 6h50 Départ de Bangkok 22h21 Arrivée à Québec	27	28	29	30	31

Excursion métallogénique
Thaïlande 2014

JOUR 0

13 MAI

Arrivée à Bangkok



Source : ROADASSOTHAI

BANGKOK

➔HÔTEL

ORCHID RESORT
62 Soi Ladkrabang, 48 Onnut-Lat Krabang Rd.,
+66 2 7391020
Check in : 12h00
Check out : 12h00

➔ADRESSES UTILES

AMBASSADE DU CANADA
990 Râma IV Rd., Abdulrahim Place Building 15^{e} étage
+66 0 26464300

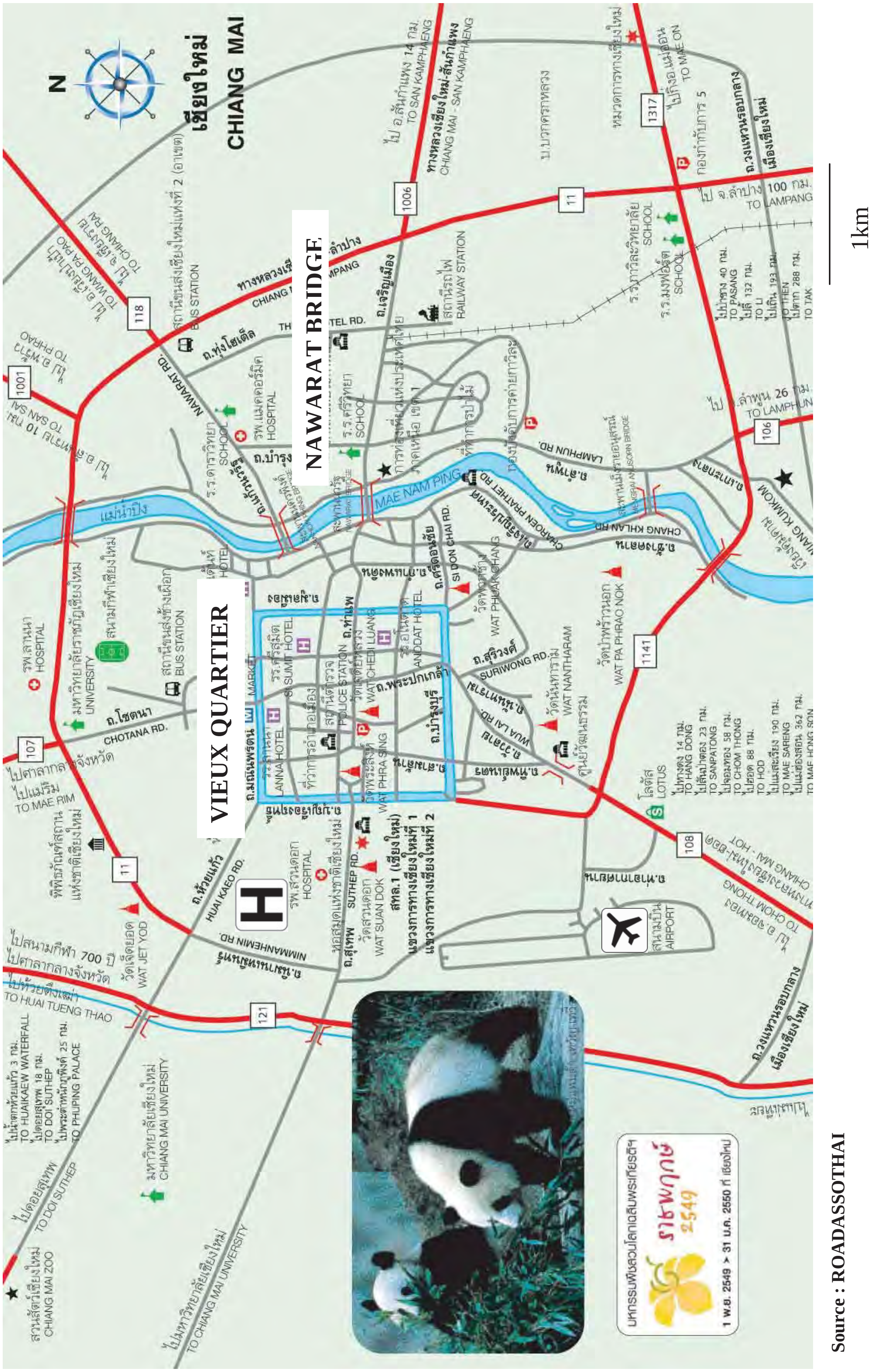
AMBASSADE DE FRANCE
35 Charoen Krung Rd., Soi 32-34
+66 0 26575100

Excursion métallogénique
Thaïlande 2014

JOUR 1

14 MAI

Transfert vers Chiang Mai



Source : ROADASSOTHAI

Source : LIMELEAFTHAILAND

CHIANG MAI

➔HÔTEL

YINDEE STYLISH GUESTHOUSE
15/1 Soi 2, Ratchawithi Rd.
+66 8 6544332
Check in : 14h00
Check out : 12h00

➔HÔPITAL

RAM HOSPITAL
8 Bunruangrit Rd.
+66 53 224861

VIEUX QUARTIER

➔RESTAURANTS

THE HOUSE RESTAURANT $$$
199 Moon Muang Rd.
Cuisine asiatique et européenne
Resto salon de thé style marocain

SOMPHET MARKET $
Moon Muang Rd.
Cuisine de rue populaire thaïe et chinoise

JERUSALEM FALAFEL $$
35/3 Moon Muang Rd.
Cuisine du moyen-orient

➔BAR

U.N. IRISH PUB
24 Ratchawithi Rd.
Section sport bar

➔À FAIRE

BOR NGUYEN
9 Moon Ruang Rd.
Massages traditionnels

CENTRE ART & CULTURE
Phra Pok Khlao Rd.
15 salles sur deux niveaux

SUNDAY MARKET
Thanon Ratchadamoen
Marché pour artisanat local

NAWARAT BRIDGE

➔RESTAURANTS

THE GALLERY $$
27 Charoen Rat Rd.
Cuisine thaïe et occidentale
Resto au bord de la rivière

ANTIQUE HOUSE 1 $$
71 Charoen Pratchet Rd.
Cuisine traditionnelle
Musique thaïe

AROON RAI $
45 Kotchasara Rd.
Cuisine thaïe du nord

➔BAR

THE RIVERSIDE
9 Charoen Rat Rd.
Concert tous les soirs

BRASSERIE
37 Charoen Rat Rd.
Terrasse sur le bord de la rivière

➔À FAIRE

NIGHT BAZAR
Chang Khlan Rd.
Restos, kiosques, spectacles

KAWILA BOXING STADIUM
San Pakhoi Khong Sai
Combat de boxe thaïe

Excursion métallogénique
Thaïlande 2014

JOUR 2

15 MAI

Université de Chiang Mai
Temple de Suthep
Souper typique

UNIVERSITÉ CHIANG MAI

15 Mai 2014

LOCALISATION

L'université de Chiang Mai se situe à l'ouest du centre-ville de Chiang Mai. Elle compte un total de quatre campus, dont un à Lamphun.

HISTORIQUE

Il s'agit d'une université publique qui compte près de 36 000 étudiants. Elle fut d'ailleurs la première en termes d'éducation supérieure à être érigée dans le nord de la Thaïlande en 1964.

Il y a un total de 20 facultés concentrées en trois grandes disciplines, soit science de la santé, science et technologie, et science sociale. Le département de géologie se spécialise dans plusieurs sujets, dont la géologie structurale, la stratigraphie et sédimentologie, la minéralogie et pétrologie, la géologie économique et l'hydrogéologie.

RÉFÉRENCE

CHIANG MAI UNIVERSITY, ***www.cmu.ac.th,*** [En ligne], Consulté le 2 mai 2014

WAT PHRA THAT DOI SUTHEP

15 Mai 2014

Prix d'entrée : 30 Bth + 30 Bth supplémentaires pour les moins vaillants
Spécifications : Chaussures non permises dans le temple

LOCALISATION

Le temple Phra That se situe au sommet de la montagne Suthep à 13 km au nord de Chiang Mai. La montagne Suthep culmine à environ 1685 mètres.

Source : PLANETDEN

HISTORIQUE

Le temple fut construit en 1383 comme monastère pour les bouddhistes. Des moines y vivent encore aujourd'hui et subviennent à leurs besoins grâce à des levés de fonds ainsi que des donations. Un imposant escalier de 300 marches permet de se rendre jusqu'au sommet de la montagne, avec des rampes représentant Naga, un serpent à plusieurs têtes. Pour ceux qui ne désirent pas faire l'ascension de cet escalier, vous pourrez faire appel à un songtahaews pour environ 30 Bth.

Source : ACTIVEPLANETTRAVEL

GÉOLOGIE

Le Doi Suthep Metamorphic Complex (DSMC) est composé principalement d'orthogneiss mylonitique recoupé par des pegmatites et des aplites granitiques. Les relations entres les dykes de roches intrusives et le complexe mylonitique suggère un lien génétique entre la mylonitisation est l'arrivée de ces dykes. Voir article en annexe pour plus de détails sur la géologie du secteur.

ARTICLE

(Rhodes et al., 2000) *Structural development of the Mid-Tertiary Doi Suthep Metamorphic Complex and Western Chiang Mai Basin, Northern Thailand*

RÉFÉRENCES

GLOAGUEN P., DUVAL M., (2013) ; ***Le routard : Thaïlande***, Hachette guide tourisme, Octobre 2012, 620p. ISBN 978-2012455702

VISIT CHIANG MAI, (2002); ***Doi Suthep***, [En ligne], www.visitchiangmai.com.au, Consulté le 16 avril 2014

RHODES, B.P., BLUM, J., DEVINE, T., (2000); ***Structural development of the Mid-Tertiary Doi Suthep Metamorphic Complex and Western Chiang Mai Basin, Northern Thailand***, *Journal of Asian Earth Sciences* **18,** 97–108

Excursion métallogénique
Thaïlande 2014

JOUR 3

16 MAI

Tour d'éléphant
Transport vers Fang
Puits de pétrole de Fang

MAE SA ELEPHANT CAMP

16 Mai 2014

Prix d'entrée : 200 Bth pour l'entrée (inclus les spectacles). Prévoir entre 800 et 1200 Bth. pour faire un tour de 30min à 1 heure d'éléphant

LOCALISATION

Environ 30 km au nord est de la ville de Chiang Mai.

Source : ANTIDOTEMAG

DESCRIPTION

Le camp Mae Sa est un refuge pour éléphants. Plus de 70 éléphants sont présents au site. Chaque jour, il est possible d'observer la baignade, plusieurs tours effectués par les éléphants ainsi que de faire une balade en forêt sur le dos de ces pachydermes. Le camp existe depuis 1976 comme centre de conservation pour éléphants domestiqués qui viennent de tous les coins de la Thaïlande. Utilisés avant dans l'industrie du bois, les éléphants ont laissé leur place à la machinerie lourde. Le camp Mae Sa permet une nouvelle vocation pour ces éléphants et leur maître.

RÉFÉRENCE

MAESA ELEPHANT CAMP, [En ligne], ***www.maesaelephant camp.com***, Consulté le 3 mai 2014

PUITS DE PÉTROLE DE FANG

16 Mai 2014

Horaire : Arrivée en début d'après-midi
Services : Souper et hébergement au site de la mine

LOCALISATION

Le bassin de Fang se situe à environ 150 km au nord de Chiang Mai.

PROPRIÉTAIRE

Diverses compagnies détiennent des puits de pétrole dans le secteur.

TYPE DE GISEMENT

Pétrole

PRODUCTION

Depuis ces débuts en 1960, 9 millions de barils ont été extraits du bassin de Fang.

Source : LERTASSAEAPHOL

HISTORIQUE

Le gisement de pétrole de Fang est le premier gisement de pétrole découvert en Thaïlande. L'exploration du bassin de Fang a commencé en 1921 sous la direction du général Pra Kampangphet Akkarayothin du Royal State Railway Department en collaboration avec le géologue américain Mr. Wallace Lee. En mars 1958, le roi et la reine de Thaïlande ont inauguré le premier puits de pétrole de la région de Fang. Sur les six sites d'exploitations depuis le début de la production, deux ont été abandonnés dans le milieu des années 80 étant donné que tout le pétrole disponible à ces endroits avait été exploité.

GÉOLOGIE

Le bassin de Fang est un petit basin intracratonique d'orientation NNE-SSW. Il s'est formé au début de la période Tertiaire dans un environnement de dépôts fluviaux-lacustres. Structuralement, le bassin de Fang se définit comme un demi-graben avec sa façade ouest abrupte et sa façade Est légèrement en pente. Le bassin se divise en trois sous-bassins soit Huai Pasang, Huai Ngu and Pa Ngew. Tous les puits en exploitation présentement se retrouvent dans le sous bassin de Huai Ngu. Une combinaison de trappes structurales (plis anticlinaux) et stratigraphiques (lits de sandstone intercalés de shales imperméables) a permis la concentration du pétrole.

ARTICLE

(Lertassaeaphol, 2008*) Spatial distribution and relationship of petroleum reservoirs in the Fang oil field*, *Amphoe Fang*, *Changwat Chiang Mai*

RÉFÉRENCES

SETTAKUL, N., (2009); ***Fang oilfield development,*** Walailak J Sci and Tech, 1-15

LERTASSAEAPHOL, P., (2008); ***Spatial distribution and relationship of petroleum reservoirs in the Fang oil field, Amphoe Fang, Changwat Chiang Mai,*** Chulalongkorn University, 106 p.

Excursion métallogénique
Thaïlande 2014

JOUR 4

17 MAI

Transport vers Lampang
Arrêts géologique
Mine Mae Moh

LAMPANG

Source : ROADASSSOTHAI

1km

➔HÔTEL

PIN HOTEL
8 Suandok Rd.
+66 54 221 509

➔RESTAURANT

MAMAISON GARDEN
Pub
Phahon Yothin Rd.

MINE MAE MOH

17 Mai 2014

Horaire : Visite en après-midi
Services : n/a

LOCALISATION

Le gisement se situe à 50 km à l'est de Lampang.

PROPRIÉTAIRE

Le gisement Mae Moh appartient à la compagnie d'état Electricity Generating Authority of Thailand.

TYPE DE GISEMENT

Gisement de lignite (charbon à 50-60% carbone)

PRODUCTION

La mine Mae Moh produit environ 52000 tonnes de charbon par jour soit l'équivalent de 16-17 millions de tonnes par année (données de 2009). Ceci représente 80-85% de toute la production de charbon de la Thaïlande. Il s'agit d'une mine à ciel ouvert.

Lit de gastéropodes dans la formation de Na Khaem (Ratanasthier et al., 2008)

HISTORIQUE

Le gisement Mae Moh fut découvert en 1917 par la State Railway alors que ceux-ci cherchaient une source alternative au bois pour faire avancer leurs trains. Par contre, ce n'est qu'après la campagne d'exploration de détail par la Royal Department of Mines and Geology dans les années 1950 que la Thaïlande décida de commencer l'exploitation de charbon à ciel ouvert. Aujourd'hui, Mae Moh est considérée comme l'une des plus grandes mines de charbon du Tertiaire de tout le sud-est de l'Asie.

GÉOLOGIE

Le bassin sédimentaire de Mae Moh se divise en trois formations distinctes. La formation de Huai King, de Na Khaem et de Huai Luang. La formation de Huai King est celle qui est en dessous de la stratigraphie. Elle est composée de conglomérat à la base avec des mudstone au sommet. Au-dessus se retrouve la formation de Na Khaem qui est la formation contenant le plus de charbon. Cette formation est constituée principalement de mudrock semi-consolidé avec cinq lits riches en charbon de 250 à 400 mètres d'épaisseur. C'est d'ailleurs dans cette formation que l'on retrouve aussi le plus de fossiles (gastéropodes). La formation de Huai Luang représente la dernière couche avant la surface de sédiments consolidés. Elle est composée en grande partie de claystone, de siltstone et de mudstone.

ARTICLE

(Ratanasthier et al., 2008) *Paleaogeography and climatic change recorded on viviparidae carbon and oxygen isotope in Mae Moh Coal Mine, Northern Thailand*

RÉFÉRENCES

RATANASTHIEN, B., TAKASHIMA, I., MATSUBAYA,O., (2008); ***Paleaogeography and climatic change recorded on viviparidae carbon and oxygen isotope in Mae Moh Coal Mine, Northern Thailand***, Bulletin of the Geological Survey of Japan,, v. 59, 327-338

RATANASTHIEN, B., (1983); ***Stratigraphy and geology of some coal fields,*** Conference on Geology and Mineral Resources of Thailand, Bangkok, 19-28 Novembre, 1983, 6 p.

WARD, C.R., (1991); ***Mineral matter in low-rank coals and associated strata of the Mae Moh basin, northern Thailand***. Int. J. Coal. Geol., 17: 69-93.

Excursion métallogénique
Thaïlande 2014

JOUR 5

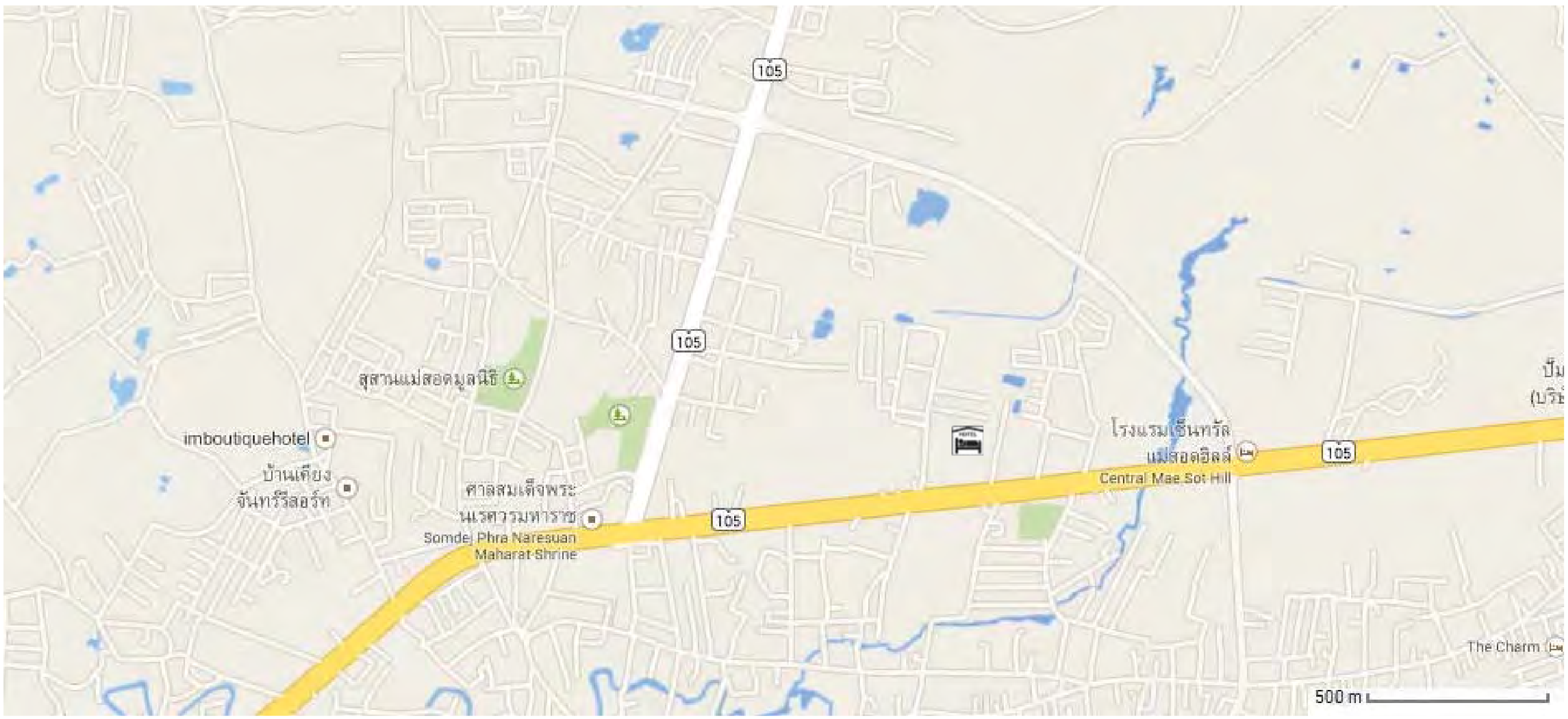
18 MAI

Transport vers Mae Sot
Arrêts géologiques
Marché Moei

MAE SOT

➔HÔTEL

BAAN MAESOT BOUTIQUE RESORT
536 Moo 1, Asia Rd., T.
+66949494121
*Déjeuner compris



Source : GOOGLEMAP

MARCHÉ TALAT RIM MOEI

18 Mai 2014

Horaire : Fin d'après-midi

LOCALISATION

Mae Sot dans la province de Tak

DESCRIPTION

Situé sur la rive de Maenam Moei, à la frontière Thaïlande-Myanmar, Talad Rim Moei est un endroit où les produits locaux et les pierres précieuses comme le jade et le grenat du Myanmar sont disponibles. Beaucoup de produits électroniques et de vêtements en vente à cet endroit. Possibilité de traverser la frontière birmane.

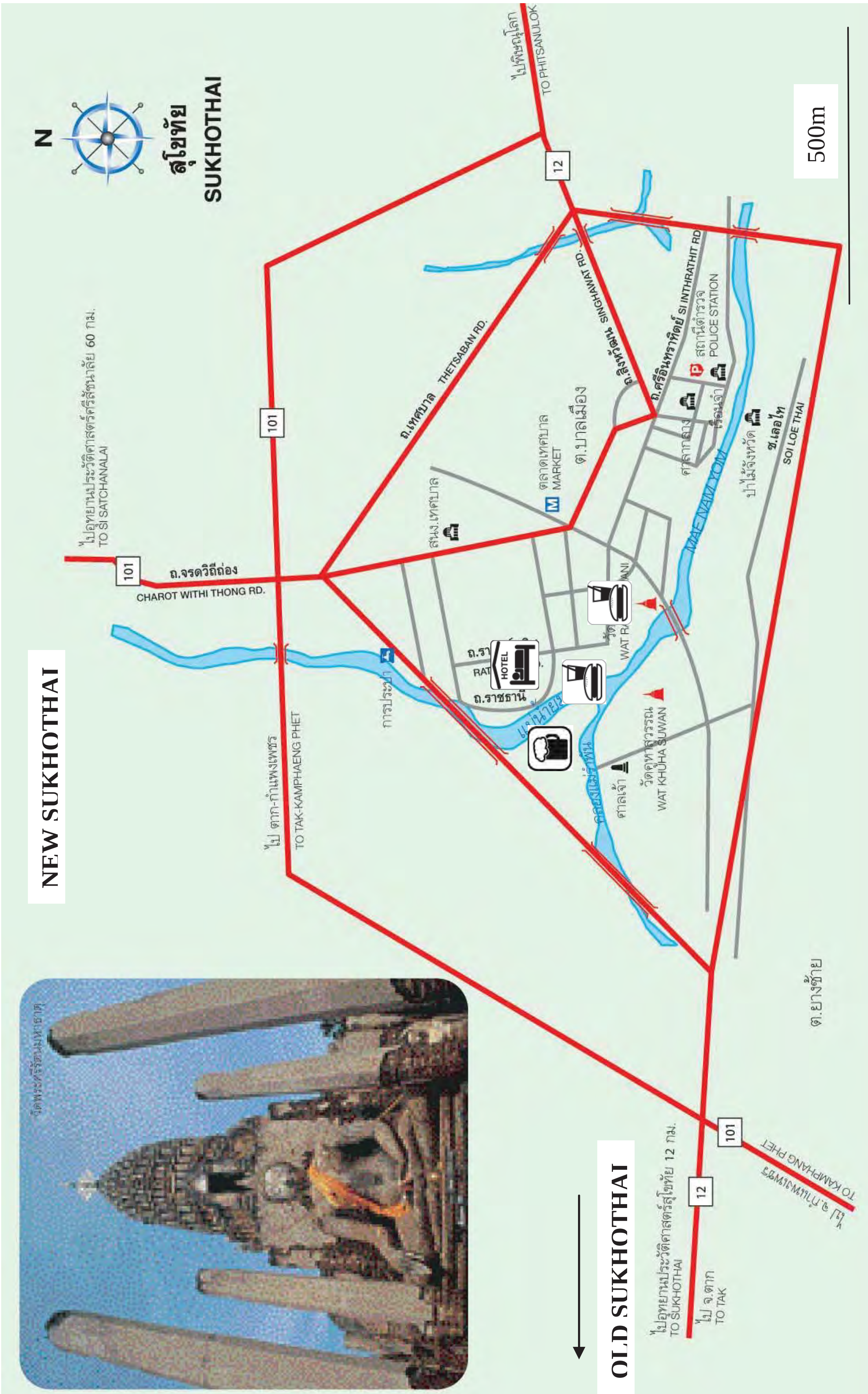
Source : TOURISMTHAILAND

Excursion métallogénique
Thaïlande 2014

JOUR 6

19 MAI

Mine Pha Daeng
Transport vers Sukhothai
Site historique Sukhothai



Source : ROADASSOTHAI

NEW SUKHOTHAI

➔HÔTEL

LOTUS VILLAGE
170 Ratchathanee Street
+66 55 621484
Check in : 12h00
Check out : 12h00
*Déjeuner compris

➔RESTAURANTS

DREAM CAFÉ $$
86/1 Singhawat Rd.
Café resto, plats thaï

LE MARCHÉ DE NUIT $
Dans le centre

➔BAR

CHOPPER BAR
Charod Withitong
Country en thaï et en anglais

➔À FAIRE

SANGKHALOK MUSEUM
10 Ban Lum.
Explications en français
Exposition de céramiques

MINE PHA DAENG

19 Mai 2014

Horaire : Départ de l'hôtel tôt le matin, visite en matinée
Services : n/a

LOCALISATION

Le gisement se situe 20 km au sud-est de la ville de Mae Sot dans le district de Tak.

PROPRIÉTAIRE

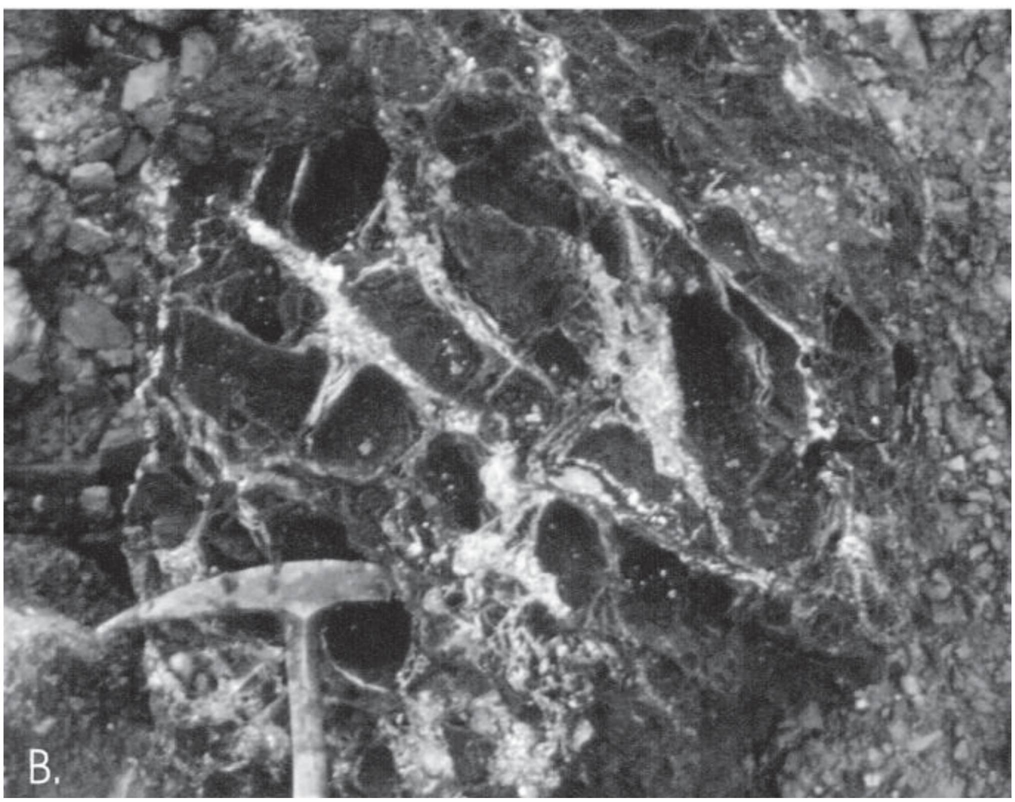
La mine appartient à la compagnie d'état Padaeng Industry Public Company Limited.

TYPE DE GISEMENT

Minéralisation supergène

PRODUCTION

L'estimation des ressources est de 5.14 Mt à 12% Zn. La teneur de coupure est de 3% Zn. La production annuelle est d'environ 105 000t de zinc. Ces données datent de 2003.



Veinules d'hémimorphite dans une roche karstique (Reynolds et al., 2003)

HISTORIQUE

Le dépôt Pha Daeng fut découvert en 1947 par le Département des Ressources Minérales de la Thaïlande. Plusieurs travaux de forage ont été effectués par des compagnies minières appartenant à l'état et des groupes de consultants de 1957 à 1975. À partir de 1981, la compagnie Padaeng Industry Public Company fut fondée par le gouvernement thaïlandais et à l'aide de la compagnie belge Vieille Montagne, le procédé d'extraction du minerai de zinc fût établi pour la fonderie de zinc situé à Tak. À ce jour, le gisement est toujours exploité par la compagnie Padaeng Industry Public Company.

GÉOLOGIE

Le dépôt Pha Daeng contient une minéralisation riche en oxydes de zinc et en carbonates de zinc. Les principaux minéraux de zinc présent dans le dépôt sont l'hémimorphite ($Zn_4Si_2O_7(OH)_2{\cdot}(H_2O)$) et la smithsonite ($ZnCO_3$). La minéralisation se présente sous forme stratoïde dans un groupe de sédiments du Jurassique provenant d'un environnement marin peu profond dans une marge passive. L'hémimorphite et la smithsonite se retrouvent principalement dans des roches dolomitiques.

Le gisement Pha Daeng est interprété comme une minéralisation de type MVT (Mississippi Valley Type) qui a complètement été altéré et remobilisé par des processus supergènes. C'est d'ailleurs pour cette raison que l'on retrouve au site de la mine très peu de sulfure de zinc, mais plutôt des oxydes ou des carbonates de zinc. La présence d'une roche hôte perméable (dolomie), d'un réseau de failles importantes et d'un climat semi-aride ont permis une météorisation importante du gisement et ainsi ont permis de concentrer le zinc dans la dolomie pour créer ce gisement supergène.

ARTICLE

(Reynolds et al., 2003) *The Padaeng supergene nonsulfide zinc deposit, Mae Sod, Thailand*.

RÉFÉRENCE

REYNOLDS, N.A., CHISNALL, T.W., KEESANEYABUTR, C., TAKSAVASU, T., (2003); ***The Padaeng supergene nonsulfide zinc deposit, Mae Sod, Thailand***. Economic Geology, 773-785

SITE HISTORIQUE SUKHOTHAI

19 Mai 2014

Prix d'entrée : 100 Bth
Spécifications : 200 Bth supplémentaires pour les 2 sites extérieurs

LOCALISATION

Sukhothai est situé à un peu plus de 450 km au nord de Bangkok dans la plaine centrale. La ville est divisée en deux, soit le Old Sukhothai et le New Sukhothai. Douze kilomètres séparent l'ancienne ville de la nouvelle partie. Le site historique se situe quant à lui dans la partie la plus vieille de la ville.

Source : THAILANDSWORLD

HISTORIQUE

Inscrite depuis 1991 au Patrimoine mondial de l'UNESCO, Sukhothai a été la capitale politique et administrative du premier royaume du Siam aux XIII^{e} et XV^{e} siècles. En 1351, la ville commença son déclin pour laisser place au royaume d'Ayutthaya, la nouvelle capitale. Bien que la plupart des palais des rois en bois soient disparus, plusieurs temples et autres édifices construits en brique et en latérite sont encore présents.

Le parc historique se situe dans une enceinte de 1,8 km de long par 1,5 km de large. Il y a également un total de quatre autres sites extérieurs à l'enceinte comme sur la figure ci-dessous. L'entrée est payant pour deux d'entre eux. Il est recommandé d'arriver très tôt pour ainsi admirer l'effet du lever du soleil sur le site. Sukhothai signifie d'ailleurs « aube » dans la langue du bouddhisme therâvada.

Source : THAILANDSWORLD

RÉFÉRENCES

UNESCO, (1991), ***Ville historique de Sukhothaï et villes historiques associées***, [En ligne], http://fr.unesco.org, Consulté le 15 avril 2014

GLOAGUEN P., DUVAL M., (2013) ; ***Le routard : Thaïlande***, Hachette guide tourisme, Octobre 2012, 620p. ISBN 978-2012455702

Excursion métallogénique
Thaïlande 2014

JOUR 7

20 MAI

Transport vers Pitchit
Mine Chatree
Visite Phitsanulok

MINE CHATREE

20 Mai 2014

Horaire : Départ de l'hôtel tôt le matin, visite en matinée
Services : Dîner à la mine

LOCALISATION

Le gisement se situe à environ 120 km au sud-est de Sukhothai.

PROPRIÉTAIRE

Kingsgate Consolidated Ltd exploite la mine de Chatree.

TYPE DE GISEMENT

Épithermale (low sulfidation)

PRODUCTION

De 2001 à 2009, la mine a produit environ 5 millions d'onces d'or et 35 millions d'onces d'argent avec une teneur moyenne de 1,07 g/t d'or et de 7,5 g/t d'argent. La mine Chatree est une mine à ciel ouvert.

Source : STRAHLEM

HISTORIQUE

L'exploration du secteur de Pichit a commencé en 1987, l'année où les compagnies étrangères venaient d'obtenir le droit de faire de l'exploration minière en Thaïlande. Une compagnie australienne (Epoch Mining NL) a donc découvert de bonnes teneurs en or dans le secteur à l'aide de forage. Il y a eu plusieurs programmes d'exploration au cours des années et ce n'est qu'en 2001 que l'exploitation de la mine commença par la compagnie australienne Kingsgate Consolidated Ltd.

GÉOLOGIE

Le dépôt de Chatree se retrouve dans une séquence de laves rhyolitiques et andésitiques qui est recouverte par des volcanoclastites, des siltstones et des mudstones. Une altération propylitique (chlorite ± épidote-calcite-pyrite) importante traverse la partie sud du gisement alors que la partie nord est dominée par une altération plutôt argilique et phyllique (séricite-illite-quartz-pyrite). La minéralisation est aussi contrôlée par les failles majeures régionales d'orientation NE-SW.

La minéralisation se présente sous forme de veines hydrothermales ou de brèches hydrothermales largement silicifiées. L'or et l'argent se retrouvent principalement dans les minéraux économiques suivants : la pyrite, la chalcopyrite, la tétraédrite ($(Cu,Fe)_{12}Sb_4S_{13}$), la sphalérite et l'électrum.

ARTICLE

(James et al., 2007) *Geology and mineralization of the Chatree epithermal Au-Ag deposit, Phetchabun Province, Central Thailand*

RÉFÉRENCES

JAMES, R.; CUMMING, G. (2007); ***Geology and mineralization of the Chatree epithermal Au-Ag deposit, Phetchabun Province, Central Thailand***. Geothai'07, 11p.

SALAM, A., et al., (2013) ***Geochemistry and geochronology of the Chatree epithermal gold–silver deposit: Implications for the tectonic setting of the Loei Fold Belt, central Thailand***, Gondwana Research 21 p.

Excursion métallogénique
Thaïlande 2014

JOUR 8

21 MAI

Parc national Phu Hin Rong Kla
Barrage Ubolratana
Transport vers Khon Kaen

Source : **ROADASSOTHAI**

KHON KAEN

➔HÔTEL

LOFT LIVING KHON KAEN
168/16 moo 16 Srimarat Road 12 A.,
Mung Khon Kaen
+66 81 4498449
Check in : 12h00
Check out : 12h00
*Déjeuner compris

➔RESTAURANTS

NAEM NUANG $
Thanon Klang uang
Cuisine vietnamienne

PRAM $$
42/14 Thanon Ammart
Spécialités isan, poissons et dips

PARC NATIONAL PHU HIN RONG KLA

21 Mai 2014

Prix d'entrée : 500 Bth pour l'entrée dans le parc
Spécifications : Randonnée en montagne, préparez-vous adéquatement.

LOCALISATION

Environ 30 km au sud-est de Nakhon Thai. Le parc couvre la province de Loei, Phitsanulok et Phetchabun. Le parc s'étend jusqu'à la frontière avec le Laos.

Source : FLICKR

DESCRIPTION

Phu Hin Rong Kla est un parc national dans les montagnes qui servit entres autres de quartier général pour le Communist Party of Thailand durant les années 1970-1980. Phu Man Khao est la montagne la plus haute de la région. Elle culmine à 1794 m d'altitude. Le climat y est généralement modéré à toute période de l'année ne dépassant pas 25°C. Bien que les conflits armées des années 1970-1980 dans la région aient fait fuir une grande partie de la faune, on peut encore observer dans le parc des tigres, des léopards, des ours noirs asiatiques, des singes et plusieurs autres animaux. La prudence est de rigueur.

RÉFÉRENCE

PHU HIN RONG KLA NATIONAL PARK, [En ligne], ***www.trekthailand.net***, Consulté le 4 mai 2014

BARRAGE UBOLRATANA

21 Mai 2014

Horaire : Après-midi

LOCALISATION

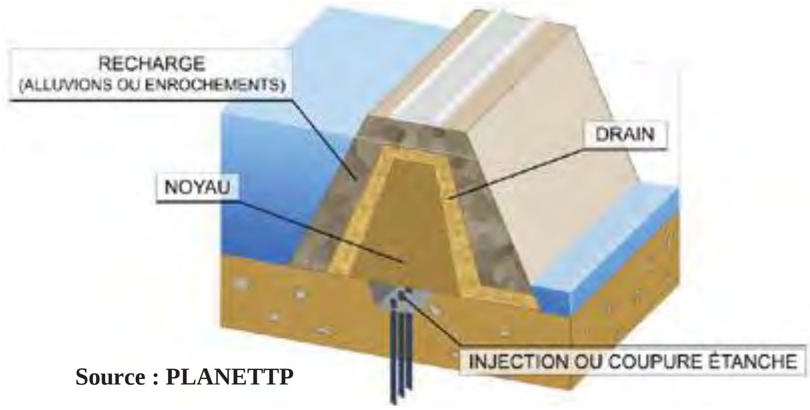
Le barrage se situe à environ 50 km au nord de Khon Kaen dans le district d'Ubolratana. Il se retrouve dans la rivière Nam Phong, qui est un affluent du fleuve Mékong.

Source : PANORAMIO

HISTORIQUE

Le barrage a été construit en 1964 afin de répondre à plusieurs besoins, dont l'irrigation, l'approvisionnement en eau, le maintien des écosystèmes, la prévention de crues, de la rivière, la pêche et bien entendu l'hydroélectricité. Au fil du temps le barrage est également devenu un important attrait touristique dans la région. Une modification majeure du barrage a eu lieu en 1984 causant une diminution de la superficie boisée dans ce bassin versant de 12 000 km^2 et ainsi une augmentation de l'érosion. Le barrage fut nommé en l'honneur de la princesse Thaïlandaise Ubolratana Rajakanya en 1966.

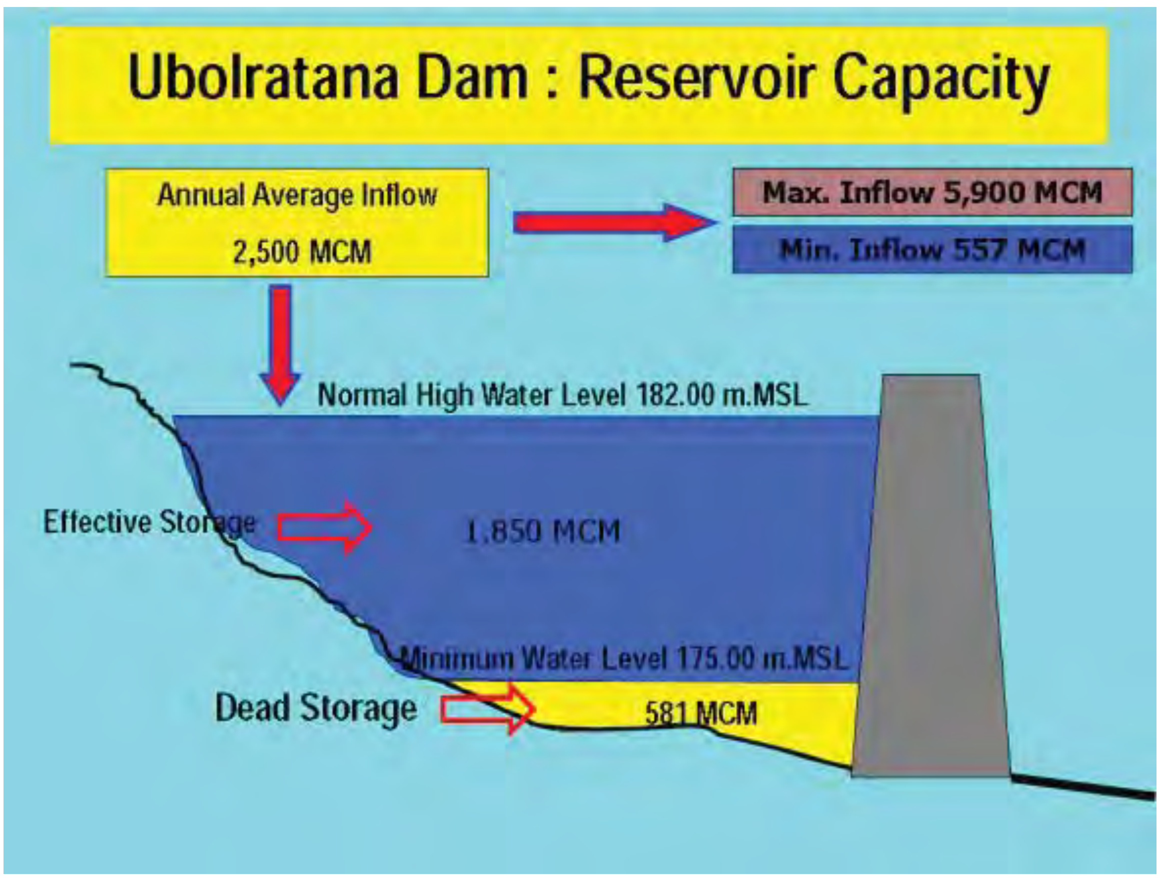
INGÉNIERIE



Source : PLANETTP

Le barrage mesure 885 m de long avec une hauteur de 31,5 m. De type barrage en remblais à noyau, les recharges sont constituées de matériaux plus perméables et très grossiers (enrochements), tandis que le noyau central est composé de matériel non perméable pour assurer l'étanchéité.

Un système de télémesure pour la prévention des crues a aussi été installé afin d'obtenir les mesures de débit et le niveau d'eau en temps réel et ainsi concevoir différents modèles. Ces modélisations permettent entre autres de prévenir des catastrophes liées à un surplus ou un manque d'eau dans le réservoir.



RÉFÉRENCE

MEETHOM, A.,CHOKKATIWAT, P.,(2010) ***Effective flood management using telemetric data : Ubolratana Dam, Thailand,*** Hydroenergia 2010, International congress and exhibition on small hydro power, 31 diapos

Excursion métallogénique
Thaïlande 2014

JOUR 9

22 MAI

Musée des dinosaures
Université Khon Kaen
Transfert vers Bangkok

MUSÉE DES DINOSAURES PHU KUM KHAO

22 Mai 2014

Prix d'entrée : 200 Bth pour l'entrée

LOCALISATION

Le musée des dinosaures de Phu Kum Khao se trouve dans la province de Kalasin qui est célèbre grâce à ses fossiles de dinosaures.

Source : PANORAMIO

DESCRIPTION

Le site se divise en deux parties soit le musée Sirhindorn accueillant les fossiles des dinosaures et autres datant de la période Paleozoïque ainsi que le Phu Kum Khao Dinosaur Excavation Site qui correspond au site où les fossiles ont été retrouvés. Ce musée des dinosaures est le plus grand de tout le sud-est de l'Asie. Le complexe habite aussi un centre de recherche qui est interdit d'accès pour les visiteurs.

HISTORIQUE

Au début des années 70, un moine aurait découvert les premiers fossiles. Croyant qu'il s'agissait de bois pétrifié, le moine conserva les fossiles dans un temple durant plusieurs années. En 1980, des géologues du département des ressources minérales de la Thaïlande étudièrent le secteur pour finalement y découvrir de nombreux fossiles.

Le musée a été créé en 1995 et il fut le premier en Thaïlande intégrant à la fois un centre de recherches et d'études ainsi qu'un bâtiment dédié au tourisme qui expose des reconstructions de fossiles et de dinosaures. Plus de 630 fossiles ont été découverts à ce jour et proviennent principales de sauropodes.

ARTICLE

(Boonchai et al., 2009) *Paleontological parks and museums and prominent fossil sites in Thailand and their importance in the conservation of fossils*

RÉFÉRENCES

BOONCHAI N., GROTE P.J., JINTASAKUL P., (2009), ***Paleontological parks and museums and prominent fossil sites in Thailand and their importance in the conservation of fossils,*** Notebooks on Geology, Brest, Book 2009/03, Chapter 07

DEPARTMENT OF MINERAL RESOURCES, ***Sirindhorn Dinosaur Museum,*** [En ligne], www.dmr.go.th, Consulté le 22 avril 2014

GLOAGUEN P., DUVAL M., (2013) ; ***Le routard : Thaïlande***, Hachette guide tourisme, Octobre 2012, 620p. ISBN 978-2012455702

UNIVERSITÉ KHON KAEN

22 Mai 2014

Horaire : Après-midi

LOCALISATION

L'université de Khon Kaen se situe dans le centre de la ville de Khon Kaen.

HISTORIQUE

Il s'agit d'une université publique qui compte près de 35 000 étudiants. Elle fut d'ailleurs la première en termes d'éducation supérieure à être érigée dans le nord-est de la Thaïlande en 1966. La faculté des technologies existe quant à elle depuis 1984.

L'université offre un total de 101 programmes de baccalauréat, 138 de maîtrises et 77 de doctorats répartis dans 17 facultés.

Le département de géotechnique de la faculté des technologies se spécialise dans plusieurs sujets, dont l'exploration minière, l'ingénierie géotechnique, l'ingénierie géoenvironnemental et la recherche en eaux souterraines.

RÉFÉRENCE

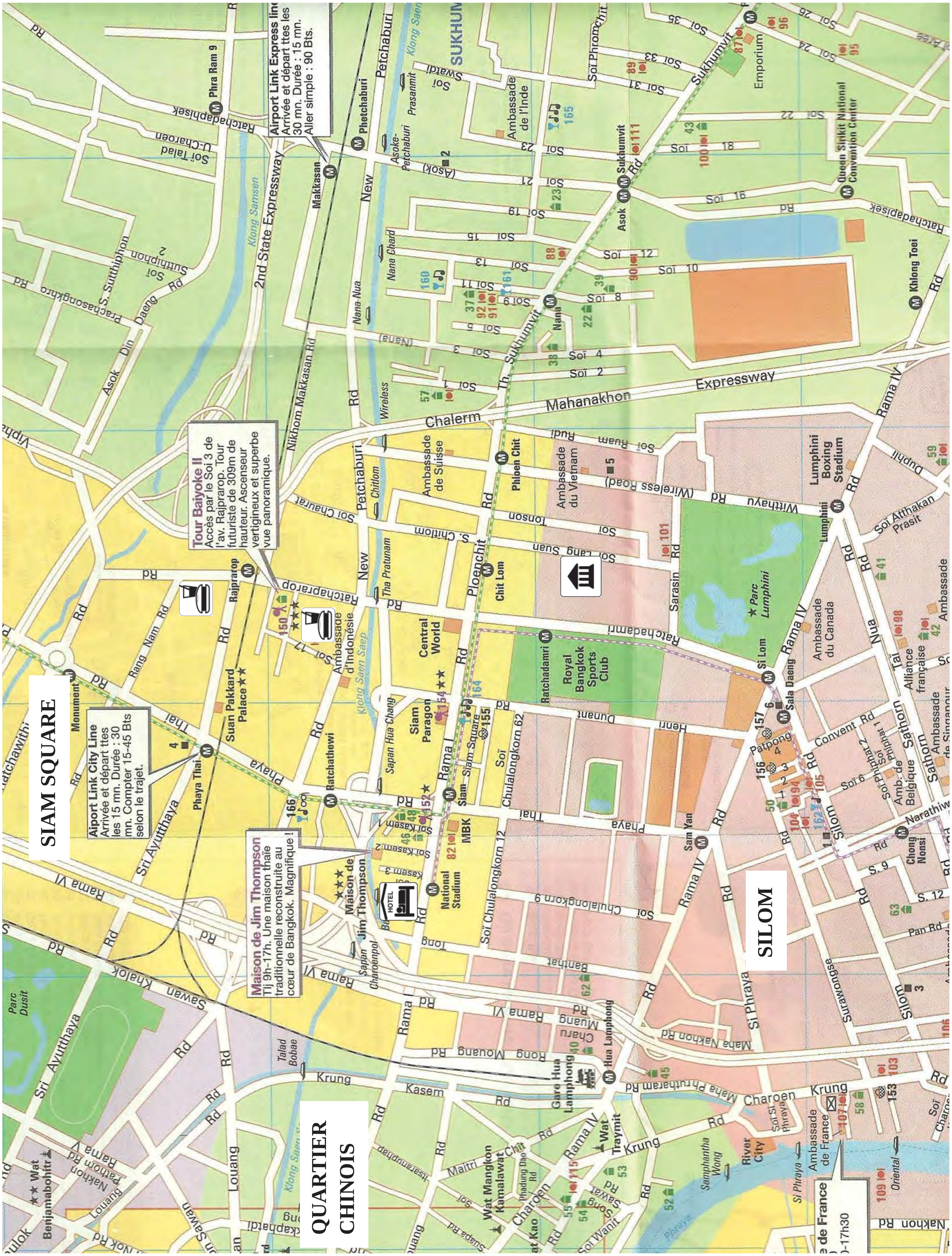
KHON KAEN UNIVERSITY, ***www.kku.ac.th,*** [En ligne], Consulté le 2 mai 2014

Excursion métallogénique
Thaïlande 2014

JOUR 10

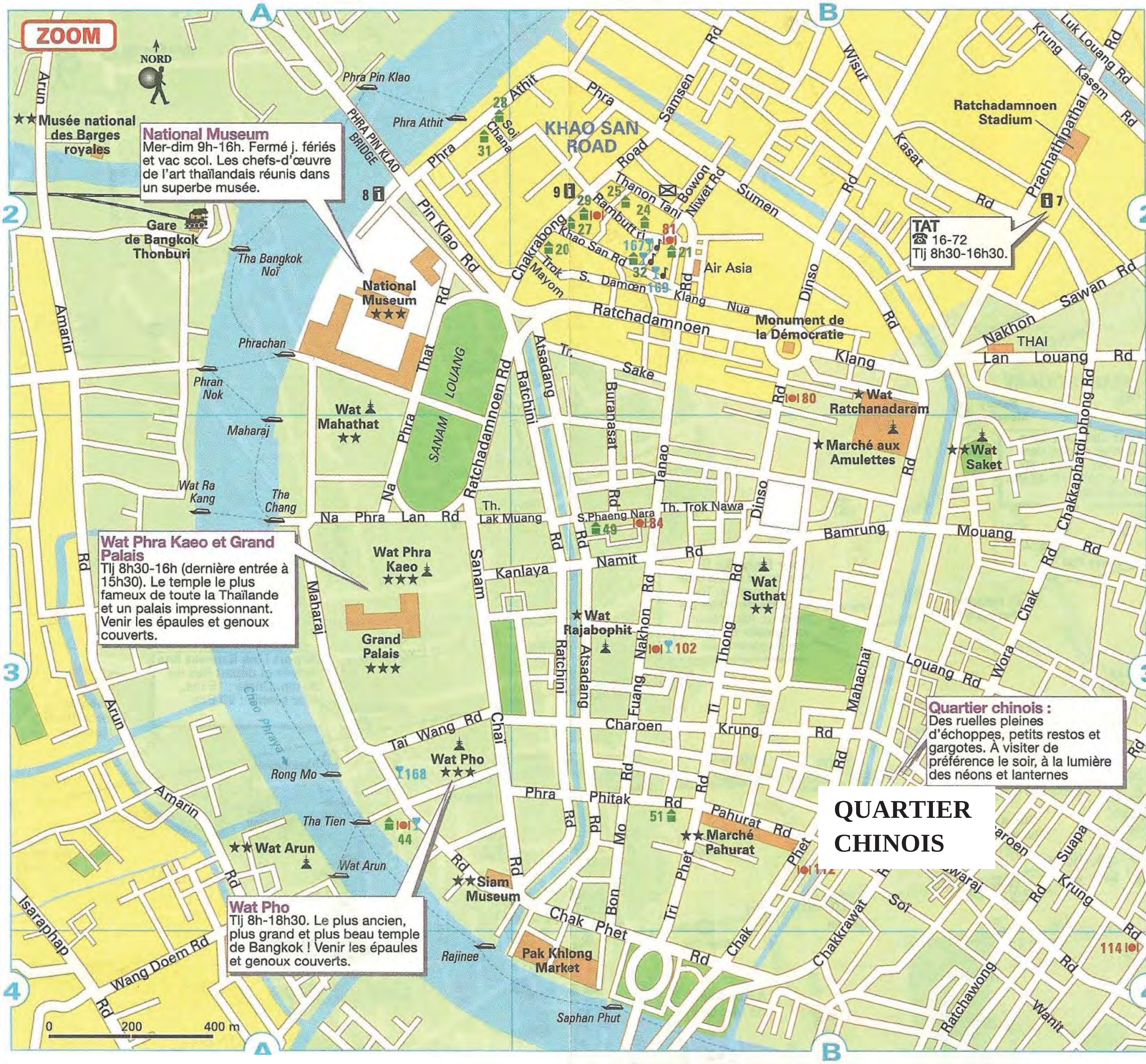
23 MAI

Université Chulalongkorn
Conclusion de l'excursion
Temple Phra Kaeo



500m

Source : ROUTARD THAILANDE 2013



Source : ROUTARD THAILANDE 2013

➔HÔTEL

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477 Si Ayuthaya Road, Phayathai
+66 2 2470174
Check in : 14h00
Check out : 12h00

➔RESTAURANTS

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Choix des poissons à même les viviers

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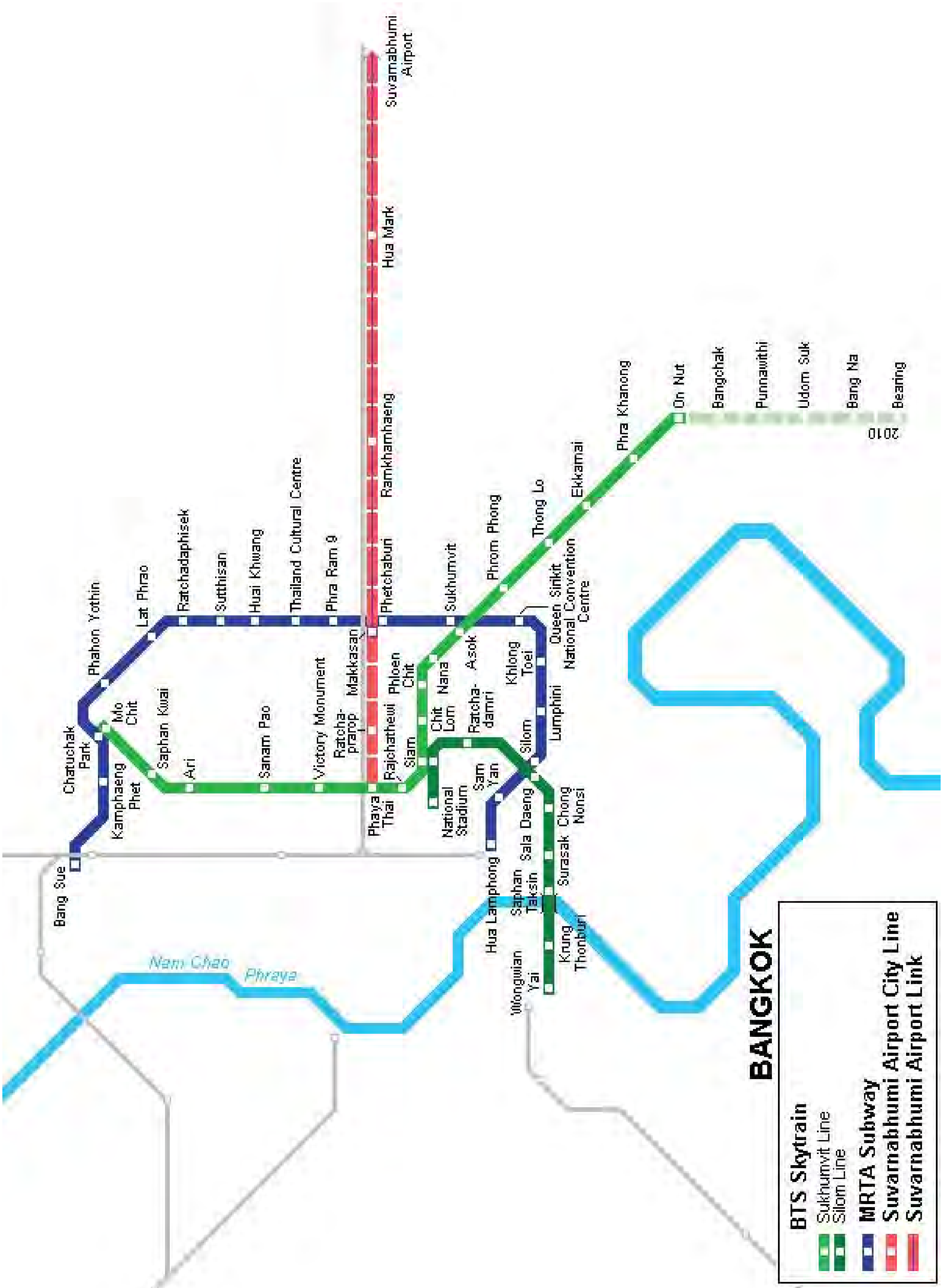
Cuisine thaïe
Dans un jardin tropical



Source : ROUTARD THAILANDE 2013

UNIVERSITÉ CHULALONGKORN

23 Mai 2014

Horaire : Avant-midi

LOCALISATION

L'université se situe dans le centre-ville de Bangkok, soit dans le quartier Silom.

HISTORIQUE

L'université Chulalongkorn est la plus vieille de la Thaïlande. Inaugurée officiellement le 26 mars 1917, elle fut longtemps considérée comme l'université la plus prestigieuse du pays. Le développement de cette université débuta au début des années 1800. En raison des changements politiques, sociaux et économiques dans le monde à cette époque, le Siam décida d'implanter une université afin de s'adapter à ces changements et ainsi d'éviter une colonisation non désirée par les puissances occidentales. L'université a été nommée en l'honneur du roi Rama V connu sous le nom Chulalongkorn qui initia le projet. C'est toutefois le fils de Rama V, le roi Vajiravudh, qui inaugura l'établissement en 1917.

L'université est composée de 19 facultés, 23 collèges et centres de recherche. Un total de 38 000 étudiants fréquente cette université qui accueille les meilleurs étudiants du pays. Plusieurs programmes sont offerts en lien étroit avec la géologie, soit dans le département de l'ingénierie minière et pétrolière, le département de l'ingénierie des ressources en eaux, le département de l'environnement et le département de géologie.

RÉFÉRENCE

CHULALONGKORN UNIVERSITY, ***www.chula.ac.th,*** [En ligne], Consulté le 3 mai 2014

WAT PHRA KAEO

23 Mai 2014

Prix d'entrée : 400 Bth + 200 Bth (audioguide en français)
Spécifications : Pantalon long et épaules couvertes obligatoires

LOCALISATION

Surnommé le temple du bouddha d'Émeraude, il est situé dans l'enceinte du Grand Palais dans le quartier chinois de Bangkok. La résidence royale, la salle du trône ainsi que plusieurs autres bureaux gouvernementaux se retrouvent dans cette enceinte de 2,2 km^2. La construction fut érigée en bordure du Chao Phraya afin de permettre une évasion par voie terrestre ou par voie maritime en cas d'invasion ennemie. Il s'agit du plus important temple bouddhiste en Thaïlande.

Source : GREENTRAILTOURISM

HISTORIQUE


Source :ZAZZLE

Le Grand Palais fut construit en 1782 par Râma 1er. Le Wat Phra Kaeo servait quant à lui de chapelle royale du Grand Palais. Selon la légende, la statue du Bouddha aurait été découverte à Chiang Rai au XVe siècle. Elle apporterait d'ailleurs la prospérité et le pouvoir au pays qui la détient. Déplacée à maintes reprises allant de Lampang à Chiang Mai, elle atterrie finalement au Laos où le roi Râma 1er la récupéra pour la rapporter en Thaïlande. La construction du temple s'acheva en 1784 en l'honneur de la statuette qui est devenue l'emblème religieux et symbolique de la dynastie Chakri.

La statue a été taillée dans un bloc de jadéite de 65 cm de haut par 45 cm de large. Le Bouddha possède trois costumes d'or et d'ornements qui sont changés au fil des saisons pas le roi. La plupart des bâtiments sont accessibles aux visiteurs à l'exception des appartements de la famille royale et du roi Rama IX qui y résident encore à ce jour. Il est interdit de filmer ou de photographier dans le temple Phra Kaeo.

RÉFÉRENCES

ASIA WEB DIRECT, (2000); ***Wat Phra Kaew in Bangkok***, [En ligne], www.bangkok.com, Consulté le 2 mai 2014

GLOAGUEN P., DUVAL M., (2013) ; ***Le routard : Thaïlande***, Hachette guide tourisme, Octobre 2012, 620p. ISBN 978-2012455702

Excursion métallogénique
Thaïlande 2014

RÉFÉRENCES

National Conference on "Geologic Resources of Thailand: Potential for Future Development"
17-24 November, 1992, Department of Mineral Resources, Bangkok, Thailand

AN INTRODUCTION TO GEOLOGY OF THAILAND

Phisit Dheeradilok, Thanis Wongwanich, Wattana Tansathien and Pol Chaodumrong

Geological Survey Division, Department of Mineral Resources, Rama VI Road, Bangkok 10400, Thailand.

ABSTRACT

Geological investigation in Thailand was intensively conducted during the last 30 years, although the Department of Mineral resources was found in 1891. As a result, geological maps of the country on the scale 1:2,500,000, 1:1,000,000, 1:500,000 and 1:250,000 have been accomplished, so were the geological maps of some high mineral-potential areas on the 1:50,000 scale.

The formal lithostratigraphic names proposed by the Department of Mineral Resources were employed here. This includes a brief description on their lithologies and depositional environments.

During the Lower Paleozoic, the Shan-Thai and Indochina terranes were probably a part of the Gondwanaland with shelf sediments on their peripherals. In the middle Paleozoic, they were rifted and drifted in the Paleotethys with extensive depositions of deep marine facies. Upper Paleozoic and Mesozoic sediments were results of interaction between the continental Shan-Thai and Indochina terranes that created a suture in late Triassic. Tertiary basins that were formed by conjugate strike-slip faults oriented in NW-SE and NNE-SSW directions and by clockwise rotation of the crustal blocks. The occurrences of three belts of I- and S-type granitoid rocks and of volcanic belts in the country support this interpretation.

The Tin-Tungsten mineralization is common in S-type granitoids of both the Western and the Central belts. Fluorite, barite, antimony, iron, manganese and feldspar are also associated with granitoid intrusions of various ages. Gold, copper-lead-zinc mineralizations are commonly related to the calc-alkali volcanic rocks. Chromite, nickel and asbestos are the main minerals found associated with basic and ultrabasic intrusive rocks. Fossil fuel deposits are common in Tertiary basins and some pre-Tertiary basins both onshore and offshore. Potash and rocksalt occur in the Maha Sarakham Formation in the Mesozoic Khorat Group. Gemstones are associated with Cenozoic basaltic volcanics. Groundwater is another most important economic resources that is essential to human and agriculture. Rocks and dimension stones are increasingly important as basic materials for industry and construction.

INTRODUCTION

Thailand is located in Southeast Asia between latitudes 5° 37' N and 20° 27' N and longitudes 97° 22' E and 105° 37' E and covers an area of 518,000 km^2. It is bounded to the west by Myanmar, to the north by Myanmar and Laos, to the east by Laos and Kampuchea, and to the south by Malaysia. Physiographically, the country can be divided into four regions; the mountainous highland in the north and northwest, the Khorat Plateau in the northeast, the central plain and the southern peninsula, which are between Andaman Sea and the Gulf of Thailand.

Geological investigation in Thailand began in the early 20th century, mostly by foreign geoscientists (Högbom, 1914; Lee, 1923; Credner, 1930, 1935; Heim and Hirshi, 1930; Reed, 1920). In 1941 a Geological Survey Division was established and was affiliated in the Royal Department of Mines (Department of Mineral Resources (DMR), since 1963) to conduct geological mapping and research and to explore mineral resources.

The geology of Thailand has been described previously by Brown et al. (1951), Kobayashi (1960, 1976, 1984), Buravas (1961, 1963), Klompe (1962), Bunopas (1976) and Suensilpong et al. (1978).

The first complete reconnaissance geologic map of Thailand (on the scale of 1:2,500,000) was published in 1953 and the second edition (on the scale of 1:1,000,00) in 1969. The systematic geological mapping program (scale 1:250,000) in northern Thailand has been undertaken during 1966-1972 by the Geological Survey Division in cooperation with the German Geological Mission to Thailand. Subsequently, the Geological Survey Division has carried out the similar geological mapping program covering the whole country. This led to publication of 52 sheets of 1:250,000 maps, 5 sheets of 1:500,000 maps and the latest edition (1987) of the geologic map of Thailand scale 1:1,000,000.

In 1982, the detail geological mapping program on the scale of 1:50,000 in the high mineral-potential areas was launched. As a result, 308 geological map sheets have been accomplished. Among these, 4 map sheets were published jointly by the Federal Institute for Geosciences and Natural Resources of Germany and the Thai Department of Mineral Resources. The specific geological research projects have been conducted with collaboration of various oversea institutes, international organizations and private sectors.

During 1986-1987, a Working Group on the Stratigraphic Nomenclature of Thailand has compiled all existed stratigraphic names to prepare the Stratigraphic Lexicon of Thailand. The accepted formal stratigraphic names have been selected as shown in Figure 1.

The concept of plate tectonics has also been applied by many geoscientists to delineate a geological development in Thailand (Asnachinda, 1978; Bunopas and Vella, 1978; Suensilpong et al., 1978; Bunopas, 1981; Helmcke, 1982).

This paper presents a common understanding on stratigraphic sequences, igneous rocks, tectonic evolutions and mineral resources of Thailand.

STRATIGRAPHY

Geologically, Thailand consists of rocks range in ages from Precambrian to Quaternary.

Precambrian

In general, the medium to high grade orthogneiss, paragneiss, and schist are regarded as inferred Precambrian rocks in Thailand. They usually formed the core of the N-S and NW-SE trending anticlinorium and faulted belts in the north, west, eastern gulf and peninsular Thailand (Buam et al., 1970;

Campbell, 1977; Piyasin, 1975; Nakinbodee et al., 1977; Bunopas, 1982 and Nakapadungrat et al., 1987).

Buam et al., (1970) reported the Precambrian rocks that have been transformed into anatexites in the lower portion of the rock sequence in northern Thailand. They are well exposed at Chiang Saen, Wiang Pa Pao, and Chiang Mai-Tak gneiss belt. The rocks include biotite schist, schistose augengneiss, paragneiss, and biotite marble. In western region, the Precambrian rocks have been substantiated in only a few areas NW of Uthai Thani and NW of Kanchanaburi (Bunopas, 1976 a, b). Bunopas (1976a, 1982) proposed the Thabsila Gneiss cropping in a few restricted area along the Three Pagodas Fault Zone for the Precambrian rocks in western Thailand. The high grade metasediment of amphibolite facies known as Chonburi gneiss is found in the eastern Gulf of Thailand. The rocks are orthogneiss, paragneiss, crystalline schist, and calc-silicate. In the peninsular Thailand, at Khanom and Lan Saka, the high grade metamorphic rocks of possible Precambrian age including granite-gneiss, augengneiss, micaschist, calc-silicate and marble were reported (Nakinbodee et al., 1977; Nakapadungrat et al., 1987).

The Precambrian rocks cover a wide range of compositions and origins. They have the complete range from paragneiss to migmatitic paragneiss and from foliated granite to granite gneiss and pegmatite (Campbell, 1974). They are also characterized by the intensive flow fold structure (Dheeradilok, 1975). The rocks have been produced through the processes of injection, anatexis and metamorphic differentiation, accompanying by regional dynamo-thermal metamorphisms (Campbell, 1974). However, it should be pointed out that a Precambrian age of this rock was based on the stratigraphic position that underlie fossiliferous Cambro-Ordovician formation. The degree of metamorphism is much higher grade than that of the Lower Paleozoic.

So far, there is no confirmed radiometric dating of this rock. However, Helmcke (pers. comm., 1992) informed that his radiometric dating of the rocks from northern Thailand did not prove the case but indicate Mesozoic age for the high grade metamorphic event. The initial results of U-Pb dating of zircon and monazite from the Doi Inthanon core complex by Barr et al. (1991) also pointed to latest Cretaceous event. They suggested that such core gneiss, as Cordilleran-type, can exhibit a wide spectrum of U-Pb age and need not represent Precambrian basement.

Paleozoic

Lower Paleozoic

Since the pioneer work of Lee (1923) and Brown et al. (1951) in southern peninsula, it is clear that the lower Paleozoic in Thailand can be divided into two conformable rock units: a lower siliciclastic, the Tarutao Group, and upper carbonate unit, the Thung Song Group (Figure 2). They can be mapped throughout the western ranges of Thailand and have often been equated simply to the Cambrian and Ordovician on the geological maps of Thailand. However, recent researches on these rocks at Tarutao Island (Teraoka et al., 1982; Wongwanich and Burrett, 1983; Stait et al., 1984) have shown that the Cambrian - Ordovician boundary is somewhere within the top most part of the Tarutao Group. This group is a shallow shelf sequence periodically subjected to storm (Akerman, 1986) whereas the Thung Song Group is a shallow to deep carbonate ramp deposit (Wongwanich and Raksaskulwong, 1991). The total thickness of this sequence exceeds 1,600 m (Bunopas, 1983). Most of the lower Paleozoic rocks in the west have been subjected to low grade dynamo-metamorphism (Bunjitradulya, 1978; Baum et al., 1970) and have locally transformed into quartzite, phyllite, schist, and recrystalline limestone.

Middle Paleozoic

Formerly, the rocks of this age were commonly referred to as the Tanao Si Group and Kanchanaburi Group (Javanaphet, 1969; Piyasin, 1980). They lie conformably above the lower Paleozoic. Based on graptolites and trilobites, it has been clear that the Ordovician-Silurian boundary lies within the lower part of black graptolitic shale and chert sequences, just above the *Dalmanitina* beds, at Satun Province (Wongwanich et al., 1990). Based on the geosyncline hypothesis, the Siluro-Devonian black graptolitic shale and chert are miogeosyncline facies whereas the graywackes, argillites, chert, and tuff are the eugeosyncline facies.

At present, the new stratigraphic names have been proposed by DMR (Figure 1) mostly based on Bunopas's interpretation of Thailand paleogeography and tectonic evolution (Bunopas, 1981, 1983, 1991). The rocks in the west, the black shale, chert, sandstone, siltstone and variegated nodular limestone of shelf facies to back-arc-basin facies are referred to as the Thong Pha Phum Group. The rocks in the east of the western province and in the Sukhothai fold belt, Fang Chert, metamorphic rocks of the Don Chai Group (Piyasin, 1972), and the Mae Ko Complex (Bunopas, 1983) are grouped into the Sukhothai Group. Moreover, the Pak Chom Formation is proposed for chert, tuff and Devonian limestone of the Loei fold belt.

Upper Paleozoic

Many formations and groups have been proposed for the Carboniferous and Permian siliciclastics and limestones (Figure 1) which lie conformably over the lower Paleozoic and widely distribute throughout Thailand.

The Kaeng Krachan Formation consists of pebbly mudstone-bearing facies in the peninsula and the west. This formation contains an exotic clasts and deposited on the rifted margin (Bunopas, 1991). In the north, the Mae Hong Son Formation is proposed for chert, sandstone and shale deposited near the cratonic axis whereas the sandstone, shale, graywacke and agglomerate of the Dan Lan Hoi Group (Mae Tha Group) were deposited in shallow marine condition further offshore. The Phrae Formation is proposed for agglomerate, conglomerate, graywacke, argillite and limestone which were deposited as arc-trench gap facies (Bunopas, 1983). The Wang Saphung Formation is proposed for the nearshore sandstone, shale, limestone lens and conglomerate of the Loei fold belt.

The Permian karstic limestone in the peninsula and the west are referred to as the Ratburi Group. The Saraburi Group is proposed for the limestone interbedded with siliciclastic rocks along western edge of the Khorat Plateau.

The Lower-Middle Permian Ratburi Group comprises transgressive/ regressive carbonate platform sequence, interpreted as having been deposited in progressively shallow-water environments. This ranges from open shoal, marginal platform to shallower, open, inner platform and protected lagoon (Dawson and Racey, 1991). The Saraburi Group is a rimmed shelf carbonate (Dawson et al., 1991) with grainstone shoals, local buildups, and deep-water siliciclastics.

Mesozoic

The Mesozoic sequences in Thailand can be lithologically subdivided into two main facies; the marine facies and the younger continental facies. The former is known as the Triassic Lampang Group, the Upper Triassic to Jurassic Mae Moei Group and the Triassic Nam Pat Formation. The latter is recognized in the Khorat Group ranging in age from Upper Triassic to Cretaceous (Figure 1).

The marine Triassic sequences in Thailand are exposed in four main areas (Figure 3); in the north (Lampang-Phrae-Nan), west (Kanchanaburi-Mae Sariang), east (Chanthaburi-Trat) and in the south (Phangnga-Songkhla). In the west and the south, there are also marine Jurassic sequences accumulated continuously. The continental facies Khorat Group occurred extensively in northeastern Thailand and sporadically in the other parts of the country.

The transition from Permian to Triassic sequences in most places is a stratigraphic hiatus, except in the Lampang and Nan areas where conformable contacts have been reported, although *Otoceras*, the indicator of Permo - Triassic boundary has not been observed.

In western Thailand, lower Triassic rocks are apparently absent whereas in northeastern Thailand, lower and middle Triassic strata are absent.

The Triassic Lampang Group occurred in forearc basins on the Shan-Thai terrane that was colliding with the westward dipping Indochina terrane in the east. It comprises seven formations in ascending order the Phra That, Pha Kan, Hong Hoi, Doi Long, Pha Daeng, Kang Pla and Wang Chin Formations (Chaodumrong, 1992). It consists of alternating sequences of ramp-platform carbonates, sub-marine fan sediments and fan-delta redbeds.

Middle Triassic deep marine sediments, on the basis of radiolarian chert, occurred in the Nan Suture, Trat, Mae Sariang, and Mae Sot areas. The marine Jurassic sediments consist of siliciclastic and carbonate sequences of shallow water origins.

The continental facies Khorat Group formed in successor basins as a result of the collision between Shan-Thai and Indochina terranes. It has a lower contact often lying unconformably on the Permian and Triassic strata. It consists of seven formations in ascending order, the Huai Hin Lat, Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, Khok Kruat and Maha Sarakham Formations (Figure 1). In general, the group consists predominantly of redbeds of sandstone, siltstone and mudstone, and displays westward to southwestward paleocurrent directions. Conglomerates with limestone and volcanic clasts, and gray beds are common in the Huai Hin Lat Formation. The remarkable giant evaporite deposits, i.e. rock salt and potash, occurred in the Maha Sarakham Formation. Uranium occurrence was found in the Sao Khua Formation. Dinosaurs were appreciably identified from many formations including Phra Wihan, Sao Khua, Phu Phan and Khok Kruat Formation, which provide good age control (Buffetaut and Suteethorn, 1991).

Cenozoic

Tertiary

Tertiary basins in Thailand are mainly N-S trending fault-bounded grabens and half grabens which were developed by conjugate strike-slip faults orientating in NW-SE and NNE-SSW directions and by clockwise rotation of the SEA crustal blocks (Polachan and Sattayarak, 1991). These movements were created by continent-continent collision between northward moving India and Eurasia terranes.

Evidence from fossils indicates that the Tertiary basins in southern Thailand including in the Peninsula, Andaman sea and in the Gulf of Thailand, were probably developed earlier than those in the north or even in the central plain. Most Tertiary basins in southern Thailand formed during Oligocene whereas in the north formed mostly in Miocene or younger age.

Sixty-one Cenozoic basins including Tertiary basins (Figure 4), occurring in the country both onshore and offshore areas, have been recognized (Chaodumrong et al., 1983). These Tertiary basins formed mainly in fluvio-lacustrine environments, except the Mergui Basin in the Andaman sea, which occurred in marine environments. Fossil fuel deposits are common in these basins. Coal have been exploited in seven basins. Other basins are also potentially commercial. Petroleum have been produced in four basins mainly from the Gulf and the central plain, and at least seven basins contain commercial petroleum deposits. Oil-shale deposit occurred in Mae Sot basin and diatomite deposit was founded in Lampang basin.

Quaternary

The Quaternary formations of Thailand consist of fluviatile, coastal, eolian, lateritic, volcanic and lacustrine deposits (Dheeradilok, 1987). They are extensively deposited in the Central Plain, in the intermontane basins of the northern region as well as in the broad alluvial plains of the Mun-Chi and the Songkram river basins of the Khorat plateau. The Quaternary marine and fluviatile formations are also widely spread along the coastal zone bordering a distance of 1,840 km around the Gulf of Thailand and about 865 km along the west coast of Thai peninsula. The establishment of Quaternary stratigraphic systems and correlations of the deposits have been attempted with progress during the last decade. They throw sufficient light on environment, tectonic development and geomorphology. The economic minerals that are associated with the Quaternary formations recently become important for the economic and industrial development of the country.

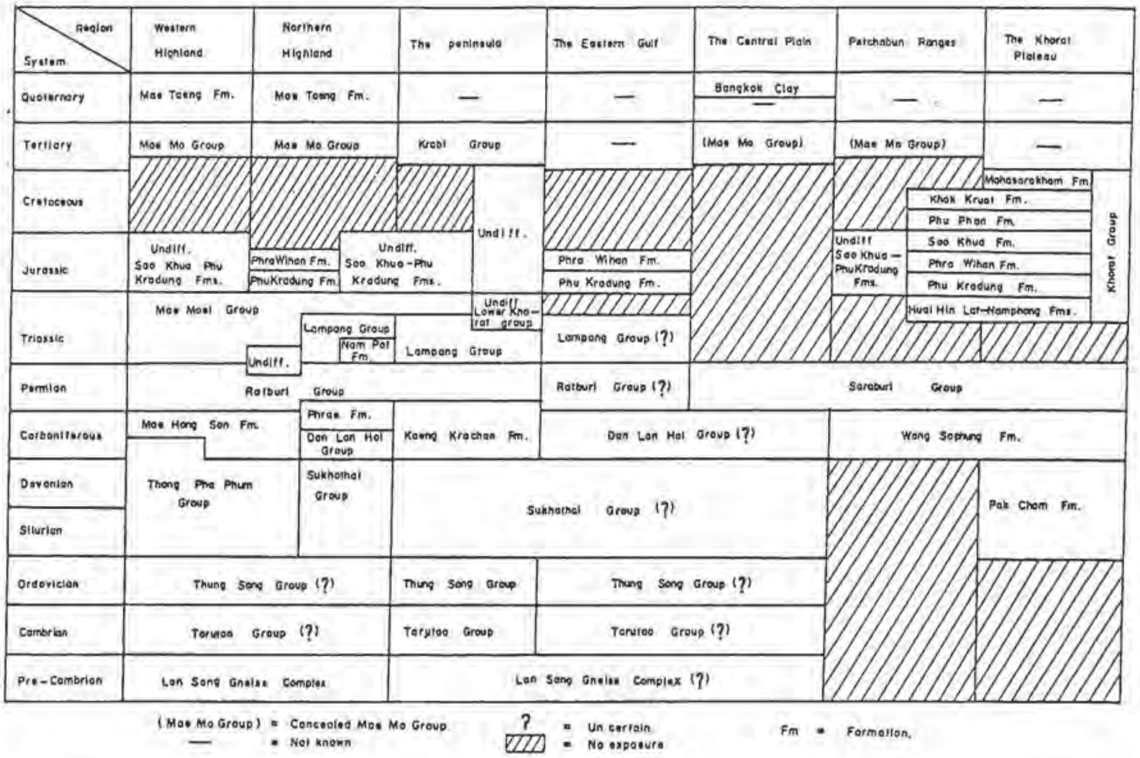


Figure 1. Correlation on stratigraphic units of Thailand (after the Stratigraphic Lexicon, DMR).

IGNEOUS ROCKS

Most of igneous rocks in Thailand belong to the acidic magmatic composition in which granite and granodiorite are the most abundant intrusive rock and rhyolite as the volcanic derivative. The more basic type such as diorite, gabbro and basalt are relatively less abundant. These igneous phase belong to different ages and can be correlated to different tectonic settings (Suensilpong and Putthapiban, 1979).

Granitoids

Granite are the most common intrusive rocks found in Thailand and are generally mineralized. Granitoids of Thailand can be broadly recognized according to their petrological, geochemical and geological environments (Nakapadungrat et al., 1985). Various geochemical parameters indicated that granites in Thailand can be grouped into I-and S-type which related respectively to subduction of oceanic lithosphere and continent-continent or continent-magmatic arc collision (Nakapadungrat et al., 1985). From a large number of Rb-Sr and K-Ar dating studies of granitoids in Thailand, it is generally accepted that the granitoids in Thailand can be divided into three approximately north-trending belts, namely, the Western, Central and Eastern belts (Figure 5).

The Western Belt is characterized by Cretaceous plutons of mixed I- and S-type granites. The granites in this belt occur as small isolated plutons and are characterized by multiple intrusions of porphyritic biotite-muscovite granite (with K-feldspar megacrysts) and equigranular hornblende granite (Mahawat, 1983). They are not associated with migmatite or gneissic granite (Mahawat, 1983). They occur predominantly along the Burmese-Thai border and along the western part of the peninsula, including the Phuket Island. Tin-tungsten mineralization is common in S-type granite of this belt (Nakapadungrat, et al., 1985; Cobbling et al., 1986; Charusiri et al., 1991) The Western Belt is possibly related to Mesozoic subduction from the west between the Indian and Shan-Thai terranes (Barr and MacDonald, 1991).

The Central belt is located east of the Western belt and consists predominantly of Permo-Triassic S-type granitoid batholiths and a variety of smaller plutons (Mahawat, 1983; Barr and MacDonald, 1991). It is characterized by biotite-muscovite granites with characteristic K-feldspar megacrysts (Mahawat,

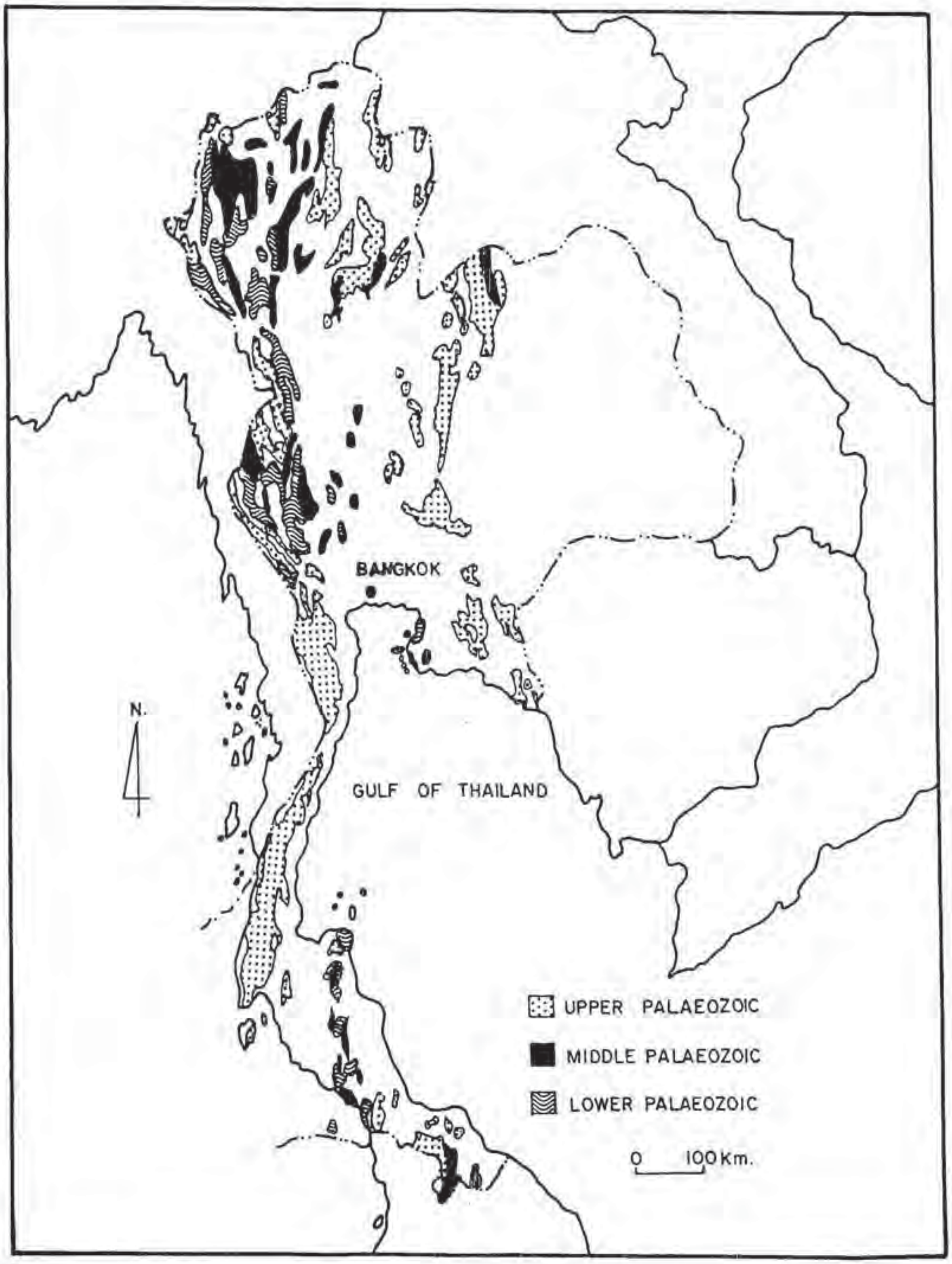


Figure 2. Map showing distribution of the Lower, Middle, and Upper Palaeozoic of Thailand (modified after Wongwanich and Burrett, 1983; DMR, 1987).

1983), and is commonly associated with foliated granites, orthogneiss, paragneiss, migmatites, anatexites and low grade sedimentary rocks (Mahawat, 1983; Barr and MacDonald, 1991). The Sn-W mineralization related with S-type granite is also common in this belt (Charusiri et al., 1991). The distribution of S-type granites in the Central belt probably reflects a widespread Triassic metamorphism and crustal melting (Barr and MacDonald, 1991).

The Eastern belt is well defined in the Chanthaburi area but includes only scattered plutons in the northern Thailand. The granites in this belt are mostly equigranular hornblende-biotite granites and occur as isolated complexes of multiple plutons or small batholiths range in age from Late Carboniferous to Triassic. These granites are usually associated with diorite, andesite and basaltic dikes and with less folded, low grade regional metasediments (Mahawat,

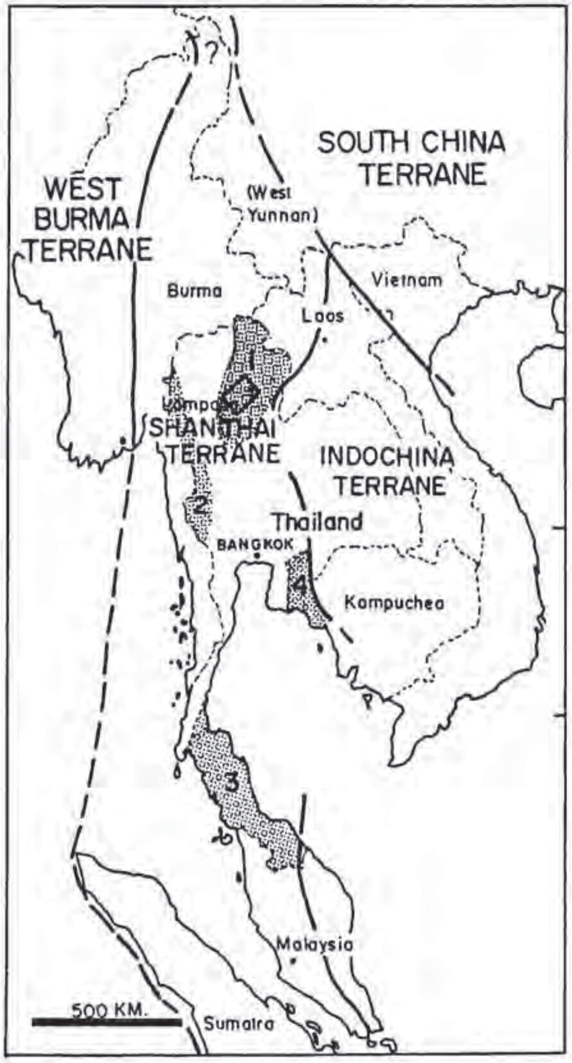


Figure 3. Map showing major distribution of Triassic rocks in Thailand, the terrane boundaries of the Shan-Thai and Indochina, and their adjacent terranes; study area is shown in block symbol, 1 = Lampang - Phrae - Nan area; 2 = Kanchanaburi - Mae Sariang area; 3 = Phang Nga - Songkhla area; and 4 = Chanthaburi - Trat area (from Chaodumrong, 1992).

1983). The Cu-Fe-Au mineralization related to the I-type granite is locally found in this belt (Charusiri et al., 1991). Features indicative of high-level emplacement (i.e., narrow thermal aureoles and miarolitic cavities) and features indicative of I-type affinity are also common in these plutons (Barr and MacDonald, 1991). The high-level I-type plutons of the Eastern belt indicate subduction-related tectonic setting (Barr and MacDonald, 1991).

Volcanics

The earliest volcanic activity in Thailand was during the Silurian and Devonian Periods and resulted in the deposition of agglomerates and tuffs in the north (Piyasin, 1972; Bunopas, 1976). Widespread andesites, rhyolites, agglomerates and tuffs in many Permo-Carboniferous and Permo-Triassic sequences suggest that extensive volcanic activity occurred at this time (Piyasin, 1972; Bunopas, 1976). The Upper Triassic-Lower Jurassic volcanic rocks consist of rhyolitic flows and associated pyroclastic rocks interbedded with clastic red beds of the lower part of the Khorat Group (Bunopas, 1981). The youngest volcanic rocks are Quaternary basalts, mostly lava flows, but with minor plugs and pyroclastics (Barr and MacDonald, 1978; Barr et al., 1976). The basaltic rocks occur as small outcrops scattered throughout Thailand except the southern region.

TECTONIC EVOLUTION

It is generally accepted that Thailand comprises two continental terranes, i.e., the Shan-Thai terrane in the west and the Indochina terrane in the east (Bunopas, 1978, 1981; Gatinsky et al., 1978; Mitchell, 1981; Piyasin, 1991). Both terranes had their origins on the northwestern margin of Gondwanaland in the Southern Hemisphere during Lower Paleozoic (Sengör, 1984; Burrett and Stait, 1986). However, the way in which the terranes were amalgamated and the time when the amalgamation took place are contentious (Bunopas, 1981; Helmcke, 1986; Barr and MacDonald, 1991; Chaodumrong, 1992).

The Shan-Thai terrane comprises eastern Burma, western Thailand, western Peninsular Malaysia and northern Sumatra. The terrane consists of Precambrian granitoids, high grade metamorphic rocks, Paleozoic and Mesozoic rocks (Bunopas, 1981; Fontaine, 1986).

The Indochina terrane consists of eastern Thailand, Laos, Kampuchea and parts of Vietnam. The terrane comprises mainly Paleozoic rocks and Permian platform carbonate and deep-water clastic rocks (Wielchowsky and Young, 1985). It is covered by gently folded Mesozoic continental sedimentary sequences of the Khorat Group.

Varying opinions on the timing of suturing have been suggested. These are Devono-Carboniferous (Hahn et al., 1986; Altermann, 1991), middle to late Carboniferous (Wolfart, 1987), middle Permian (Helmcke and Lindenberg, 1983; Helmcke, 1985), late Permian (Burton, 1985), late Permian to early Triassic (Thanasuthipitak, 1978; Cooper et al., 1989; Sattayarak et al., 1989; Hayashi, 1989; Piyasin, 1991),

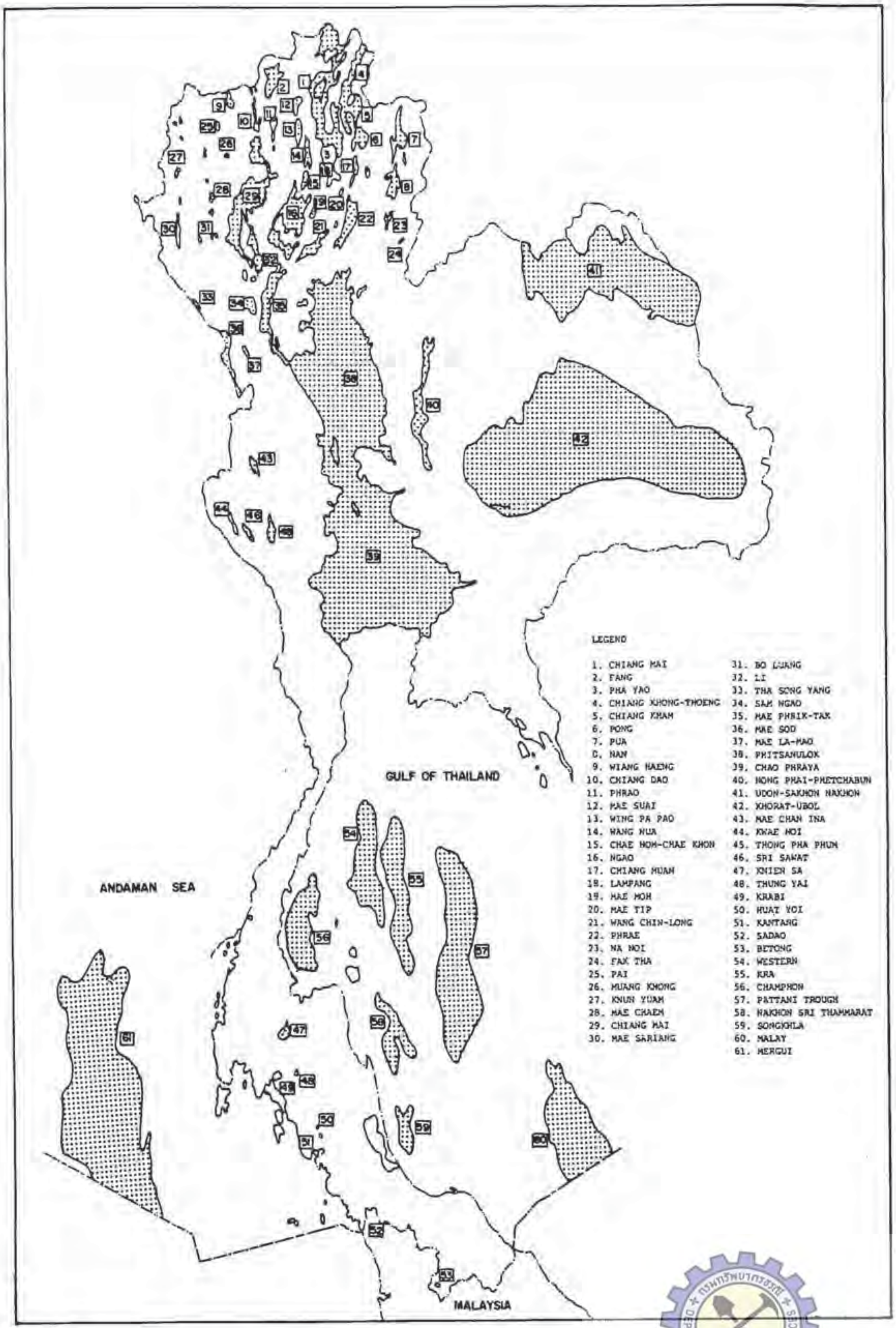


Figure 4. **The Cenozoic basin of Thailand (modified after Chaodumrong et al., 1983).**

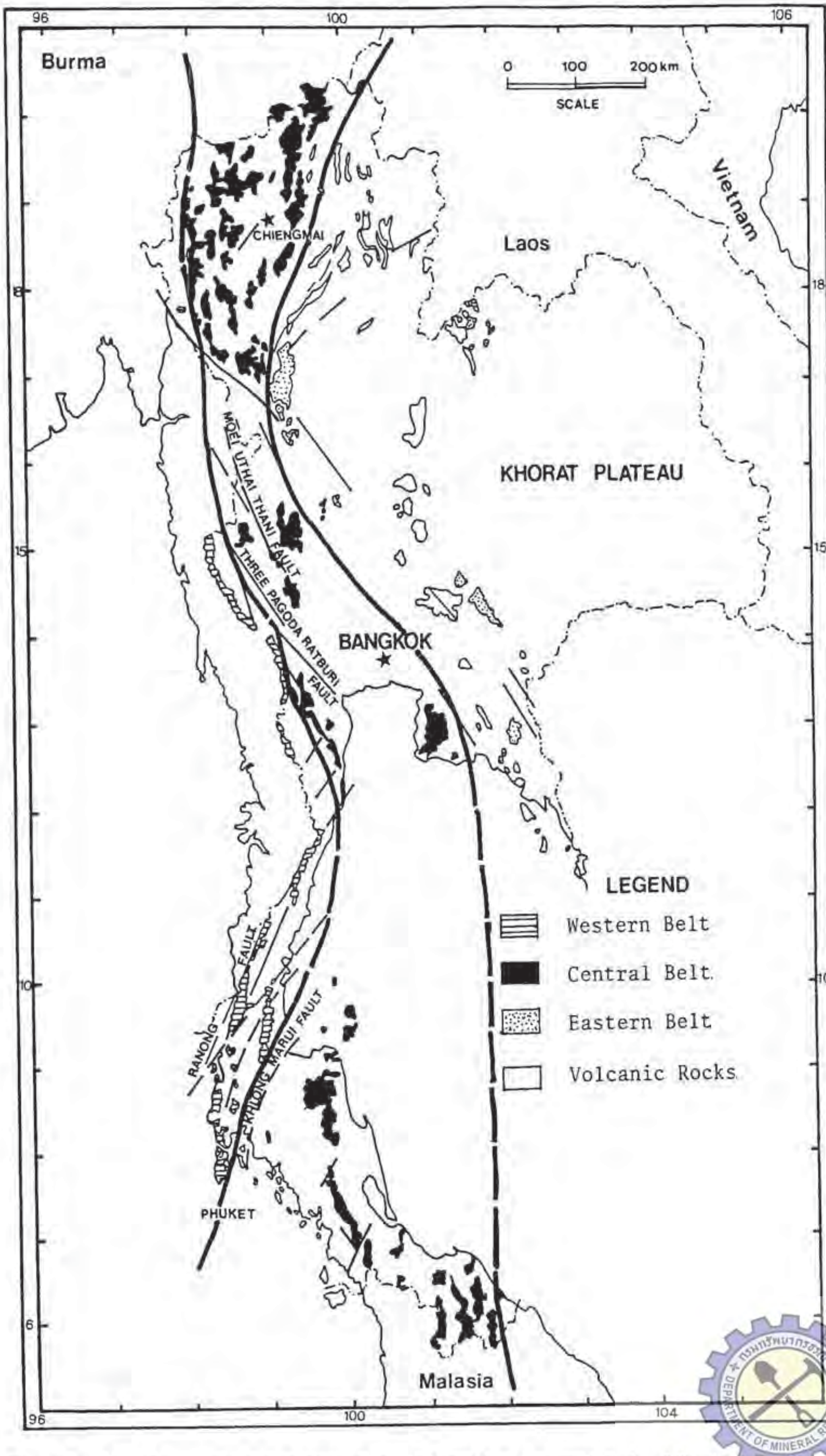


Figure 5. Map showing the distributions of granitoid rocks and volcanic rocks of Thailand (modified after Nakapadungrat, 1985; Garr and Macdonald, 1991).

early Triassic (Metcalfe, 1990), middle to late Triassic (Bunopas and Vella, 1978, 1983; Gatinsky et al., 1978; Asnachinda, 1989; Hada, 1990; Panjasawatwong, 1991), and even middle- late Cretaceous (Audley-Charles, 1988).

Westward subduction beneath Shan-Thai, prior to collision, was proposed by several researchers (Bunopas and Vella, 1978; Chantaramee, 1978; Asnachinda, 1978; Bunopas, 1981; Sengör, 1984; Barr and MacDonald, 1987; Hayashi, 1989), based on the wide distribution of volcanics in central north Thailand and on the eastward structural vergence. Whereas Beckinsale et al., (1979) and Cooper et al., (1989) suggested a eastward subduction beneath Indochina, based on the position of S- and I-type intrusive rocks.

The boundary between the Shan-Thai and the Indochina terrane is represented by the Nan-Chanthaburi Suture Zone (Hada et al., 1991) which also called Nan Suture or Nan-Uttaradit Suture by the others (Barr and MacDonald, 1987, 1992). This suture is a mobile area of repeated orogenic movements since the Paleozoic (Burri, 1989) and most consider to be the Late Triassic collision (e.g. Chaodumrong, 1992).

The Indochina terrane probably rifted from the Gondwanaland during Paleozoic times. Although the precise age of rifting is not known, the presence of a regional unconformity of late Devonian-early Carboniferous period seems to support a Devonian rifting (Bunopas, 1981; Metcalfe, 1990).

The Shan-Thai terrane must have remained attached or close to Australia Gondwanaland until the early Permian as indicated by early Permian glaciomarine deposits (i.e., pebbly mudstones in the Kang Krachan Formation or the Phuket Group), cool-water faunas and fauna with northwest Australian affinities (Waterhouse, 1982) and by middle-late Permian and early Triassic faunas showing affinities to Cathaysialand and to northern tethys province type (Metcalfe, 1989a; 1989b).

In late Permian times, the Shan-Thai began its collision with Cathaysialand and the suturing to Indochina was largely completed by the late Triassic (Bunopas 1981; Chaodumrong 1992). The I- and S-type granites generated during the late Triassic to early Jurassic (Cobbling et al., 1986) also supported late Triassic collision.

During Cenozoic, most of the tectonic features in Thailand (and Southeast Asia) are mainly the consequence of the India-Eurasia collision (Molnar and Tapponnier, 1975; Tapponnier, et al., 1982, 1986). Several large strike-slip faults were activated successively as Indian terrane moving northward against Eurasian terrane and, thus, the Red River Fault was activated. Consequently, the Southeast Asian crustal block was rotated clockwise and then extruded several hundreds kilometers southeastward (Achache et al., 1983; Lin and Watts, 1988).

The extrusion and rotation of the Southeast Asian crustal block resulted in a series of extensional basins extending from the Gulf of Thailand to the south South China Sea (Harder, 1991). Stratigraphic records in the region indicate that normal block-faulting began in the Early Oligocene.

In Thailand, two different fault systems can be distinguished: (1) N-S normal faults and (2) conjugated NW-SE and NNE-SSW strike-slip faults. The NW-SE trending fault zones are the Mae Ping and Three Pagodas while the NNE- SSW trending are the Uttaradit, Ranong and Khlong Marui faults (Polachan, 1991).

Strike-slip motions in the Three Pagodas and Mae Ping fault zones also created SW-NE extensional tectonic regimes at the terminations of these faults. Accompanied by the initial extrusion was a small clockwise rotation of continental blocks in Southeast Asia (Harder, 1991).

MINERAL RESOURCES

A number of mineral deposits have been found in Thailand. Among them tin, tungsten, niobium, tantalum, lead, zinc, gold, iron and stibnite are the most important metallic minerals. Whereas feldspar, clay minerals, fluorite, barite, potash and rocksalt are also most important non-metallic minerals (Figure 6).

Fossil fuels have been found in Tertiary basins as well as in the pre-Tertiary basins both on shore and offshore. In addition, groundwater is another most important economic resources. It is also essential to human and agriculture. Rocks and dimension stones are increasingly important as basic materials for industry and construction.

Tin, Tungsten, Niobium, and Tantalum Deposits

Economic mineral deposits of syngenetic type in Thailand are related to plutonism and volcanism resulting from various tectonic events. Pyrometasomatic and hydrothermal deposits of tin and its associated minerals, tungsten, tantalite, columbite and molybdenite, are associated with the granitoid intrusions of various ages.

Tin and tungsten have been regarded as the main productive minerals of the country. They occur in the metallogenic province confined to the Southeast Asia tin-tungsten belt which is one of the important tin field in the world. The mineralization is essentially controlled by granite intrusives throughout the belt.

Primary tin deposits are in numerous styles, for instance, disseminate, stock work and greisen, replacement, hydrothermal veins and pipes, pegmatite and aplites.

Copper, Lead, Zinc, Silver, Antimony

Most of this deposits are related to the calc-alkali volcanic rock, mainly andesite. Some of these deposits are replacement and vein deposits. Stratiform lead and zinc deposits are found at Nong Phai and Song Tho in Kanchanaburi in the middle Ordovician limestone. Zinc deposit at Pha Daeng, Mae Sot is the largest zinc deposit in Thailand. The ore are zinc carbonate and zinc silicate in the supergene enrichment in the Jurassic Kamawkala limestone near the Thai-Burmese border.

Chromium, Nickel and Asbestos Deposits

Chromite, nickel and asbestos are the main minerals found associated with basic-ultra basic intrusive rocks which consist predominantly of serpentinite, pyroxenite or gabbro. They are found mainly in the Nan-Uttaradit suture zone. These deposits have not been exploited.

Gold Deposits

Gold has been found in Thailand for many centuries. Numerous placer golds occur in alluvium and weathering residuum. Occurrences of gold in primary bedrock have been found in several parts of the country (Vudhichatvanich et al., 1980; Nuchanong, 1992). Gold has also been recovered as a by product from some placer tin mining operations in the southern part of Thailand (Nuchanong, 1992). Few deposits of gold in bedrock have been mined the past, i.e.. at the To Moh deposit in the peninsula, in the Kabin Buri and Ban Bo Nang Ching in the east of the country (Vudhichatvanich et al., 1980; Nuchanong, 1992). At present, gold exploration in Thailand has received more attention. Several potential gold areas have been re-investigated by the Department of Mineral Resources (DMR) in the Prachin Buri and Loei provinces. Recently, concession have been granted over four potential gold areas in Loei Province in northeastern Thailand (Nuchanong, 1992).

Potash and Rock Salt

Thick beds of rock salt have been found in the Sakon Nakhon and Khorat basins in the northeastern Thailand. These deposits occurred in the Cretaceous Maha Sarakham Formation. Substantial reserve of Potash and salt in these deposit resulted in the establishment of the Potash Project. The Thai Government has invited the Asian member countries and local enterprises to explore and exploit this resource.

Gypsum

Gypsum deposits in Phichit and Nakhon Sawan areas are being exploited. Another significant gypsum deposit are also exploited in Nakhon Sri Thammarat and Surat Thani provinces in peninsular Thailand.

Hydrocarbons

Hydrocarbons (oil and natural gas) in commercial quantities occur in Tertiary basins both onshore and offshore. Some petroleum reservoirs, however, were found trapped in the pre-Tertiary strata.

Thailand can be divided into 6 petroleum regions: Northern intermontane basin, Central plain, Khorat Plateau, Gulf of Thailand, Southern plain and the Andaman Sea. The lacustrine and shallow marine beds of Permian are believed to be good source rocks. The reserves of the country from these Tertiary basins amount to 352 million barrels of oil condensate and 10 trillions trillion cubic feet of gas (Mineral Fuel Division, DMR, January 1992). Apparently the upstream activities of petroleum in 1992 are the same as those in 1988 and 1990. More development wells were drilled and more wells were put into production. This resulted in greater production capacity. The petroleum productive areas were expanded from offshore to onshore.

Coal and Oil Shale

Coal and oil shale are often found in the Tertiary basins which are quite extensive, especially in the northern and western parts of Thailand. Large volumes of coal and oil shale have been found within several intermontane basins. Many of lignite deposits have already been developed such as at Mae Moh, Lampang Provinces and in Krabi Province in peninsular Thailand. One important oil shale deposit is at Mae Sot Basin which covers an area of approximately 500 sq.km.

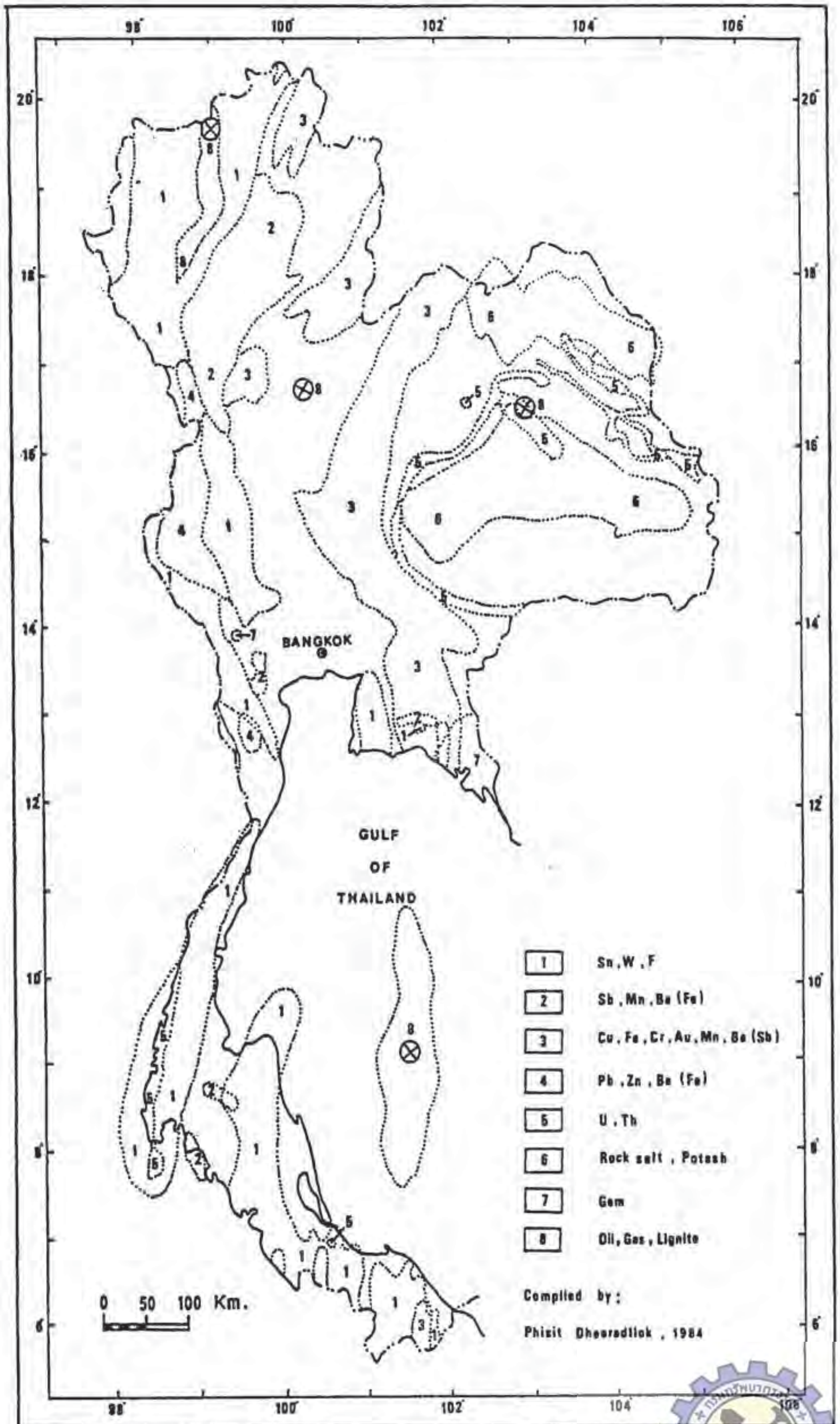


Figure 6. Map showing metallogenic provinces of Thailand (After Dheeradilok, 1985).

Gemstones

Gemstones (sapphire and ruby) were derived from Cenozoic basic volcanics. Besides, spinel, quartz, chalcedony, tektite and petrified woods are also important as precious stone. The well-known productive areas of gems in Thailand are Chanthaburi and Trat provinces in eastern region. Others are Kanchanaburi in the west, Phrae and Chiang Rai in the north as well as Sri Saket and Ubon Ratchathani in the northeast.

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PERGAMON

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Structural development of the Mid-Tertiary Doi Suthep Metamorphic Complex and Western Chiang Mai Basin, Northern Thailand

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Abstract

The northern Western Ranges of Thailand contain mylonitic gneisses of the Doi Suthep Metamorphic Complex (DSMC). Near Chiang Mai, mylonitic foliations outline a southeast-trending dome, and stretching lineations trend N80°W. Low-grade metasedimentary rocks and Tertiary fanglomerates flank the dome on the east, and widespread chloritic breccia marks the intervening Doi Suthep detachment fault.

We interpret that the metamorphic complex developed between Triassic and early Miocene, with detachment faulting, mylonitization, and uplift during Oligocene to Miocene. Within the DSMC, dikes of mutually cross-cutting, hence coeval, granitic pegmatite and aplite cut mylonitic orthogneiss. Although the contacts of the dikes-are sharp, the dikes contain a mylonitic fabric that parallels the fabric in the surrounding mylonitic orthogneiss; thus, we infer that intrusion occurred during mylonitization.

East of Doi Suthep, Tertiary fanglomerates of the Mae Rim Formation overlie the Doi Suthep detachment fault. Variable strikes, with dips of 10°–50°, and several outcrop-scale fold hinges suggest that the Mae Rim Formation is deformed into a set of non-cylindrical folds. Numerous, variably-striking, high-angle normal faults suggest either multiple deformations or deformation in a three-dimensional strain field. The discovery of an intraformational angular unconformity confirms that the Mae Rim Formation accumulated during folding.

1. Introduction

Extension, marked by the development of several continental basins, characterizes the Cenozoic tectonic history of northern Thailand (Polachan and Saattayarak, 1989). The north–south trend of many of these basins suggests an east–west orientation for this extension, but lack of well exposed high-angle normal faults has precluded estimates of the magnitude of strain. Elsewhere, major low-angle normal faults and accompanying zones of ductile, normal-sense shear typically form in response to large extensional strains within continental crust. Barr et al. (1991), first recognized such structures within the gneissic complex near Doi Inthanon, within Thailand's Western Ranges, and compared them to the mylonitic zones and detachment faults of the Cordilleran metamorphic core complexes of western North America. These high-grade ortho- and paragneisses, previously considered to be Precambrian (e.g., Baum et al., 1981), may hold the key to a better understanding of the magnitude and direction of this extension. We describe new structural data from the Doi Suthep area of the northeastern Western Ranges (Fig. 1), that: (1) provide confirmation of the existence a detachment fault along the eastern flank of the Western Ranges; (2) reveal that mylonitic rocks within the northern part of the Western Ranges likely formed during top-to-the-east ductile shearing; and (3) delineate the structure of folded and faulted syn-extensional fluvial conglomerate and sandstone that lie along the western side of the Chiang Mai Basin.

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Fig. 1. Index map of northern Thailand. Shaded area represents the crystalline rocks of the Western Ranges. The box delineates the region covered by Fig. 2.

2. Geologic setting

The crystalline complex of the north–south trending Western Ranges extends for over 400 km from near the Thai-Burmese border in the north to west-central Thailand where they flank the western side of the Chao Phraya-Sukhothai lowlands, and form a major part of the Shan Thai terrane (Bunopas and Vella, 1983; Bunopas, 1992). West of the Chiang Mai Basin, various gneissic rocks, originally mapped as Precambrian basement (Baum et al., 1981), underlie the high peaks of the Western Ranges (Fig. 2). Voluminous S-type granitic rocks, many of Triassic age, intruded the gneisses (Beckinsale et al., 1979; Hutchison, 1983). Paleozoic sedimentary and low-grade metasedimentary rocks, mainly continental shelf limestone and phyllitic shale, structurally overlie the crystalline complex. These rocks were likely metamorphosed, deformed, and intruded by granitoids during the Permo-Triassic collision of the Shan Thai terrane with the Indosinian Craton (Bunopas, 1992).

The contact between the crystalline core of the Western Ranges and the supracrustal Paleozoic sedimentary rocks to the east is extremely sinuous. Originally mapped as a thrust fault (Baum et al., 1981), we re-interpreted this contact as a regional low-angle normal fault that dips gently eastward. A similarly sinuous contact to the west of the crystalline complex (Dunning et al., 1995) apparently dips gently to the west (Fig. 2), and suggests that this same detachment fault may reappear to the west as a consequence of regional, post-detachment doming.

The Chiang Mai Basin lies directly to the east of the Western Ranges. The basin trends generally north–south, but with a distinct sigmoidal bend where the central and widest part of the basin trends northeast–southwest. Sedimentary rocks of unknown age underlie the rolling lowlands along the edges of the basin (Fig. 2). The central, very flat portion of the basin contains Quaternary alluvial sediments, including Holocene floodplain sediments. The stratigraphy of the interior of the basin is poorly established due to the lack of any deeply penetrating wells (Polachan and Saatayarak, 1989).

3. The Doi Suthep Metamorphic Complex

Orthogneiss and metasedimentary rocks underlie the mountainous area around Doi Suthep, west of the city of Chiang Mai, defining the Doi Suthep Metamorphic Complex (Fig. 3) (Rhodes et al., 1996, 1997). Medium grained, generally homogeneous granodioritic to tonalitic orthogneiss is the dominate lithology in the complex. The orthogneiss typically contains approximately 50–60% sodium-rich plagioclase, 20–30% quartz, approximately 0–10% each of orthoclase and biotite, and trace amounts of zircon and apatite.

Metasedimentary rocks occurs locally as concordant layers within the orthogneiss. The most common metasedimentary lithology is biotite-quartz-feldspar paragneiss and schist, with lesser amounts of quartzite and calc-silicate schist. Rare occurrence of sillimanite in the paragneiss, and of diopside and forsterite in the calc-silicate schist, suggest peak metamorphic grades in the amphibolite facies. The generally medium- to coarse-grained textures also suggest a high metamorphic grade. This interpretation is consistent with relations farther south, in the Doi Inthanon area. There, metasedimentary rocks form a thick mantle over a core of orthogneiss and the widespread occurrence of sillimanite and altered cordierite suggest low-pressure upper amphibolite facies (Dunning et al., 1995). The thorough intermingling of the orthogneiss and metasedimentary rocks, combined with generally poor exposure over large areas, precludes the separate mapping of these lithologies. Although outcrop-scale contacts are generally concordant, the discontinuous nature of the metasedimentary layers suggest an originally intrusive relationship.

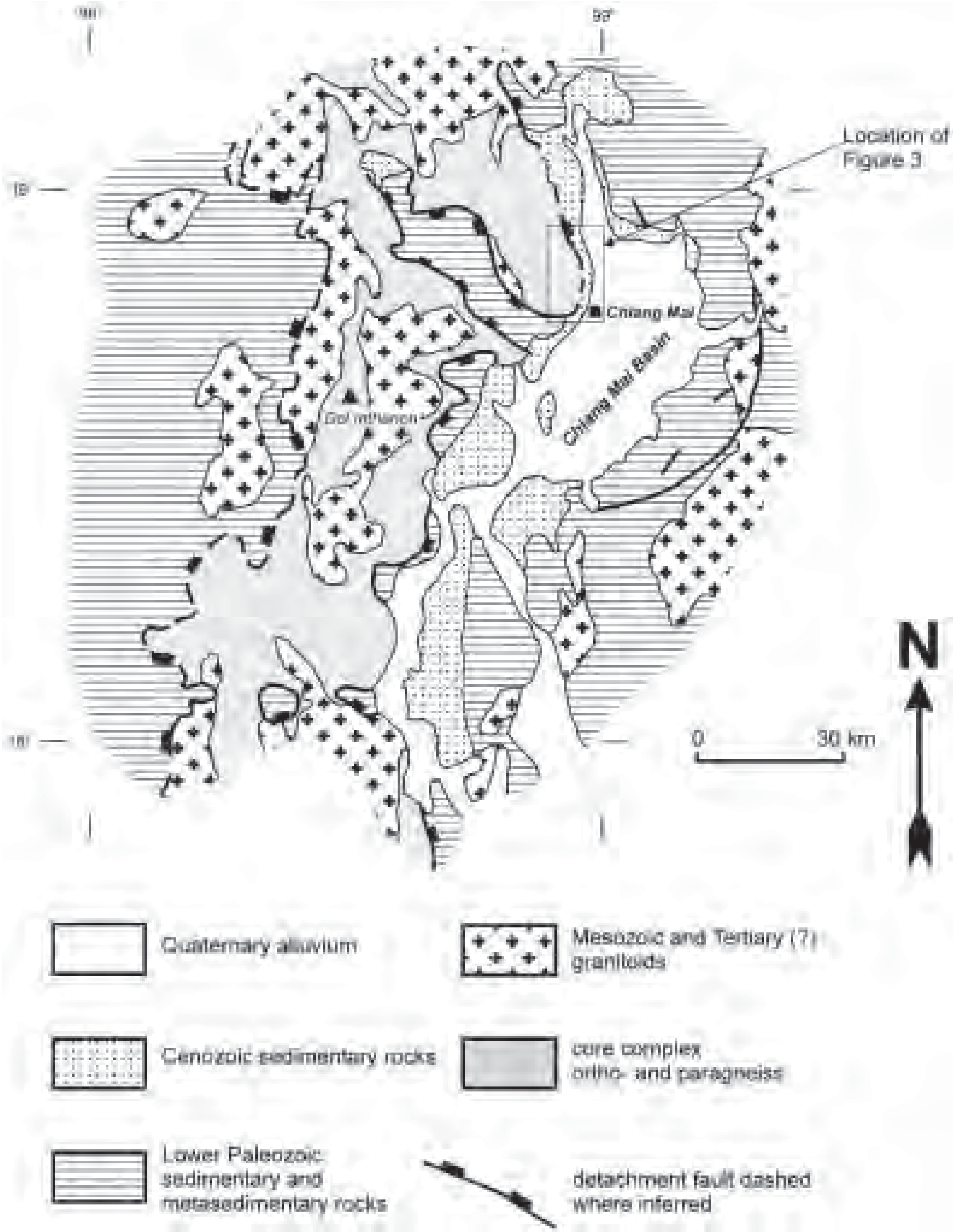

Fig. 2. Geologic map of the northern part of the Western Ranges. See Fig. 1 for location.

Widespread discordant to semi-concordant dikes and masses of pegmatite and aplite commonly intruded the other lithologies at virtually all scales. Dikes of pegmatite and aplite mutually cross cut each other, suggesting multiple injections of nearly the same age. The aplite contain 45–70% plagioclase, 20–30% quartz, and 5–25% orthoclase, with less than 10% biotite and/or muscovite. Although much more heterogeneous in texture, the pegmatite is similar in mineral content to the aplite.

Both the orthogneiss and metasedimentary rocks contain a mylonitic foliation. Although the development of this foliation is variable at an outcrop-scale, it generally increases in intensity structurally upward in the complex, with the most strongly mylonitized rocks occurring along the eastern edge of the complex, adjacent to the Chiang Mai Basin. The orientation of the mylonitic foliation outlines a gently southeast-plunging dome, with dips on the limbs of the dome rarely steeper than 30° (Fig. 3). A nearly unidirectional lineation,

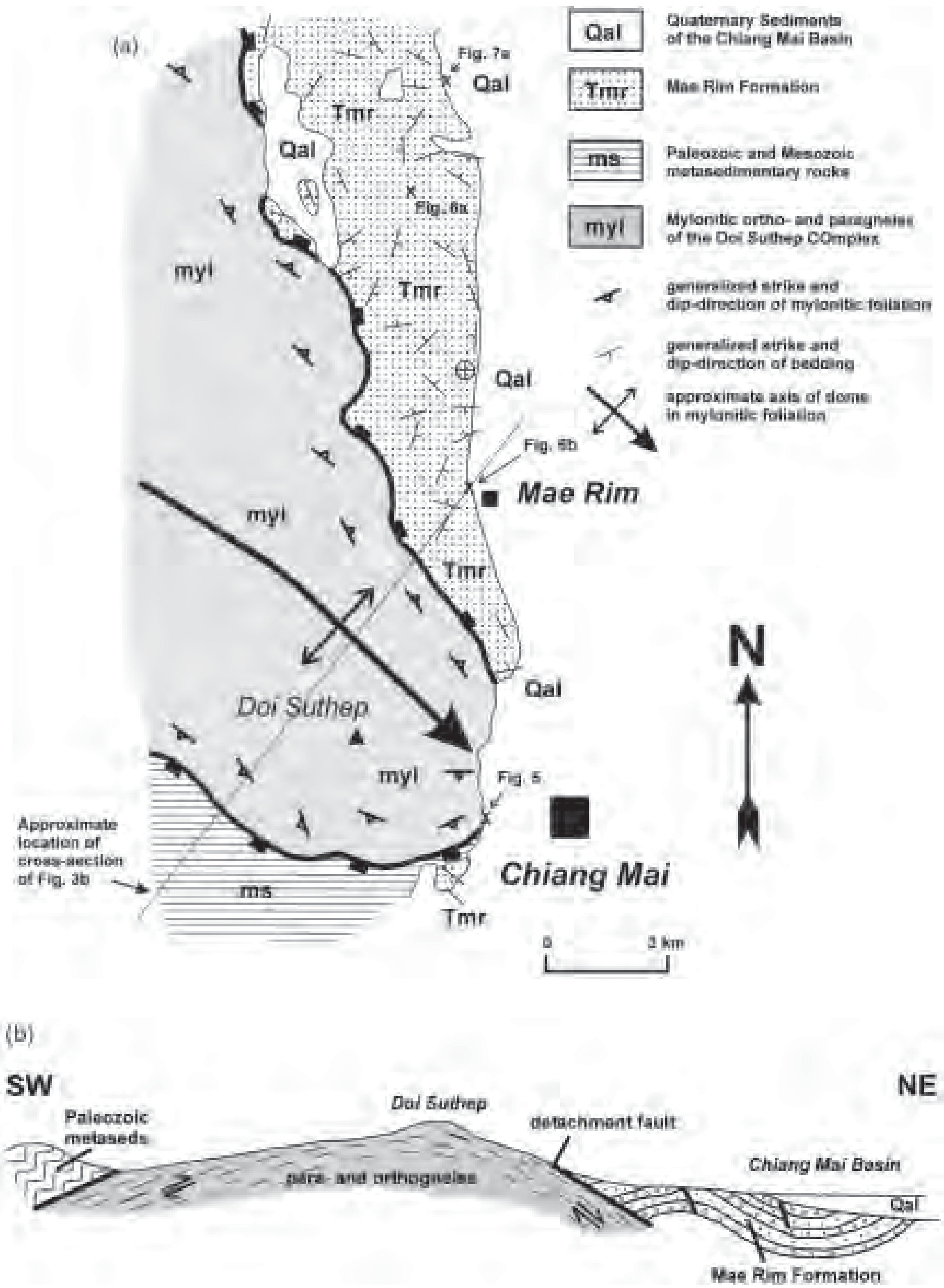

Fig. 3. (a) Generalized geologic map of the Doi Suthep area and western part of the Chiang Mai Basin. See Fig. 2 for location. (b) Conceptual southwest to northeast cross section across the Doi Suthep dome. Folds shown in the Mae Rim Formation and Paleozoic metasedimentary rocks are schematic. Dashed lines represent the general attitude of the mylonitic foliation. Arrows show the shear sense (top-to-the-east) as obtained from asymmetric fabrics within the mylonitic gneisses.

Fig. 4. Stereonet diagrams showing (a) mylonitic lineation data in the Doi Suthep gneisses, that indicate west–northwest/east–southeast stretching direction and (b) poles to bedding and high-angle normal faults within the Mae Rim Formation north of Chiang Mai. Note the predominance of moderate to gentle dips and the lack of a preferred strike direction in the Mae Rim Formation and the lack of a systematic strike for the faults.

defined by rod-like quartz/biotite segregations, slickenside-like striae, and/or the axes of intrafolial isoclinal folds, lies in the mylonitic foliation. The orientation of the lineation is strongly unidirectional on both limbs of the dome, indicating a stretching direction of N80°W/S80°E prior to doming (Fig. 4).

Widespread asymmetric textures, including asymmetric porphyroclasts and S–C fabrics, can be used as

Table 1
Summary of recent geochronological interpretations for the Western Ranges

Reference	Protoliths of paragneiss	Metamorphism	Mylonitization	Uplift	Mechanism for mylonitization and uplift
Lacassin et al. (1997)	na	Paleozoic (?)	Mylonitization along the Wang Chao (Mae Ping) fault > 30.5 my	Rapid uplift at 23 my	Mid-Tertiary extension
Dunning et al. (1995)	Precambrian	Late Cretaceous	Oligocene–Miocene	Miocene	Mid-Tertiary extension
Upton et al. (1997)	na	Late Cretaceous (onset of cooling)	na	Late Oligocene/early Miocene	Mid-Tertiary extension
Ahrendt et al. (1997)	Paragneiss protoliths are Proterozoic	Maximum age of 200 my	Upper Cretaceous/Early Tertiary	Middle Tertiary	Late Cretaceous–Tertiary thrusting

kinematic indictors for sense of shear during mylonitization of the Doi Suthep Metamorphic Complex. These fabrics are particularly well developed in homogenous, strongly mylonitized orthogneiss on the northeastern limb of the dome, where they give an unambiguous top-to-the-east (or normal) sense of shear. On the southwest-dipping limb of the dome, such fabrics are less common, but also show a top-to-the-east (reverse) sense of shear. Thus, the sense of shear was uniformly eastward, parallel to the mylonitic lineation, and shearing predates the doming of the mylonitic foliation.

Interestingly, although clearly cross-cutting the mylonitic foliation, the pegmatite and aplite dikes generally contain a mylonitic foliation and lineation parallel to the surrounding rocks. The strength of the mylonitic fabric is generally similar to the degree of concordance of the dike. The most strongly mylonitized pegmatites are nearly concordant with the enclosing rocks. Thus, these dikes were most likely injected during the ductile shearing, making them ideal candidates for radiometric dating—their age would also give the age of mylonitization.

4. Geochronology

Data from recent geochronologic studies in the Western Ranges have added detail to the chronology, but with no clear agreement on the tectonic interpretation of these new data (Table 1). Ahrendt et al. (1997) have reported U–Pb, Rb–Sr, Sm–Nd, and K–Ar data from the Western Ranges, and have drawn the following conclusions: (1) No Precambrian metamorphism occurred in the Western Ranges; (2) The peak of metamorphism occurred sometime after 200 ma; (3) Protoliths of paragneiss are middle to late Proterozoic; (4) K–Ar cooling ages average 30 ma in the crystalline core, but 200 ma in the surrounding, lower-grade Paleozoic and Mesozoic rocks, with the juxtaposition of the crystalline core with the surrounding rocks caused by Tertiary thrusting.

In contrast, Upton et al. (1997) reported fission track ages from apatite that document rapid uplift during late Oligocene/early Miocene. Likewise, Lacassin et al. (1997) reported $^{40}Ar/^{39}Ar$ data from the southern Western Ranges, in the vicinity of the Wang Chao (Mae Ping) fault that also support an early Miocene age for uplift.

Dunning et al. (1995) reported U–Pb dates from the southward continuation of the Doi Suthep complex, near Doi Inthanon. U–Pb ages on zircons from orthogneiss suggest that late Triassic granites are the most likely protolith, whereas protoliths of paragneiss are most likely Precambrian. Ages on monzanite from orthogneiss suggest that peak metamorphic grades were reached during the late Cretaceous. The foliated, sheet-like Mae Klang granite, which Dunning et al. (1995) interpreted to have intruded during the mylonitization, yielded a late Oligocene age. Thus they concluded that the age of mylonitization falls between the late Cretaceous thermal peak. and early Miocene.

We favor the interpretations of Dunning et al. (1995), and Upton et al. (1997) for the age and causes of mylonitization and uplift for the following reasons:

1. Young cooling ages are confined to the core of the Western Ranges, west of the Doi Suthep detachment fault. They are best explained by the rise of the metamorphic core along one or more major normal fault zones into juxtaposition with cover rocks and granite that had not been buried deeply since 200 ma.
2. Retrograde metamorphism and the over-printing of ductile structures by brecciation is difficult to reconcile with thrust faulting. Overthrusting of the western core of the range over the lower-grade eastern terranes should have resulted in late-Cretaceous prograde metamorphism of the buried rocks. No evidence of such an event exists.
3. The existence of Tertiary extensional basins is not consistent with a Tertiary thrusting event.
4. If early Tertiary thrusting was from west to east as suggested by Ahrendt et al. (1997), then the thrust faults must be folded to their present east-dip, and they must resurface farther east as west-dipping faults. Such faults would have to cut Mesozoic granitic rocks that voluminously intruded the ranges to the east. No such faults have been documented.
5. Widespread Tertiary basaltic eruptions are consistent with continued late Tertiary extension (Upton et al., 1997).
6. Active basin-bounding normal faults (Fenton et al., 1997) suggest an extensional origin for the basins of northern Thailand, rather than being the result of nappe tectonics as suggested by Ahrendt et al. (1997).

5. The Doi Suthep detachment fault

The Doi Suthep Metamorphic Complex is structurally overlain by a gently dipping fault previously mapped as a thrust (Baum et al., 1981), but here reinterpreted as a low-angle normal detachment fault. South of Doi Suthep, the fault separates the mylonitic rocks of the footwall from Ordovician (?) phyllitic shales (Fig. 3). Although the fault plane itself is unexposed, the mapped trace indicates a gentle southward dip, generally parallel to the orientation of the mylonitic foliation in the lower plate. In one location just

Fig. 5. Photograph of chloritic breccia from the Doi Suthep detachment fault.

west of Chiang Mai, a zone of strongly brecciated and chloritized orthogneiss lies along the trace of the fault, with unbrecciated phyllite exposed a few meters away (Fig. 5). Brecciation gradually diminishes structurally downward within the orthogneiss over a zone of about 100 m. Elsewhere, zones of chloritic brecciation are locally developed in footwall rocks near the mapped trace of the detachment fault.

To the north of Chiang Mai and west of Mae Rim, the fault strikes approximately north–south, and juxtaposes unmetamorphosed Cenozoic sedimentary rocks of the Mae Rim Formation against mylonitic gneisses of the footwall. The relationship of the Mae Rim Formation to the detachment fault is critical to determining the relative age of the fault. Unfortunately, we could locate no exposure of the contact between the Mae Rim Formation and metamorphic rocks of the Doi Suthep Complex. The approximately located trace of the contact indicates that it dips gently eastward. However, bedding in the Mae Rim Formation does not strike parallel to this contact as it would if this contact were an nonconformity. Instead, the pattern visible on Fig. 3 suggests that this contact cuts across bedding in the Mae Rim Formation. Furthermore, zones of chloritic brecciation occur locally in the Doi Suthep Metamorphic Complex near this contact. Thus, we interpret this contact as an east-dipping, low-angle normal fault.

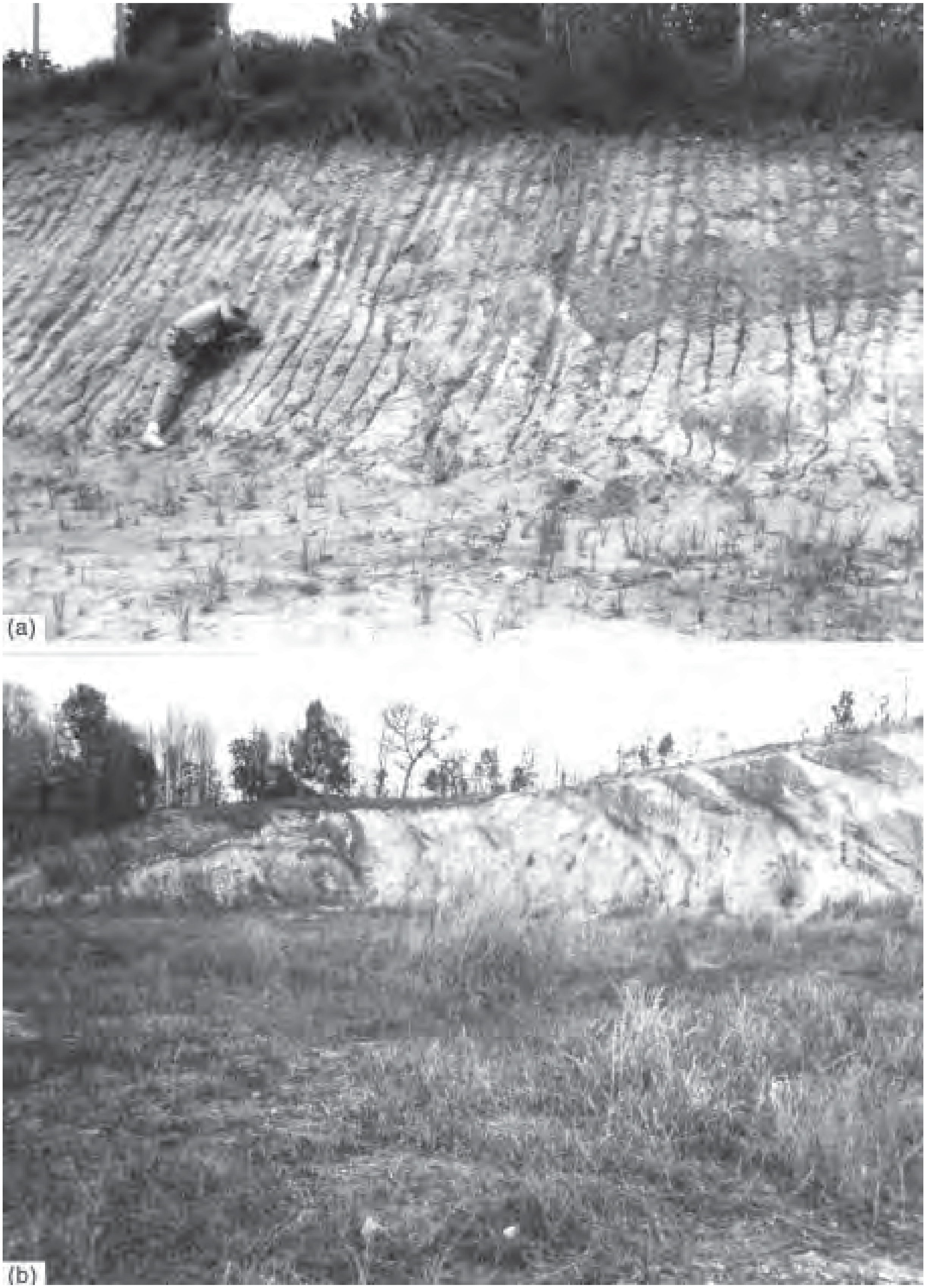

Fig. 6. (a) Parallel normal faults cutting fanglomerates the Mae Rim Formation. (b) Mae Rim Formation exposed in quarry showing northwest-trending fold hinge.

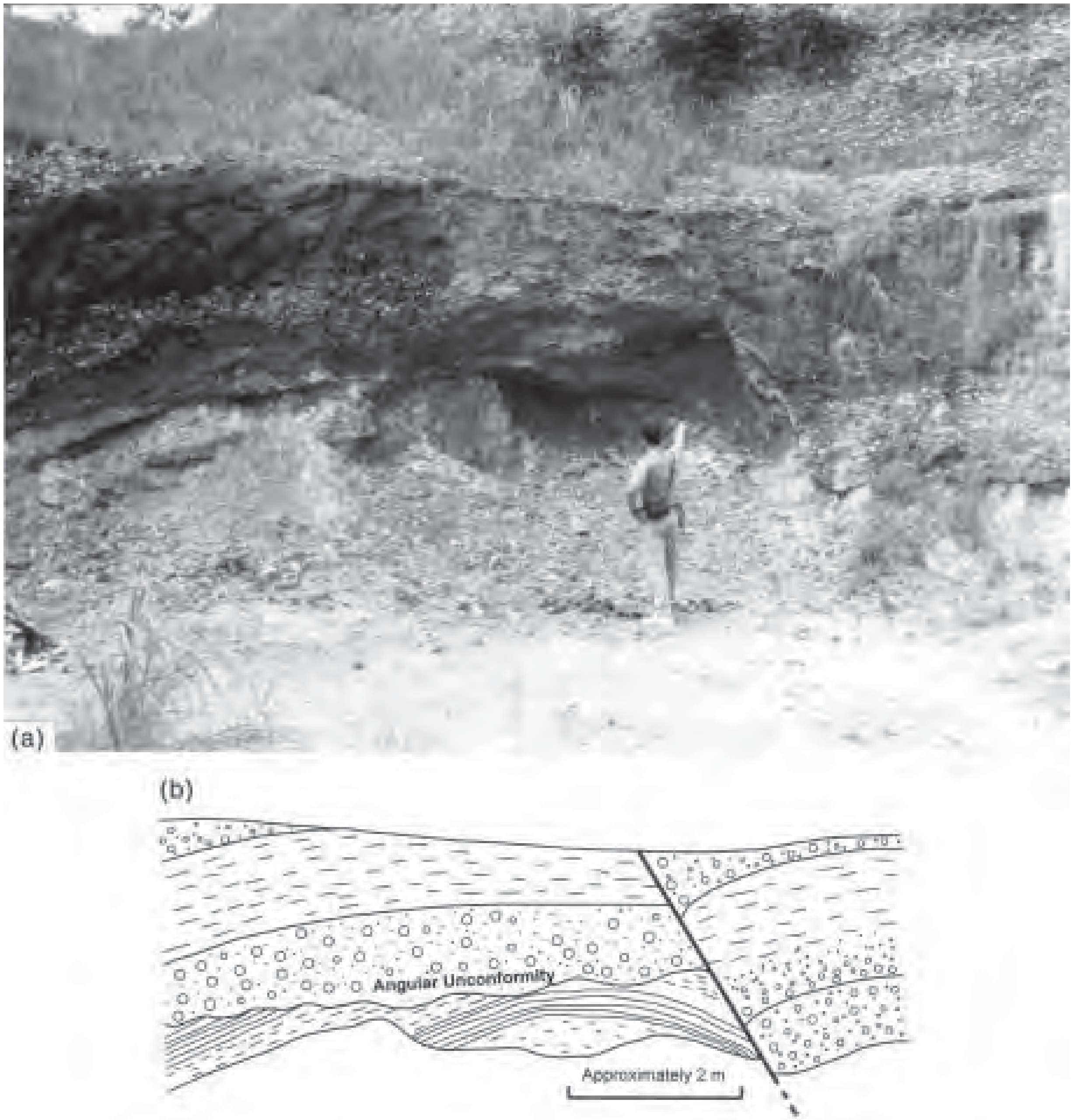

Fig. 7. (a) Photograph of an angular unconformity within the Mae Rim Formation. (b) Sketch of the same photograph. Bubble pattern indicates conglomerate, dashed pattern indicates sandy siltstone, and lined pattern indicates shale. The thick line indicates the trace of a high-angle normal fault.

The trace of the detachment fault is generally parallel to the domal structure defined by the mylonitic foliation in the footwall. Thus the regional doming must have postdated both mylonitization and slip along the detachment surface itself. To the south of Doi Suthep, the trace of the detachment fault defines a southeast plunging synform (Fig. 2) that separates the domal culminations of Doi Inthanon to the south and Doi Suthep to the north.

On the western flank of the Western Ranges, west of Doi Inthanon, MacDonald et al. (1993) mapped a west-dipping detachment fault that they interpreted as the west limb of a post-detachment dome. A reinterpretation of mapping by Baum et al. (1981) suggests that this detachment may continue along the entire western flank of the Western Ranges. If this detachment represents the west limb of a regional, crustal-scale top-to-the-east detachment fault similar to those found in the western Cordillera of the western United States (e.g., Wernicke, 1985), then a break away zone must exist still farther to the west. A possible candidate is the complexly faulted area parallel to the

Table 2
Summary of the tectonic history of the Doi Suthep area

Age	Events	Notes
Proterozoic (?)	Deposition of the protoliths of paragneiss in the Western Ranges	Poor compositional match between paragneiss and Paleozoic and Mesozoic rocks in the area perhaps precludes a younger age for the protoliths
Ordovician	Deposition of shale and limestone in a continental shelf environment	Phyllite and marble represent the metamorphosed equivalents of these rocks in the hanging wall of the Doi Suthep detachment fault
Triassic	Intrusion of voluminous granitoids, deformation and low-grade metamorphism likely accompanied the collision of the Shan-Thai Terrane with the Indosinian Craton	Triassic granitoids are likely the protoliths for orthogneisses in the Doi Suthep Metamorphic Complex
Triassic to Late Cretaceous	Peak of metamorphism at high temperature and low pressure (Dunning et al., 1995)	This event may have been accompanied by localized partial melting, generating magma for pegmatitic and aplitic dikes in the Doi Suthep Metamorphic Complex
Oligocene–Miocene	Mylonitization	Onset of crustal extension with mylonitization representing the earliest and deepest expression of this extension
Late Oligocene–Miocene (?)	Detachment faulting, deposition of the Mae Rim Formation, and regional doming	Age of these events are poorly constrained. Uplift (i.e., doming), detachment faulting, and folding and faulting within the Mae Rim Formation must have been synchronous with deposition of Mae Rim fanglomerates

north–south striking Mae Yuam Fault Zone. If the analogy with detachment faults in the Cordillera of the western United States is correct, then this detachment fault represents the youngest, brittle displacement along an originally planar, crustal scale shear zone (cf. Wernicke, 1985).

6. Mae Rim Formation

North of Chiang Mai, and west and north of Mae Rim, moderately indurated conglomerate, sandstone, and minor shale underlie low rolling hills on the edge of the Chiang Mai Basin (Fig. 3). Herein, we have informally assigned the name Mae Rim Formation after the nearby town of Mae Rim. Most exposures of the Mae Rim Formation occur in quarries and road cuts; natural exposures are rare.

Conglomerate is the dominant lithology, consisting of massive to thick layers of angular to rounded pebbles, cobbles and locally boulders, interlayered with generally massive, friable sandstone. Shale occurs as locally thick interbeds. General lack of organization and coarse grain size suggests an alluvial-fan origin, with the shale interbeds representing localized lacustrine environments. The conglomerates contain clasts of most of the lithologies now exposed in the Doi Suthep Metamorphic Complex, including clasts of lineated orthogneiss, paragneiss, and quartzite. Thus, erosion and/or tectonic denudation had exposed the mylonitic rocks of the Doi Suthep Metamorphic Complex prior to or during the deposition of the Mae Rim. Clasts of various Paleozoic metasedimentary rocks are also represented, one of the most common being black chert and phyllite. All of these lithologies crop out to the west, suggesting a western source area for the Mae Rim Formation, although a detailed paleocurrent analysis would be needed to confirm this. Because of sparse exposure and likely repetition of beds by folds and or faults, it is not possible to estimate the overall thickness of the Mae Rim Formation.

Deformation of the Mae Rim Formation includes both normal faulting and folding. Outcrop-scale normal faults (Fig. 6a) with generally steep dips crop out in several of the larger quarries, with offsets, where discernible, of at most a few meters. Larger displacement, map-scale faults probably exist, but lack of exposure or distinctive marker beds made it impossible to locate any such faults. The variable strikes of these faults (Fig. 4b) suggest either multiple episodes of faulting as the strain field changed, or faulting occurred in a complex three dimensional strain field.

Bedding in the Mae Rim Formation dips up to 50°, with variable strikes. Poles to bedding plotted on a stereonet show no preferred strike direction (Fig. 4b). The Mae Rim Formation is clearly folded, as demonstrated by visible outcrop-scale fold hinges in at least three of the larger quarries (Fig. 6b). Fig. 3 shows no clear pattern of folding, thus the wavelength of individual folds must be smaller than the average spacing of exposures. The simplest interpretation is that the Mae Rim Formation is folded into gentle domes and basins, and this is consistent with the observed, outcrop-scale fold hinges. Interestingly, the pattern of poles to bedding for the Mae Rim Formation is nearly identical to that obtained by plotting poles to mylonitic foliation in the Doi Suthep complex. Perhaps both were effected by the same deformation.

In one spectacular exposure, a distinct angular unconformity is visible within the Mae Rim Formation (Fig. 7). Here, a gentle anticline is clearly breached by a gently folded unconformity, which in turn is offset by a high-angle, probably normal fault. Gravel beds overlying the unconformity are also gently folded. Interestingly, dips within the Mae Rim Formation generally lessen toward the east with horizontal bedding most common along the eastern edge of Fig. 3. We can not rule out the possibility that the more gently dipping exposures overlie one or more angular unconformities. These observations make it clear that deformation and deposition of the Mae Rim must have been synchronous.

7. Structural history

The tectonic history of the Doi Suthep area is outlined in Table 2. The timing of these events is based on geochronology by Dunning et al. (1995) and Upton et al. (1997); however, many of these ages are still poorly constrained. Of particular importance is the age of the Mae Rim Formation; its age is critical to the timing of the latest movement on the Doi Suthep detachment fault, and unroofing of the metamorphic core of the Western Ranges. Further study is also needed of other Cenozoic sedimentary rocks that crop out at the southern and northern ends of the Chiang Mai Basin (Fig. 2), as they may be correlative with the Mae Rim Formation. Finally, more detailed geochronologic work on the metamorphic core is needed, utilizing a variety of isotopic systems, before we will fully understand the timing of metamorphic and ductile-shearing events in the Western Ranges.

8. Conclusions

Future models explaining the Cenozoic tectonic development of the Western Ranges must take into account the following conclusions:

- East–west extension persisted in northern Thailand during the time of deposition of the Mae Rim Formation.
- Erosion and/or tectonic denudation must have exposed the core of the Western Ranges during the deposition of the Mae Rim Formation.
- A regional mid-Tertiary or younger detachment fault extends along the entire eastern flank of the Western Ranges. This fault was subsequently domed, and the metamorphic complex of the Western Ranges represents the footwall core of this dome.
- Kinematic indicators in the mylonitic rocks of the footwall of the detachment fault indicate uniform top-to-the-east simple shear consistent with eastward detachment faulting.
- Latest movement on the Doi Suthep detachment fault came after the deposition of the Mae Rim Formation.
- Any estimates of the magnitude of extension in northern Thailand must take into account extension accommodated by detachment faulting and ductile flow of the mid- to lower-crust.

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MINIREVIEW ARTICLES

Fang Oilfield Development

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ABSTRACT

Fang Oilfield is the oldest oilfield in Thailand and is still producing oil. The first oil seepage was found on the ground surface in the dense jungle over a hundred years ago by local inhabitants. The oilfield has been investigated by pioneer explorers from different government sectors involved in oil exploration and production but is still far away from being economically viable. When the Defense Energy Department (DED) took responsibility for the site in 1956, a new era of modern technologies of geological survey, 3-D seismic survey, and directional drilling wells have been seriously applied. From a gallon to a thousand barrels of oil daily production has significantly increased. The oil discovery in Fang basin encourages further activities in petroleum exploration both onshore and offshore in Thailand. Today, Thailand can produce oil and gas equivalent to 300,000 barrels of oil daily, close to 30 % of national consumption. The history and current activities of the oilfield are still of interest to the public. This paper intends to integrate available data from the first era to the present day to explore the nature of this small oilfield.

Keywords: Fang Oilfield, geological survey, directional drilling wells, 3-D seismic survey, petroleum exploration

INTRODUCTION

The Fang Oilfield is located in Fang intermontane basin, Northern Thailand. It is approximately 150 km north of Chiang Mai or 850 km from Bangkok, the capital of Thailand. The surface area is approximately 600 km^2 (W 12 × L 50 km), probably the smallest intermontane basin in which petroleum has been discovered in the country. The basin lies NE-SW with an elongated shape and is surrounded by older formations of rocks from Cambrian and Igneous rocks to more recent sediments (**Figure 1**). The highest peak is around 2,000 m and the basin is about 450 m above mean sea level [1,2].

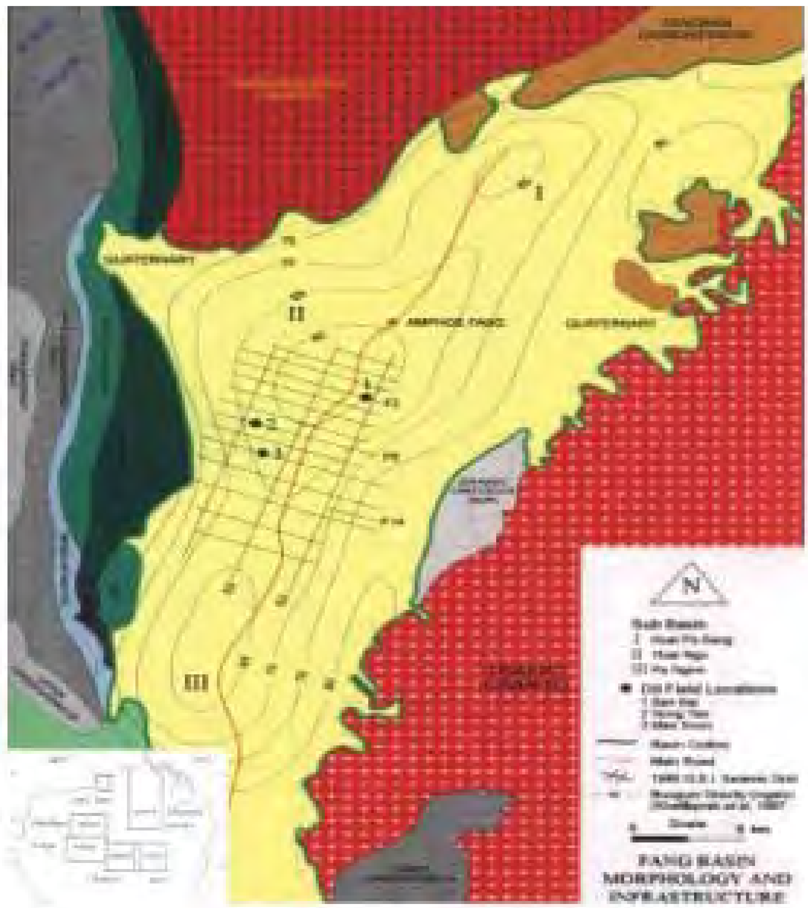


Figure 1 Geomorphology and geologic setting of the Fang basin.

People living in the area are Thai citizens and also more than 10 groups of minority hill tribes including Chinese, Mong, Muser, E-koe, Palong, Dai Yai, Karen, Yao, Wa, Lisor and local northern people with different dialects and cultures.

The area is hilly with green mountain forest and beautiful nature. As such, Fang is one of the most attractive places for both Thai and foreign tourists who visit all year long. During December and January, some days the temperature might drop down to 5 - 10 °C and sometimes even as low as 0 °C on the peak of Doi Angkang. Such climatic conditions are rarely found in other places of the country.

Agriculture and commerce are the main economies in the region. Among most popular fruits from this area are lychees and honey oranges which are very tasty. On the top of Doi Angkang where the Royal King's project station is located, many plants, floras and vegetables from cold countries are planted aimed at reducing drug activities previously common in the area.

Exploration History

1) Exploration

Oil was first found in the Fang basin over a hundred years ago when local inhabitants discovered oil seepage on the ground in the dense jungle. They believed it to be a magic oil and used the oil as an ointment for skin infections. The Lord of Chiang Mai ordered a shallow well to be built called the “Lord’s Well”. Today, there is a memorial well called “Boh Tonkam” (**Figures 2**)

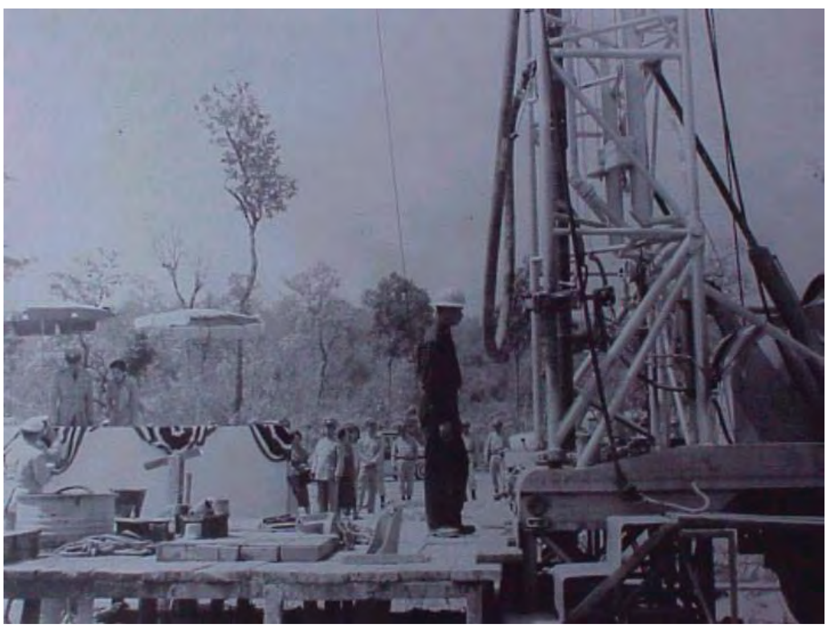
Figure 2 Boh Tonkam, ancient oil seepage well at Chiprakarn field discovered over 100 years ago.

Figure 3 General Pra Kampaengphet (right) and Mr. Wallace Lee (left), pioneer explorers sitting on the giant logs at Fang (1921).

In 1921, General Pra Kampangphet Akkarayothin (HM) (**Figure 3**), the Director General of the Royal State Railway Department and a US geologist, Mr. Wallace Lee conducted a geological survey and drilled 2 shallow wells with a steam engine drilling rig in 1922 but these wells were dry and abandoned.

March 9th 1958, His Majesty the King and Queen of Thailand paid a visit to the oil field and ceremonially spud the Well F 15. They spent a night there to visit local people (**Figure 4**) [3,4].

(a)



(b)

Figure 4 His Majesty King Bhumipol and Queen Sirikit visited and ceremonially spud the well of Chiprakarn field (1958).

2) Drilling

A total of over 240 wells have been recorded since the first drilling well started in the Fang basin over 40 years ago. The wells are from different locations. Now only 5 locations are producing oil and 2 fields have been abandoned.

3) Production

The total production from the Fang basin is approximately 9 million barrels (MMBbl) from the following 7 reservoirs since early 1960 to the present day.

I. Chaiprakarn Reservoir (abandoned 1984), II. Maesoon Reservoir, III. Pongnok Reservoir (abandoned 1985), IV. Sansai Reservoir, V. Nongyao Reservoir, VI. Sanjang Reservoir, VII. Banthi Reservoir [5-7].

The latest Banthi reservoir was discovered from 3-D seismic interpretation in 2001 [8]. A total of 7 wells were drilled, 3 wells were directional wells. Five wells are producing at a rate of 150 BOD. The seismic section across the Fang basin shows complex structures, fault systems and potential traps (**Figure 5**) and the isochrone map shows the reservoirs are delimited by a system of normal faults (**Figure 6**)

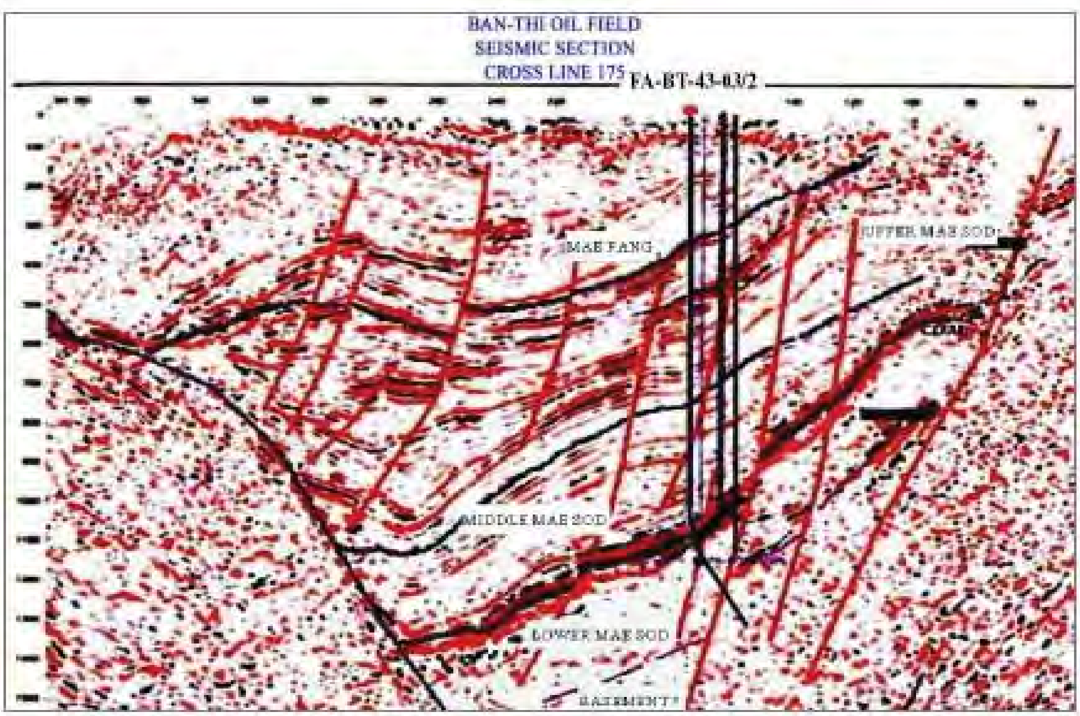


Figure 5 Seismic cross section shows structures, faulted system and potential traps.

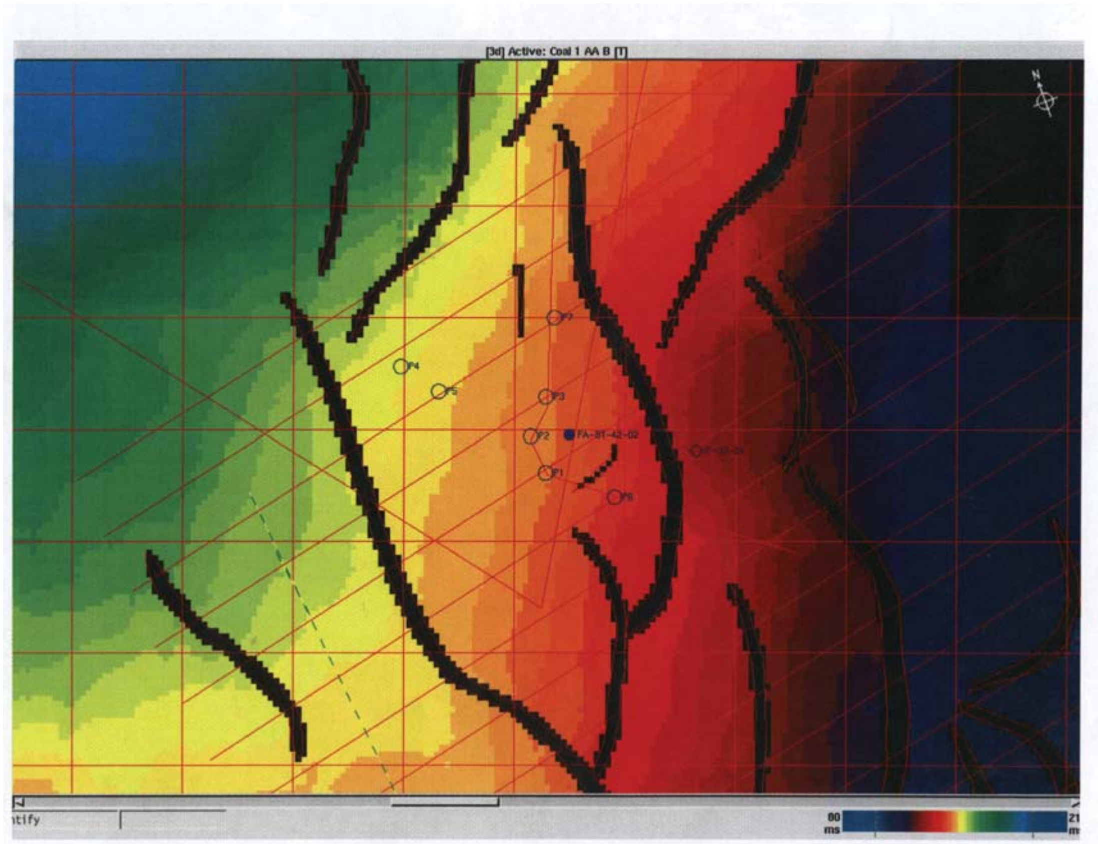


Figure 6 Isochrone map of Banthi structure.

Geologic Setting

The Fang basin is approximately 25 - 40 million years old and with layers in the Oligocene period. It is as deep as 10,000 ft in the deepest part of the basin. The lithologic assemblage is related to an episode of extension. Rifting started over 20 million years ago when the thick sequences of lacustrine sediments were deposited during the Miocene period. This sequence is called Maesod formation. Subsequent tectonic activity resulted in the deposition of thick sequences of coarse alluvial sediments that unconformably overlay the lacustrine sequences. This tectonic activity may be broadly related to changes in tectonic stress patterns caused by the progressive Indo-Eurasian collision. The coarse clastics are termed Maefang formation and possibly span the latter Miocene to the Pliocene-Pleistocene period [5].

Subsurface Structure

Internally, the Fang basin can be divided into 3 extensional sub-basins as interpreted from gravity and seismic surveys. These sub-basins are postulated by first order Riedel shear faults. The Riedel shears are clearly visible on satellite images cutting across Pre-Tertiary basements surrounding the Fang basin. These shears result from left lateral shear coupled with movement that initiated the basin. Within the sub-basins, there occurs a swarm of cross-basin faults which are parallel with the Riedel shears; these are interpreted as coincident second order Riedel shears. The interpretation is based partly on the extensive network of seismic profiles across the Huai Ngu sub-basin.

Subsurface Lithostratigraphy

From the geological data there are 2 major formations from the upper zone of Maefang formation to lower zones of Maesod formation as follows:

Maefang Formation (Quaternary + Recent)

The post-rift of Maefang formation overlies discordantly above the Maesod formation. The thickness of the Maefang formation from the surface varies from 1,000 - 1,800 ft. The minimum thickness is found on top of the Maesoon structure. The thickness will increase down dip from the crest of the structure.

Maefang formation is mainly composed of coarse clastic sediments of soil, lateritic sands, loose sands, gravels, cobbles and pebbles, carbonized woods and clay on the top and towards the basin edge. Sizes of sands vary from coarse to very coarse grains, roundness from angular to subangular, poorly sorted and interbedded with reddish clays. While down dip towards the central basin clay-shale and arkosic sandstone are interbedded. This formation overlies discordantly with the Maesod formation. The Maefang formation shows energetic alluvial and fluvial deposits.

Maesod Formation (Middle Tertiary)

The Maesod formation is composed of brown to gray shale, yellowish mud stone generally interbedded with sand and sandstone with a series of channels of sand paleodelta and fluvial sand.

Basal conglomerate lies unconformity with Pre-Tertiary rocks and continues with sequences of lacustrine shale and mudstone. The color of the sediments indicates a reducing environment in the central, deeper part of the basin while an oxidizing environment develops in the shallow part of basin. Organic shale in the central part of the basin plays an important role as a potential source of rocks. The upper part of the Tertiary sediments is interbedded with 4 packages of sand which are important reservoir rocks in the Fang basin. Only 2 packages of sands have been proven to be producing sands. The sand thickness varies from 1 - 10 m.

The thickness of the Maesod formation varies from the margin of the basin towards the centre of the basin. At the Maesoon structure the thickness is approximately 3,500 ft or total thickness (Maefang + Maesod formation) 5,000 ft from the surface. Seismic interpretations indicate that the thickest part of the Maesod formation might reach up to 8,000 ft at the deepest part of the basin.

Basement (Pre-Tertiary)

The age of the basement of the Fang basin ranges from Mesozoic continental clastics to Cambrian marine clastics.

Environment of Deposition

The Maesod Formation was laid down following initial basin rifting in the later Oligocene or early Miocene periods. Sands and shale alternate in the lower part of the formation indicating a fluvial to shallow lacustrine environment of deposition. This lower sequence is capped by a 75 - 100 ft lignite seam indicating a change in environment to swamps and peat bogs for a period of time. The upper portion of the Maesod is dominated by organic rich shale with minor sandstone beds occurring, especially in the lower part of the upper section. This lithology indicates a lacustrine dominated environment following the deposition of the peat. The Maesod formation is then overlain by the coarse clastic dominated Maefang formation, returning to a more fluvial tile dominated environment. The Maefang is not considered a viable rock source because of its dominant sandy lithology and shallow, immature depth of burial. The above description is based on the Fang basin but appears to be a valid generalization for most of the Thai Cenozoic intermontane basins.

Petroleum Source Rocks

Source or potential source samples can be found from both outcrops and cores. Oil seepage can be seen near the edge of the basin. The oil found in the Fang basin is most likely from lacustrine shales found in the Maesod formation.

The geochemical analysis of potential source rocks has been done by using cores and cuttings from selected wells of Maesoon and Sansai reservoirs. The analysis indicated very interesting results. Total organic carbons (TOC) are very abundant between 1.12 - 2.67 % with a maximum of 3.03 %. Extraction soluble organic matter (EOM) is as high as 1,646 ppm. Kerogen type III is approximately 20 - 25 %, indicative of a lacustrine paleo-environment. The maturation scale indicates that the top oil window should start below 4,000 ft. While the core indicates that maturation starts from 7,750 ft. Mean vitrinite reflectance (R_O %) from core analysis is only 0.44 % at 3,000 ft which is lower than the ideal level of maturation of R_O 0.5 - 1.2 % and with a temperature (T max) of 437 - 470 °C in the Fang basin. So, the most favorable source rocks are the Maesod shales which are within and below the oil window [9].

Migration

The current producing pay intervals are above the mature source rocks. This indicates the migration of fluids at certain distances from the source rocks to charge the oil reservoirs above. The contributing factors in the migration path from the depths are fractures and faults along permeable rocks during compaction and compression in the late Tertiary period. From the size of the basin and location of reservoirs and production zones the distance of migration is short. After oil generation, oil might migrate in different directions around to the potential traps. Evidence supporting this statement comes from biodegradation of oil being found at a very shallow depth in Chaiprakarn and Pongnok reservoirs, both sides of the basin, suggesting migration routes from the depths.

Oil Reservoirs

Within the Fang basin, all productions come from the Maesod formation. The current producing reservoirs are distributed into widespread sections of the sorted sands and coarse clastics in some cases.

Reservoir Distribution

Generally, interbedded sand and sandstones in the upper zones of the Maesod formation are dominant reservoir rocks in the Maesoon reservoir and others.

The sand member which gives the lowest production includes 4 layers of sand. The thickness of each sand layer varies from 5 - 45 ft. The depth of this sand is about 2,386 - 2,487 ft which is the main producer of wells. The thickest part of this sand is in a North-South direction. Porosity decreases towards the margin of the reservoir.

The sand member gives the highest production includes 5 sands, 5 - 15 ft in thickness for each sand, with a total thickness of about 55 ft. The depth is about 2,160 - 2,255 ft. Most of the old wells are from this sand 2,300 ft in depth. The thickness of the sand varies from place to place. The trend in thickness North-South is 55 ft and decreasing to 10 - 15 ft at the edge of reservoir.

Reservoir Properties

Cores analysis from some wells shows interesting results of porosity up to 25 %, permeability higher than 200 milliDarcy (mD), some loose clastics as high as 2,000 - 3,000 mD found in the well IF 26 (**Table 1**) [10,11].

Table 1 Reservoir properties.

Well	Depth (ft)	Permeability (mD)	Porosity (%) (abs)	Fluid Saturation (%)		Density (gm/cc)
				Oil (Sor)	Wat (Sw)	
BS - 110	2,755.0	231	25.7	6.1	54.4	2.67
IF - 26 1)	2,581.1	2,390	25.4	17.5	33.0	2.65
2)	2,587.1	3,440	26.7	20.5	34.7	2.64

Fluid Properties

Physical properties of oil from Maesoon, Pongnok and Lankrabreau are quite similar with a very high content of paraffin wax up to 18 % (**Table 2**).

Table 2 Crude oil properties.

Properties	Chiprakarn Crude	Maesoon Crude	Pongnok Crude	Lankrabreau Crude
API gravity	16.40	30.8	37.6	38.2
Pout point	65 °F	95 °F	92 °F	90 °F
Sulphur (%)	0.28	0.18	016	0.5
Paraffin wax (% wt)	-	18	18.62	14.5 - 20
Specific gravity	0.957	0.872	0.873	0.675 - 0.85* (depending on gas content)
Color	Brownish black	Brownish black	Brownish black	Brownish black

Reserve Estimation

The Maesoon reservoir has produced a total of 7 MMBbl since 1963. Production started from 100 barrel per day up to nearly 1,000 barrels per day at the peak of production (**Table 3**). The mature reservoir needs to maintain pressure to extend the life of the reservoir.

Table 3 Reserve estimation.

Field	Probable (MMBbl)	Proven (MMBbl)	Recoverable (MMBbl)
Maesoon	23.0 - 30.0	10.0 - 15.0	8.00
Sansai	20.0	7.0	3.00
Nongyao	5.0	3.0	2.00
Samjang	5.0	1.5	0.75
Pongnok	6.0	3.0	1.50
Banthi	8.0	3.0	1.50
Chiprakarn	4.5	1.5	1.00

From the decline curve the life of the Maesoon reservoir will terminate in the next 4 - 5 years. Secondary recovery will be needed for this reservoir to prolong production.

Seals

Due to the interbedded sand/shale nature of the Maesod formation, the sands are effectively sealed from each other in a vertical sense by the thick, intervening shale. In the upper part of the Maesod the shale to sand ratio is higher than the lower section. Many of reservoir sands appear to be lateraling continuous over larger distances, allowing for lengthy up dip migration pathways. Up dip structural seals are formed by both stratigraphic and faulting mechanisms.

Traps

Combinations of structural and stratigraphic traps are very important at the Maesoon reservoir in the Fang basin. Traps or plays in the Fang basin will reflect its evolution during much of its history as a continental interior subsidence. Traps will thus exclusively involve tension faults as well as unconformities caused by uplift and erosional systems.

Proven Traps

Structural traps of rollover anticlines originate from growth faulting and compaction on the Pre-Tertiary basement. The anticlinal axis consists of a NNW-SSE trending conforming to the basin N-S trending, dipping 5 - 10° around the crest. Major faults are characterized by a listric geometry which has resulted in the formation of a rollover structure in the hanging wall of the fault. The major fault identified from seismic interpretations is in the NE-SW direction and dipping 85 °W. The fault is characteristic of a trust and strike slip fault. The western block has moved along the strike south about 150 ft and vertical displacement is about 250 ft. Minor faults are also found associated with the Maesoon and Nongyao reservoirs.

Combination traps of up dip truncation and lithostratigraphic pinchout from porous rocks to impermeable rocks have been proved to exist in Sansai, Pongnok, and Banthi reservoirs along the eastern trend of the Fang basin. In Chaiprakarn, some leakage of oil, probably uplift of the basin and erosion exposed crude oil near the surface and this degraded oil may have provided an effective trap (**Figure 7**) [12].

Potential Traps

These traps might be formed under unconformities in the Pre-Tertiary basement (**Figure 7**). Drape anticline during the initial rifting are draped by synrift sediments forming potential anticlines. Paleogeomorphogic traps of burial Pre-Tertiary limestone or sandstones would form a good quality reservoir under unconformity (**Figure 7**) [13].

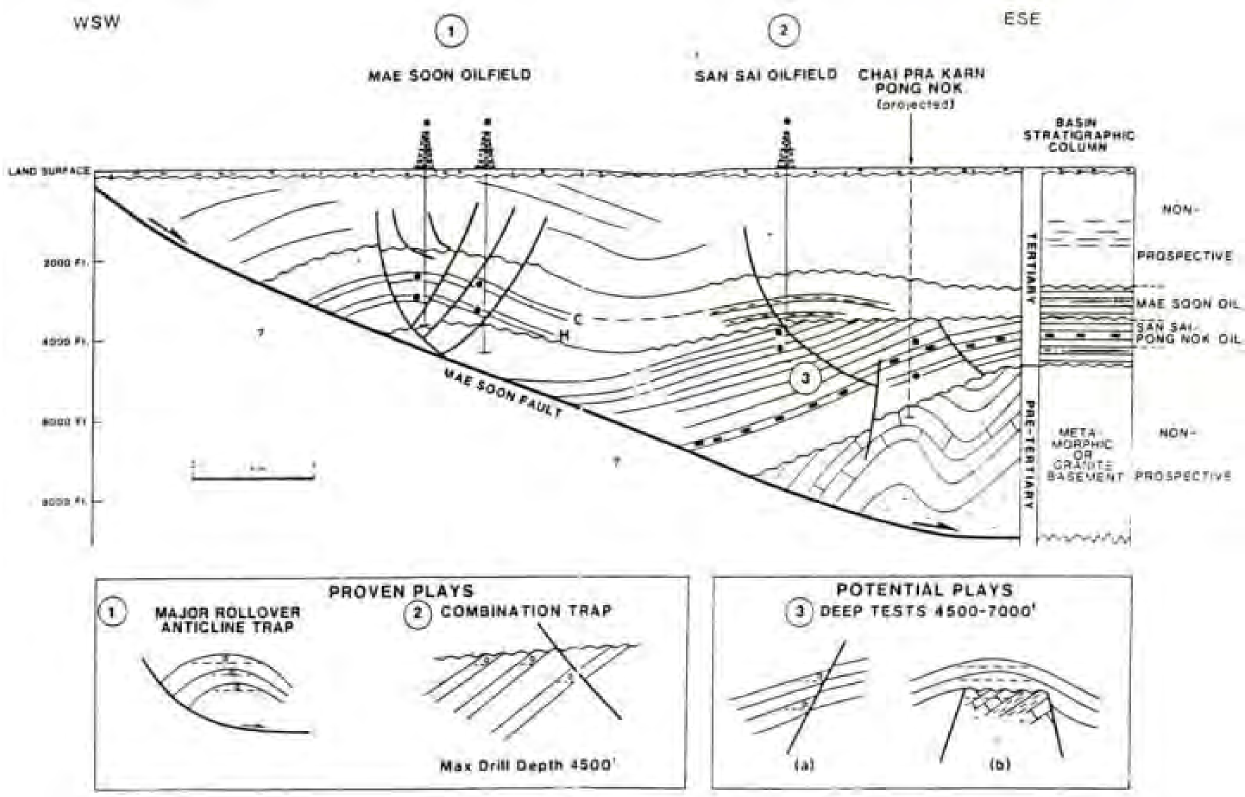


Figure 7 Fang basin showing both proven and potential traps.

CONCLUSIONS

Although Fang basin is a very small intermontane basin, but a number of economical oil pools have been discovered, and are producing till this day. Subsurface geological data from drilled wells and togather with palynological and geochemical studies have revealed the development of environmental deposition and source rocks potential of Fang basin. Migrations of oil along permeable rocks have been trapped in delimited reservoirs. Tertiary fluvial and deltaic sands of litho-stratigraphic traps play an important role but are limited in extent by impermeable shale. Future exploration strategies should focus not just on these shallow subtle traps but the deeper zones down under the Pre-Tertiary basement should be future target areas.

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Paleaogeography and Climatic Change recorded on Viviparidae Carbon and Oxygen Isotope in Mae Moh Coal Mine, Northern Thailand

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Benjavun Ratanasthien, Isao Takashima and Osamu Matsubaya (2008) Paleaogeography and Climatic Change recorded on Viviparidae Carbon and Oxygen Isotope in Mae Moh Coal Mine, Northern Thailand. *Bull. Geol. Surv. Japan*, vol. 59 (7/8), 327-338, 3 figs. 1 table, 1 plate.

Abstract: Viviparidae fossil collected from the R-, Q-, and K-coal zones of the Mae Moh coal mine, northern Thailand were analyzed for ^{13}Carbon and ^{18}Oxygen isotopes at Akita University, Japan. The result reveals that Viviparidae of the lower part of the coal mine contribute much heavier carbon isotopes than the upper part. The results revealed that Viviparidae shell ^{13}C values are between 3.52 to 6.92 ‰ PDB in the R-coal zone, between 4.17 to 5.77 ‰ PDB in the Q-coal zone and between 1.41 to 1.34 ‰ PDB in the K-coal zone. For oxygen isotopes the lower part of the basin showed heavier isotopes than the upper part, where the ^{18}O values are between -3.15 to -5.10 ‰ PDB in the R-coal zone, between -4.19 to -6.04 ‰ PDB in the Q-coal zone, and between -7.05 to -8.04 ‰ PDB in the K-coal zone. The isotope valued of Viviparidae shells collected in the Kew Lom reservoir in the Lampang area yielded ^{13}C values between -11.01 to -12.19 ‰ PDB and the ^{18}O ‰ value between -6.64 to -7.04 ‰ PDB. The isotopic results of Viviparidae fossil shells from Mae Moh basin show the gradually change from the R-coal zone to the Q-, and the K-coal zone and significantly different from the Recent Viviparidae in the area. The heavy carbon isotopes in the R-coal zone could imply a much cooler climate than during the Q- and K-coal zone depositing period and the area were more close to the sea. The climatic condition during the Q- and K-coal zone depositing period was warmer and at a geographically higher elevation or latitude than during depositing the R-coal zone. The changing records in Mae Moh coal field are confirmed by temperate fossils in the other Oligocene to Lower Miocene basins in Northern Thailand. The change to a more tropical climate could have occurred during the Middle Miocene period, as indicated by paleomagnetic age dating in the K- and Q-coal zone. The northward movement of the Australian-Indian plate and collision with the Eurasian plate are suspected to be the main cause of the change.

Keywords: carbon isotope, oxygen isotope, Viviparidae, climatic change, paleaogeography, Mae Moh coal mine, Miocene, Australian-Indian plate, Eurasian plate, Thailand

1. Introduction

The Mae Moh coal mine is operated in the largest coal deposit in Thailand. It is situated in Mae Moh basin, Lampang province, northern Thailand. Each day, and approximately 40,000 tons of coal of lignite to sub-bituminous C in rank (ASTM, 1988) are mined for 10 units coal-fired power plants (total of 2400 MW) in the mining area. The mine pit covers an area of 4 x 8 km^2 at depths varied up to 200 meters. During the exploration drilling and excavation, there were many shell beds, mainly gastropods, which have been found associated with the coal beds, and some of these are used as key beds. The important shell beds used as keys beds are those below the R-coal zone, below the Q-coal zone, and the most important bed, due to the great thickness of Vivipridae shell (maximum 12 meters), lying between the K3- and K4-coal zone. During the mining history, this shell bed has shown to be only 4 meters thick in the northeastern pit. Later, when the southwest pit was opened, the largest part of the shell bed in terms of thickness and width, consists of nearly 100 percent pure *Bellemya* sp. without clays intercalation are shown (Plate 1). The environment of depositions of these shell beds become interested and required investigation. Isotopic analysis is one of the tools in this investigation. The important of this method is the possibility to interpret the role of changing depositional environment.

2. Geology of the Mae Moh Basin

Mae Moh coalfield is the largest Tertiary coal deposit

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in Southeast Asia. It is located at latitude 18°18'21"N, longitude 99°44'02"E, in Mae Moh District, Lampang Province, approximately 631 kilometers north of Bangkok and 26 kilometers east of Lampang township. The basin is bounded mostly by marine Triassic rocks of Lampang Group (Fig. 1), which are composed of limestone, shale, and sandstone. Exceptionally, in the southern part of the basin, the Tertiary sequence is overlain by the Quaternary basalt (Sasada *et al.*, 1987; Charoenprawat *et al.*, 1995; Chaodamrong and Burrett, 1997). Unconsolidated sediment of fluviatile deposits form a thin veneer throughout the basin. It consists of superficial gravel deposits in the lower part, lacustrine to fluviolacustrine in the middle part and alluvium deposits in the upper part (Chaodamrong, 1985; Jitapankul *et al.*, 1985; Uttamo *et al.*, 2003).

The Tertiary sequences of Mae Moh basin (Mae Moh Group) have been divided into three formations (Fig. 2). Each formation consists of sediments that strongly differ in lithology, sedimentary structures, degree of con-

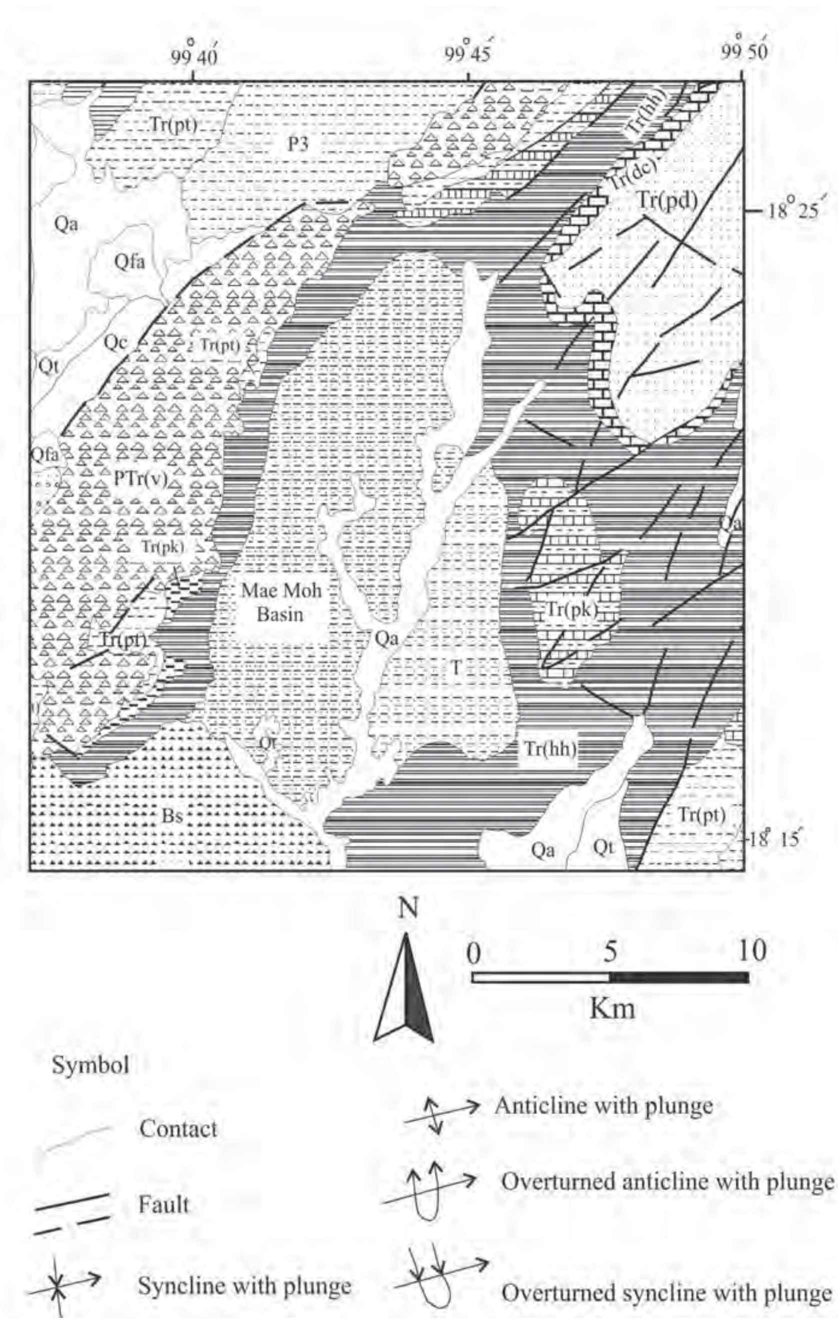

Fig. 1 Geologic map of Mae Moh basin (modified from Charoenprawat *et al.*, 1995).

Legend	Age	Rock Unit	Description
Sedimentary rock			
Qfa	Quaternary	Mae Taeng Group	Alluvial fan sand and clay unit: sand, clayey and silty, light gray, interbedded with sandy clay.
Qa	Quaternary	Mae Taeng Group	Alluvial deposits: gravel, sand, silt, clay and mud.
Qt	Quaternary	Mae Taeng Group	Terrace deposits: gravel, sand, silt, clay, and lateritic soil.
Qc	Quaternary	Mae Taeng Group	Colluvial unit: rock fragments, gray, orangish red, covered with clayey sand and laterite.
T	Tertiary	Mae Moh Group	Interbedded claystone, sandstone, mudstone, diatomite, coal, and shale with fossil leaves, stems, bone of fish, and *Viviparus* sp. and vertebrate remains.
	Lampang Group		
Tr(pd)	Triassic	Pha Daeng Formation	Sandstone, red to reddish brown, cross-bedded; siltstone, conglomerate and shale.
Tr(dc)	Triassic	Doi Chang Formation	Limestone, gray to light gray, finely crystalline, massive; limestone conglomerate with fossil bivalves, brachiopods and gastropods.
Tr(hh)	Triassic	Hong Hoi Formation	Silicified mudstone, gray to black, light brown to yellowish brown; intercalated with quartzite, light gray to dark gray, fine-grained; tuffaceous sandstone, gray to brownish gray, fine-to medium-grained, intercalated with shale, gray to dark gray; shale and siltstone, gray to greenish gray, with fossil *Halobia* sp., *Posidonia* sp., *Paratrachycerus* sp.
Tr(pk)	Triassic	Pha Khan Formation	Limestone, thin-beded to massive, oolith, oncolith, fossiliferous; interbedded with shale, sandstone, and mudstone, with fossils of *Daonella* sp. crinoid stems, bivalves, corals, and algaes.
Tr(pt)	Triassic	Phra That Formation	Lower part: Interbedded black shale, tuff and sandstone; Upper part: interbedded conglomerate, agglomerate, conglomeratic sandstone, tuff, sandstone, shale, mudstone, and siltstone, red, gray to dark gray and reddish brown; with limestone lens; locally developed phyllitic and slaty clevage with fossils *Claraia* sp., *Costatoria* sp., and other bivalves.
P3	Permian	Kiu Lom Formation, Ngao Group	Interbedded black shale, gray sandstone, dark gray mudstone, and gray limestone with chert nodules; intercalated with fossiliferous limestone and mudstone.
Igneous rock Bs	Pleistocene volcanic		Olivine basalt, gray to dark gray, vesicular texture, flow structure (Pahoehoe) with some volcanic bomb and scoria.
PTr(v)	Permo-Triassic volcanic		Volcanic rocks: rhyolite, andesite, flow and dike; agglomerate; volcanic conglomerate; rhyolitic tuff, and andesitic tuff.

Fig. 1 (continued)

solidation, and fossils, as described below from the lower to upper parts (Chaodumrong, 1985; Jitapankul *et al.*, 1985; Songtham *et al.*, 2005a and b; Silaratana *et al.*, 2004, 2004), as shown in Figs. 1, 2 and in the following descriptions:

2.1 Huai King Formation

It is the lowermost formation of the Tertiary succession that unconformably overlies the basement rock, the Lampang Group. The typical character is a fining upward sequence grading from conglomerate to mudstone or claystone on top. It is variegated in color, red, gray, green, yellow, blue and purple, common calcrete

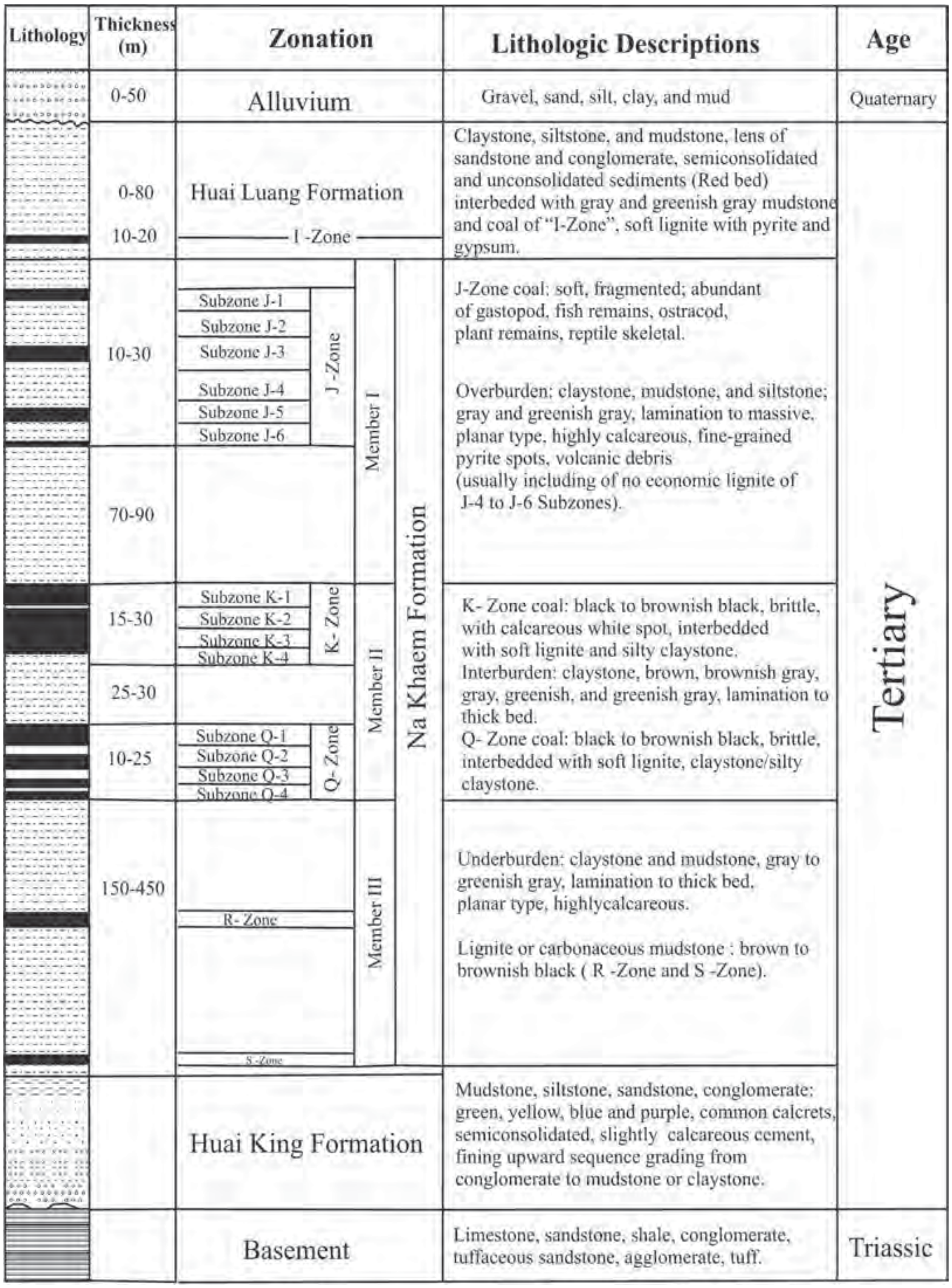

Fig. 2 Stratigraphic succession of Mae Moh coal mine (modified from Jitapankul, *et al.*, 1985).

in part, slightly calcareous cement, no macrofossils (except on the southern part found abundant *Viviparus* sp. in the lower portion of this formation). The thickness is varied from less than 15 meters on the border to 150 meters on the central part of the basin (Jitapankul *et al.*, 1985). The uppermost part of the formation is marked by a thin layer of coal named the O-Zone which occurs locally.

2.2 Na Khaem Formation

This Formation is the major coal deposit of the Mae Moh basin, and consists of semi-consolidated mudrock and five coal zones with varying thickness of 250 to 400 meters. Two of these coal zones are the major production of this mine. Jitapankul *et al.* (1985), Chaodamrong (1985), and Evans and Jitapankul (1990) divided this formation into three members as describe from lower part to the upper part:

Member III (Underburden) is a sequence of gray to greenish gray claystone and mudstone with a thin layer of coal of sub-bituminous rank, named the R-Zone. These beds are laminated to thick bed, planar type, highly calcareous, in the upper part with abundant gastropod beds, fish remains, ostracod, plant roots, intraformational conglomeratic texture and intermixed color texture near a coal seam or lignitic layer, burrow and boring, and load cast. At the Underburden / Q-Zone boundary downward is the ? *Paludina* Molluscan Zone of Songtham *et al.* (2005b). They suggested that the Mae Moh basin was a lake along a shallow shore in quiet conditions without any vegetation growing nearby. The thickness varies from 150 to 230 meters.

Member II is the most economically attractive coal sequence and is separated into three portions: Q-Zone, Interburden, and K-Zone.

The Q-Zone is a lower portion of coal that is black to brownish black and brittle, with abundant siliceous calcareous diatoms, the pyritized gastropod *Viviparussp.*, and Planorbidae and plant remains. It is interbedded with coal of sub-bituminous rank, with partings (about 30%) of light brown claystone/silty claystone. Technically the seams are divided into Q-1 to Q-4 with total thickness that vary from 25 to 30 meters. However, it separates to the north and south with thicker silty mudstone and changes laterally from coal layers to carbonaceous claystone and clay. The Planorbidae Molluscan Zone is located at the Underburden / Q coal boundary and the K-4 / K-3 boundary. Planorbidae are common in places, especially under the Q coal bed. This implies a swampy environment containing sparse to densely distributed vegetation (Songtham *et al.*, 2005a, b). A proboscidean fossil was discovered in the Q-2 Subzone (Permsook, 2007 personal communication).

The interburden is a sequence (10 to 30 meters thick) of brown, brownish gray, gray, green and greenish gray claystone that lies between the two major coal seams. These beds are laminated to thick-bedded, planar type, with common lignite flakes, fish remains, plant roots, rare ostracods, common intraformational conglomeratic texture on the lower part, common gastropods (*Viviparus* sp.), load cast, and abundant micro slip planes. This sequence is thicker in the east flank but thinner in the west flank of the main basin. The K-Zone is a sequence of black to brownish black, brittle, high calcareous coal in the upper part. Diatomite flourishes in the eastern part and can be used to separate the K-Zone into four layers, and there are common gastropods (*Planorbis* sp., *Mellanoides* sp., and *Viviparus* sp.) and rare fish remains and plant remains. This zone is interbedded with some coal of sub-bituminous rank with partings of light yellowish gray to gray silty claystone. The thickness varies from 10 to 30 meters. However, it is split in the north and south with thicker silty claystone partings and a lateral change to carbonaceous claystone and clay. The coal series are named K-1 to K-4. The K-4 Subzone of thin coal layer is the end of the Planorbidae Molluscan Zone. It was interpreted as a swamp deposit (Songtham *et al.*, 2005a, b). Between the K-3 and K-4 Subzones, the thick Viviparidae beds of *Bellamyawere* were deposited. The thickest layer is about 12 meters, deposited in the southwest margin of the coal pit. In K-3 and K-2 were found *Planorbis* sp. In K-2, Planobidae occurred widely associated with *Paludina* in carbonaceous claystone. All taxa are missing from the carbonaceous claystone K-1 where mastodont remaly, the skeletons of mastodons with tusks and molars were discovered in this K-Zone (Songtham *et al.*, 2005a, b). At the boundary of the K-1 Subzone and the overburden claystone indicated is *Melanosides* sp., cf. *M. tuberculata* Molluscan Zone. This zone is covered by the overburden claystone and J-Zone. The sulfur isotope of pyrite from the Q-zone, K-zone, and the lower part of J-zone indicate the source of sulfur was from organic sulfur inferring in the freshwater environment (Silaratana *et al.*, 2004).

Member I is the upper most of Na Khaem Formation. The coal beds of J-Zone are thin and not much economic. J-Zone consists of six sequences of gray and greenish gray claystone, mudstone, and occasional siltstone and coal (J-1 to J-6). These beds are laminated to massive, planar type, highly calcareous, with fine grain pyrite spots common in some part, and with abundant gastropods (*Mellanoides* sp., *Physa* sp., *Viviparus* sp.), fish remains, ostracod, plant remains, reptile skeletal elements, load structures, intraformational conglomeratic texture of pumice and volcanic debris, and intermixed color texture near coal seams or coal layers, and burrows and borings. The thickness is about 100 to 150 meters. The upper part of this zone consists of two thin argillaceous layers (thickness less than 2 meters) and 13 thin seams of coal within J-1 to J-6. The sulfur isotope from the middle part of the J-zone indicate a volcanic source, and then in the upper part the sulfur isotope may indicate a marine incursion or opening of the basin during coal deposition (Tankaya, 2001, Silaratana *et al.*, 2003; 2004).

2.3 Huai Luang Formation

This formation was call the "red bed" by Longworth-CMPS Engineers (1981), It is the uppermost formation which consists of red to brownish red, semi-consolidated and unconsolidated claystone, siltstone, and mudstone with some lenses of sandstone and conglomerate, with some gray layer interbeds in some parts. No macrofossils were found but abundant gypsum and pyrite, rare roots and flame structures exist. The thickness of this unit varies from less than 5 to 350 meters. It is thickest in the central part of the main and western sub-basin, thinning rapidly towards the eastern and western margins, where it is entirely absent from the stratigraphic sequence or only a few meters thick. The upper part of the "red bed" is the coal I-Zone with an abundance of *Margarya* mollusks, partly pyritizatized (Songtham *et al.*, 2005b), about 50-150 cm thick and found especially where the sequences are completely present. Longworth-CMPS Engineers (1981) concluded that their red/brown colors are likely to be due to the oxidation of fine-grained pyrite and hematite disseminated throughout certain layers within the formation. However, the results of sulfur isotope deduce from the red bed zone indicated a sulfur source from marine vaporized sulfate, but from pyrite in gastropod from the I-zone coal indicated a sulfur source from bacterial reduction of sulfate to sulfur (Silaratana *et al.*, 2003, 2004).

2.4 Coal Quality

The coal quality at Mae Moh is classified as low coal, not only low rank but also low quality, suitable only for feeding coal-fired power plants, due to a high ash and sulphur content. The proximate analysis of Mae Moh coal varies: moisture 15-33%, ash 11-34%, volatile matter 18-40%, and fixed carbon 6-36%. The sulphur content varies from 1-5% and calorific values between 1,750-4,250 cal/gm. Vitrinite reflectance is between 0.34-0.40 %Ro. Coal petrography indicates that a majority of macerals are densiniteand gelinite with an abundance of alginite, sporinite, liptodetrinite, but rare inertinite. The mineral matter shows an abundance of framboidal pyrite, especially in J coal zone.

2.5 Age of Mae Moh Basin

The age of the Mae Moh coal has been given by Ginsburg *et al.* (1983) to be Middle Miocene, deduced from its association with *Stegolophodon* sp. Later, paleomagnetic investigations of the Mae Moh basin (Benammi *et al.*, 2002), in the lower third of the Na Khaem Formation, and contining into the Huai Luang Formation showed that this sequence correlates on the geomagnetic polarity time scale from the C5ACn chron to C5An.2n chron, (Fig. 3), between 13.5 and 12.1 million years ago. The average sedimentation accumulation rate is about 17.5 cm/ka, and ages of 12.5 and 12.8 million years ago can be extrapolated to the fossiliferous levels (J-5 and K-1, K-2 coal)

3. Methodology

Viviparidae shells from Mae Moh Mine were selected from stratigraphic sequences in the open pit. The collected samples were from the under R-zone, Under Q-Zone and the thick *Bellemya* bed in the K-zone. The samples of living fresh water mollusks were collected from the Kew Lom Reservoir, about 40 km. north of Mae Moh. Shell samples were crushed into powder to determine the mineral contents in the shells using x-ray diffractometry. The isotopes $^{13}C/^{12}C$ and $^{18}O/^{16}O$ were analyzed from dissolved, crushed shells by mass spectroscopy at the Center for Geo-Environmental Science, Faculty of Engineering and Resource Science, Akita University, 1-1 Tegatagakuen, Akita 010-8502 Japan.

3.1 Mineral determination

The samples were crushed and underwent d-spacing determination using a Rigogu x-ray diffractometer. The conditions used Cu K ? radiation with voltage of 40 kv and 20 mA., slit width DS 1 RS 0.3 SS 1, scan speed 2 degree/min and step/sample 0.2 degree. The samples were scanned from 2 degree 2 to 60 degree 2. The diffraction peaks were converted to d-spacing and the mineral contents were identified by comparing the set of d-spacing with the ASTM XRD Powder Data File.

3.2 Isotopic analysis

Approximately 25 milligram of samples were weighed and placed at the bottom part of the two arms of the reactor tube. Two milliliters of phosphoric acid were placed in the side arms. The reactor tubes were vacuumed until no gas or vapor were left in the reactor before placing them to reach equilibrium at 25 °C water bath. The reactor tubes were tilted, allowing the acid to react with the samples and were left in the water bath for complete reaction. The carbon dioxide gas from the reaction was purified using the cryogenic process with the aid of liquid nitrogen (temperature -190 °C.), a mixture of dry ice and acetone (temperature -88 °C.), and a vacuum pump. The volume of gas obtained from the reaction of each sample was measured for its percentage yield. The purified carbon dioxide was kept in an air-tight glass tube waiting for analyze by mass spectrometer for carbon and oxygen isotopes. The 12 Asc-2 L. No. 3 Carbon -oxygen isotopic standard was used to convert the isotopic ratio to PDB.

4. Results and Discussion

4.1 Mineral identification

The results of x-ray diffraction reveal the shells of Viviparidae in Mae Moh area, both fossils and Recent, are composed of only the single mineral aragonite.

4.2 Isotopic analysis

The isotopic results are shown in Table 1. The results reveal the Viviparidae shell ^{13}C values in Mae Moh Mine are between 3.52 - 6.92 ‰ PDB with the average of 5.52 ‰ PDB in the R-coal zone. In the Q-coal the ^{13}C value are between 4.17 - 5.77 ‰ PDB with the average of 5.12 ‰ PDB, which indicates a heavy isotope. In the K-coal zone the ^{13}C values are between 1.41 - 3.34 ‰ PDB with an average of 2.38 ‰ PDB. For oxygen isotopes the lower part of the basin showed the heavier isotope than the upper part, where the of ^{18}O values are between -3.15 and -5.10 ‰ PDB with an average of -

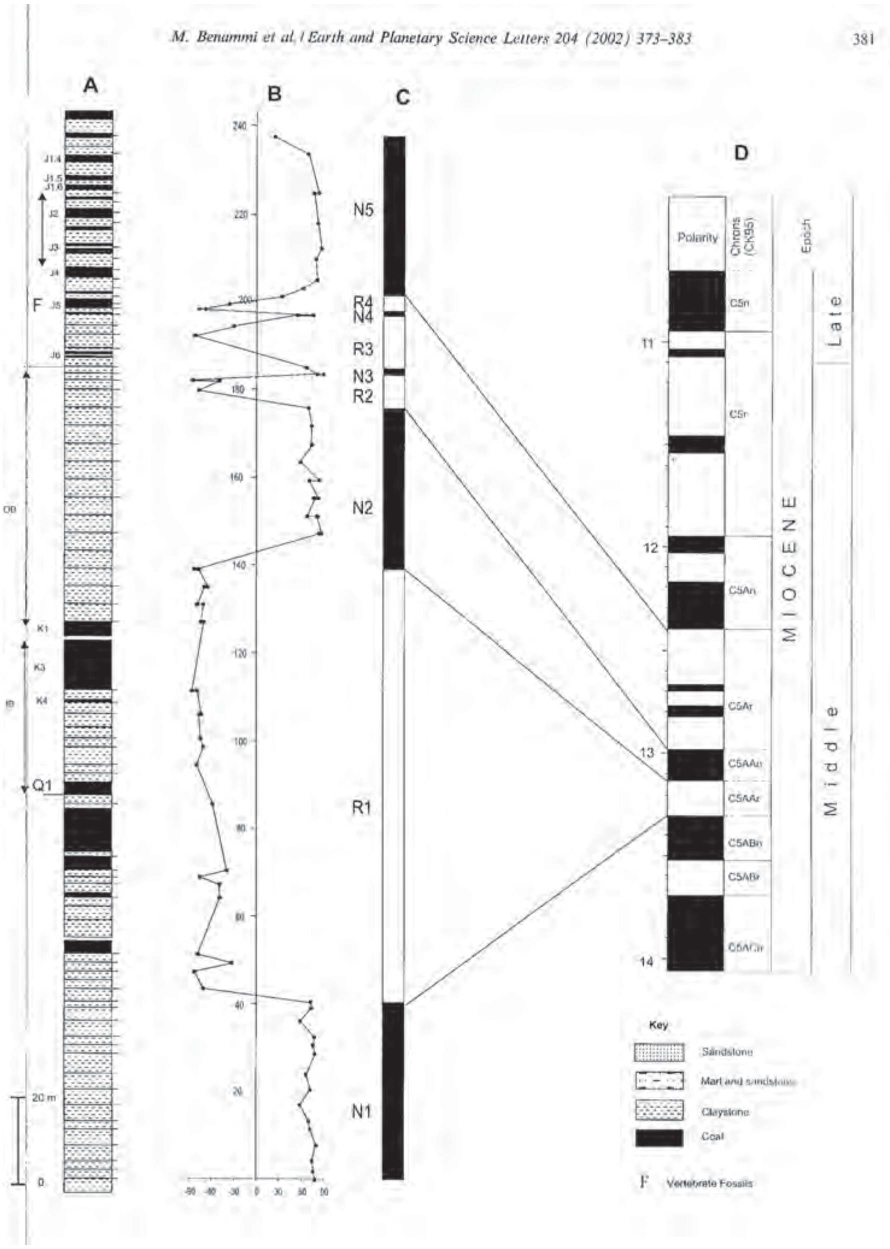

Fig. 3 Palaeomagnetic age dating of Mae Moh deposit (after Benammi *et al.*, 2002)

3.74 ‰ PDB in the R-coal zone, between -4.19 and -6.04 ‰ PDB with an average of -5.41 ‰ PDB in the Q-coal zone, and between -7.05 and -8.04 ‰ PDB with an average of -7.91 ‰ PDB in the K-coal zone. The isotope value of a Viviparidae shell collected from the Kew Lom reservoir in the Lampang area yielded ^{13}C values between -11.01 and -12.19 ‰ PDB with an average of -11.65 ‰ PDB and ^{18}O ‰ values between -6.64 and -7.04 ‰ PDB with an average of -6.76 ‰ PDB.

The isotopic results of Viviparidae fossil shells from the Mae Moh basin show a gradually change from the R-coal zone to the Q-, and the K-coal zone and significantly differ from Recent Viviparidae in the area. The heavy carbon isotope in the R-coal zone may imply a much cooler climate than during the Q- and K-coal zone deposition period when the area was much closer to the sea, especially when compared to the ^{13}C in the foraminifera (Srinivasan and Chaturvedi, 1990). Climatic conditions during Q- and K-coal zone deposition period were warmer and at a higher elevation or latitude than during deposition of the R-coal zone, as seen by the depletion of oxygen isotopes and enrichment of carbon isotopes (Andrusevich *et al.*, 2000). The changing records in the Mae Moh coal field are confirmed by temperate plant

Table 1 Result of carbon and oxygen isotopic analysis of Viviparidae from Mae Moh area.

Isotopic Analysis Viviparidae				
Analyze No.	**Sample Name**	**Type and locality**	**δ ^{13}C PDB**	**δ ^{18}O PDB**
		Mean of 12 Asc-2 L.No. 3 value **δ ^{13}C** measure =**33.88** **δ ^{18}O** measure = **21.75**	**0.72**	**-6.91**
Recent Viviparidae in Lampang Area				
7973	V1	*Filopaludina* sp. Kew Lom Dam Reservoir, Jae Hom, Lampang	**-11.01**	**-6.66**
7989	V111	F*ilopaludina* sp. Inner whirl, Kew Lom Dam Reservoir, Jae Hom, Lampang	**-12.19**	**-7.04**
7991	V112	*Filopaludina* sp. Middle whirl, Kew Lom Dam Reservoir, Jae Hom, Lampang	**-11.46**	**-6.76**
7992	V113	*Filopaludina* sp. Outer whirl, Kew Lom Dam Reservoir, Jae Hom, Lampang	**-11.92**	**-6.64**
		Average	**-11.65**	**-6.76**
Fossil Viviparidae in Mae Moh Mine, Lampang				
8055	V21	*Bellemya* sp. Mae Moh Mine K311-K4 Zone small and broken shell	**3.34**	**-7.05**
7976	V6	*Bellemya* sp., Mae Moh Mine, Lampang, K3	**1.41**	**-8.77**
		Average	**2.38**	**-7.91**
7977	V7	*Bellemya* sp. Mae Moh Mine, Lampang Under Q Zone	**5.77**	**-6.04**
7974	V4	*Bellemya* sp. Mae Moh Mine, Lampang Under Q Zone	**5.42**	**-4.19**
7975	V5	*Bellemya* sp. Mae Moh Mine, Lampang Under Q Zone	**4.17**	**-5.20**
		Average	**5.12**	**-5.14**
7988	V141	*Bellemya* sp., Mae Moh Mine R-Zone	**5.61**	**-6.52**
8034	V15	Bellemya sp., Mae Moh Mine R-Zone -0.5 m.	**4.37**	**-5.10**
8044	V16	*Bellemya* sp., Mae Moh Mine R-Zone-1m.	**3.52**	**-3.15**
8036	V17	*Bellemya* sp., Mae Moh Mine R-Zone-1m	**6.38**	**-3.07**
8037	V18	*Viviparus* sp.(small or Brit sp.) Mae Moh Mine R-Zone -1 m.	**6.92**	**-3.71**
8039	V20	*Viviparus* sp.R-Zone 10 m (Above the high wall)	**4.9**	**-3.68**
		Average	**5.22**	**-3.74**

fossils in other Oligocene to Lower Miocene basins in Northern Thailand. Palynofloras and fossil leaves have been recovered from the sedimentary sequences of the Na Hong coal mine in Mae Chaem, Chiang Mai, the Ban Pa Kha coal mine, and the Ban Pu and Na Klang coal mines in Li Basin, northern Thailand (Endo, 1963; 1964; 1966, Songtham *et al.* 2003; 2005a & b).

The basins and vicinity were occupied by warm temperate plant communities. The taxa include *Pinuspollenites*, *Alnipollenites verus*, *Momipites coryloides*, *Tsugaepollenites*, and *Inaperturopollenites*. The climate became warmer and wetter with time. This is indicated by the appearance of some pollen and spores, including *Lagerstroemia*, *Striatriletes*, *Perfotricolpites* *digitatus*, *Sporotrapoidites*, the algae *Pediastrum* and *Botryococcus*, and the fungus *Desmidiospora willoughbyi*. The age of the floras is Late Oligocene to Early Miocene. The change to a more tropical climate observed in Mae Moh stratigraphy, as recorded by the palynological assemblage (Meesuk,1986; Watanasak, 1988; Songtham *et al.*, 2005a, b) may have occurred during the Middle Miocene, as indicated by paleomagnetic age dating in the K- and Q-coal zone (Benammi *et al.*, 2002, 2003; Fig. 3).

The beginning of northern Thailand segment movement from the warm temperate area is not clearly understood. However, the age dating of the Mae Ping Fault zone at 29-31 Ma (Lacassin *et al.*, 1997; Ahrendt *et al.* 1993, 1994, 1997) may be the closest related events. The northward movement of the Australian-Indian plate and collision with the Eurasian plate, and the westward subduction of the Pacific plate, are suspected to be two major causes of the splitting and pushing of the northern Thailand segment southwestward along the Sakiang, Mae Ping and Red River Fault zones.

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Plate 1 *Bellemya* sp.bed between K3-K4 coal zone, Southwest Pit, Mae Moh Mine. **a.** *Bellemya* sp. bed. **b.** Close up the *Bellemya* sp. shell.

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The Padaeng Supergene Nonsulfide Zinc Deposit, Mae Sod, Thailand

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Abstract

The Padaeng deposit near Mae Sod in western Thailand was the first supergene nonsulfide zinc deposit in the world to be developed as a large modern mining operation. The mine and associated zinc smelter, operated by Padaeng Industry Public Company Ltd. since 1984, went into production with reserves of 4.59 Mt at a grade of 28.9 percent zinc with a 10 percent zinc cutoff. Current resources are 5.14 Mt at a grade of 12.0 percent zinc with a 3 percent zinc cutoff.

The Padaeng deposit is hosted by a mixed carbonate-clastic sequence of Middle Jurassic age. The deposit occurs in the hanging wall of the Padaeng fault, a major northwest-trending structure that was active through Cretaceous and Tertiary tectonism and uplift. Nonsulfide zinc ore comprises dominant hemimorphite with minor smithsonite and hydrozincite. Strata-bound ore zones occur within a northwest-dipping, deeply weathered, dolomitic sandstone; steeply dipping and irregular karstic zones in underlying massive, silty dolomite are controlled by north-trending fracture zones.

Sulfide zinc-lead mineralization of Mississippi Valley type occured extensively in the vicinity of the Padaeng mine, most notably the small resources at Pha De and Hua Lon. Mineral deposits are typically sphalerite rich with minor galena and pyrite, forming small-scale open-space fillings, veins, and replacements within hydrothermal dolomite. Mineralization is dominantly strata bound within a horizon of intense hydrothermal dolomitization that forms the stratigraphic hanging wall to the nonsulfide ore zones at Padaeng. The only significant sulfide at the Padaeng mine is within this unit. Only trace sulfide occurs peripheral to, or down dip of, strata-bound or steeply dipping, nonsulfide orebodies.

Sulfide mineralization is believed to have accompanied Cretaceous uplift and deformation, related to the onset of oblique subduction beneath the western margin of the Shan-Thai terrane. The nonsulfide deposit is believed to have formed when a substantial body of sulfide ore was uplifted on the margin of the Mae Sod Tertiary intermontane basin, commencing in the middle to late Miocene. Zinc-bearing acidic supergene fluids, generated by oxidation of the precursor sulfide body, reacted with carbonate in the underlying stratigraphic section to precipitate hemimorphite and smithsonite. Fluids were channeled by permeable dolomitic sandstones and by steep fracture and fault zones. Acidic fluids promoted deep weathering and karst formation, allowing mineralization to extend down dip in sandstone units for at least 150 m and vertically for a similar distance in steep structural zones. Transport of zinc out of the precursor sulfide body was facilitated by a falling water table, owing to uplift of the Padaeng fault block and a change from wet tropical to monsoonal or semiarid climatic conditions. There is no evidence for significant in situ replacement of sulfide deposits, and the leached remnants of the precursor sulfide body have been removed by erosion.

The supergene process of dissolution and reprecipitation of zinc in the host rocks increased zinc grades and separation of zinc from lead, producing an economically attractive deposit. Successful exploration for this type of deposit requires a good understanding of the controls on primary sulfide mineralization and a good knowledge of local neotectonism, uplift history, hydrogeology, climatic evolution, and weathering history.

Introduction

THE PADAENG mine is situated in Tak Province in northwestern Thailand, about 20 km southeast of Mae Sod town, close to the Myanmar border (Fig. 1). Located at an elevation of 420 to 640 m in hill country on the eastern edge of the Mae Sod intermontane basin, the mine commenced production in 1984 from a high-grade, nonsulfide zinc deposit having an initial reserve of 4.59 Mt at 28.9 percent zinc at a 10 percent zinc cutoff. To date, about 4.8 Mt of ore at a grade of 20 percent zinc have been mined. The mine and a purpose-built zinc smelter in the provincial capital, Tak, are owned and operated by Padaeng Industry Public Company Ltd., which is 46 percent owned by Umicore of Belgium.

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The Padaeng deposit was discovered in 1947 by the Thai Department of Mineral Resources. The local name Padaeng means “red cliff,” referring to the red secondary zinc outcrops on the hillside and a treeless vegetation anomaly on which a Buddhist chedi (or stupa) was sited. The deposit was drilled intermittently by Thai government-controlled companies and consultant groups in the period from 1957 to 1975. Padaeng Industry Public Company Ltd. was established by the Thai government in 1981 in a joint venture with Vielle Montagne of Belgium, which designed the treatment process for the Tak smelter. Annual mine production peaked at over 427,000 t in 1991 and is currently about 150,000 t. The ore is treated by acid leaching, filtration, and electowinning at the Tak smelter to produce Special High Grade zinc and zinc alloy. Commissioning of the Rayong roaster in 1995 provided an additional feed source for the Tak smelter. Blending of mine production

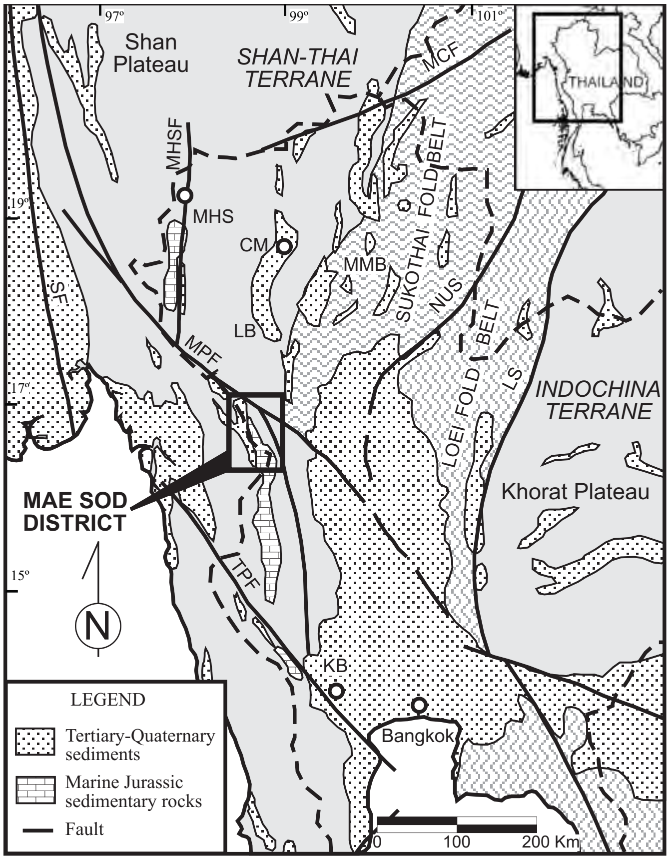

Fig. 1. Major tectonic features and Tertiary basins of Thailand, showing distribution of marine Jurassic sedimentary rocks and location of the Mae Sod district. CM = Chiang Mai, KB = Kanchanaburi, LB = Li basin, LS = Loei suture, MCF = Mae Chan fault, MHS = Mae Hong Song, MHSF = Mae Hong Song fault, MMB = Mae Moh basin, MPF = Mae Ping fault, NUS = Nan-Uttaradit suture, SF = Sagaing fault, TPF = Three Pagodas fault.

with higher-grade calcine from the roaster allowed the mine cutoff grade to be lowered to 5 percent zinc. Current annual production at Tak is about 105,000 t of zinc.

Renewed exploration in and around the Padaeng mine since 1998 has resulted in the delineation of significant resource extensions. Pilot beneficiation by screening and flotation has allowed the cutoff grade to be further reduced to 3 percent zinc. On this basis, total resources and reserves in January 2002 were estimated at 5.14 Mt at 12.0 percent zinc.

The Padaeng deposit was first described by Morinaga (1963). Geological work and research on the deposit has been limited, particularly in the first 10 years of production. Mining since 1998 has allowed examination of progressive exposure through the deposit, and detailed mapping and logging of drill core in this period has generated a much-improved understanding of the setting and controls of the zinc mineralization.

Regional Geologic Setting

The Padaeng deposit is situated in the Shan-Thai or Sibumasu terrane, a crustal block that includes western Thailand and eastern Myanmar (extending north into Yunnan), western peninsular Malaysia, and much of Sumatra. This crustal block, of Gondwanan origin, drifted north in the Permian to collide with the Indochina terrane in the Triassic, forming the Sukothai and Loei fold belts of central Thailand (Fig. 1; Bunopas, 1981; Mitchell, 1981; Metcalfe, 1988, 1995, 1996).

The Padaeng deposit occurs within a Middle Jurassic sequence deposited unconformably on Permo-Triassic clastic, carbonate, and volcanic rocks that were subjected to lower greenschist facies metamorphism in the Triassic collisional event. Late orogenic Triassic batholithic granitoids were emplaced to the east of the district.

The dominantly marine Middle Jurassic host sequence includes significant carbonates and forms a broadly synformal belt that extends 200 km from north to south through the Mae Sod district (Fig. 2). Meesook and Grant-Mackie (1997) considered the Mae Sod sequence together with marine Jurassic sequences to the north in Mae Hong Son and to the south in Kanchanaburi to represent a single Jurassic depositional basin, termed the Mae Hong Son-Kanchanaburi basin (Fig. 1). Middle Jurassic carbonates and deep-water flysch sedimentary rocks are also reported from the northern and southern Shan Plateau of Myanmar, indicating that marine conditions had returned to the western part of the Shan-Thai block by the Middle Jurassic. The setting was probably a marginal marine shelf on a passive continental margin with significant clastic inputs derived from large river systems.

Increased tectonism and uplift accompanied the initiation of Indian Ocean spreading in the Late Jurassic and collision of the West Burma terrane with the western margin of the Shan-Thai terrane in the Late Cretaceous. The development of numerous fault-controlled intermontane basins through northern Thailand (Fig. 1), filled with continental sedimentary rocks of Eocene to Pliocene age, may be related to a change in relative plate movements in the Eocene. North-south–oriented basins may have opened in response to clockwise rotational stress and dextral movement on a number of major northwest-trending strike-slip faults, accompanying dextral strike-slip movement on the Sagaing fault and oblique subduction beneath the western margin of the West Burma terrane (Packham, 1993). A middle Miocene unconformity recognized in a number of basins may be related to initiation of spreading in the Andaman Sea, which relieved extensional stresses within the Southeast Asia block. An alternative theory suggests that Tertiary movement on these faults was sinistral, accommodating Indian collision and the "extrusion" of Southeast Asia (Tapponier et al., 1982; Lacassin et al., 1997).

The Mae Sod intermontane basin is a north-south–oriented half-graben, about 65 km long and 35 km wide, containing significant oil shale deposits of Pliocene to Pleistocene age. Oil shales were deposited in perennial lakes within a sandstone and marl sedimentary sequence that was deposited in ephemeral lake and alluvial flat environments (Gibling et al., 1985).

Both the Jurassic belt and the Mae Sod basin are terminated to the north by the Mae Ping fault, one of the major northwest-trending, strike-slip structures of late Mesozoic to Tertiary age (Fig. 2).

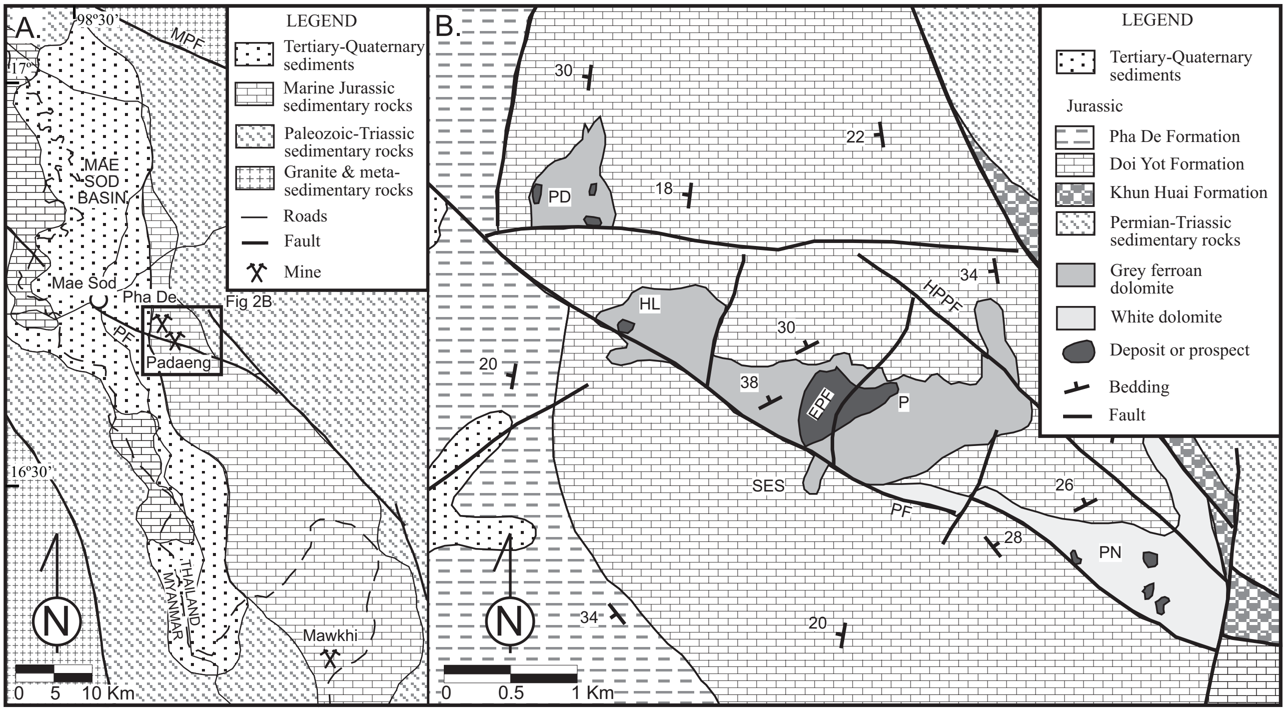

FIG. 2. A. Summary geology of the Mae Sod district showing location of the Padaeng mine and other Jurassic-hosted zinc deposits. B. Geology and mineral deposits of the Padaeng fault zone showing principal sulfide and nonsulfide zinc deposits and prospects. EPF = East Pit fault, HL = Hua Lon sulfide deposit, HPPF = Huai Pa Pu fault, MPF = Mae Ping fault, P = Padaeng mine, PD = Pha De sulfide deposit, PF = Padaeng fault, PN = Padaeng Noi nonsulfide deposit, SES = Southern Extension slump.

Local Geology

Jurassic stratigraphy

The Jurassic sequence is characterized by interbedded mixed clastic and carbonate lithologies. Formal terminology for the Jurassic stratigraphy in the Mae Sod area was established by Meesook and Grant-Mackie (1997) following that of von Braun and Jordan (1976). The Jurassic comprises a mixed clastic-carbonate sequence of Toarcian to early Bajocian age, assigned to the Huai Fai Group in the Mae Sod area and to the Umphang Group south of Padaeng. Both groups are equivalent to the upper Mae Moei Group of von Braun and Jordan (1976). The Hua Fai Group is subdivided from base to top into the Khun Huai Formation, Doi Yot Formation, and Pha De Formation, on the basis of the type section along the Huai Mae Sod River. The sequence generally dips shallowly and becomes younger to the west (Fig. 2).

As defined by Meesook and Grant-Mackie (1997), the Khun Huai Formation is about 140 m thick and comprises basal limestone conglomerate, interpreted to lie unconformably on the Triassic, overlain by limestone, marl, and interbedded mudstone. The Doi Yot Formation consists of mudstone with interbedded limestone and lenses of cross-stratified sandstone, totaling about 370 m in thickness. The upper part comprises alternating limestone and mudstone with abundant fossils. The Pha De Formation is a limestone-marl–dominated sequence with minor mudstone, including oncolitic beds. The upper contact is concealed by overlying Tertiary sedimentary rocks.

The Jurassic sequence in the Padaeng mine area is shown in Figure 2, on the basis of the formations defined by Meesook and Grant-Mackie (1997). However, direct lithologic correlations with their stratigraphy are difficult, which may partly reflect significant lateral facies variations. Characteristic lithologies in the mine area include micritic wackestone, bioclastic argillaceous limestone, oncolitic limestone, sandy oolitic limestone, calcareous sandstone, siltstone, and mudstone. Similar lithologies are repeated throughout the sequence, making stratigraphic subdivision difficult. There is evidence of lateral facies variation, and sandy units may be quite lensoid.

The stratigraphic interpretation of the Padaeng mine and Padaeng fault zone is shown in Figure 2. Basal limestone conglomerate and sandstone, unconformably overlying Triassic clastic and carbonate sedimentary rocks to the east, are assigned to a thinned Khun Huai Formation. Mineralization is interpreted to be hosted by the Doi Yot Formation, composed of basal sparry bioclastic and micritic limestone overlain by interbedded calcareous siltstone and mudstone, passing up into a sequence including interbedded micritic limestone, bioclastic and oncolitic argillaceous limestone, sandy oolitic limestone, and calcareous sandstone. In the west, the Pha De

Formation is dominated by sandstone with sandy oolitic limestone horizons and subordinate horizons of calcareous mudstone. These rock units dip west under coarse Tertiary clastics.

Sedimentology

The Jurassic sedimentary rocks are interpreted to have accumulated in a shallow shelf to marginal marine environment. Limestones vary from high-energy, variably sandy, oolitic units to moderate-energy, peloidal bioclastic units with oncoids and coated ooids, to low-energy, micritic wackestones with sparse bioclasts. Coral bafflestone and boundstone occur in the upper part of the Doi Yot Formation. Sandstones and sandy limestone units may show a lensoid, channelized morphology and commonly display trough cross-lamination. Sandstone and sandy limestone commonly contains coaly plant debris, indicating proximity to terrestrial clastic source areas. Mudstones and siltstones are parallel laminated and calcareous or dolomitic, and locally they contain gypsum bands, suggesting a lagoonal to intertidal depositional environment.

Limited sedimentological studies have been undertaken in the area by Ratanasthein (1993). The lithologic relationships suggest a pattern of tidal shoal, reefal, and sheltered to lagoonal depositional environments that received partly channelized influxes of sandy terrigenous sediment. Minor argillaceous limestones contain scattered ammonites and may reflect deeper water, subwave-base environments.

Deformation and metamorphism

The Middle Jurassic sequence that hosts base-metal mineralization at Padaeng was deposited after Triassic orogenesis and is essentially unmetamorphosed. Deformation is limited to faulting and open folding, reflecting Cretaceous to Tertiary events accompanying the subduction and collision of the West Burma and Indian terranes to the west. The Jurassic sequence generally dips west at 20° to 40° toward the Mae Sod basin, which may occupy a synformal zone rifted as a half-graben in the Tertiary.

The basement structural grain in the district is approximately north-northwest, reflecting the Triassic deformational event. The major northwest-trending Padaeng fault and related structures are oblique to this grain and subparallel to the Mae Ping strike-slip zone to the north and the Three Pagodas fault to the south (Figs. 1 and 2). Although the overall offset on these faults is sinistral, current motion is dextral, and Packham (1993) argues that movement has been dextral-transpressive since at least the Late Cretaceous. Dextral transpression is compatible with the observed geometry of the Padaeng fault, which is interpreted as a dextral thrust dipping shallowly northeast at 40° to 60° and forming a flower structure (a number of clockwise splays such as the Huai Pa Pu fault) in the area of the Padaeng mine (Fig. 2). Bedding strike within the fault zone is rotated clockwise, resulting in a northwest to north dip direction (Fig. 2).

The total amount of movement on the Padaeng fault is unknown. Significant displacement would be expected across such a major structure, but Jurassic sedimentary units appear to continue across the fault without major offset (Fig. 2). This observation could be explained by later dextral movement that cancelled out earlier sinistral movement. It could also be explained by dextral transpressive displacement with a movement vector close to the plunge intersection of bedding with the fault plane. Although some stratigraphic variation is evident across the fault zone, there is no definite evidence that the Padaeng fault was active during Jurassic sedimentation.

The Padaeng fault is up to 100 m wide, as indicated by drill hole intersections and exposure along a major topographic scarp (Fig. 3). The footwall is marked by increasing fractures, veins, and steepening dips, transitional into a zone of intense shearing and brecciation. The hanging wall is marked by a zone of rubble, mosaic and crackle breccia, interpreted to be of hydraulic origin, and it is typically intensely dolomitized.

Padaeng Mine

Geology

The Padaeng deposit occurs on Padaeng Hill, a prominent topographic feature rising to 650 m and bounded to the southwest by the Padaeng fault scarp (Figs. 3 and 4). The orebody is situated in a saddle between two summits, and ore-grade mineralization extends from elevations of about 620 to 400 m. Bedding dips to the northwest at 25° to 35° in the mine area.

Zinc mineralization at Padaeng is hosted within dolostone, weathered dolomitic sandstone, and sandy dolostone of the Jurassic Doi Yot Formation (Fig. 2). The deposit is bounded to the south by the northeast-dipping Padaeng fault, intersected in deep drill holes in the south of the pit where it consists of a thick breccia zone overlying sheared and veined argillaceous and silty limestones. Only trace sphalerite occurs in the dolomitic breccias.

The stratigraphy in the pit is offset by the East Pit fault, a shallowly west-dipping north- to north-northwest–striking normal fault with an offset of about 100 m (Fig. 5). The East Pit fault zone comprises a broad, 10- to 20-m-wide zone of mosaic to crackle breccias cut by later shear planes.

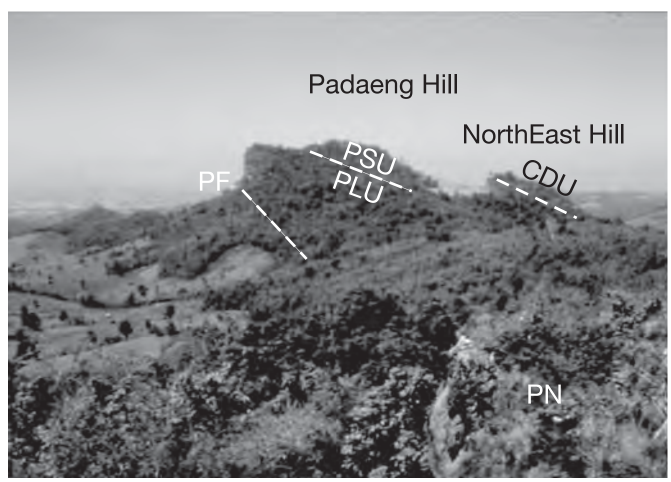

FIG. 3. View of the Padaeng fault scarp from Padaeng Noi, looking west over the Tertiary Mae Sod basin. The Padaeng mine is behind the high ridge formed by carbonates of the Pit Limestone unit. Outcrop in the foreground is dolomitized breccia in the hanging wall of the fault, hosting low-grade supergene zinc mineralization (1–3% Zn). CDU = Crystalline Dolostone unit, PF = Padaeng Fault, PLU = Pit Limestone unit, PN = Padaeng Noi low-grade zinc outcrop, PSU = Pit Sandstone unit.

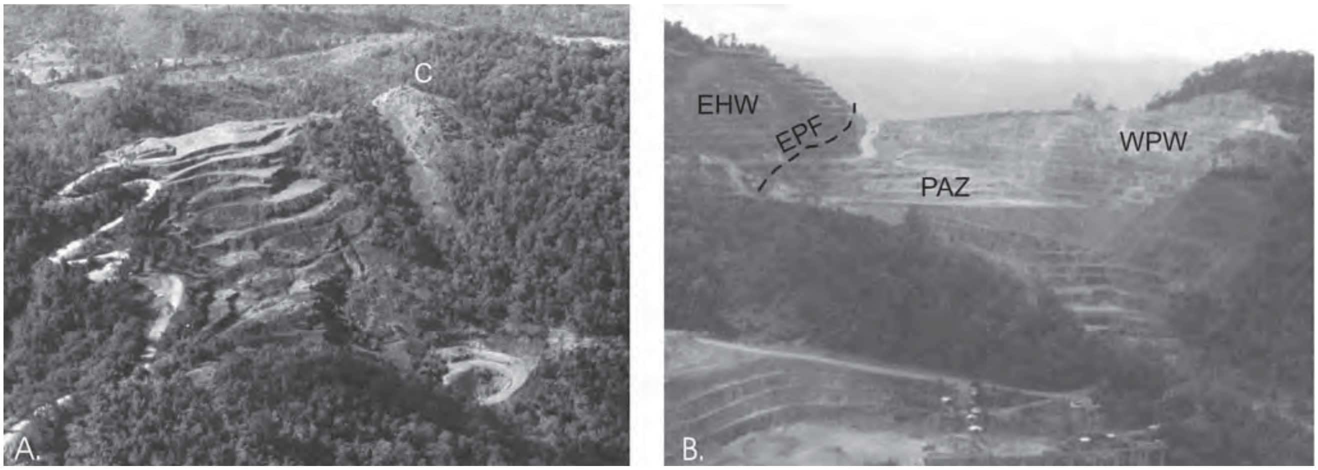

FIG. 4. A. Photograph of the Padaeng mine viewed from the north in 1985, shortly after the commencement of mining. Benches on the left are developed on the main high-grade strata-bound blanket, which dips northwest close to the slope of the hill. On the right, a Buddhist chedi (or stupa) is sited on top of high-grade hemimorphite outcrops. B. Photograph of the Padaeng mine from the north in 2000. The Eastern high wall on the left is the footwall to the original high-grade strata-bound blanket, on the eastern hanging wall side of the East Pit fault. Strata-bound ore zones on the western footwall side of the fault dip under the western pit wall. The central axis of the pit is occupied by steep structural and karstic ore zones in the footwall of the fault. C = Chedi, EHW = Eastern high wall, EPF = Eastern Pit fault, PAZ = Pit axis zone, WPW = Western pit wall.

The local stratigraphic sequence comprises (1) Lower Limestone unit, exposed in the southern part of the pit as black argillaceous to shaly limestone and oncolitic, fossiliferous micritic wackestone; (2) Pit Limestone unit, dominated by thick-bedded, fine-grained, variably silty limestone with minor sandy oolitic and bioclastic argillaceous beds, all pervasively replaced by hydrothermal dolomite in the mine area; (3) Pit Sandstone unit, comprising cross-laminated calcareous sandstone, oolitic sandy limestone, and minor argillaceous bioclastic limestone, pervasively dolomitized in the mine area; (4) Crystalline Dolostone unit, comprising medium to coarsely crystalline hydrothermal dolostone, commonly vuggy, with partial or complete destruction of primary textures (it apparently preferentially replaces a clean oolitic limestone, but is discordant in part and extensively replaces the overlying Upper Bioclastic Limestone unit); (5) Upper Bioclastic Limestone unit, including oolitic bioclastic argillaceous limestone at the base passing up into oncolitic and bioclastic, micritic wackestone, and packstone with thin argillaceous interbeds.

Nonsulfide mineralization

Prior to mining, high-grade, nonsulfide zinc ore formed an outcropping blanket on the northwest-facing dip-slope of the southeastern summit, where zinc grades commonly attained 30 to 40 percent (Fig. 4). Poor and inconsistent logging of early drill holes, due in part to strong weathering, ensures some uncertainty in determining the exact stratigraphic position of the original high-grade zinc blanket. Data suggest that it was hosted largely within the upper part of the Pit Sandstone unit and extended into the Crystalline Dolostone unit, in the footwall of the East Pit fault (Fig. 5). This interpretation conforms with descriptions in early company reports indicating that the western part of the deposit was “sandy,” contained significant quartz, and was dominated by hemimorphite, whereas the eastern part was dominated by smithsonite at the surface with minor dolomite and calcite and passed down into hemimorphite at depth (Morinaga, 1963; T.O. Veit, unpub. report for Watts, Griffis and McOuat to Thai Zinc Ltd., 1973). The irregular base to the high-grade blanket has become more apparent as mining has progressed and with the additional information provided by drilling.

At the current pit level, three dominant geometries of mineralization are present: (1) strata-bound zones, occurring mostly within sandy horizons in the Pit Sandstone unit; (2) steeply dipping, linear, north-northwest– to north-northeast–trending mineralized zones; and (3) irregular karstic zones in the Pit Limestone unit. A fourth style of supergene zinc mineralization occurs at Khang Phiban, 100 m northwest of the current pit in the stratigraphic hanging wall of the main ore zones (Fig. 5). Here, high-grade smithsonite occurs in outcrop, capping low-grade sphalerite mineralization in the Crystalline Dolostone unit. Weaker sphalerite mineralization and minor smithsonite occur in the same stratigraphic position on the Northeast Hill, immediately northeast of the pit.

The dominant ore zone geometry is strata bound, principally within the Pit Sandstone unit as downdip extensions of the original high-grade blanket (Figs. 5 and 6). Although low-level zinc enrichment (>0.5% zinc) is extensive within the weathered Pit Sandstone unit, higher-grade strata-bound ore zones (3–15% zinc) are constrained to favorable coarse sandstone units. Strata-bound zones are also found within sandy units of the underlying Pit Limestone unit. The highest grade and thickest mineralized zones may terminate abruptly within the plane of bedding; they are apparently related to zones of steep fracturing or faulting (Figs. 5 and 6C). Hemimorphite occurs as a secondary cement within the weathered sandstone units, as network veinlets, or as semimassive botryoidal replacements (Fig. 6).

Strata-bound ore extends northwest down the dip of the sandstone units for over 150 m from the pit surface (Fig. 5).

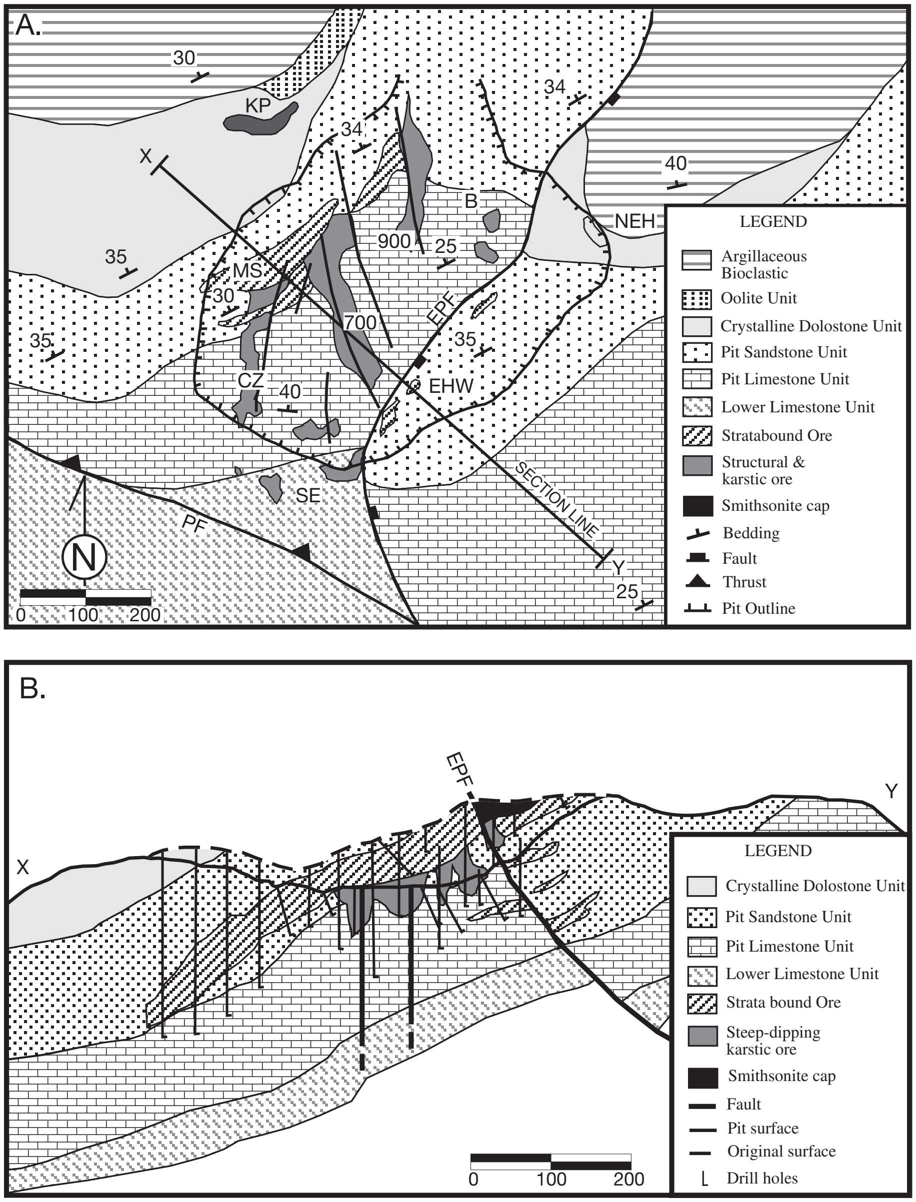

FIG. 5. A. Geology of the Padaeng mine pit and environs. B. Cross section of the Padaeng deposit; the orebody is projected from the current pit surface to the original land surface to show the geometry of the high-grade outcrop zone, defined on the basis of drill hole intersections. Mineralization at the original surface in the hanging wall of the East Pit fault was probably hosted by the Crystalline Dolostone unit. 700 = 700 ore zone, 900 = 900 ore zone, BZ = Box zone, CZ = Chedi ore zone; EHW = Eastern high wall, EPF = East Pit fault, KP = Khang Phiban smithsonite zone, MS = main strata-bound ore zone, NEH = northeast hill, PF = Padaeng fault, SE = southern extension.

Boundaries of mineralization correspond with the weathering front within fresh dolomitic sandstone, and may be irregular and diffuse in the plane of bedding. No significant sulfide mineralization occurs down dip of the strata-bound supergene ore zones. Strata-bound mineralized zones may vertically underlie up to 180 m of less-weathered dolomitic sandstone and dolostone.

Steeply dipping mineralized zones are best developed in the Pit Limestone unit, underlying the strata-bound zones in the Pit Sandstone. Mineral deposits occur in deeply weathered bedrock and karst-fill, apparently controlled by northwest-trending to north-northeast–trending fracture zones (Figs. 5 and 7), although most structures are not well defined at the present level of exposure and some well-defined faults are poorly mineralized. The important ore zones through the axis of the pit (Chedi, 700 and 900 ore zones; Fig. 5) are deeply oxidized with karstic cavities or fissures filled with clay, sand, and lithic fragments derived from overlying weathered sandstone (Fig. 7A). Hemimorphite occurs as disseminations, as vein networks, and as semimassive botryoidal zones termed "hard ore" (Fig. 7B, D). Hemimorphite may also form a cement in zones of shattered dolostone.

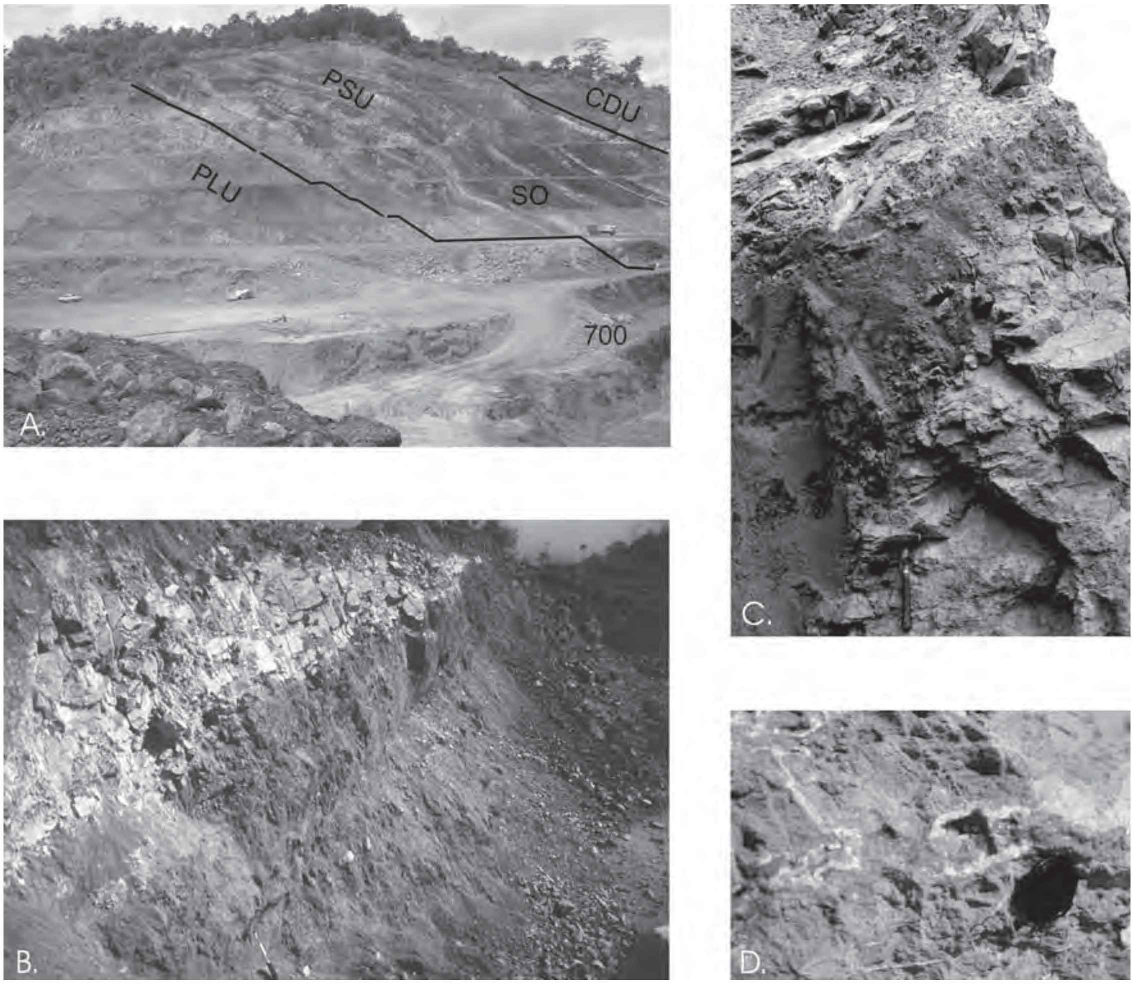

FIG. 6. A. Western wall of the Padaeng pit, showing thick-bedded massive Pit Limestone unit on the left passing up into more thinly bedded Pit Sandstone unit containing dark-brown, deeply weathered, strata-bound mineralized horizons. The Crystalline Dolostone unit crops out in the extreme top right of the picture. In the bottom foreground, the karstic 700 ore zone cuts the Pit Limestone unit through the axis of the pit. Bench height is 6 m on west wall. B. Deeply weathered, strata-bound ore zone (dark) in the western pit wall, overlain by less-weathered and weakly mineralized dolomitic sandstone (light). Bench height is 3 m. C. Low-grade strata-bound ore in sandstone cut by high-grade hemimorphite ore (dark) in a steeply dipping fracture zone. Hammer (bottom) is 32 cm long. D. Close-up view of moderate-grade, strata-bound mineralization in sandstone; hemimorphite is present as cement in the weathered sandstone and as crosscutting vuggy vein zones. Lens cap diameter is 6 cm. Abbreviations: 700 = 700 Ore zone, CDU = Crystalline Dolostone unit, PLU = Pit Limestone unit, PSU = Pit Sandstone unit, SO = Strata-bound ore.

The steeply dipping ore zones appear to be contiguous with the highest grade and thickest strata-bound ore zones in the overlying Pit Sandstone unit (Fig. 5). Crosscutting hemimorphite mineralized zones are exposed within the sandstone along the northern strike extension of the Chedi structural ore zone, and they appear continuous with strata-bound mineralized zones, indicating a degree of structural control on the strata-bound mineralization.

Irregular karstic zones are less clearly constrained by linear structures but appear to reflect interaction of multiple fracture and joint orientations. The "Box zone" in the northeast pit is a 20 × 20 m ore zone in plan view that cuts vertically through at least 80 m of weathered silty dolostone (Figs. 5 and 7C). Karstic fill in the Box zone is similar to that within the linear fracture zones. Boundaries of steeply dipping and karstic ore zones are typically sharp and discordant to variably weathered lithologies of the Pit Limestone unit. No significant sulfide ore occur peripheral to, or vertically beneath, steeply dipping or karstic ore zones.

Supergene mineralization does not show any strong spatial association with the East Pit fault. Fault-related breccias are locally cut by hemimorphite veins and breccias, and locally by semimassive, high-grade "hard ore." However, in places hemimorphite zones are also cut by shear planes within the fault zone (Fig. 7D).

South of the pit, at the base of the Padaeng fault scarp, the Southern Extension zone comprises blocks of high-grade secondary zinc deposits in a low-grade, zinc-mineralized clay matrix (Fig. 2). The mineralized zone is up to 5 m thick and overlies unmineralized silty limestone and argillaceous siltstone in

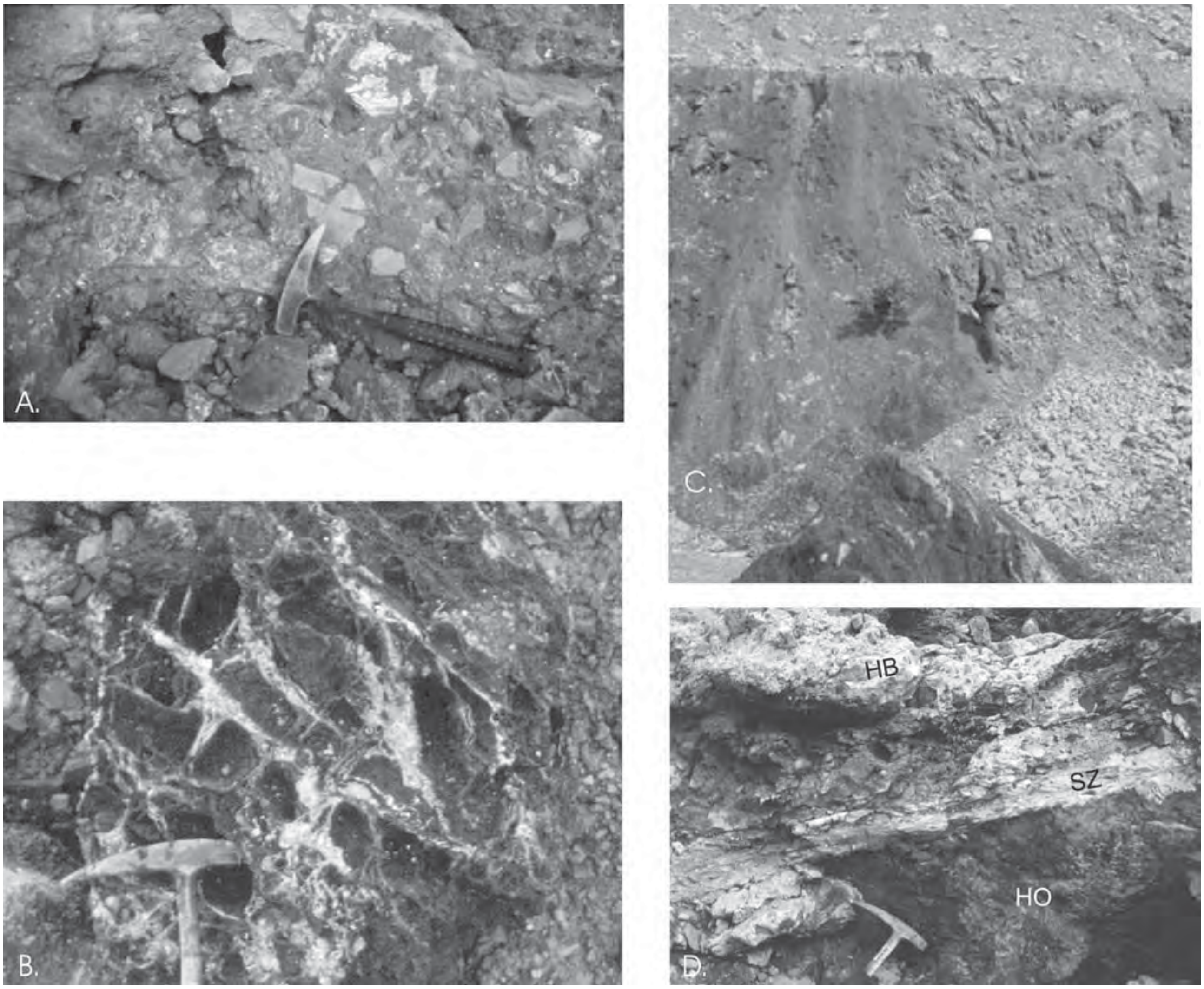

FIG. 7. A. Karstic breccia comprising sand and lithic clasts in an iron-rich clay matrix with low-grade hemimorphite mineralization. Hammer is 32 cm long. B. Network of hemimorphite veins in clay-rich, karst-fill material. Hammer head is 17 cm long. C. Contact of the Box zone, showing karstic ore (dark) cutting bedding in weathered silty dolostone. Bench height is 3 m. D. Shear zone within the Eastern Pit fault cuts fault-related breccias that are partly replaced by high-grade hemimorphite "hard ore." Hammer head is 17 cm long. FB = fault breccias, HO = hard ore, SZ = shear zone.

the footwall of the Padaeng fault. This relationship is interpreted to reflect slumping of secondary ore owing to gravity collapse along the fault scarp, prior to mining.

Mineralogy and geochemistry

The mineralogy of the supergene zinc ore at the current pit level is overwhelmingly dominated by hemimorphite. In high-grade "hard ore" within karstic or strata-bound zones, hemimorphite occurs as radiating, crystalline botryoidal masses that may contain minor remnant quartz. Much of the remaining ore is of strata-bound type, consisting dominantly of lithic arenite to subarkose with grains cemented by radiating crystalline hemimorphite that has entirely replaced the dolomitized carbonate cement. Quartz grains are preserved, but feldspar and lithic grains are replaced by sericite and clays. Iron oxides and hydroxides also occur within the matrix and replace feldspar and lithic clasts. The weathered sandstone ore is generally friable and "free digging." Crystalline hemimorphite also occurs in places within fracture veins in sandstone and more rarely in dolostone. The mineralogy of clay-rich karstic ore is not well defined, but recent X-ray diffraction studies suggest that fine-grained hemimorphite and smithsonite are present. Sauconite clays have not been identified.

Previous descriptions indicate that smithsonite zones were present at the surface in the eastern part of the deposit but were underlain by hemimorphite (T.O. Veit, unpub. report for Watts, Griffis and McOuat to Thai Zinc Ltd., 1973). The highest zinc grades (>40%) occurred in an indurated surface layer, within both the smithsonite and hemimorphite zones, underlain by softer ore having lower zinc grades. Hydrozincite occurred mostly as cavity fill within the near-surface part of the orebody, accompanied by loseyite ($[Mn, Zn]_7[CO_3]_2[OH]_{10}$) and clay minerals. Goethite, maghemite, chamosite, limonite, and clay minerals occurred throughout the deposit. The iron content of the ore was interpreted to be inversely related to zinc grade and generally constituted about 5 percent Fe in high-grade ore but reached 20 percent in some low-grade zones (T.O. Veit, unpub. report for Watts, Griffis and McOuat to Thai Zinc Ltd., 1973). Clay mineral content and the percentage of aluminum also increased with decreasing zinc grade.

During the period 1999 to 2002, when zinc production grades averaged about 15 percent, iron concentrations averaged 3.3 percent Fe and cadmium 3,000 ppm. This trend suggests that iron contents decrease with depth.

Lead contents in the supergene ore are uniformly low, typically 500 to 700 ppm. Cadmium contents are high, and concentrations above 1 percent have been recorded in shallow, high-grade smithsonite zones. Manganese concentrations are generally between 0.1 percent and 0.4 percent. On the basis of a limited number of multielement analyses, antimony and arsenic concentrations are significantly elevated, up to 132 ppm and 280 ppm, respectively. Copper content is typically low, less than 10 ppm.

Sulfide Mineralization

Zinc-lead sulfide deposits occur at a number of locations around the Padaeng nonsulfide zinc deposit, including sulfide zones immediately adjacent to the Padaeng pit (Figs. 2 and 5). The largest known sulfide bodies occur at Pha De, 2.4 km northwest of the Padaeng mine; reported premining sulfide resources were 0.43 Mt at about 15 percent zinc and 1.5 percent lead. Two of the sulfide bodies at Pha De were recently mined in small open pit and underground operations. Production grades have been closer to 8 to 9 percent zinc, but data are not available to determine if the lower grades reflect unrealistic premining resource estimates or mining dilution. At Hua Lon, 1.6 km northwest of the Padaeng mine, a sulfide resource of 0.3 Mt at 6 percent zinc and 0.5 percent lead has been defined by drilling.

The Pha De and Hua Lon deposits occur at elevations of 300 to 400 m. Both deposits were capped by 1- to 5-m-thick supergene zones comprising smithsonite and mixed smithsonite-sphalerite-galena. These small secondary resources have been mined; hand cobbing was used to separate sulfides from smithsonite in the mixed ore zones.

Sulfide deposits at Pha De and Hua Lon are hosted by hydrothermal dolostone. Mineralized bodies are strata bound within dolomitized units, and dolomite replaces sparry bioclastic and micritic limestone, overlain at Pha De by an argillaceous limestone horizon. Crystalline reddish to yellowish-green sphalerite occurs in fracture veins as small-scale, open-space fillings in vuggy dolomite and as disseminated to semimassive replacements of the host dolostone (Fig. 8). Irregular to banded, high-grade colloform sphalerite with remnant open space also occurs as cavity and breccia fillings, rimming dolostone wall-rock or breccia clasts that are partly replaced by sphalerite. Galena is relatively minor and occurs mainly in late veins with calcite (Fig. 8). Pyrite is also relatively minor, occurring with earlier high-grade sphalerite and with later galena but generally forming less than 5 to 10 percent by volume of the mineralized zones. Minor fine-grained disseminated pyrite also occurs in hydrothermal dolostone peripheral to the sphalerite ore zones.

Sulfide ore shows high cadmium contents, and concentrations up to 1.27 percent cadmium are recorded with 36.7 percent zinc at Hua Lon. Arsenic and antimony are present in elevated concentrations up to 200 ppm. No barite occurs with this type of zinc-lead deposit. A distinct style of barite-quartz veins with lead, copper, and minor zinc occurs in Padaeng Noi, but it appears unrelated to the zinc-lead deposits.

The low-grade sulfide mineralization in the Crystalline Dolostone unit at Padaeng mine occurs stratigraphically above most of the supergene zinc ore. This comprises pale yellow to brown crystalline sphalerite disseminated through coarsely crystalline dolostone and accompanied by minor pyrite and trace galena. Grades of this hypogene mineralization are typically 2 to 3 percent zinc and 0.1 to 0.2 percent lead with about 5 percent iron.

Sulfide ore at Hua Lon is interpreted to occur at a stratigraphic level similar to that of sulfide mineralization at the Padaeng mine, although stratigraphic relationships are not clearly defined owing to structural complexity and destructive

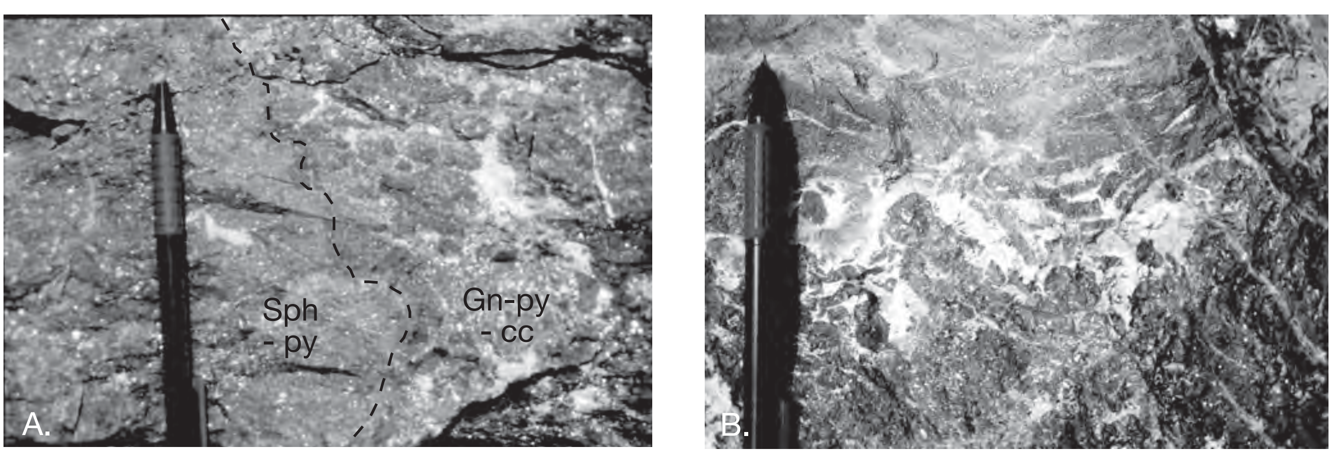

FIG. 8. A. Semimassive sphalerite (sph) ore with minor pyrite (py) cut by later calcite (cc) veins with coarse galena (gn). B. Coarse, banded, replacive sphalerite ore veined and brecciated by later calcite. Pencil is 13 cm long.

dolomitization. Sulfide orebodies at Pha De are currently interpreted to lie at a higher stratigraphic level than that at the Padaeng mine, but stratigraphic equivalence cannot be ruled out. Although sulfide mineralization is dominantly strata-bound, there is evidence for a preferential orientation along approximately north-south zones of fractures and calcite veins, particularly at Pha De.

Minor sulfide mineralization has been recorded within the Padaeng fault and the overlying dolomitic breccias, particularly in the area southeast of the Padaeng mine. Minor galena-rich mineralized zones occur in sheared, coarse white dolostone in the fault zone 1 km southeast of the mine. The dolostone immediately overlies clay gouge and passes upward into less-sheared dolomitized breccia. Galena occurs within sheared-out sparry dolomite lenses, indicating that movement along the fault occurred after dolomitization and mineralization.

Dolomitization

Almost all known sulfide and supergene zinc mineralization in the Padaeng area is hosted by dolostone. There is evidence for at least three stages of dolomitization. Early nonferroan dolomite is present in drill holes north of the Padaeng fault and is nonpervasive. Petrographic studies suggest that this widespread partial dolomite formed during early diagenesis (J. Praditwan, unpub. report for J&W Minex to Padaeng Industry Public Company Ltd., 2000).

Hydrothermal, weakly ferroan dolomite is medium to dark gray, medium to coarse grained, and only partially destructive of primary textures. Most sulfide ore in the area is hosted by ferroan dolostone and has sparry ferroan dolomite gangue. This dolostone has significant permeability and in places is coarsely vuggy, commonly with later calcite cement and vug fill. Dolomite shows the greatest intensity of development and lateral continuity within the Crystalline Dolostone unit and is pervasive over 1.5 km of strike from the Padaeng pit to the sulfide deposits at Hua Lon and Pha De (Fig. 2). This distribution is interpreted to reflect preferential replacement of reactive and/or permeable, precursor oolitic and bioclastic limestone lithologies, overlain by argillaceous units that may have acted as an impermeable cap. Minor fine-grained pyrite and local trace sphalerite occur throughout the unit. In the vicinity of the Padaeng pit, hydrothermal dolomite extends pervasively through the underlying Pit Sandstone and Pit Limestone units but is finer grained and less vuggy than in the Crystalline Dolostone unit. Ferroan dolomite dies out north of the Padaeng fault; the Pha De sulfide deposits appear to be situated close to the dolomite front (Fig. 2). Minor sulfide deposits occur with sparry ferroan dolomite in crackle breccias developed in limestone 600 m north of the Pha De deposits.

In the Padaeng Noi area, 1 to 3 km southeast of the Padaeng mine, a broad zone of pervasive nonferroan white dolomite occurs along the Padaeng fault; it thins from 500 m wide in the southeast to less than 100 m in the northwest near the mine (Fig. 2). The dolomite is pale gray or pinkish and is almost totally destructive of primary texture. It affects the thick breccia zone in the hanging wall of the Padaeng fault and the overlying carbonate units, and it appears to be partly strata bound in a zone that extends up to 1.4 km north of the Padaeng fault. The white dolomite appears to be a later event that at least partly overprints the hydrothermal ferroan dolomite south of the Padaeng pit. The white dolomite does, however, host minor sulfide mineralization in the hanging wall of the fault throughout the Padaeng Noi area, mostly as late veins containing sphalerite and/or galena.

Discussion

Sulfide zinc-lead mineralization

Hypogene zinc-lead sulfides in the Mae Sod Jurassic sequence show many characteristics of Mississippi Valley-type mineralization in the broad sense, despite some significant differences from that of "typical" Mississippi Valley-type districts, such as the central United States, Pine Point, and Upper Silesia (Leach and Sangster, 1993).

Mineralization is geochemically and mineralogically simple, dominated by zinc with a lower concentration of lead and composed of sphalerite, galena, and pyrite. Ore is hosted by zones of hydrothermal dolomite, interpreted to represent an earlier stage of the hydrothermal system that generated the sulfide ore. Both hydrothermal dolostone and sulfide zones are dominantly strata bound, reflecting permeability and reactivity of favorable precursor limestone units. Despite the strata-bound geometry, mineralization also exhibits a strong structural control. All significant known sulfide mineralization occurs close to the Padaeng fault, although the fault zone itself is sparsely mineralized. At Pha De, ore is partly controlled by north-south–oriented fracture-vein systems.

Mineralization textures are dominated by small-scale, open-space fillings in vuggy dolomite but include replacive and vein-hosted styles. There is no evidence for meteoric karst formation preceding sulfide mineralization and no indication of significant hydrothermal karst formation accompanying the mineralization.

The timing of sulfide mineralization is poorly constrained. Mineralization postdated lithification and hydrothermal dolomitization of the host sequence. The empirical spatial relationship with the Padaeng fault suggests that mineralization may be related to movement on the fault zone, for example where fluid flux was maximized by seismic pumping effects. This inference is supported by the association of sulfides with north-south–oriented fracture-vein zones that are believed to have formed in a dilational orientation within the dextral northwest-trending fault zone. Deformed sulfide ore zones within the fault and the largely postmineralization white dolomite event along the fault indicate that movement continued after sulfide deposition. The Padaeng fault is one of a set of northwest-trending faults in Southeast Asia that are believed to have been active from the Jurassic until the middle Miocene (Bunopas, 1981; Packham, 1993), a time period that does not provide much of a constraint on the age of mineralization.

Limited data are available to constrain fluid characteristics and their possible sources. A fluid inclusion study on two sphalerite samples from the Hua Lon deposit indicated trapping temperatures of 205° to 219°C and salinities of 9 to 10.5 wt percent NaCl equiv for primary inclusions (Naraballobh, 1996). Sulfur isotope analysis of nine sphalerite samples from Hua Lon by Naraballobh (1996) indicated a narrow range of $\delta^{34}S$ concentrations between 4.1 and 5.8 per mil. The fluid inclusion temperatures are high for typical Mississippi Valley-type deposits, whereas salinities are at the low end of the typical range (Leach and Sangster, 1993). Sulfur isotope concentrations fall within the broad range seen in Mississippi Valley-type deposits and may reflect high-temperature thermal reduction of Triassic-Jurassic seawater sulfate (Naraballobh, 1996). These moderate-salinity, high-temperature fluids are comparable to the metal-bearing fluids interpreted to have formed the zinc-lead deposits of the Irish Midlands (Everett et al., 1999).

The interpretation of broad zones of hydraulic breccias in the hanging wall of the Padaeng fault suggests that fluid flow was focused along the fault and involved phases of disruptive fluid overpressure. Although movement on the fault appears to have been dominantly dextral transpressive thrusting, phases of transtensional movement may also have occurred. Dextral transtension could have resulted in dilation within the flower structure in the Padaeng area. The broadening of the white dolomite alteration zone to the southeast, toward the Triassic basement, suggests that fluids may have originated to the southeast, possibly through basal clastic aquifers in the Jurassic sequence that pinch out against the basement.

There is no evidence that metalliferous fluids were derived from the Tertiary Mae Sod basin. The basin is largely filled with Pliocene-Pleistocene sediments that are younger than the middle Miocene uplift event that is interpreted to have formed the Mae Sod half-graben and the marginal horst blocks, where the Padaeng host sequence is situated. There is no evidence for a significant thickness of pre-Miocene sediments in the basin. It is considered more likely that the mineralizing fluids were derived from deeper-water, clastic-dominated Jurassic sequences outboard to the west of the shelf carbonates. The most likely fluid-flow mechanism was uplift and compression of these Jurassic basinal lithologies in the Cretaceous. Fluids may have been focused by formational aquifers near the base of the Jurassic Mae Sod sequence and may have been released into the Padaeng fault zone close to the Triassic basement pinch-out. This process may have led to fluid overpressure, or the fluids may have been released during phases of dextral transtensional movement on the fault. Initial hydrothermal dolomitization is believed to have generated permeable aquifers for the mineralizing fluids. Sulfide was deposited in traps formed by a combination of structural extension zones and permeability barriers at lithologic contacts and dolomite fronts. The limited fluid inclusion and stable isotope data (Naraballobh, 1996) do not provide evidence for more than one fluid or for fluid mixing as a depositional mechanism.

Nonsulfide zinc mineralization

Nonsulfide supergene zinc deposits at the Padaeng mine occur stratigraphically below the main horizon of hydrothermal dolomitization that hosts the only significant sulfide mineralization in the mine area. The supergene ore occurs in strata-bound zones in weathered sandy horizons beneath the sulfidic unit and in structurally controlled and karstic zones in the underlying silty dolostones.

Nonsulfide zinc ore shows very high zinc grades (up to 50% Zn) relative to sulfide ore in the district (6–15% Zn), although extensive low-grade (1–10% Zn) supergene mineralization is also present. Although lead contents are low in primary sulfide ore at Pha De and Hua Lon (0.5–1.5% Pb), the supergene deposits have an extremely low lead content (0.01–0.1% Pb). Iron contents in the supergene ore are higher than in most of the observable sulfide mineralization.

Geologic relations, textures, and geochemical data indicate that the deposit formed dominantly by the dissolution of primary sulfide zinc mineralization, transport of zinc out of the primary sulfide body, and supergene precipitation of zinc in secondary trap sites. Sphalerite is preferentially dissolved relative to galena or pyrite in an oxidizing sulfide body, and zinc is highly mobile in the acidic supergene fluids created by sulfide oxidation and metal hydrolysis (Thornber and Taylor, 1992). Less-mobile lead is more likely to remain in the leached gossan formed by oxidation of the sulfide body and to be removed by erosional processes. The relatively high iron content of the supergene ore may indicate that the precursor sulfide body at Padaeng was more pyritic than the Hua Lon or Pha De deposits. The high acid-generating capacity of oxidizing pyrite would assist in leaching zinc from the precursor sulfide body.

The eastern smithsonite-rich part of the original high-grade zinc blanket at Padaeng may have formed by direct replacement of primary sulfide ore minerals. High grades could be generated by a supergene “zone refining” process, by which zinc is progressively dissolved and then reprecipitated at the base of the sulfide zone as the land surface was reduced. However, analytical data suggest that lead contents in the smithsonite ore were less than 500 ppm, lower than the 500 to 1,000 ppm lead in hemimorphite ore. Supergene deposits formed by the direct replacement of sulfide would be expected to have a higher lead content than zinc ore formed by sulfide dissolution, transport, and supergene reprecipitation. It is possible that the smithsonite ore zones formed by replacement of the Crystalline Dolostone unit, immediately underlying the primary sulfide mineralization.

There is little basis to constrain the age of supergene mineralization at the Padaeng deposit. The presence of shear planes in the East Pit fault zone cutting hemimorphite ore indicates that movement continued during or after supergene mineralization. Outcropping, topographically lower, sulfide bodies at Pha De and Hua Lon are not deeply weathered, suggesting that the sulfide body that was the precursor to the Padaeng deposit was not oxidized in recent times or in a comparably dissected landscape.

The geology of the Tertiary intermontane basins of northern Thailand provides some context for the tectonic and climatic conditions under which the Padaeng deposit is likely to have formed. A widely recognized unconformity in the basins records a tectonic uplift event in the middle Miocene (Packham, 1993). Little sedimentologic data are available for most of these basins, but some data are reported for the Li and Mae Moh basins, which host significant coal deposits (Fig. 1; Uttamo et al. 1999). Oligocene to early Miocene sedimentation in the Li basin is interpreted to have occurred under hot, humid climatic conditions, and decreasing clastic sediment input reflects increasing planation of the hinterland. By late early Miocene time, coarse clastic inputs began to increase, recording the onset of middle Miocene tectonism. Following middle to late Miocene tectonism and uplift, Pliocene-Pleistocene sedimentation above the middle Miocene unconformity is dominated by coarse clastics in alluvial fans and braided river systems, reflecting uplift of the source regions. Pliocene-Pleistocene sedimentation is believed to have occurred under monsoonal, semiarid climatic conditions. The interpretation that oil-shale sequences of Pliocene age in the Mae Sod basin were deposited in perennial and playa lake environments (Gibling et al., 1985) supports this climatic interpretation.

It is postulated that formation of the supergene Padaeng deposit reflects middle to late Miocene tectonic uplift of a relatively subdued topographic surface on the east side of the Mae Sod basin, subjected to deep weathering in the wet tropical climatic conditions prevalent since the Paleocene. Uplift and increasing aridity would progressively lower water tables, possibly with substantial seasonal fluctuations in a monsoonal climate. These circumstances would have provided optimum conditions for deep weathering of the sulfide body that was the precursor of the Padaeng deposit, and lowered water tables would also have promoted flushing of zinc from the sulfide body. The Padaeng fault block is likely to have been pushed up as a local topographic high in a dextral transpressional regime; uplift and fault movement may have continued during formation of the supergene orebody. Increasing dissection of the topography, and possibly continuing uplift, would have eroded the gossanous remnants of the sulfide body and gradually exposed and eroded the secondary zinc body. The slump deposits of secondary zinc ore south of the Padaeng fault scarp provide evidence for this continuing uplift.

The smaller Pha De and Hua Lon deposits were not exposed to oxidation until the land surface was further reduced in more recent times. The limited period of exposure and the more active dissection have militated against deep weathering of the deposits, with the result that supergene mineralization at these deposits is restricted to shallow smithsonite caps.

Supergene mineralization model

The Padaeng deposit is believed to have formed by the oxidation of a strata-bound sulfide body within the Crystalline Dolostone unit, situated above and up-dip of the high-grade supergene blanket that was exploited in the early years of mining. Primary sulfide mineralization may have been controlled by approximate north-south–oriented zones of fracturing and faulting, now represented by the Chedi, 700, and 900 zones. Assuming primary sulfide grades of about 10 percent zinc, weathering of a sulfide deposit of about 16 Mt would be necessary to produce the original nonsulfide resource (production and reserves) of about 1.6 Mt of contained zinc metal.

Oxidation occurred in an uplifted terrane with deep weathering promoted by lowered and seasonally fluctuating water tables and is unlikely to have produced highly acidic supergene fluids, owing to low pyrite content and the presence of carbonate gangue. Supergene fluids were sufficiently acidic to transport zinc out of the primary sulfide body, assisted by the vuggy permeable dolomite host, by the existence of steep dilational fracture zones, and by the lowered water table and seasonal flushing.

Supergene zinc-bearing fluids were neutralized by reaction with the underlying sandy dolostones and dolomitic sandstones, precipitating zinc primarily as hemimorphite. Fluids moved more than 150 m down dip through permeable dolomitic sandstone beds. Primary permeability may have been increased by dolomitization and dissolution of dolomite by descending acidic fluids that generated their own permeability. Fluids were also channeled by fault and fracture zones, where their acidity promoted karstic dissolution in the silty dolostone units underlying the dolomitic sandstones. Karst-related fissures and cavities, filled with residual clays, sand, and lithic fragments derived from overlying weathered sandstone, extend up to 200 m vertically beneath the postulated precursor sulfide body.

Uplift continued during supergene mineralization, particularly within the Padaeng fault block, enhancing the effectiveness of the dissolution and concentration process. This uplift also resulted in the complete removal by erosion of the gossanous remnants of the sulfide body and the partial erosion of the underlying nonsulfide body.

Conclusions

The Padaeng deposit is an attractive economic target having an original total resource of about 1.6 Mt of contained zinc metal in ore zones of high grade and purity. The deposit formed by supergene processes acting on sulfide zinc-lead deposits of Mississippi Valley type, which were probably of lower grade, more dispersed, and less economically attractive.

The Padaeng deposit formed by replacement of dolomitic host rock and by karstic dissolution in the footwall of the precursor sulfide body. Dissolution of zinc sulfide in the original sulfide body and transport and reprecipitation of zinc resulted in enhanced grades and separation of zinc from lead. This grade-enhancement and purification process is more effective for wall-rock replacement deposits than for direct replacement deposits formed by in situ oxidation of mixed sulfide mineralization (Heyl and Bozion, 1962; Hitzman et al., 2003).

Formation of a large supergene orebody like Padaeng required circumstances that enhanced deep oxidation and promoted transport and effective reprecipitation of zinc. Leaching and removal of zinc from the primary sulfide body at Padaeng was efficient, despite the fact that acid-generating capacity was probably relatively low. The permeable dolomite host and the presence of zones of strong fracturing may have enhanced this process. Uplift in a monsoonal to semiarid climate with a falling water table also favored deep weathering and transport of zinc out of the system. A porous and permeable dolomitic sandstone unit stratigraphically beneath the sulfide body formed an effective trap, together with karstic zones controlled by steep fracturing and faulting.

In terms of exploration implications, the Padaeng deposit emphasizes that (1) large, supergene, nonsulfide zinc deposits can be found in districts without known large sulfide deposits; (2) effective supergene remobilization and concentration of zinc can occur in low-pyrite sulfide deposits without high acid-generating capacity; (3) wall-rock replacement processes are likely to lead to the formation of more economically attractive deposits than direct-replacement processes; (4) wall-rock replacement processes are probably most effective where mature, weathered terrains are uplifted under monsoonal to semiarid climatic conditions; (5) supergene mineralization may extend to substantial depths and may occur beneath unweathered bedrock; (6) in a slightly different uplift and erosional situation, it is quite feasible that a deposit formed by processes similar to those that formed the Padaeng orebody could be buried beneath products of deep weathering or younger sediments, as is the case for the Shaimerden deposit in Kazakhstan (Boland et al., 2003) and the Skorpion deposit in Namibia (Borg et al., 2003); (7) in addition to understanding the controls on precursor sulfide mineralization, exploration for supergene zinc deposits at a regional and local scale must take into account all aspects of neotectonism, climatic evolution, and hydrogeology, and favorable pathways and trapping situations for supergene fluids.

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GEOLOGY AND MINERALIZATION OF THE CHATREE EPITHERMAL AU-AG DEPOSIT, PHETCHABUN PROVINCE, CENTRAL THAILAND

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ABSTRACT

The Chatree low to intermediate sulphidation style epithermal gold-silver deposit, central Thailand, comprises multiple vein systems that span 7.5 km. Current mineral resources estimate that this system has approximately 5 million ounces of contained Au, making it the largest hard-rock Au resource in Thailand. Au and Ag are hosted in multiple hydrothermal alteration assemblages, occurring as veins and breccias. The bulk of the ore is found in quartz-carbonate (chlorite-adularia) replacements, veins and breccias. Chlorite (-pyrite)-rich veins cut more adularia-rich variants to the quartz-carbonate veins. Sphalerite, galena and electrum are commonly found in the earlier, chlorite-rich assemblages. Alteration zones surrounding these veins and breccias include pervasive chalcedony and silica alteration and are considered a precursor to mineralisation. Quartz-carbonate veins are intimately associated with sericite-illite-quartz-pyrite and illite-smectite alteration zones, and later chlorite-(epidote-calcite-pyrite) and adularia-quartz-sericite-pyrite assemblages. Geologic mapping and field observations reported here show that ore-bearing veins and alteration assemblages are influenced by host rock lithologies.

The host succession to the Chatree deposit includes a gently folded 350 m thick package of polymictic and monomictic andesitic breccias; calc-alkaline andesite flows with isolated dacite dome complexes; monomictic and polymictic rhyolitic breccias and fine epiclastic sedimentary rocks. Quartz and lithic-rich fiamme breccias occur in the upper part of the succession. Mineralisation is contained within the finer grained, silicified volcaniclastic and epiclastic facies which contain intervals of rhyolitic breccia. The tectonic setting of the succession based from non-mobile trace elements shows that the majority of these facies were sourced from a continental arc type environment.

Across the vein field, alteration assemblages are zoned from chlorite ± epidote-calcite-pyrite (propylitic) to intermediate argillic alteration assemblages in the south and silica, chlorite ± epidote - calcite - pyrite (propylitic) and sericite-illite-quartz-pyrite (phyllic) alteration in the north. Spatial variations in mineralogy and alteration intensity corresponds to finer-grained (<1/16mm to 2 mm) volcaniclastics in the north (A and Q Prospects) and coarse-grained chlorite-alerted volcaniclastic rocks (namely monomictic and polymictic andesitic breccias) in the southern areas (C-H, J, D Pits).

A variety of chronologic techniques constrain the absolute timing of hydrothermal alteration to regional magmatism. Mineralization has been constrained as Early Triassic (250.9 ± 0.8 Ma) based on the analysis of adularia from coarse-grained quartz-sulphide (chalcopyrite – pyrite – sphalerite) veins by laser ablation Ar-Ar methods. The host volcanic succession has been dated with Laser Ablation ICP-MS U-Pb zircon techniques to reveal an age of 250 ± 6 Ma. The succession and mineralisation is cross-cut by a 244 ± 7 Ma xenolithic andesite dyke (dated using ICP-MS U-Pb zircon techniques). A granodiorite south of the mine is anomalous in copper and is shown to have intruded during the Middle Triassic (with a Re – Os age of 244 ± 1 Ma). The age dates show that gold deposition and associated hydrothermal alteration is related to regional magmatism rather than the 244 ± 1 Ma granodiorite to the south of the deposit. Such findings, if correct imply district-scale zonation in observed alteration assemblages and the temporal evolution of the hydrothermal system.

Keywords: epithermal Au-Ag, central Thailand, sulphidation, Chatree

INTRODUCTION

The Chatree epithermal Au-Ag deposit occurs in the Loei-Phetchabun volcanic belt (Fig. 1) associated with a volcanic centre (Fig. 2) which spans approximately 7.5 by 2.5km and consists of 7 defined prospect areas and 7 operating mine areas (Fig. 3). Studies of the sulphides mineral assemblages have classified the deposit as low sulphidation epithermal (Heald et. al., 1987) as sulphides contents are generally less than 3%, with low base metal contents (<300ppm of copper, zinc, and lead). Veins display crustiform to colloform vein textures, typical of low-sulphidation conditions, but the deposit has very minor adularia alteration. Gold – silver ratios vary between deposits and are in the range of 5 to 20:1. The mineral resource contains 1.6 g/t of Au and 13 g/t of Ag, and together with the previously mined ore totals 4.5 million ounces of gold. Chatree is an unusual epithermal deposit due to the association of Au with chlorite bearing veins, and the lack of any widespread adularia alteration.

The objective of this study is to develop a model to better understand the hydrothermal system which formed the deposit. The model will be developed by a comprehensive analysis of the stratigraphy, geochemistry, geochronology, structure and vein and alteration paragenesis. The volcanic facies and their emplacement processes are discussed to constrain the volcanic processes which formed the host lithogies. The geochemistry of the host succession will be examined to constrain the tectonic setting of the magmatism, the timing of mineralization and the host succession is determined using U-Pb and Ar-Ar geochronology. The structure, position and nature of mineralization in the stratigraphy will be documented together with the alteration and vein paragenesis to determine the processes which controlled the hydrothermal system. Finally, this study will review the stable isotope data for the deposit to determine the source of the sulfur and the temperature of the fluids

REGIONAL GEOLOGICAL SETTING

The Chatree epithermal gold deposit is located in the Late Paleozoic to Early Mesozoic north-south trending Loei-Phetchabun Fold Belt (Jungyasuk and Kositanont, 1992; Chasuri, 2002, Fig. 1) This fold belt was formed during and prior to the closure of Tethys (Meltcalfe, 2006) and modified during the extension of SE Asia during the collision of India and Eurasia (Barr and McDonald, 1991) The Loei-Phetchabun Volcanic belt is thought to have originated during the northward subduction of a large ocean basin (Paleo-Thethys) beneath the Indochina Terrane during the Late Permian and Triassic (Intasopa, 1992; Metcalfe, 1996). The closure of this ocean basin is thought to have been responsible for the northwards drift of the Shan Thai terrane and eventual collision with Indochina (Metcalfe, 2006).

Both the Shan-Thai and Indo-china Terranes are thought to be allochthonous Gondwana cratonic fragments (Bunopas and Vella 1983; Hutchinson, 1989; Bunopas 1991). Both the Shan-Thai and the Indochina Terrane contain Early to Late Paleozoic clastic sedimentary rocks, platform carbonates and deep water clastic sedimentary rocks. The Indochina terranes these have been overlain by Triassic volcanics and intruded by Triassic granites. In the Shan Thai terrane the Paleozoic rocks are intruded by Triassic and Cretaceous granites which were, in turn, strongly metamorphosed in the Tertiary (Dunning et al. 1995). All of these rocks are .overlain by sedimentary units of the Triassic-Jurassic Khorat Group. The timing and nature of collision between these two terranes is contentious with different studies postulating alternative subduction geometries and timing for collision (e.g. Bunopas, 1981; Helmcke, 1986; Chaodumrong, 1992).

Cenozoic uplift and rotation has caused extensional zones from the Gulf of Thailand to the South China Sea (Harder, 1991), and the effect is preserved as N-S and NW-SE trending normal fault zones and NNE-SSW strike-slip faults (Diemar and Diemar, 1999). Both of which intersect the Chatree deposit.

HISTORY OF DISCOVERY

Folk-lore describes colluvial and alluvial gold workings by Japanese worker during World War II in areas to the east and south of the present day Chatree mine (Diemar and Diemar, 1999) yet systematic exploration did not occur until 1987 after the Thailand Government allowed foreign enterprises to survey for gold.

The Thai Goldfields Limited team, a wholly owned subsidiary of Epoch Mining NL explored along the Loei-Phetchabun belt for porphyry copper and related epithermal gold mineralization from 1987 to 1993. Exploration methods involved mapping, panning, soil sampling, trenching, auger drilling and diamond core drilling. The team first noted gold at Khao Mo (now A Pit at Chatree) in 1988 (Diemar and Diemar, 1999), in outcropping epithermal colloform banded quartz veins during an exploration program to prioritize all Thai Goldfields Limited targets (Diemar and Diemar, 1999).

During 1991 and 1992 the Thailand Department of Mineral Resources (DMR) also prospected for gold in the Chatree district by conducting soil sampling and electromagnetic conductivity surveys (De Little, 2005). In 1992 Kingsgate Limited (Ltd.) acquired Thai Goldfields Ltd. from Epoch Mining NL and formed the wholly owned Akara Mining Ltd. which then conducted grid-based auger laterite geochemical surveys in 1996, leading to the discovery of ore in C, D, H and J vein zones which are presently being mined.

GEOLOGICAL SETTING

The Chatree deposit is located on the eastern edge of the Tertiary Chao Phraya Basin, 280km north of Bangkok (Fig. 1). The district-scale geology (shown in Fig. 2) is dominated by thick Carboniferous to Early Permian sedimentary sequences composed of conglomerate, sandstone, shale and limestone (DMR, 1994, Fontaine et al., 2005). New U-Pb zircon geochronology on rhyolites and granites interbedded and intruding into these sequences indicate the presence of a Carboniferous magmatic event in the area. These Carboniferous sequences are the dominant rock types in the south-east area of Chatree district area (Fig. 2) and may also form the basement beneath the Late Permian to Triassic rocks at Chatree.

The Chatree deposit is hosted in Late Permian to Triassic intermediate to felsic volcaniclastic rocks (Jungysuk and Koshitanont, 1992, Diemar and Diemar, 1999) which form coherent andesitic and rhyolitic centers that interfinger and overlie fine-grained volcaniclastics and epiclastic siltstone, mudstone and fossiliferous limestone (Jungysuk and Koshitanont, 1992, Crossing, 2006). Alteration in the region is associated with these volcanic centers and major NE-SW fault systems (Corbett, 2006; 2005; Crossing, 2006; Hill, 2005).

The Triassic rocks are gently folded (with dips less than 45°) and are intersected by NE-SW trending faults (Fig. 2 and Fig. 4). Granodiorite intrusions are associated with these faults, and mostly post-date mineralization in the area (Crossing, 2006). Approximately 80% of the area surrounding the deposit is overlain by thick laterite and unconsolidated sediments.

STRATIGRAPHY OF THE CHATREE VOLCANIC COMPLEX

Mineralisation at Chatree is strongly influenced by the host lithologies. Understanding the stratigraphy and volcanic facies architecture of the deposit is critical to understanding the position of mineralisation and developing an ore deposit model.
The Chatree host succession can be divided into four main units that are cross-cut by basaltic to dioritic dykes. The stratigraphic units are described below, from stratigraphically highest to lowest:

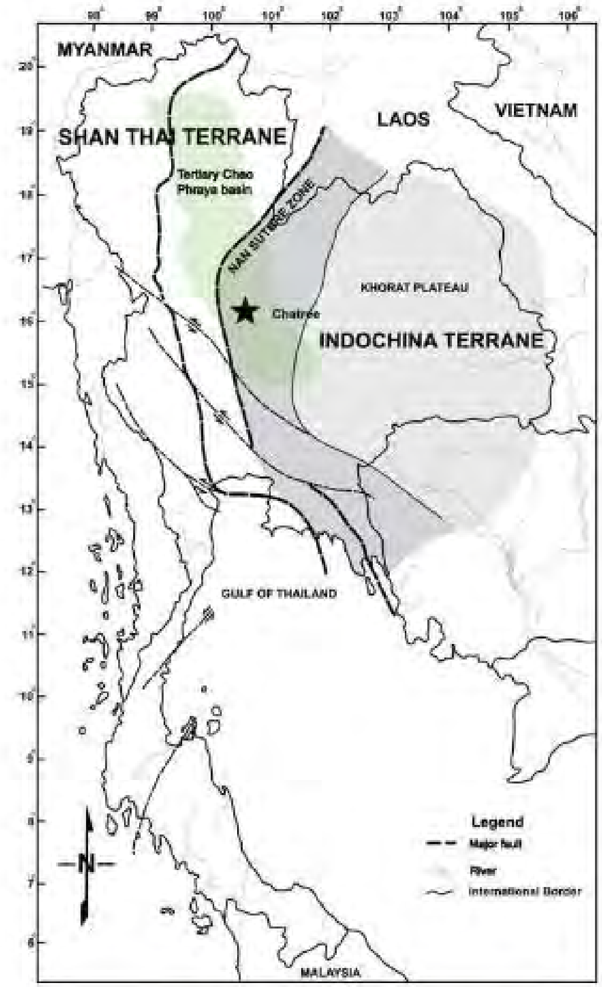


Figure 1 Map of Thailand, showing the location of the Chatree deposit in which Thailand's Loei-Phetchabun Volcanic belt is bound by the Nan and Loei Suture zones. The volcanic belt represents the remnant oceanic and continental arc complexes that developed prior and associated with the suturing of the Shan-Thai and Indochina Terranes (modified from Chausiri, 2000).

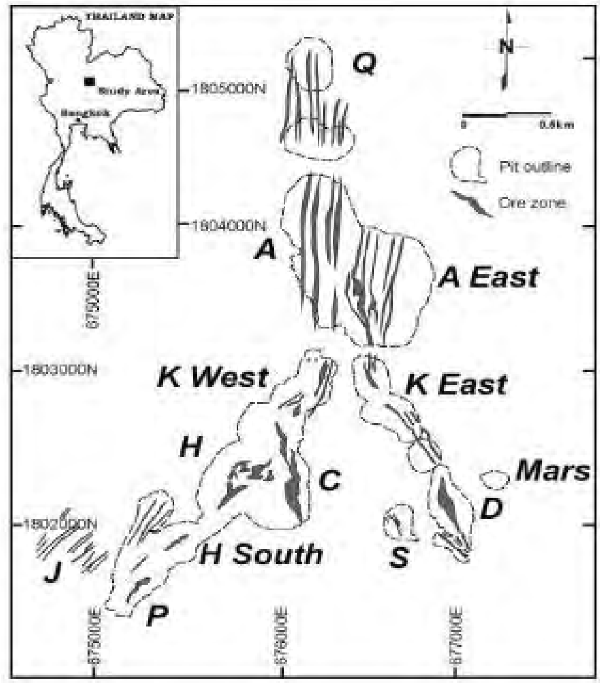


Figure 3 Map of Thailand showing the location and position of open cut Pits and prospects at the Chatree deposit. The vein zones trend NNW-SSE and NE-SW conforming to regional structural trends. Mined areas are termed D, C, H and H - South, P, S, Mars, and A are currently being mined by open Pit methods.

Unit 1 Lithic rich fiamme breccia with interbedded fine-grained fiamme rich sandstone and siltstone with thin layers of accretionary lapilli-rich siltstone and Polymictic mud matrix breccia. This unit un-conformably overlies the lower units.

Unit 2 Fine grained epiclastic and minor sedimentary facies including laminated siltstone, mudstone and carbonaceous to calcareous (fossiliferous) siltstone; quartz-rich fiamme breccia, polymictic and monomictic rhyolitic breccia facies

Unit 3 Polymictic andesitic breccia, polymictic andesitic basaltic breccia which is partly inter-bedded and overlain by volcaniclastic sandstones, laminated carbonaceous mudstones and minor calcareous siltstone. This unit also includes thin isolated intervals of monomictic andesitic breccia, plagioclase phyric andesite. The hornblende phyric andesite

Unit 4 This unit is the lowest intersected stratigraphic unit. It contains monomictic andesitic breccia, plagioclase phyric andesite and hornblende phyric andesite and minor polymictic andesitic breccia with isolated small bodies of coherent dacite and rhyolite with associated thin zones of monomictic dacitic and rhyolitic breccia. Andesite, dacite and basalt dykes cross-cut the whole succession.

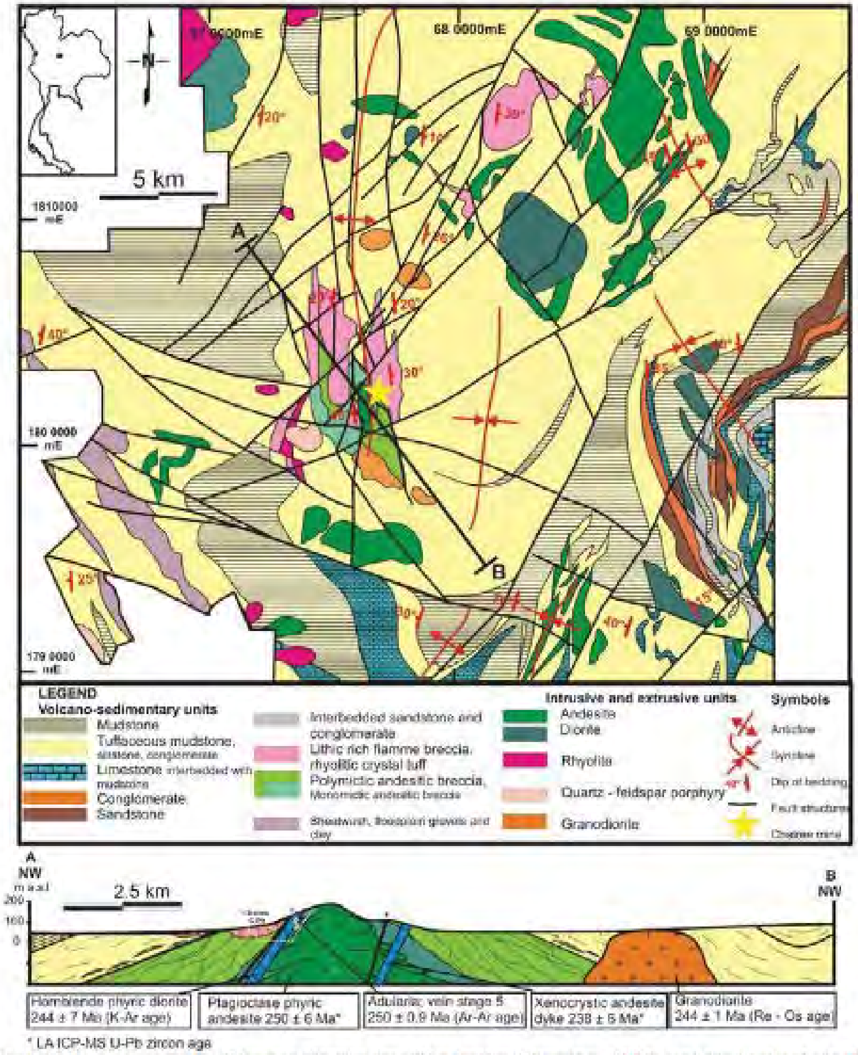


***Figure 2** Generalized geology map of the Chatree district (modified after Crossing, 2006; updated to include the observations of Cumming et al, 2005) showing the location of Chatree (yellow star) which is positioned on a north-south trending axial plane of a gently folded anticline, intersected by NE-SW, N-S, NNW-SSE striking faults.*

STRUCTURE OF THE CHATREE DEPOSIT

The precious metal veins in the Chatree district are related to faults and host rock competency. Mineralized zones either follow steep E-dipping, NE to NW striking faults or occur at the intersection of faults (Corbett, 2006).

Some of these faults, such as a large NW striking fault which occurs in the A, Q and D Pits and the eastern part of K Prospect, have moderate NE dips and dextral displacements (Corbett, 2005 and Hill, 2004). Others, such as the NE-striking, NW-dipping fault in the southern part of H Pit, J Prospect and P Prospects also shows dextral fault movement (Corbett, 2005 and Hill, 2004).

Although much of the faulting is thought to have occurred after mineralisation, it is probable that some faults existed prior to, or during, mineralization. Pre and syn-mineralization faults have been noted in other hydrothermal deposits such as the Mount Blitzen volcanic center in the Tuscarora district (Castor et al., 2003). Faulting at Chatree is likely to be partially related to rock competency in the host succession, as faults splay outside of the brittle coherent plagioclase-phyric andesite (Unit 4) and breccia in the lower part of the succession. Post-mineralized faulting has re-activated earlier north-west and south-east striking faults and produced minor north-south striking extensional faults (Corbett, 2005 and Hill, 2004).

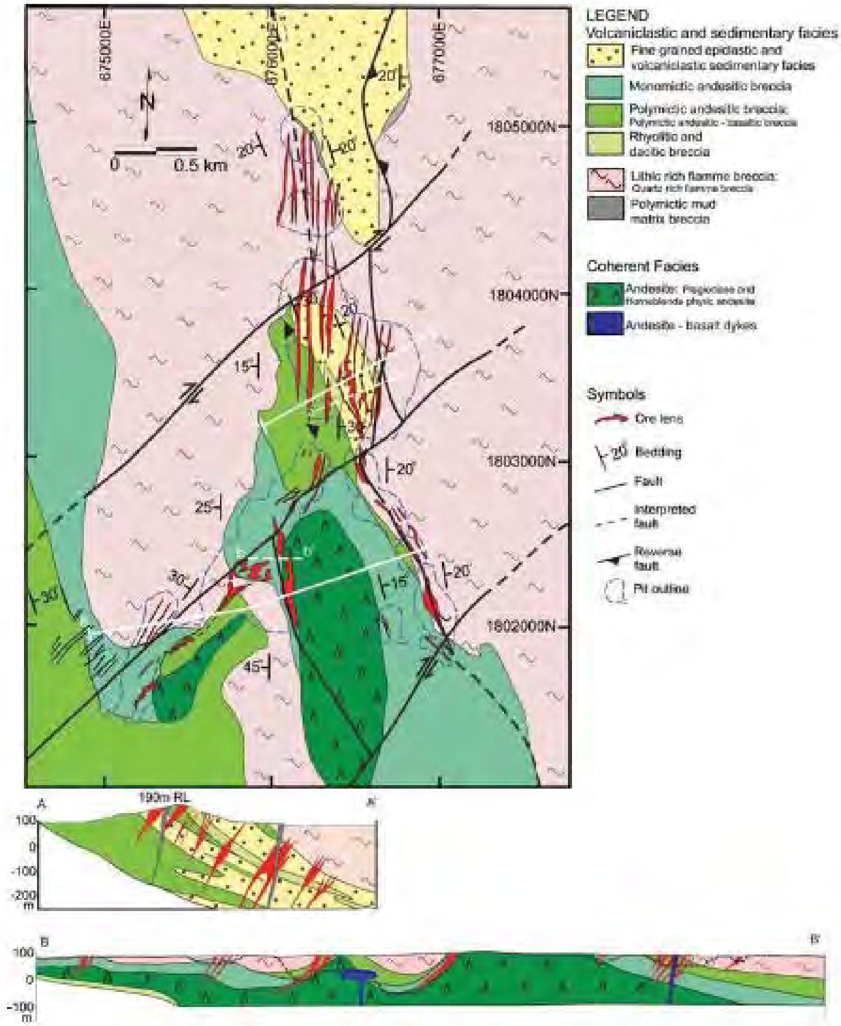


Figure 4 Geological Map and cross sections of the Chatree mine and prospect areas showing NW – SE and NE – SW fault structures intersecting the region, an abundance of coherent Plagioclase phyric andesite and Polymictic andesitic breccia in the southern areas and Fine epiclastic and volcaniclastic sedimentary facies in the northern area. Fiamme Breccia is widespread, capping the upper part of the succession

VEIN MINERALOGY AND TEXTURES, VEIN PARAGENESIS AND ALTERATION

Extensive core logging and paragenetic studies at Chatree have shown that the mineralized veins can be classified into six types. These are as follows:

1) silica replacement veins
2) grey silica breccia and veins/veinlets
3) quartz ± carbonate ± chlorite - pyrite ± sphalerite ± chalcopyrite ± galena-electrum breccia and veins/veinlets
4) quartz-carbonate-adularia (K-feldspar?)-chlorite-epidote
5) quartz ± carbonate veins
6) quartz-carbonate-zeolite veins

Mineralisation occurs as poorly to moderately banded, crustiform and massive, stockwork veins and disseminated ore (Fig. 5 A, B). Locally, the Au-Ag ore texture is stratigraphically controlled, extending from narrow zones in the lower coherent flows and coarse volcaniclastic rocks, and spreading outward into the finer volcaniclastic sedimentary rocks and rhyolite breccia. The association of fine to coarse-grained chlorite with the ore forming vein stages is an unusual feature of the Chatree deposit when compared with typical epithermal deposits world-wide. Chlorite occurs with carbonate, chalcedony and as dark green coarse-grained patches and/or layers associated with pyrite. Gold, silver and electrum are associated with pyrite, sphalerite, chalcopyrite, galena and boulangerite. Pyrite is the most abundant sulphides mineral in mineralized vein stages 3 and 4 and occurs as colloform and massive aggregates associated with sphalerite, chalcopyrite, galena boulangerite, electrum and microcrystalline quartz. Sulfide and base metal mineral contents (sphalerite, chalcopyrite and galena) are higher at the southern areas of the Chatree deposit (namely S, C, H, H-south and P Pits) and increase in abundance with depth.

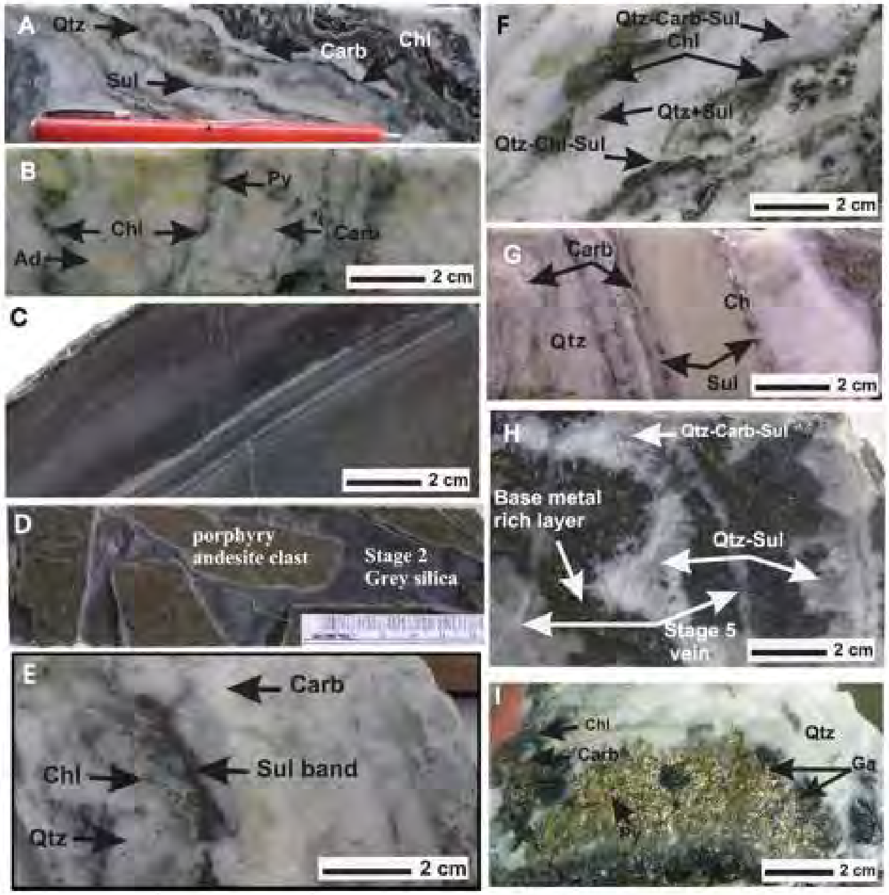
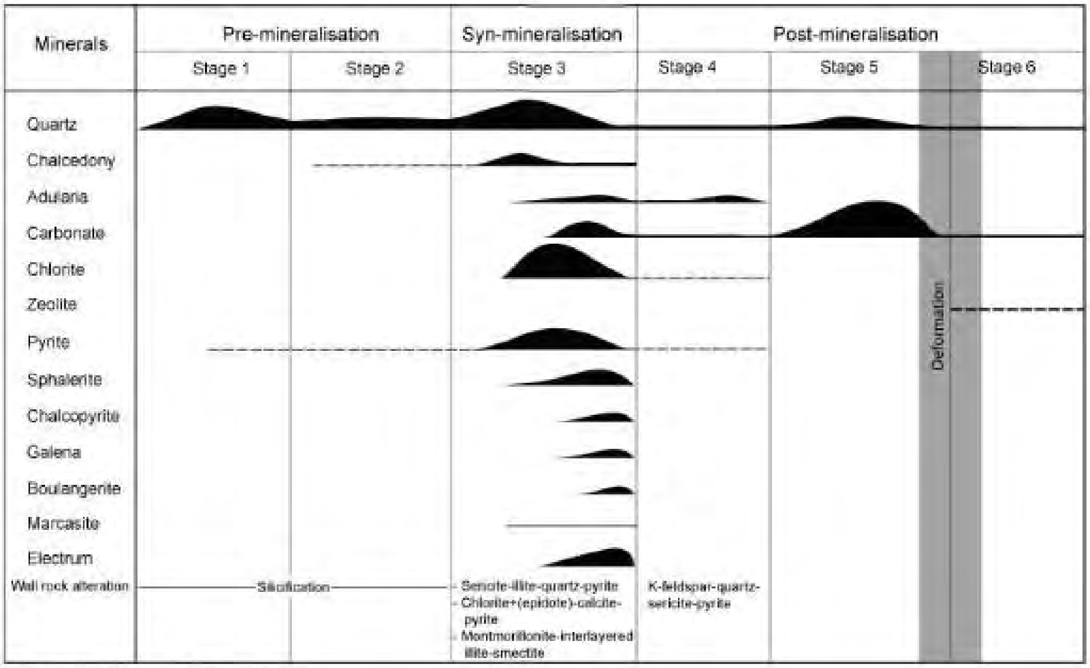


***Figure 5** Photographs of drill core and hand samples of A. Laminated volcanic siltstone with pervasive silica replacement, B. Plagioclase phyric andesite clasts in grey silica matrix, C. Sulfide-rich layer and patchy sulphidess in quartz ± carbonate ± chlorite vein, D. Well banded quartz, carbonate, chlorite and chalcedony vein with (dark) sulphides layers, E. Moderately banded quartz ± carbonate ± chlorite ± sulphides vein, showing moderately distinct dark green chlorite bands, F. Banded quartz ± carbonate ± chlorite ± sulphides vein showing white – cream quartz-carbonate bands and dark chlorite layers. Adularia (pink) is stained yellow in the upper part of the sample, G. Well banded quartz - chalcedony banded vein with thin sulphides layers, H. Base metal rich quartz-carbonate vein, coarse-grained sphalerite-galena-chalcopyrite band (left) and fine disseminated chalcopyrite, I. Coarse-grained pyrite and marcasite.*

VEIN AND MINERAL PARAGENESIS

On the basis of cross-cutting relationships, a chronology of the 6 different types of veins has been established (Fig. 6). The first 2 of these vein stages occurs before the introduction of gold into the system. Stage 1 is characterized by silica replacement and occurs as both veins and pervasive alteration. It is recognized at A, A-east and Q-Prospects where fine-grained volcano sedimentary rocks predominate (shown in Fig.5, C, D) and to a lesser extent the coarser volcaniclastic rocks (e.g., polymictic andesitic breccia monomictic andesitic breccia, and fiamme breccia). In thin section microcrystalline quartz is shown to replace the original mineral assemblages. Pre- mineralized (Stage 2) grey silica breccia and veins occur in most Pits and prospects and are distinctive where the vein/alteration from Stage 1 is absent (such C, H, S Pits and K-west prospect). It is characterized by grey to dark grey microcrystalline quartz and minor pyrite and is the matrix to hydrothermal 3-5 m breccia zones in C Pit (Fig.5, D). Vein Stage 3 is the major gold-bearing stage and consists of quartz ± carbonate ± chlorite - pyrite ± sphalerite ± chalcopyrite ± galena-electrum breccia and veins/veinlets. This stage is characterized by weakly banded (Fig.5 E) crustiform, colloform textures and moderate to well-banded textures (Figs.5 A, F) ranges from quartz-rich, carbonate-rich to chlorite-rich and as quartz-sulphides veins, quartz-carbonate-sulphides and quartz-carbonate-chlorite-sulphides veins. Gold mostly forms as electrum and is closely associated with pyrite, sphalerite, chalcopyrite and galena. Electrum also occurs as free grains interstitially infilling in calcite and/or quartz (Fig. 7, A). Electrum inclusions in pyrite are common (Fig. 7, B) and less prominent in sphalerite, galena and chalcopyrite. Chlorite is a common gangue mineral of this stage and usually forms as fine to coarse-grained and a coarse-grained component in colloform-banded veins and infills open-space. Chalcedony is also common in Stage 3 particularly at A and A-east Prospect and is usually associated with variably banded quartz. Gold and sulphides (pyrite, sphalerite, chalcopyrite and galena) are associated with microcrystalline quartz and chlorite, and to some extent with euhedral crystalline quartz, calcite and chlorite in interior of the veins (Fig.5, G).



Remarks: Stage 1 Pervasive silica emplacement
2 Silica breccia filling
3 Quartz±carbonate±chlorite-sulphide-electrum vein breccia
4 Quartz-carbonate-adularia±chlorite veins
5 Carbonate±quartz veins/veinlets
6 Zeolite-quartz-carbonate veins/veinlets

Figure 6 Paragenetic sequence and alteration facies for the Chatree deposit

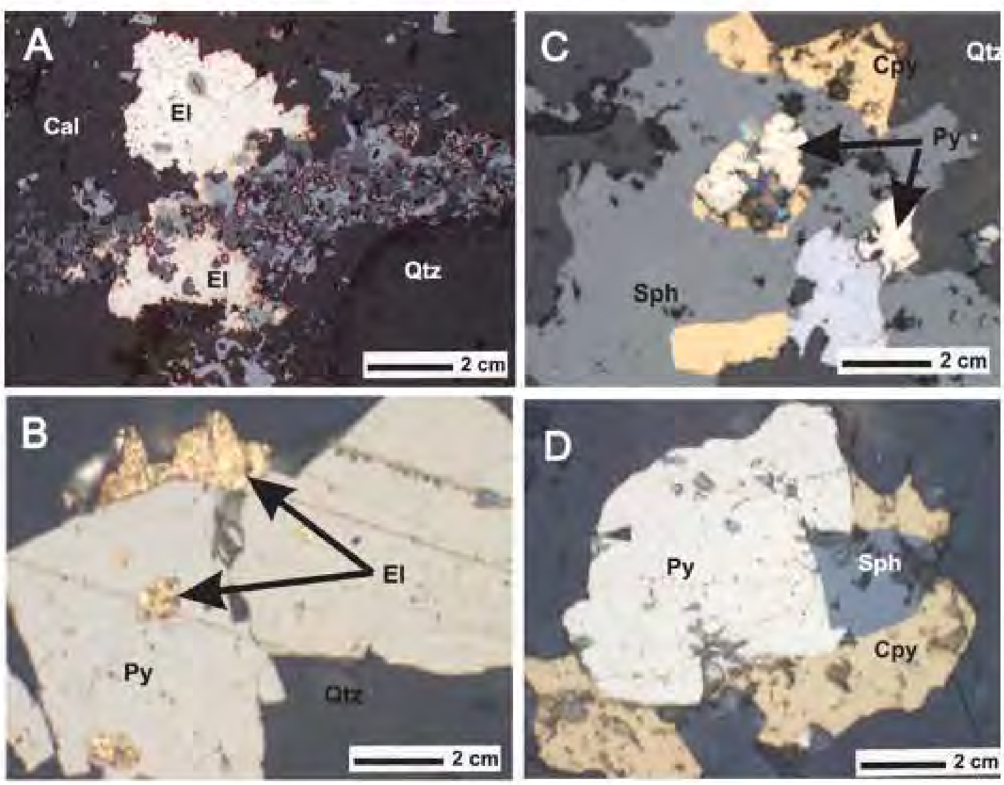


Figure. 7 Photomicrograph of Stage 3 mineralisation showing A. Close associated of pyrite, sphalerite, galena, and chalcopyrite surrounded by quartz, B. Free electrum.

The post-mineralized vein assemblages are Stages 4 to 6. Stage 4 is composed of quartz-carbonate-adularia-(K-feldspar?)-chlorite-epidote veins. These veins are characterized by spectacular pink-orange adularia along the margins to the veins, white to creamy carbonate, pale grey to white quartz and rare chlorite and epidote with sulphides patches and layers. Quartz ranges from microcrystalline to euhedral with comb textures and the carbonate is coarse-grained creamy calcite. Sulfides consist of pyrite and rare chalcopyrite. Stage 5 quartz ± carbonate veins are colloform and crustiform banded and occur throughout the deposit. They consist of quartz (chalcedony) and/or carbonate with few sulphides minerals. Mineralized zones that have been cross-cut by this vein stage have significantly lower gold grades. It is thought that this stage quickly followed the gold bearing stage and diluted the ore grade (specifically in C and H Pit). Stage 6 (zeolite-quartz-carbonate-veins) occur in the faults and fractures of cross cutting (post mineralized) dykes and contain distinctive pink to red zeolites, quartz, carbonate and minor epidote and chlorite.

ALTERATION

Alteration assemblages at Chatree are
1) silica
2) sericite-illite-quartz-pyrite, chlorite-(epidote)-calcite-pyrite, montmorillonite-interlayered illite-smectite
3) K-feldspar-quartz-sericite-pyrite.

Pervasive silica is the earliest alteration phase and occurs in stratigraphic Unit 2 (Fig. 7 A, B) specifically in the fine-grained volcano-sedimentary facies, rhyolite and dacite breccia and quartz-rich fiamme breccia. The most highly silicified zones have replaced both clasts and matrix in the rhyolitic and dacitic breccias. Higher gold grades correlate well with these silicified zones, a similar feature is observed in the Pani Volcanic Complex, Indonesia (documented by Kavalieris et. Al., 1990). Silicification is less widespread below and above Unit 2. Some 1-5 m wide cross-cutting silicified zones are associated with isolated rhyolite and dacite bodies observed in the lower Units (in C and H Pits

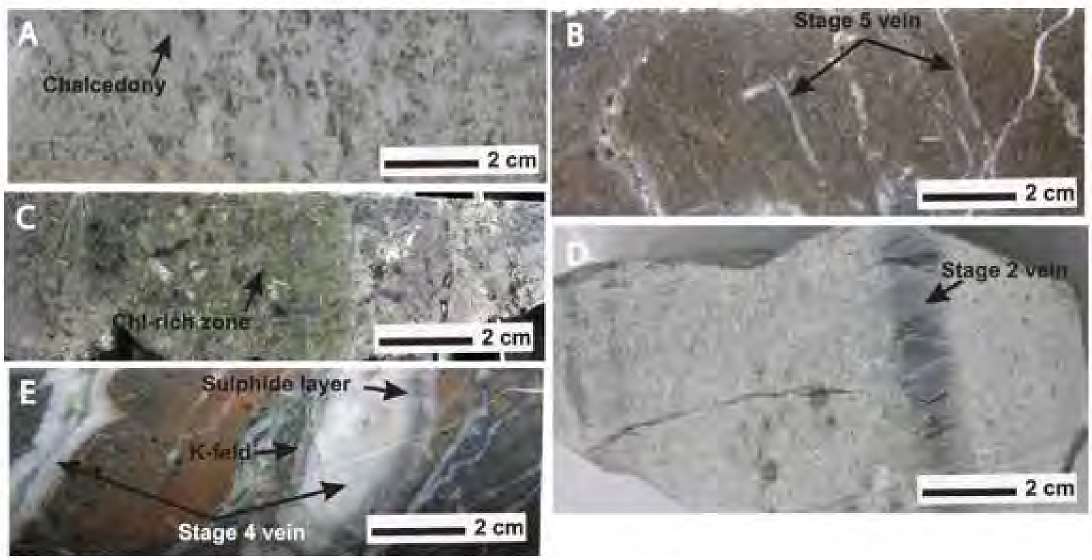


Figure 7 Pervasive alteration at Chatree A., Chalcedony, and chlorite C. and alteration associated with specific vein assemblages (B, D and E).

Patchy silicification occurs in the lower portion (1-5 m) of the lithic rich fiamme breccia in Unit 1. These patchy zones are characterized by microcrystalline quartz and chalcedony (Fig. 7, A). Silicification was probably ongoing during the growth of vein stages 1-4, but may pre-date later quartz – carbonate veining (vein stage 5). Observations clearly show that silicification and alteration is related to rock type, and is more commonly associated with rhyolitic and dacitic breccias, quartz rich fiamme breccia and the finer associated sedimentary facies)

Sericite-illite (illite-smectite)-quartz-pyrite alteration (Fig. 7, C) has been related to gold-bearing mineralisation (Stage 3) and occurs in the lower stratigraphic units particularly in volcaniclastic and coherent rocks. This alteration is directly related to quartz ± carbonate ± chlorite ± adularia-electrum veins/veinlets and occurs as haloes (with variable thickness) on the margins of these veins (Fig. 7, B, D).

More intense (propylitic) chlorite-epidote-calcite-pyrite (± epidote) alteration occurs lower down in the succession (in Units 4 and 3) and is related to the post-mineralized quartz-carbonate-adularia ± chlorite veins.

K-feldspar-quartz-sericite-pyrite (intermediate argillic alteration) has been identified by Kromkhun (2005) at H-west, H Pit and isolated zones in Q Prospect. It is characterized by the presence of montmorillonite and interlayered illite-smectite and occurs at the margin of the gold bearing vein stage and is thought to be related. This alteration stage occurs as a 1 -3 m thick halo around the margins of 1-2 m thick gold bearing veins in H Pit and as a replacement phase of phenocrysts in the plagioclase phyric andesite and clasts in the volcaniclastic facies. It is characterized by a high proportion of disseminated pyrite (10 to 20 % volume). A zone of supergene argillic alteration was recognized by Krompkhun (2005) in the hanging wall of H Pit.

STABLE ISOTOPE STUDIES

Sulfur, carbon and oxygen isotopes have been analysed from A Prospect and C, H and D Pits by Dedenczuk (1998), Greener (1999), and Krompkhun (2005) and Salam (2006). The main conclusions based from these studies showed that pyrite was sourced from (reduced) H2S- dominant fluids (Greener,1999) with sulfur isotope values becoming lighter at depth and heavier at higher levels (Krompkhun, 2005) in H Pit. Dedenczuk (1998) observed zoned pyrite with depleted cores and enriched rims, suggesting that pyrite nucleated during a period of boiling.

Analysis by Krompkhun (2005) of oxygen δ18O compositions in the gold bearing vein stages has shown that oxygen isotope values range from 8.1 to 15.7 ‰, unpublished δ18O analysis by Salam (2006) appears to support this. The two highest oxygen isotope values, 12.7 and 15.7 ‰ are recorded associated with the post - mineralized granodiorite (N Prospect) in the south. There is a possibility that low oxygen isotope values are spatially more or less confined to the centre of the major ore zones located along H and D structures and values increase outwards from the centre of the main ore zones to the margin of the Pits. However, at present most of the data is focused on the ore zones and to fully confirm this trend more oxygen isotopes will need to be determined outside the main mineralized zone.

At Q, A, A-east and northern part of K-east Prospects, the oxygen isotope composition ranges from 9.5 to 11.9 ‰ (N = 16) with low values being generally occurring lower in the succession. The oxygen isotope values tend to show low values at deeper levels in all areas. Oxygen isotope values in the gold-bearing vein stage tend to show lower values than the late post-mineralized vein stages.

To fully evaluate oxygen isotope data and distinguish between meteoric and magmatic sources of oxygen, precise temperature measurements are required. This is due to the temperature dependence of the oxygen isotope partitioning coefficient between quartz and fluids (Zheng 1993). Typically oxygen isotope studies rely on fluid inclusion homogenization temperatures to obtain precise temperature of quartz formation. At Chatree fluid inclusions are rare and, when present, they are generally too small for precise temperature determination. However, based on temperatures consistent with the assemblages at Chatree (250° to 300°) (Greener 1999) a mixed meteoric and magmatic source is likely for the oxygen in the Chatree veins.

The oxygen isotopic values and zonation could be explained by channeling magmatic fluids with low oxygen isotope values along fault zones and which subsequently mix with meteoric water. This could produce oxygen isotope values increase outwards from the centre of the main ore zones to the margin of the Pits.

Timing of hydrothermal activity

Timing on mineralisation is constrained to prior to the Middle Triassic by the U-Pb zircon age of dykes which cross-cut mineralisation. The two dykes dated are a xenolith-rich dyke from D Pit (238 ± 6 Ma) and a hornblende-phyric diorite dyke from H Pit (244 ± 7 Ma)

Epithermal gold-silver mineralisation has been directly dated to the latest Permian or earliest Triassic (250.9 ± 0.8 Ma) using laser Ar-Ar method on adularia from a gold-bearing quartz ± carbonate ± chlorite ± adularia - pyrite ± sphalerite ± galena ± chalcopyrite - electrum vein from C Pit.

Mineralisation was probably associated with magmatic fluids related to an earlier magmatic event. However, although the laser Ar-Ar age is very close to the U-Pb zircon age on the andesitic volcanics from Unit 4., there is no direct evidence to suggest that the ore forming fluids were formed by the same magmatism which formed the host sequence. Two scenarios are possible for ore genesis: either fluids were released during the intrusion of rhyolite and dacite dome complexes (in Unit 2) or related eruption products (rhyolite breccia, dacite breccia and quartz rich fiamme breccia) or the fluids were generated by an unrelated event.

MODEL FOR ORE DEPOSITION

Two scenarios for ore deposition have been devised using the data outlined in this study (shown in Fig. 8). In scenario 1 gold mineralisation is thought to be related to an unconstrained magmatic source within the district and the position/location and geometry of the ore is controlled by structures and host rock competency. Ore bearing fluids have exploited fractures and faults in the succession and the highest gold grades occur associated with the finer grained sedimentary facies and rhyolite breccias (in the northern area of the deposit) in Unit 2 and lower in stratigraphic Unit 4 at the margin between the monomictic andesitic breccia and coherent andesite facies. In this scenario, the silicification in Unit 2 could be genetically linked to the same magmatic events that formed the rhyolite dome and breccia. Silica-rich fluids circulating in Unit 2 during the intrusion and extrusion of the small isolated rhyolite dome complexes may have hardened the rocks and prepared them for the development of brittle conduits and ore deposition during later circulation of magmatic and meteoric fluids. In this hypothesis, the hydrothermal system overprints the host succession and is not associated with the magmatism which formed the host succession. The lack of mineralized ore in certain parts of the succession is due to competency contrasts with the lithic-rich fiamme breccia, the polymictic andesitic breccias and the lower plagioclase-phyric andesite being an unfavourable host for mineralisation.

In scenario 2 (in Fig. 9) we speculate that mineralisation was related to the same magmatic event which formed the upper part of the host succession (namely the lithic-rich fiamme breccia). Both hydrothermal activity and volcanism ceased after the emplacement of a large volume of pyroclastic material (Unit 1).

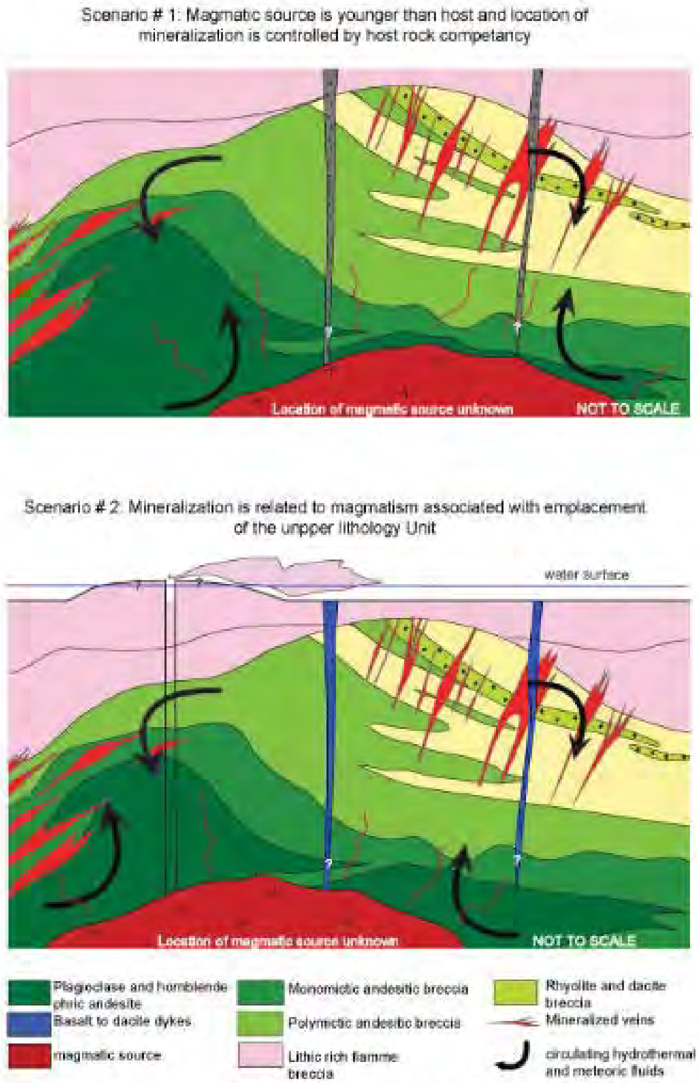


***Figure 8** Two scenarios for gold deposition at Chatree. Scenario # 1 shows that mineralization occurred later than the emplacement of the host volcanic facies and was related to an unrelated magmatic source. Scenario #2 illustrated that mineralization is related to magmatism associated with the same magmatic source to the upper lithic rich fiamme breccia, is ongoing during the emplacement of the unit and ceases when volcanism ceases. It should be noted however, that the source of mineralization may be related to any one of the volcanic centres in the area and not necessarily related to the upper Lithic rich fiamme breccia.*

More precise dating of the succession (with a lower error margin) would help to provide the foundation for a more accurate model for ore deposition at Chatree. Currently with an error margin of ± 6 Ma and with the entire host succession relying on a single date, we cannot preclude that the volcanism of the host is the source of the fluids.

Both scenarios are compatible with a subduction-related tectonic setting for the host succession similar to other epithermal deposit worldwide. Possible analogues include the Nicauragua and the Eastern Trans Mexican Volcanic Belt (Besch and Verma et al., 1995), the Kyushu arc in Japan closely associated with the Hishikari low sulphidation epithermal deposit (Izawa et al., 1993; Sanematsu et al., 2006; Faure and Matsuhisa, 2002) and the north island of New Zealand where the Golden cross epithermal deposit is located (Simmons et al, 1992; Simpson et al, 2001and Mauk and Hall, 2004).

A comparison of Chatree with other low-intermediate sulphidation deposits is shown in Table 12. The host volcanic rocks to the Chatree deposit display similar tectonic setting (with regards to geochemical characteristics) to the Cerro Vanguardia epithermal deposit in Argentina, Pajingo in Northern Australia, Comaguey, Cuba, Golden Cross, New Zealand and the Hishikari deposit, Japan. Of these deposits Pajingo's host rocks are older than Chatree, the remainder of the deposits mentioned forming in younger rocks to Chatree. However, the mineral assemblages are most comparable to the Pajingo deposit and Cerro Vanguardia due to the presence of illite-quartz and chlorite in the alteration assemblages or to Pajingo and Hishikari due to the similarities in the vein assemblages (quartz-adularia-electrum and colloform-crustiform vein textures).

SUMMARY AND CONCLUSION

The Chatree epithermal deposit is hosted in a succession of dominantly calc-alkaline andesite flows and associated autobreccia, polymictic breccias, fine sedimentary facies with rhyolite and dacite breccias and quartz phyric fiamme breccia. The whole succession is capped by lithic-rich fiamme breccia and has been emplaced in a subaqueous environment, related to continental arc magmatism. A detailed analysis of the stratigraphy and volcanic architecture indicates that the earliest volcanic eruptions were subaqueous and effusive and evolved to mixed effusive and explosive eruption styles as magma compositions changed from intermediate (andesitic) to silicic (dacitic to rhyolitic) compositions.

Chatree is intersected by NW-SE and NE-SW striking sub-vertical dipping faults and mineralization is structurally and stratigraphically controlled. Analysis of the paragenetic sequence has showed six vein assemblages, the ore bearing veins are 3) quartz ± carbonate ± chlorite - pyrite ± sphalerite ± chalcopyrite ± galena-electrum breccia and veins. Pervasive silica is associated with higher gold grades in the northern part of the succession and was probably ongoing during the growth of vein stages 1-4, but probably pre-dates later quartz – carbonate veining (vein stage 5) and is related to rock type, and more specifically the felsic rocks. Silicification is considered to be the ground preparation for later mineralisation events (Salam, 2007). Sericite-illite (illite-smectite)-quartz-pyrite alteration occurs at the margins of gold-bearing to quartz ± carbonate ± chlorite ± adularia-sulphides – electrum veins/veinlets. Propylitic chlorite-epidote-calcite-pyrite (± epidote) alteration occurs lower down in the succession and related to quartz-carbonate-adularia±chlorite veins. K-feldspar-quartz-sericite-pyrite (intermediate argillic alteration) has been identified at H-west, H pit and isolated zones in Q Prospect. Intermediate argillic alteration occurs in the lower part of the lithic rich fiamme breccia at the hanging wall at H Pit.

Age dating shows that the granodiorite (to the south of the mine) and the dykes which cross-cut the succession at Chatree are a similar age (Early to Middle Triassic), and postdate the development of epithermal gold-silver mineralisation which occurred in the Late Permian to Earliest Triassic (250.9 ± 0.8 Ma). Mineralisation could be related to the same felsic magmatism that formed the top of the host succession or to an unrelated and as yet unconstrained magmatic event.

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Paleontological parks and museums and prominent fossil sites in Thailand and their importance in the conservation of fossils

[Les parcs et musées paléontologiques et les principaux gisements fossilifères de Thaïlande : leur rôle dans la sauvegarde des fossiles]

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Abstract: Many important fossils have been recently discovered in Thailand and serve as important keys for learning about the diversity and evolution of life through time. However, some fossils have been lost to private collectors both in Thailand and overseas. To protect these natural heritages, paleontological parks and museums have been established through the joint efforts of many organizations: the Department of Mineral Resources, universities, public enterprises, local administrative governments, and private companies. The result of the collaboration has been the establishment of the Museum of the Lignite Study Center (Mae Moh) and Petrified Forest Park in northern Thailand, Phuwiang National Park, Phuwiang Dinosaur Museum, Phu Kum Khao Dinosaur Research Center, Phu Kum Khao Dinosaur Site Museum, and the Museum of Petrified Wood and Mineral Resources in northeastern Thailand, and the Fossil Shell Cemetery in southern Thailand. In addition, the Geological Museum and national Geological Museum were established in central Thailand. All of these paleontological parks and museums, plus several local museums, play very important roles in fossil conservation. The goals are not only to preserve the fossils in collections but also to educate the public about the values of fossils, to instill a desire to protect these valuable national resources, and to act as centers for international collaboration in research and conservation.

Key Words: Paleontological park; museum; Thailand; fossils; petrified wood; dinosaurs.

Résumé : ***Les parcs et musées paléontologiques et les principaux gisements fossilifères de Thaïlande : leur rôle dans la sauvegarde des fossiles.-*** De nombreux gîtes fossilifères importants récemment découverts en Thaïlande fournissent des données essentielles pour comprendre la biodiversité passée et l'évolution de la vie au cours du temps. Nous devons cependant déplorer le fait que certains fossiles soient perdus ou détenus par des collectionneurs privés, tant en Thaïlande qu'à l'étranger. Afin de protéger cet héritage naturel, des musées et parcs paléontologiques régionaux ont été créés grâce aux efforts de plusieurs organisations : le Département des Ressources Minérales, les Universités, les administrations gouvernementales locales, les entreprises publiques et plusieurs compagnies privées. Cette collaboration a permis la création du Centre d'étude de la lignite de Mae Moh et du Parc de la forêt pétrifiée, dans le Nord de la Thaïlande ; le Parc national et le Musée des dinosaures de Phuwiang, le centre de recherche et le musée des dinosaures de Phu Kum Khao ; le Musée des ressources minérales et bois pétrifiés dans le Nord-Est de la Thaïlande et, enfin, dans le Sud de la Thaïlande le Cimetière de coquilles fossiles. De plus, un Musée géologique et un Musée national

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de géologie ont été créés dans le centre de la Thaïlande. Tous ces musées et parcs paléontologiques, ainsi que plusieurs musées locaux, jouent un rôle essentiel dans la conservation des fossiles. Le but n'est pas seulement de préserver les fossiles en collections, mais également d'éduquer le public et de le sensibiliser à l'importance de la préservation et de la mise en valeur de ces ressources nationales. Enfin, ces institutions jouent un rôle fondamental dans les collaborations internationales, aussi bien en terme de recherches scientifiques que de conservation.

Mots-Clefs : Parc paléontologique ; musée ; Thaïlande ; fossiles ; bois fossiles ; dinosaures.

1. Introduction

Numerous fossils have been discovered in Thailand over the past fifty years, and especially during the last decade. Some of the earliest reports of fossils in Thailand were on fish from the North in 1916 and on trilobites from the Carboniferous Period in Phatthalung Province in the South in 1920 (Department of Mineral Resources (DMR), 1969; SUTEETHORN, 2002). The known fossil record in Thailand ranges from Cambrian trilobites up to Holocene pollen. Although these fossils are considered part of the national heritage, many of them face multitudinous threats. Numerous fossils have been damaged and the sites destroyed during the process of mining lignite, sand, limestone, and other economically important rocks. Additional fossils have ended up in private collections both locally and overseas. Some of the fossils have been used to make jewelry and other items. To protect these fossils and fossil sites and to increase awareness of fossils in the public, the Department of Mineral Resources (DMR) with the collaboration of other organizations, such as the National Park, Wildlife and Plant Conservation Department, universities, local governments, public enterprises, and some private enterprises, have set up paleontological parks and museums in Thailand. In this paper, after a brief overview of the fossil record in Thailand, we will describe paleoparks, museums, and some prominent fossil sites (Fig. 1), examine their importance for paleontology and conservation, and discuss what the future may hold.

2. Fossils in Thailand: overview

Thailand is located in the center of the Southeast Asian mainland, from 5°37' - 20°27' N latitude and from 97°22' - 105°37' E longitude. The total area is 514,000 km². The local climate is tropical and characterized by monsoons. Thailand shares its border with Myanmar in the west and north, Laos in the northeast, Cambodia in the east, and Malaysia in the south. Thailand is mountainous in the north and west resulting from the uplift of Precambrian to Mesozoic rocks. The central plains overlie Cenozoic deposits. East of the plains are hills often capped with Jurassic sandstone. Northeastern Thailand comprises the Khorat Plateau, underlain by Jurassic-Cretaceous rocks. The east consists of plains and hills underlain by Precambrian to Mesozoic rocks. In Southern Thailand lie a series of longitudinal mountain ranges, formed from Paleozoic-Mesozoic sedimentary rocks and Mesozoic granites (WORKMAN, 1997).

PALEOZOIC ERA

The oldest records of ancient life in Thailand are trilobite fossils from the Cambrian Period. The fossils were found in the Tarutao Formation (about 500 million years ago) on Tarutao Island, Satun Province, southern Thailand. Fossil records from the Ordovician Period in Thailand are few, but include nautiloids, other mollusks, and trilobites from Kanchanaburi Province in the West and Satun and Nakhon Si Thammarat provinces in the South. From the Silurian Period, fossils were discovered in the Northeast and North of Thailand, including corals and mollusks from Loei Province and graptolites from Chiang Mai Province. Fossils from the Devonian Period are mostly invertebrate marine animals, such as corals and stromatoporoids from Loei Province, trilobites from Satun, and graptolites from Chiang Mai. Vertebrate remains of shark teeth have also been recovered from Mae Hong Son Province in the North (DMR, 2006).

The oldest confirmed records of plant macrofossils in Thailand are from the Carboniferous Period. Carboniferous plants include lepidophytes, sphenophytes, pteridospermophytes, and cordaitophytes from Loei Province (LAVEINE *et alii*, 2003). However, most fossils from this period are from animals, especially marine invertebrates, such as ammonites, trilobites, corals, and mollusks, distributed in all regions of Thailand (DMR, 2006).

Permian fossils of Thailand are mostly found in limestone scattered in many parts of Thailand. A variety of invertebrate marine animals, including sponges, bryozoans, corals, brachiopods, bivalves, ammonites, trilobites, and ostracodes, plus fusulinids have been found (DMR, 2006). Permian plants are uncommon in Thailand, but plant fossils, including sphenophytes, pteridosperms, cycadaleans, and cordaitaleans, have been found in Petchabun Province in Central Thailand and in Loei Province in the Northeast (ASAMA, 1966, 1968). Petrified wood assigned to *Dadoxylon* (Coniferales) and wood with possible affinity to *Ginkgo* were found in Petchabun Province (BERTHELIN, 2006).

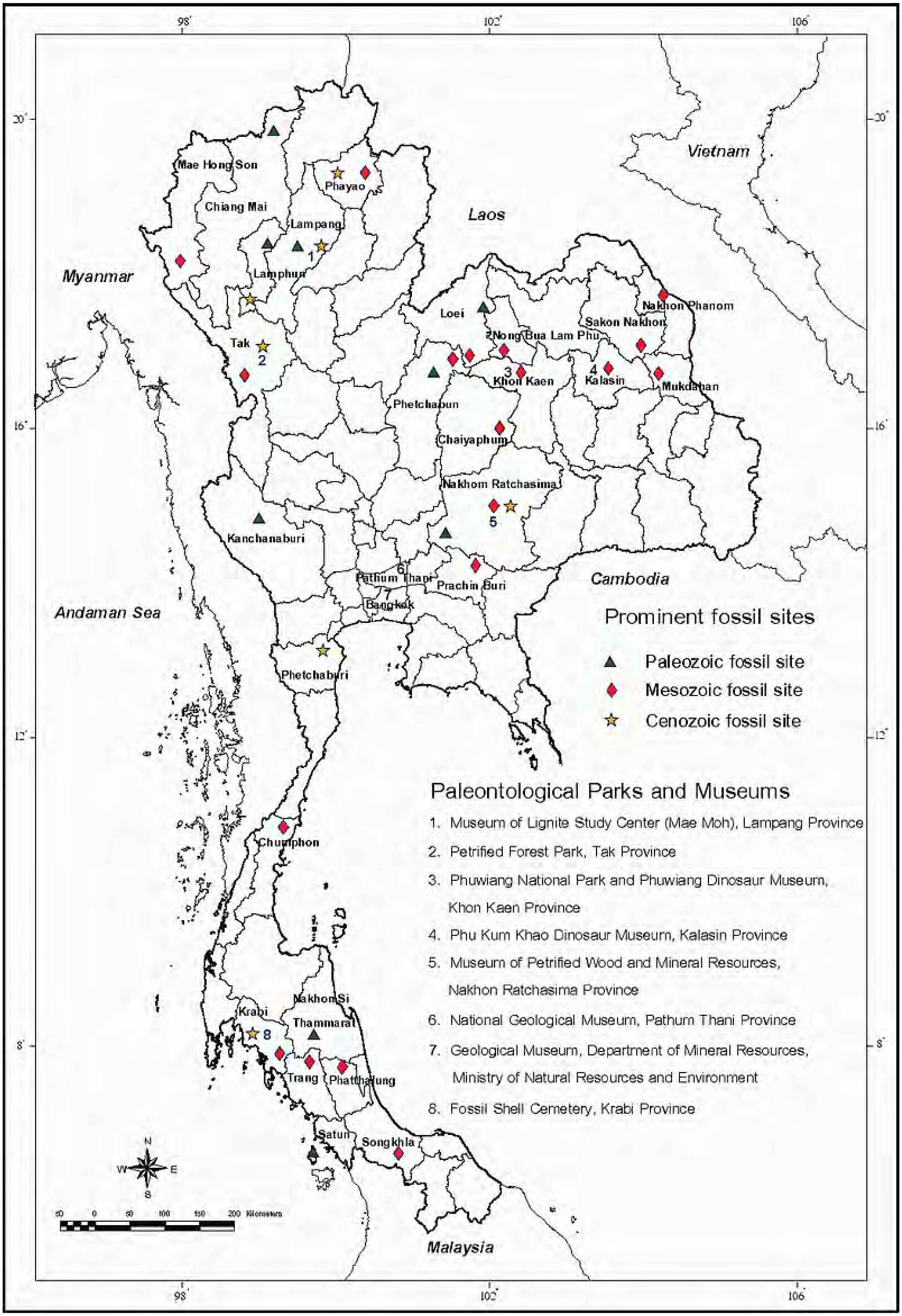


Figure 1: Paleontological parks, museums, and major prominent fossil sites in Thailand.

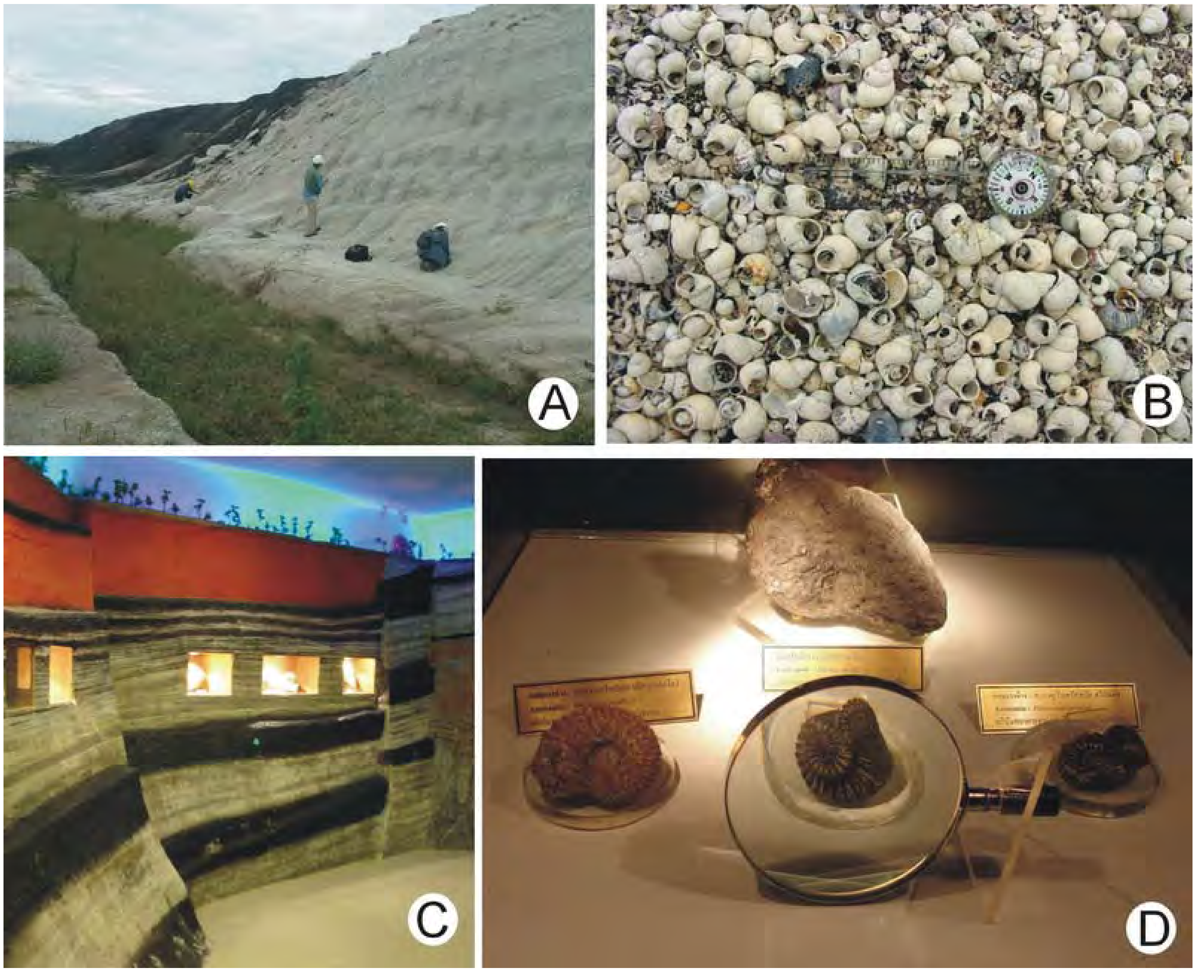


Figure 2: Mae Moh Lignite Mine, where the world's thickest fossil shell bed was found (A). Freshwater mud snails, *Bellamya* (Viviparidae) (B). Stratigraphic model of lignite mine (C) in the museum with fossils shown in each glass cabinet (D). Photos courtesy of Y. THASOD and J. DUANGKRAYOM.

MESOZOIC ERA

Fossils from the Triassic Period are invertebrate marine animals and protists, such as bivalves and ammonites from Lampang Province and foraminifera, radiolarians, and conodonts in limestone along the western edge of Thailand from Mae Hong Son in the North to Songkhla Province in the South. The vertebrate remains of ichthyosaurs have been found from Phatthalung, southern Thailand. The oldest dinosaur fossils of Thailand, dating back to the Late Triassic, are prosauropods from Phetchabun Province and the sauropod *Isanosaurus attavipachi* from Chaiyaphum Province. Other vertebrate fossils are amphibians, fresh water crocodiles, bony fishes, sharks, and turtles from Khon Kaen and Chaiyaphum provinces in the Northeast (DMR, 2006).

From the Jurassic, a greater diversity of fossils, both marine and terrestrial, have been found. The discovery of marine fossils along the western side of Thailand, such as ammonites, bivalves, and corals in Tak Province in the North and Chumphon Province in the South, indicate that the land in the western zone of Thailand was separated from the rest of Thailand by a narrow sea at that time. Terrestrial and freshwater deposits have yielded fossils of insects, conchostraceans, and dinosaurs from Krabi Province and oysters, freshwater hybodont sharks, semionotiform fish, lungfish, temnospondyl amphibians, turtles, and crocodiles from Nakhon Si Thammarat Province in the South (PHILIPPE *et alii*, 2006). In the Northeast, vertebrate fossils include a lungfish, hybodont sharks, a temnospondyl amphibian, a fresh water crocodile, carnivorous and herbivorous dinosaurs, and a giant turtle (CAVIN *et alii*, 2003; CUNY *et alii*, 2003; DMR, 2006). Numerous *Lepidotes* fish have been found at Phu Nam Jun site, Kalasin Province (CAVIN *et alii*, 2004).

Most dinosaur remains in Thailand, which range from the Late Triassic to the mid Cretaceous, have been found in the Khorat Plateau in the Northeast, including the Jurassic dinosaurs mentioned above and numerous specimens from the Early Cretaceous. *Siamotyrannus isanensis*, *Phuwiangosaurus sirindhornae*, *Siamosaurus suteethorni*, and *Psittacosaurus sattayaraki* are all new species of dinosaurs from the Early Cretaceous (BUFFETAUT *et alii*, 2003a). Besides dinosaur bones and teeth, many dinosaur footprints are found in Khon Kaen, Loei, Prachinburi, Kalasin, Nong Bua Lamphu, and Nakhon Phanom provinces (DMR, 2006). A recent fascinating discovery is that of very small dinosaur eggs, possibly of theropods, including one with the remains of an embryo (BUFFETAUT *et alii*, 2003a, 2005). Other vertebrate fossils from the Early Cretaceous of the Northeast include the remains of freshwater sharks, actinopterygian fish, turtles, crocodiles, and the tooth of a pterodactyloid pterosaur (BUFFETAUT *et alii*, 2003b).

Mesozoic plants are not especially common in Thailand, although silicified wood is abundant in some areas of the Northeast. From the Late Triassic of the Northeast are fossils of Sphenophyta, Pteridophyta, Cycadales, Bennettitales, and Coniferales (ASAMA *et alii*, 1981). Silicified conifer wood has been found in Jurassic and Early Cretaceous deposits in the Northeast (PHILIPPE *et alii*, 2004). Fossils of Pteridophyta, Benettitales, and Coniferales, including a rare occurrence of amber, have been reported from Jurassic sites in Trang and Krabi provinces in the South (ASAMA *et alii*, 1981; PHILIPPE *et alii*, 2006).

CENOZOIC ERA

A series of Paleogene – Neogene basins extend from Northern to Southern Thailand. The Krabi Basin in the South, considered to be Late Eocene based on vertebrate fossils, has yielded many fossils, including approximately 6 reptile species: snakes, crocodiles, and turtles, and 27 species of mammals: primates, artiodactyls, perrissodactyls (DMR, 2001). A thick deposit of shells, predominantly of gastropods, also occurs. In addition, plant macrofossils and pollen were collected (SONGTHAM *et alii*, 1999) from the basin.

The basins in Northern Thailand include Mae Moh, Mae Tip, Pong, Chiang Muan, Lampang, Li, and Mae Sod basins. About 43 mammalian species, including a primate, carnivores, artiodactyls, bats, tree shrews, rodents, and proboscideans, have been recovered (DMR, 2001). Reptiles and mollusks also occur as fossils. Plant macrofossils, especially angiosperm leaves and conifer twigs and needles, as well pollen, have been found in some of these basins (ENDO, 1964, 1966; GROTE & SAWANGCHOTE, 2003; SONGTHAM *et alii*, 2005a). Although the animal remains are mostly Miocene, the plant fossils range from Middle Miocene to Early Miocene or Oligocene.

In the Northeast, vertebrate fossils consist of numerous mammalian species, including about 9 proboscidean species, a primate, carnivores, hoofed mammals, and reptiles, such as crocodiles, gavials, soft-shelled turtles, and turtles. Many specimens were found in the Mun River floodplains in Nakhon Ratchasima Province (CHAIMANEE *et alii*, 2004; THASOD, pers. comm., 2007).

Petrified wood from Miocene – Pleistocene deposits has been found abundantly throughout the Northeast. The wood shows a high diversity, particularly of the families Leguminosae, Dipterocarpaceae, and Combretaceae (BENYASUTA, 2003; WANG *et alii*, 2006). Leaves, wood, fruits, seeds, resin, and pollen have also been found, especially in Pleistocene deposits. A wide variety of vertebrates have been found in caves throughout Thailand, including pandas, hyenas, orangutans, and rodents, mostly from the Pleistocene and Holocene (CHAIMANEE, 1998). Numerous Holocene fossils, especially mollusks, have been recovered from Thai marine deposits (ROBBA *et alii*, 2003).

3. Paleontological parks, museums, prominent fossil sites, and fossils conservation

NORTHERN THAILAND

Among the prominent fossil sites in the North of Thailand, two places conserve and display fossils to the public: a museum in Mae Moh, Lampang Province and the Petrified Forest Park in Tak Province.

Lampang Province

Mae Moh prominent fossil site and Museum of Lignite Study Center (Mae Moh)

In Lampang, numerous and various vertebrate fossils have been found in Mae Moh lignite mine, Mae Moh District, one of the largest lignite mines in Thailand, which is owned and operated by the Electricity Generating Authority of Thailand (EGAT), a state enterprise under the Ministry of Energy. The mine, 26 kilometers from the town of Lampang, has been operated since 1955 (DMR, 2006). Geologists and paleontologists from the DMR and other researchers have come to study the fossils and geological data of the Mae Moh mine. Most fossils are found in lignite zones, aged to the Middle Miocene (about 12-13 million years ago) based upon the fossil assemblage and magnetostratigraphy (BENNAMI *et alii*, 2002). Vertebrate fossils include fishes, snakes, turtles, soft-shelled turtles, crocodiles, and mammals. The mammals were identified as proboscideans: *Stegolophodon* sp., gomphotheres; rhinoceros: *Gaindatherium* sp.; otters: *Siamogale thailandicus*; and artiodactyls: *Stephanocemus rucha* (DMR, 2006; PEIGNÉ *et alii*, 2006). Among these mammalian fossils, teeth of a carnivore from the family Amphicyonidae were discovered. They were assigned to a new species, *Maemohcyon potisati*, thought to be related to the ancestors of bears and pandas (PEIGNÉ *et alii*, 2006). Plant fossils, including wood, leaves, and pollen have also been recovered from the mine (SONGTHAM *et alii*, 2005a).

Figure 3: Thailand's first Petrified Forest Park, Tak Province (A). The first petrified trunk partly excavated to about 21 m in length (B). The whole trunk, 72.22 m. long and probably the world's longest petrified trunk (C). Petrified wood sites in the Petrified Forest Park (D). Photo of Fig. 3.D courtesy of K. KRUAYOO (Petrified Forest Park).

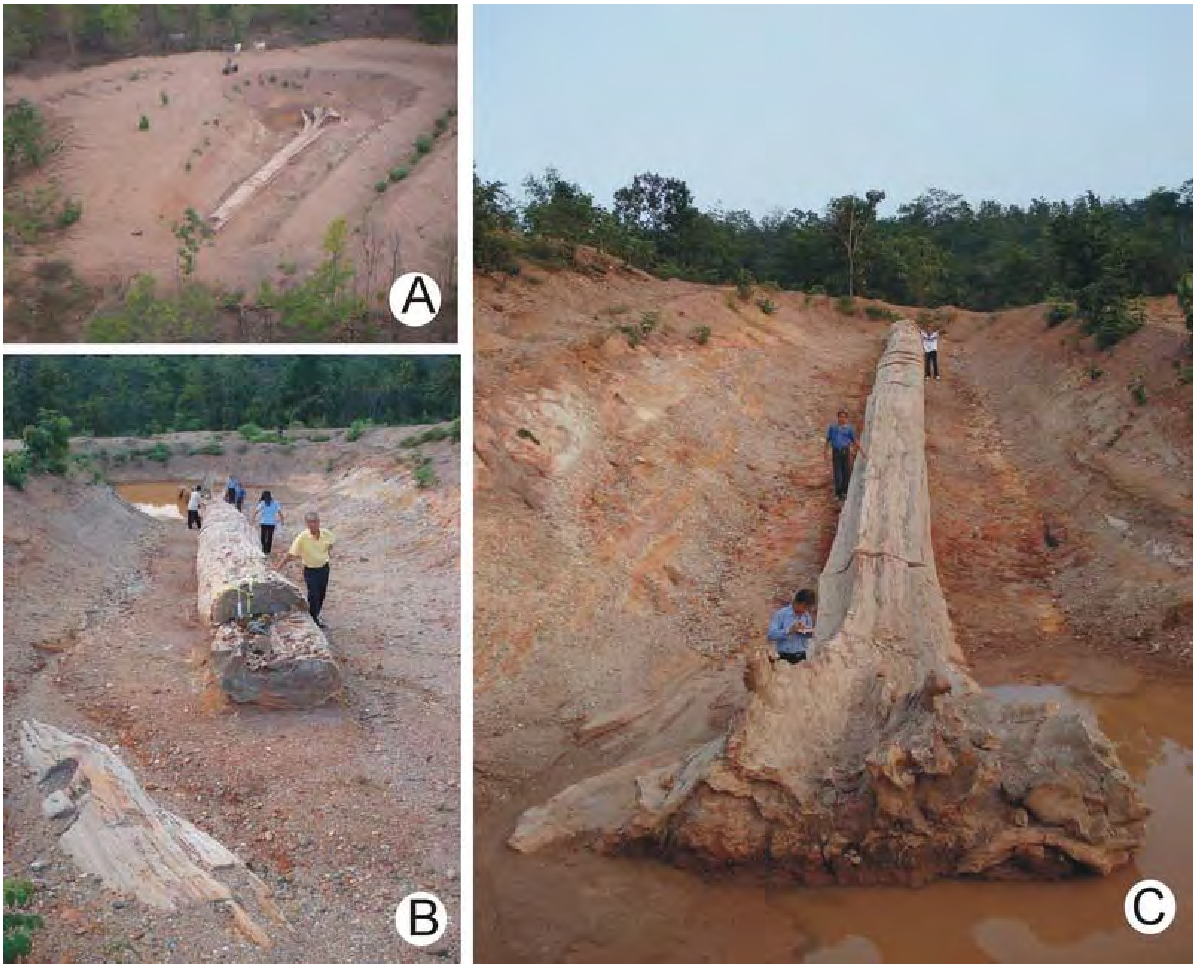


Figure 4: Petrified wood site n° 7. Viewed from a helicopter (A). A petrified log is partially exposed next to a long petrified trunk in the same site (B). The petrified trunk of site n° 7. is about 34 m. long with very large buttresses (C). Photo of Fig. 4.A courtesy of K. KRUAYOO (Petrified Forest Park).

A twelve meter thick freshwater shell bed was found in 2003 deposited between two lignite layers and extending about 300 meters (Fig. 2.A). The shell bed was dominated by freshwater mud snails, *Bellamya* (Viviparidae) (Fig. 2.B), with rare occurrences of tiny spiral snails, *Bithynia*. It may be the world's thickest freshwater shell bed. The DMR suggested that this site be conserved as a world heritage site and would like to develop it into a GeoPark (SONGTHAM *et alii*, 2005b). The Thai cabinet originally resolved that 6.88 hectares would be preserved, but later reduced the protected area to 2.88 hectares after EGAT claimed that the site would cause them to lose access to billions of dollars worth of coal. Subsequently, in March 2005, EGAT started blasting some of the site to reach the coal (Anonymous, 2005).

In 2003, the Museum of the Lignite Study Center (Mae Moh Mine) in honor of King Prajadhipok (Rama VII), funded by EGAT, was built next to the mine to serve as a learning center. It was opened to the public in 2005. It is divided into three zones: King Rama VII and the history of lignite, geological sciences, and operation of the mine. The geological section includes displays on paleontology and evolution of life. Visitors can learn about the origin of the earth and the evolution of life through geological time in a 3 dimensional movie theater. Most kinds of fossils from the lignite mine and some donated specimens are displayed in glass cabinets (Fig. 2.D), in the layers of the stratigrapic model of the lignite mine fossil site (Fig. 2.C).

Tak Province

Thailand's First Petrified Forest Park

A large petrified log, partially exposed for about 1 meter, was found by a villager in a reserve forest at Ban Tak District, Tak Province, in October 2003. The discovery of the petrified wood was reported to the National Park, Wildlife and Plant Conservation Department, under the administration of the Ministry of Natural Resources and Environment. The officer from the department subsequently came to examine the petrified log and survey the surrounding area. The petrified log was further excavated and was found to be about 4 m and 1.8 m wide at the base and the middle, respectively. The trunk was exposed to a length of 21 m without reaching the upper end (Fig. 3.B). Many additional pieces of petrified wood were found scattered in the surrounding area covering 35 km^2 or more. Some pieces were found on the soil surface and some only partly exposed. From the survey and potentiality of the natural resources of the area, it was proposed on 29 December 2003 that a forest park be set up, covering an area of 2,000 hectares (KRUAYOO, 2006).

In 2004, 14 petrified wood specimens were collected and examined for preliminary identification. Most of them belonged to the family Leguminosae: *Pahudioxylon* sp., *Afzelioxylon* sp., and *Peltophoroxylon* sp. One specimen showed close resemblance to the living species *Octomeles sumatrana* (Datiscaceae) and is possibly a new taxon. Another specimen is probably a new genus of angiosperms (ZHANG *et alii*, 2004).

The park asked for cooperation from the DMR to use Ground Penetrating Radar (G.P. R.) to check the length of the trunk and found that 30 meters of trunk were still unexposed. In 2005, the forest park received funds to excavate the whole trunk. The result was the appearance of what is considered the world's longest piece of petrified wood, with a length of 72.22 m (Fig. 3.C). In 2006, the name of the park was changed to the Petrified Forest Park because of the fascinating discoveries (KRUAYOO, 2006) (Fig. 3.A & D). The Ministry of Natural Resources and Environment has collaborated with the DMR to examine the geological and geographical information of the area to search for more petrified wood. The silicified wood is buried in gravel, sand, and clay as part of a fluvial system. Based upon preliminary investigations, an age of approximately 800,000 years has been suggested (SONGTHAM & SAETIAN, 2006, unpublished progress report).

At present, seven of nine discovered petrified trunks have been excavated, mostly in 2005, to expose the whole trunks at seven sites, with the two remaining trunks still mostly buried. The first site is where the largest petrified trunk is lying. The second to fourth trunks are cracked into many small pieces. They are 31.30 m long and 0.50 m wide, 32.40 m long and 2.10 m wide, and 44.20 m long and 1.40 m wide, respectively. The fifth trunk is 22.20 m long and 1.20 m wide, with cracks in some areas. The sixth trunk is also cracked in

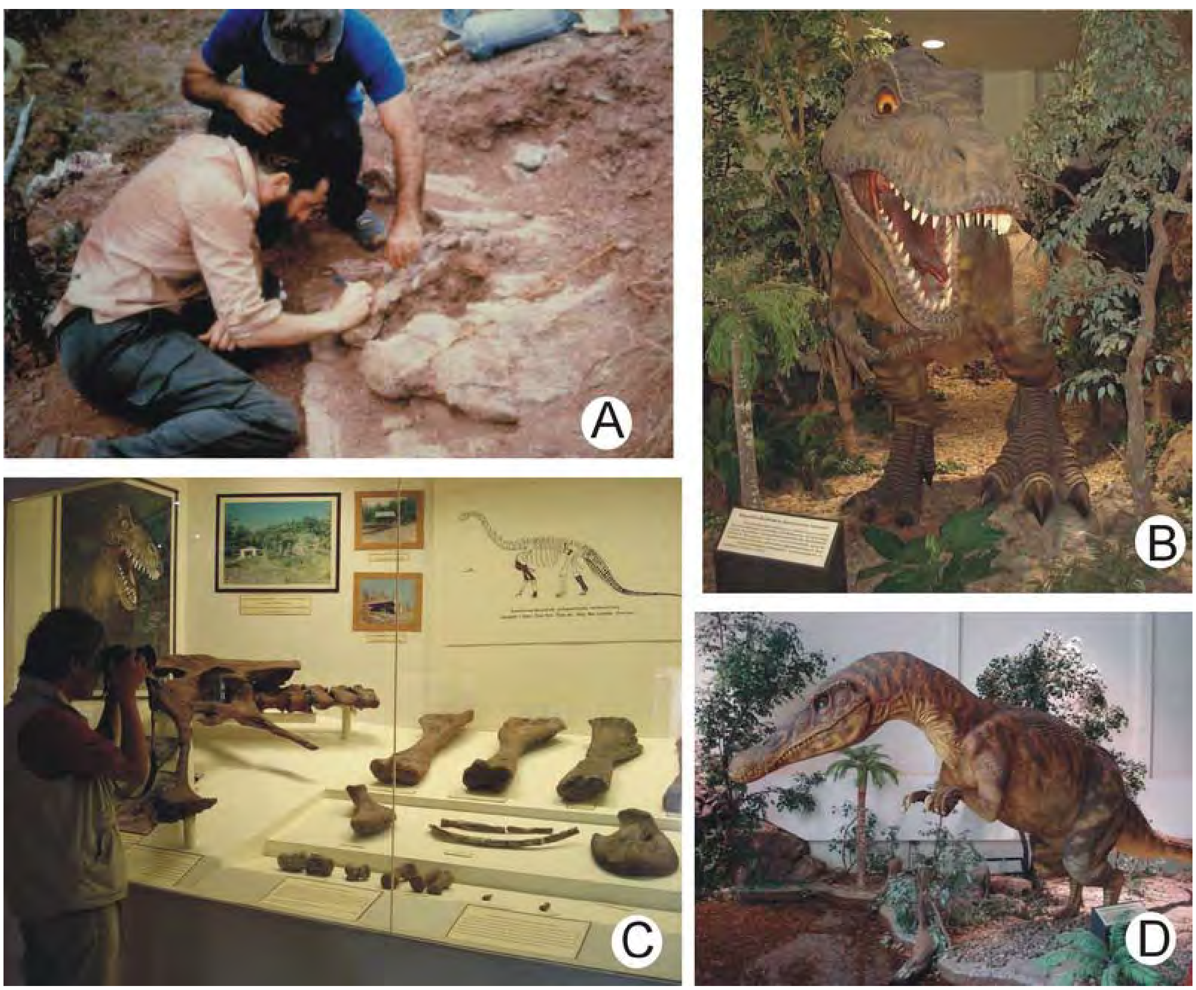


Figure 5: Dinosaur fossils found and excavated by paleontologists in what is now Phuwiang National Park (A). A dinosaur model of *Siamotyrannus isanensis* (B), some dinosaur bones or replicas from Phuwiang (C), and *Siamosaurus suteethorni* (D) exhibited in Phuwiang Dinosaur Museum. Photo of Fig. 5.A courtesy of V. SUTEETHORN.

some parts. The actual size of this trunk was approximately 50 meters long, but the upper 20 meters were removed without permission during the digging of a water reservoir. The seventh trunk is very well preserved (Fig. 4.A & C). It has very large buttresses at the base and is 34 m long. The eighth trunk is very close to the seventh one in the same site, but is not completely exposed (Fig. 4.B), and the ninth trunk is still mostly buried in the forest. A temporary cover is being built to preserve the exposed trunks *in situ*. Many additional petrified trunks are still unexcavated inside the Petrified Forest Park.

Since 2004, many people, both general visitors and students, have visited the park at about 60,000 – 100,000 persons per year (KRUAYOO, 2006). The National Park, Wildlife and Plant Conservation Department has asked a construction company to design an exhibition hall and permanent covering for the sites. Currently, the plan is in the examination process by the department. A nature trail will run between each petrified wood site so people can walk though the living forest to see marvelous stone trunks. It is expected to be a popular ecotourism spot and a place to study both ecology and paleoecology. The exhibition hall will explain the history and geology of the park, including how petrified wood occurs, its importance, and its conservation (KRUAYOO, pers. comm., 2007).

In addition to the two sites above, numerous fossils have been collected from Northern Thailand. As mentioned previously, vertebrate, invertebrate, and plant fossils are often found in lignite mines in Cenozoic basins. Additional fossils, including Permian and Triassic, have been found in road cuts. Most of these sites, however, have not been set up as permanent parks. In 2002, Jurassic dinosaur fossils were found in Doi Phu Nang National Park, Chiang Muan District, Phayao Province. After investigation by a team of paleontologists in 2003, many of them are thought to be sauropod remains. However, some were removed for personal collection or sale. The local governments, both district and subdistrict, are trying to preserve them *in situ*, including developing the area to be a new tourism spot. This area may be set up as another paleontological park in the future (Faculty of Environment and Resource Studies, 2005).

NORTHEASTERN THAILAND

Khon Kaen Province

Phuwiang National Park and Phuwiang Dinosaur Museum

Many fossils, especially Mesozoic to Cenozoic vertebrate fossils and wood, have been discovered in northeastern Thailand. Among them, the most famous and popular are dinosaur fossils. Many dinosaur remains have been found in Khon Kaen and Kalasin provinces. The first report of dinosaurs from Thailand was based on a bone discovered in 1976 by a Thai geologist and his team from the DMR, during a survey for uranium sources in Phuwiang District, Khon Kaen. The specimen was examined by French paleontologists and determined to be the distal end of a sauropod femur. In 1981, the area was surveyed under collaboration of a Thai- French team and more dinosaur remains were found (Fig. 5.A). This region was considered to be the first prominent dinosaur site in Southeast Asia and was established as Phuwiang National Park in 1992 (SUTEETHORN, 2002). The dinosaur fossil sites cover an area of approximately 400 km^2 in the national park, which is under the administration of the National Park, Wildlife and Plant Conservation Department.

From the discoveries up to 1993, nine sites with dinosaur remains have been found within the park. Each of these sites has had a building constructed over it to protect the localities. Eight of the sites yielded dinosaur bones and teeth of sauropods, including juveniles, and/or theropods from the Sao Khua Formation, considered to be Early Cretaceous based on palynomorph studies of the underlying formation (BUFFETAUT *et alii*, 1997; SUTEETHORN, 2002). The actual bones are displayed *in situ* or have been replaced with replicas. Another site (n° 8) has footprints of small ornithomimosaurs and other dinosaurs from the Early Cretaceous Phra Wihan Formation, which underlies the Sao Khua Fm. In addition, other vertebrate fossils, such as scales of the fish *Lepidotes* and turtle shells were found in some sites and in nearby areas. Unfortunately, the bones in some of the sites were damaged from disturbance and trespassing (site n° 4) or during the dismantling and replacing of the temporary cover over the site (n° 2), so only scraps of the bones were left at these sites (SUTEETHORN, 2002).

In 1999-2000, the DMR set up the Phuwiang Dinosaur Museum, about 3 km from the national park, with cooperation from the Tourism Authority of Thailand and the Khon Kaen provincial government, to be both a tourist spot and learning center of the province. The museum has displays on two floors about earth sciences, rocks and minerals, the discovery of dinosaurs in Thailand, why dinosaur fossils were found at Phuwiang, the geology of Phuwiang and the surrounding area, and how to conserve fossils. The exhibitions include the bones (Fig. 5.C) and life-sized models of Thai dinosaurs, such as *Phuwiangosaurus sirindhornae*, *Siamosaurus suteethorni* (Fig. 5.D), *Siamotyrannus isanensis* (Fig. 5.B), *Compsognathus*, *Gallimimus*, and *Psittacosaurus*. On the first floor, visitors can see how the work in the laboratory is done through glass. The museum is open free of charge to the public.

Kalasin Province

Phu Kum Khao Dinosaur Site Museum

In 1970, dinosaur fossils from an unknown locality were collected by a monk, who mistook them for petrified wood, and kept at Wat Sakkawan, a temple located at Phu Kum Khao hill, Sahat Sakhan District, about 25 km. north of the main town of Kalasin. The area was surveyed by geologists from the DMR in 1980 and some additional information about dinosaur remains was found. In September 1994, more dinosaur bones were exposed and found by the monk, which was again reported to the DMR. The site showed a very interesting dinosaur fossil assemblage, but as it was the rainy season, the excavation was postponed and the site was closed temporarily and strictly protected (SUTEETHORN, 2002; SUTEETHORN *et alii*, 2003). The excavation was started in November 1994 by a Thai – French Team and over one hundred bones were discovered within a month. A temporary building was built to cover the site of about 240 square meters. The excavation continued until the end of 1995 (SUTEETHORN, 2002). The fossils were mapped and studied and found to consist of two species of sauropods and two species of carnosaurs. More than 630 dinosaur bones were eventually found and thought to comprise at least six individuals. Most of the bones were from sauropods. As at the Phuwiang sites, the site is part of the Sao Khua Formation, thought to be Early Cretaceous in age (BUFFETAUT *et alii*, 1997).

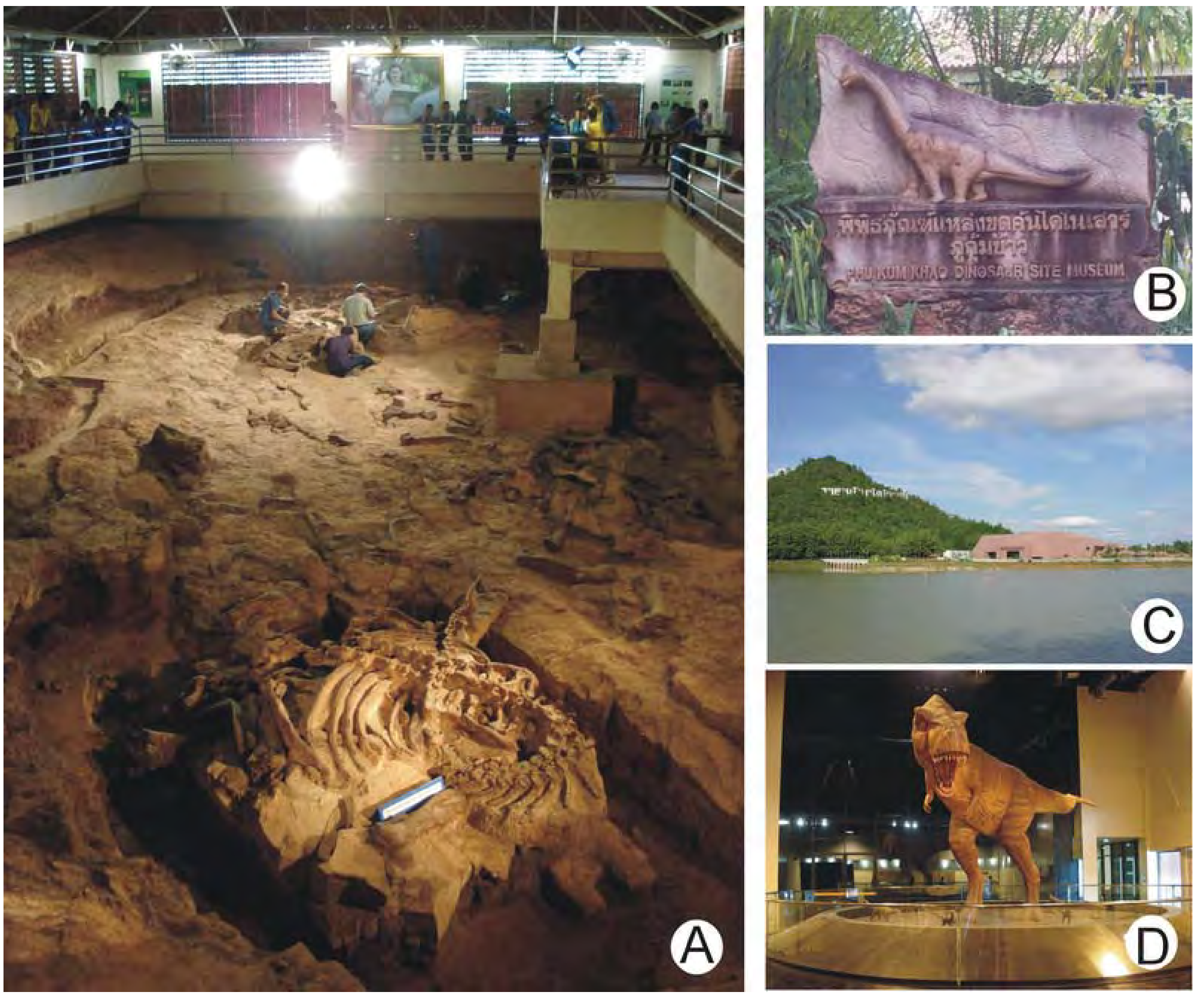


Figure 6: Dinosaur bones found and conserved *in situ* (A) at Phu Kum Khao Dinosaur Site Museum (B). A new large dinosaur museum at the base of Phu Kum Khao hill (C). A dinosaur model inside the new dinosaur museum (D). Photo of Fig. 6.C courtesy of S. SUTEETHORN.

Some dinosaur bones were dug out and replaced with replicas to protect the real specimens from damage, especially because of the monsoon climate. In 1996, the DMR built and set up the Phu Kum Khao Dinosaur Research Center close to the site. Dinosaur fossils, which had been stored at the temple, were moved to the laboratory for preservation and study, along with other plant and animal fossils from other localities (SUTEETHORN, 2002). In 1999, a permanent building was built to cover the site and set up as Phu Kum Khao Dinosaur Site Museum. Here visitors can see bones or replicas in their original positions in the sandstone (Fig. 6.A & B).

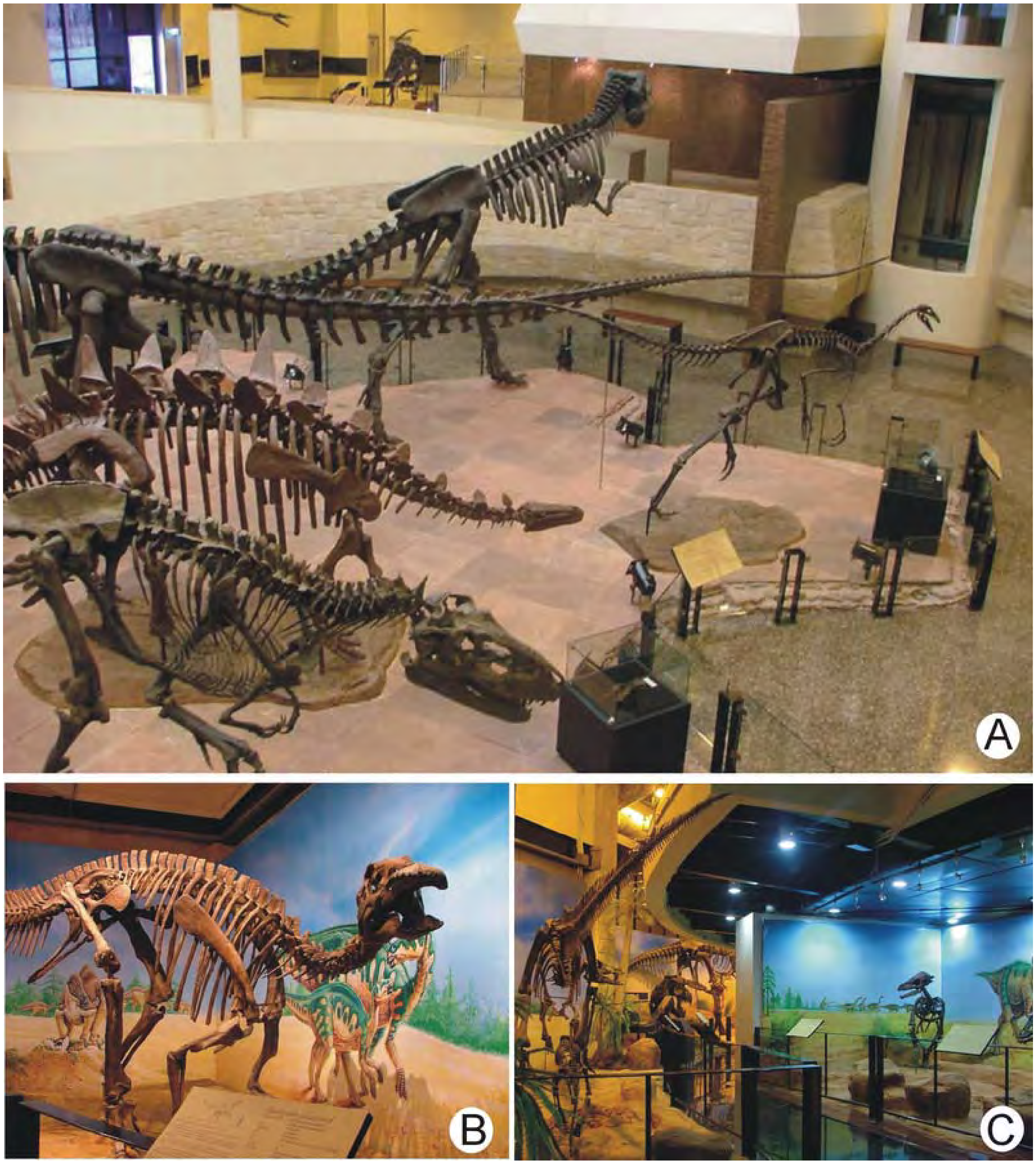


Figure 7: Reconstructions of various dinosaur skeletons from around the world with panoramas recreating their lifestyles (A, B, and C) at Sirindhorn Dinosaur Museum. Photos courtesy of T. SUTEETHORN.

A new dinosaur museum at Phu Kum Khao was constructed in 2001, not far from the fossil excavation site (Fig. 6.A & B). However, the interior exhibitions were not built because of the limited budget. Research, training, and preparing of fossils in the laboratory were done at Phu Kum Khao Dinosaur Research Center. Many thousands of dinosaur and other vertebrate fossils, including those of fishes, turtles, proboscideans, gavials, and crocodiles, have been collected from throughout the country, especially the Northeast. Many activities, such as young paleontologist camps, have been organized. With the approval of additional budgets in 2004 and 2006, the interior exhibitions were constructed at the new museum. This new dinosaur museum (Fig. 7) has been named "Sirindhorn Museum" in honor of Her Royal Highness Princess Maha Chakri Sirindhorn. It is the largest dinosaur museum in Thailand and is expected to open to the public in 2007. The museum consists of a large conference room for about 400 people and a large exhibition hall. The museum displays exhibits on the evolution and diversity of life through geological time, geology, the history of discovery of dinosaurs in Thailand, and many other aspects about dinosaurs (Figs. 6.D & 7.A-C). The museum has a very large, well equipped laboratory for fossil collection, preparation, and preservation. In 2006, all fossils from the Phu Kum Khao Dinosaur Research Center were moved to the new laboratory at the Sirindhorn Museum. Many life-sized models of dinosaurs were built near the site and around the district (Fig. 8).

The museum aims to be a learning center for the public, including organizing paleontological and geological training programs for teachers and students, to serve as a paleontological research center in Thailand, and to support the local people in producing and selling their local products, which is known as OTOP (One Tambon (Subdistrict) One Product).

Figure 8: Life-sized models of Thai dinosaurs built in the park, Kalasin Province.

Nakhon Ratchasima Province

Ban Saphan Hin Fossil Site

Besides Kalasin and Khon Kaen provinces, a high diversity and number of fossil plants and animals have been discovered in many districts of Nakhon Ratchasima in the Northeast. A new prominent dinosaur site of the Northeast was recently discovered in 2004 at Ban Saphan Hin, Suranaree Subdistrict (Fig. 9.A-B), where approximately one thousand dinosaur bones and teeth have been found (Fig. 9.C), preliminarily classified as iguanodontids, hadrosaurids, ornithomimids, dromeosaurids, tyrannosaurids, and sauropods, including *Phuwiangosaurus* (DONG, 2005). Discovered together with the dinosaurs was an assemblage of other vertebrate remains, including well-preserved hybodont shark teeth (CUNY, unpublished report, 2005), fish scales, turtles, and soft-shelled turtles (TONG *et alii*, 2005), crocodile teeth, and a gavial skull. The specimens were scattered under a corn field covering an area about 1,225 m^2.

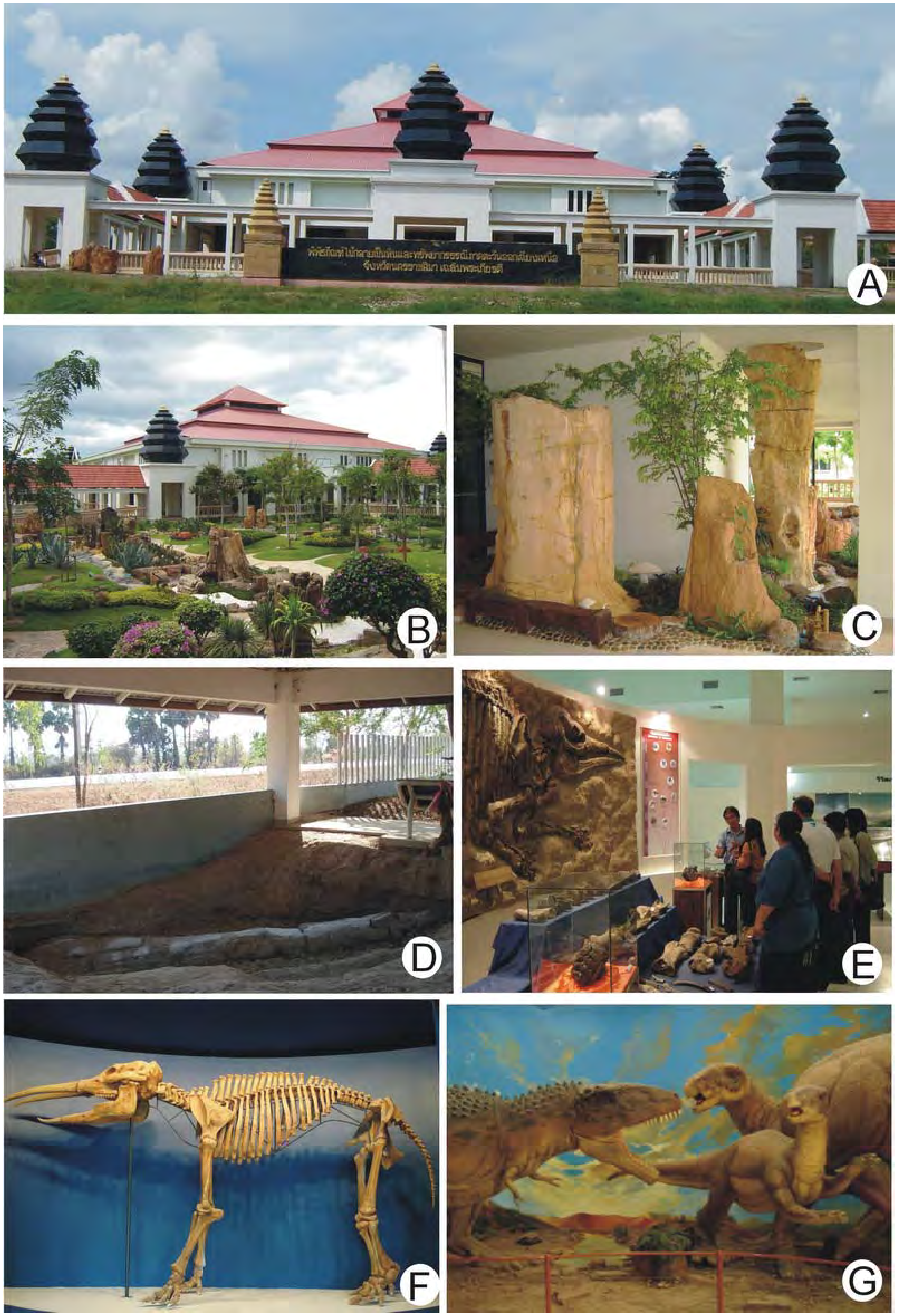
Museum of Petrified Wood and Mineral Resources

Abundant and very well preserved Cenozoic petrified wood has been found in Suranaree and Khok Kruat subdistricts, Mueang District, Nakhon Ratchasima Province. However, many specimens of petrified wood and animal fossils have been sold to private collectors, including to overseas buyers. To preserve these fossils, the Northeastern Research Center for Petrified Wood and Mineral Resources (Fig. 10.A) was first established and constructed in 1995 at Suranaree Subdistrict, Nakhon Ratchasima, by the collaboration among Nakhon Ratchasima Rajabhat University (NRRU), the provincial government, and the Department of Public Works and Town and Country Planning. From 2000 to 2002, the exhibition halls and some interior exhibitions were built with major support from the DMR. The center is now under the administration of NRRU and has received further support from the province, and is expected to formally open to the public in 2007. The site covers approximately 12.4 hectares and includes three museum buildings highlighting the dominant fossils of Nakhon Ratchasima: petrified wood (Fig. 10.C), proboscideans

(Fig. 10.E-F), and dinosaurs (Fig. 10.G), research buildings, a library, and a tourist center. The museum collections comprise over one thousand vertebrate fossils, including turtles, dinosaurs, and mammals, as well as invertebrates and plants, especially petrified wood. Several large petrified logs have been found at the site and are exhibited *in situ* (Fig. 10.D). Small pavilions have been built over these logs. In addition, two outdoor petrified wood gardens display petrified wood from the Northeast. One of them conveys the geological and geographical information about the northeastern provinces where petrified wood was found (Fig. 10.B).

In addition, small local museums have been set up near two Cenozoic fossil sites in Nakhon Ratchasima, namely, at Tha Chang and Khok Sung subdistricts, where numerous vertebrate and plant fossils have been recovered.

Figure 9: Ban Saphan Hin fossil site, Nakhon Ratchasima Province (A). Calcareous conglomerate containing many dinosaur and other vertebrate fossils (B). A dinosaur tooth from the site (C).


A
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Tha Chang Fossil Site

Tha Chang Subdistrict, Chaloem Prakiat District, is famous for Miocene – Pleistocene mammalian sites. Fossils have been discovered since 1986 during sandpit operations (Fig. 11.A). This area became more well known in 1995 and especially 1997 when paleontologists came to investigate and identify fossils. Local people and fossil hunters have also come to collect fossils for business purposes. Many fossils were sold in Bangkok and some were sent overseas. To protect the fossils, some were stored and temporarily displayed at Rajabhat Institute Nakhon Ratchasima (which is now the university, NRRU). In 2004, all the specimens were moved for preservation and display at the Museum of Petrified Wood and Mineral Resources.

Thousands of mammalian fossils have been found at nine commercial sandpits at Tha Chang. Among them, nine genera of proboscideans (Fig. 11.B) [*Gomphotherium*, *Prodeinotherium*, *Tetralophodon*, *Protanancus*, *Sinomastodon*, *Stegolophodon*, *Stegodon*, *Elephas* (THASOD *et alii*, 2003; THASOD & RATANASATHIEN, 2005) and *Anacus*? (THASOD, pers. comm., 2007)], rhinoceros, giraffes, antilopes, *Hipparion* sp., and *Merycopotamus* sp. (HANTA *et alii*, 2005) were found from the alluvial deposits of the sandpits near the Mun River. A new hominoid species, *Khoratpithecus piriyai* (Fig. 11.C) (CHAIMANEE *et alii*, 2004) and a large tortoise shell about 1.5 meters long (Fig. 11.D) were also discovered. Besides animals, much wood and pollen has also been found at the sites. Some fossils were collected for study at the DMR, and many were collected by the Museum of Petrified Wood and Mineral Resources. The sites became flooded after mining operations were finished in some sandpits, along with the problem of sliding sand, so the fossil excavations mostly stopped in 2004. Moreover, the sediment in sandpits contains much sulfite, especially pyrite. Therefore, a park cannot be set up for keeping *in situ* fossils. However, a fossil elephant museum was built in the town of Chaloem Prakiat with collaboration from local governments at both the district and provincial level and the Tourist Authority of Thailand. However, because of limited support and scarcity of staff and paleontologists to work at the museum, it was not successful, and now part of the building is being used for other purposes.

Nevertheless, the Chaloem Prakiat District has proposed to set up a new Proboscidean Site Museum again on local government land provided by the Tha Chang Subdistrict Administrative Organization. The museum would be close to one of the sandpits and cover an area of about 2.56 hectares, including an area for excavating. The proposed museum building would be about 20 m X 45 m with three floors. This project is currently under the consideration of the central government.

Khok Sung Fossil Site

In March 2005, a new fossil site of Nakhon Ratchasima was discovered in Khok Sung Subdistrict, Mueang District. Numerous animal fossils were found in the area covering about 1.6 hectares of private land while digging out the sediment for making a water reservoir (Fig. 10.F). Many animal and plant remains were found in a layer of sand and gravel interbedded with clay about 5 m from the soil surface (DMR, 2006). The site is now entirely flooded, precluding the collection of additional fossils.

Vertebrate fossils from the site include *Stegodon*, bovids, cervids, a hyena skull (Fig. 10.E), gavials, turtles, and soft-shelled turtles and are being studied by Thai paleontologists from the DMR and overseas collaborators. Plant fossils, including wood, fruits, seeds, leaves, amber, and pollen were also collected and are being studied at Suranaree University of Technology, Nakhon Ratchasima.

Khok Sung Subdistrict Administrative Organization has built a small museum to house many of the fossils from the site (Fig. 10.G) with cooperation from the DMR on paleontological information of the site. Plans are ready to set up a larger museum in the future.

CENTRAL THAILAND

The first geological museum of Thailand was set up in the capital, Bangkok, at the DMR main office (Fig. 12.A). The museum is divided into nine sections: museum history, geological history, rocks, minerals, groundwater, mineral fuels, evolution of life, geology of Thailand, and applied geology. The section on evolution of life has displays about paleontology, including fossils of Thailand and replicas of dinosaur skeletons (Fig. 12.B).

A new larger national Geological Museum including a paleontological section was constructed in 1999 - 2001 in Pathum Thani Province, north of Bangkok. Now the interior exhibits are under construction.

SRISUK's House Museum is a small private museum, which houses, nevertheless, many important specimens of animal and plant fossils from many geological ages. The museum is open to visitors and has been involved with collaboration with Thai and overseas researchers.

◀ **Figure 10:** Museum of Petrified Wood and Mineral Resources (A). Petrified trunks from several provinces in the Northeast displayed in a geological garden (B). Large petrified trunks on display in petrified wood hall (C). Petrified wood conserved *in situ* under a pavilion (D). Proboscidean fossils from Tha Chang (E) and reconstructed skeleton (F) exhibited in proboscidean hall. Movable dinosaur models in dinosaur hall (G).

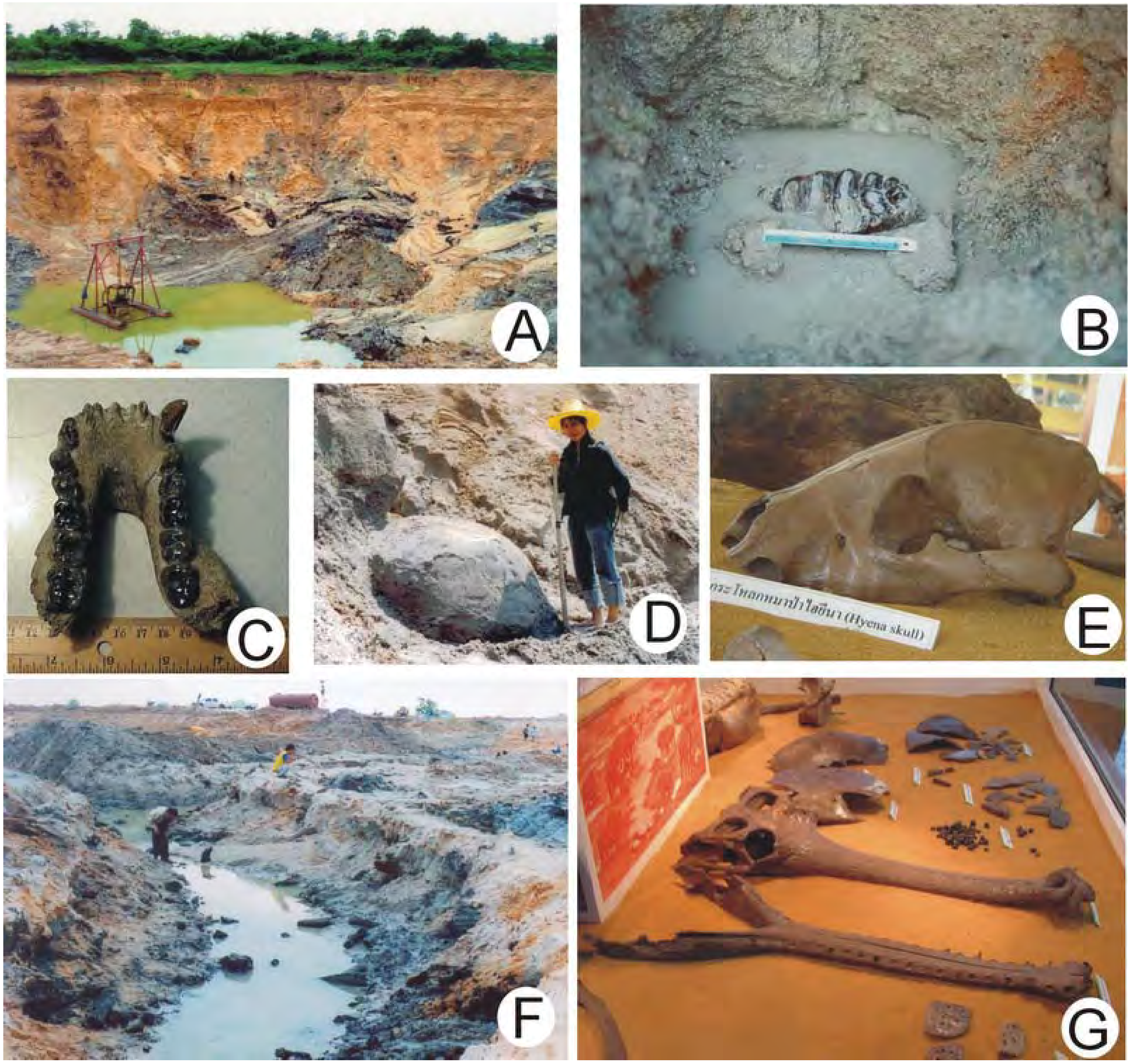

Figure 11: One of several sandpits at Tha Chang (A), where vertebrate fossils, such as a proboscidean molar (B), jaw of a new ape species, *Khoratpithecus piriyai*. (C), and a giant tortoise (D) were found. A hyena skull (E) and other fossils found at Khok Sung (F). Some specimens, including a gavial skull and lower jaw (G), displayed in the local museum at Khok Sung Subdistrict. Photos of Fig. 11.E-G courtesy of J. DUANGKRAYOM.

SOUTHERN THAILAND

The Shell Fossil Cemetery, or Susan Hoi, in Thai, is located at Ban Laem Pho, Mueang District, along the Andaman Sea, about 19 km from Krabi city. The site is part of a national park under the supervision of the National Park, Wildlife and Plant Conservation Department. This site comprises a thick bed of fossils, predominantly gastropods, with three principal species, the largest being *Viviparus* sp. The age of the deposits is considered to be Late Eocene based on vertebrates (BENNAMI *et alii*, 2001) or Early to Middle Miocene based on palynomorphs (WATANASAK *et alii*, 1995). This site has been popular with tourists. However, the shell bed has been damaged by many people walking on it and by erosion from sea water. The bed should be protected as a paleopark by dividing it into three areas: a preservation area to be kept undisturbed, a conservation area with limited access, and a developed area with a walkway and information sign to be staffed by a guide. A museum was also proposed (Faculty of Environment and Resource Studies, 2005).

4. Discussion and Conclusions

Controversies exist over some fossil sites, especially those on the private lands. For example, at Mae Moh mine, it was claimed that billions of dollars would be lost if all of the fossil shell beds were to be conserved because of lost access to lignite layers and eventually part of the beds were removed to reach the lignite. At Tha Chang fossil sites, fossil-containing sediments have been eroded during the mining process. Sliding of the sand caused the sediments from different layers to become mixed together, making it difficult to get accurate geological information.

A **B**

Figure 12: Geological Museum, the Department of Mineral Resources, Bangkok (A), and fossil exhibits, including dinosaur replicas (B). Photos courtesy of S. BOONLAMPOO.

In Ban Saphan Hin village, dinosaur and other vertebrate fossils were found scattered in calcareous conglomerate rock under private land. Many of the fossils were damaged from improper digging to take out the fossil-containing rocks for sale. In Tak, and especially in many provinces in the Northeast, numerous large petrified trunks were unearthed during construction and quarrying for gravel. The price of the rocks with embedded fossils increased. Fossils, including petrified wood, are in high demand, resulting in fossil hunting becoming a business.

Some local villagers in Thailand have earned their living from selling fossils for over twenty years. Paleontologists have been trying to protect fossils by explaining their importance and requesting that the villagers donate the fossils for research and refrain from selling them. However, these attempts have not always been successful as it would interfere with the earnings of the villagers or others. In fact, fossils are sometimes concealed, including covering up fossil localities, so that the fossils can be sold secretly later. To make the people understand and realize the scientific value of fossils without causing conflict, collaboration with concerned organizations, including local governments, are needed. The villagers should be helped in finding other ways to earn their living, rather than selling fossils, such as by supporting them to make products from other local renewable natural resources and providing vocational training.

Unclear laws on fossils, limited budget, and the small number of Thai paleontologists are other factors that impede fossil conservation. More precise laws on the protection of fossils in Thailand are currently being considered by the DMR.

Since Thailand is a tropical country, much of which is covered with dense vegetation, perhaps the majority of fossils are exposed or made accessible in areas of human activity, such as in mines, quarries, and road cuts. Because of the low number of paleontologists, many fossils are lost in the process of mining and quarrying. Often when mining is completed in an area, such as at the Tha Chang sandpits and in lignite mines in the Li and Krabi basins, the site becomes flooded preventing further collecting of fossils at least in the lower levels.

One of the best ways to perpetually conserve fossils is the setting up of paleontological parks and/or museums where the prominent fossil sites are found in each part of Thailand. Paleontological parks can protect not only fossils but also the sites and the surrounding areas, where visitors can learn about the fossils in their original position and about the geological structure of the area. However, if the sites are not appropriate for setting up a park, museums are another way to preserve fossils in Thailand.

Paleontology is considered a new science in Thailand that is not well known. Therefore, paleontological parks and museums have important roles as both learning and training centers (Fig. 13.C) for the public, including teaching about paleontology, geology, the evolution of life, paleobiodiversity, and the dominant natural resources of that area (Fig. 13.D-G), in other words, serving as living paleontological encyclopedias of Thailand.

Figure 13: Chinese paleobotanists identifying petrified wood at the Museum of Petrified Wood (A). Researchers studying fossil wood in the garden (B). A student practicing paleontological work in the laboratory of Phu Kum Khao Dinosaur Research Center (C). Children learning about Thailand's dinosaurs at the Museum of Petrified Wood (D) and Phuwiang Dinosaur Museum (E). Overseas students learning about opalized wood (F) and students studying proboscidean fossils and their evolution (G) at the Museum of Petrified Wood. Photo of Fig. 13.C courtesy of S. SUTEETHORN.

Paleontological parks and museums in Thailand have the same stated aims to not only preserve and collect fossils, but also to foster the public to realize the values of fossils and infuse in them a desire to protect these natural heritages, to encourage more young Thai paleontologists, and to serve as centers for international collaboration in research (Fig. 13.A-B) and conservation. A variety of activities, such as camping, meetings, workshops, and conferences, have been arranged with collaboration from public and other organizations. According to the records of visitors to these places, the increasing numbers from year to year indicate that Thai people are more interested in fossils now than in the past. The paleontological parks and museums help the general public have better understanding of why we need to conserve fossils and how to preserve fossils in the proper way.

Moreover, paleontological parks and museums set up in each part of Thailand increase income to local areas and support tourism. They help local people have more jobs in their hometown and reduce the jobless problem, including providing opportunities for villagers to make souvenirs from local products and sell them in souvenir shops of the parks and museums. Some products are applied to match with the museums, such as earthenware and handicrafts with dinosaurs or other animal patterns of the fossils found locally.

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