Wladyslaw Altermann

FACIES DEVELOPMENT IN THE PERMIAN PETCHABUN BASIN

CENTRAL THAILAND

REIHE GEOWISSENSCHAFTEN

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RERUM COGNOSCERE CAUSAS

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CONTENTS

I Abstracts 9
II Zusammenfassung 11
III Preface 23
IV Introduction 25

PART I
Facies development in the Permian Petchabun Basin, Central Thailand.

1. Geology and stratigraphy of Northern and Central Thailand . . . 31
1.1. Plate tectonic discussion 36
2. New research 43
2.1. Saraburi - Pak Chong area 49
2.2. Saraburi - Lop Buri area 53
2.3. Saraburi - Lam Na Rai area 53
2.4. Thuak Khao Sompot area 56
2.5. Khok Samrong - Tak Fa area 59
2.6. Phu Khao Samo Rat area 61
2.7. Khao Khi Nok area 63
2.7.1. Silicification processes 65
2.8. Khao Yang Ta Po area 67
2.9. Ban Sapsamothot area 69
2.10. West of Nong Pai area 70
2.11. Nong Pai - Chon Daen area 71
2.12. Petchabun area 72
2.13. The Petchabun Fold and Thrust Belt 72
2.13.1. East of Lom Kao area 78
2.13.2. Huai Nam Lao area (east of Petchabun) 79
2.13.3. East of Nong Pai area 80
2.13.4. East of Wichian Buri area 81
2.14. Khao Tha Mon area 81
2.15. West of Chum Phae area 82
2.16. Wang Saphung area 86
2.17. Loei area 89
2.17.1. Loei - Dan Sai road 89
2.17.2. Loei - Tha Li road 90
2.17.3. Loei - Chiang Khan area 91
2.17.4. West of Chiang Khan area 92
2.17.5. East of Chiang Khan area 95
3. Volcanic rocks 96
3.1. XRF - Analysis and discussion 99
3.2. Description of thin sections 113

4. Upper Paleozoic facies development in Central Thailand 116
4.1. Carboniferous 116
4.2. Early Permian 117
4.3. Middle Permian 119
4.4. Late Permian 121
4.5. Discussion 121

PART II
The pebbly mudstone facies in peninsular Thailand and western Malaysia

1. Introduction 131
2. Pebbly mudstones investigation 135
2.1. Langkawi area 135
2.2. Ko Pi Pi area 136
2.3. Phuket area 136
2.4. Khaeng Krachan area 138
3. Facies description and discussion 139
4. Conclusions and intrpretation 144
5. Last word 145

References 147

APPENDIX

A) Fossil tabels
B) Log Profiles
C) Photograph plates

I. ABSTRACT

The Permo-Carboniferous sedimentary facies development in Thailand reflects the late Variscan orogeny in SE-Asia.

During the Carboniferous and Lower Permian, a N-S trending trough separated the Shan Thai Craton and the Indosinia Craton. This basin was flanked on its eastern side by a shelf on which Upper Carboniferous through Murgabian carbonates and siliciclastics were deposited.

West of the basin platform carbonates are again present.

The carbonate sedimentation on the western platform was occasionally oppressed by siliciclastic influx during Moscovian to Midian times. Periodic desiccation in Middle Carboniferous and transgressive and regressive cycles in the Permian are indicated. Mainly Asselian and Sakmarian keratophyric to quartzkeratophyric tuffs and tuffites are interbedded with these sediments. Subsequently, spilitic sills intruded these strata.

In the pelagic Petchabun basin, sedimentation of ribbon cherts continued from pre-Asselian to Kubergandian. In the Lower Permian, carbonate and tuff turbidites were transported from the neighbouring platforms into the basin.

The Middle Permian flysch sedimentation resulted from a strong orogenic activity. The basin was E-vergent, isoclinally folded and overthrusted. Because the ?pre-Asselian, easternmost parts of the basin exhibit steep dipping fold axes (B-axes), they are affected by at least two folding events. Parts of the Petchabun basin are metamorphosed into the greenschist facies.

In the eastern, marginal parts of the basin, Kubergandian to Midian molasse was deposited from the new rising fold belt. The intensity of folding of the molasse decreases towards the east or the younger strata.

The total width of the basin was probably not greater than 200 km. The pelagic sediments, flysch and molasse, represent a thick coarsening-upwards sequence, typical of subduction-related sutures. The tectonic interpretation is that of a folded marginal marine basin. The folding was probably caused by a westward-directed subduction (A-subduction) under the volcanic arc.

West of the arc, pebbly mudstones were laid down on the trench slope or the continental margin of Paleo-eurasia. The deposition of these mixtites continued through the Carboniferous to Lower Permian and came to an end contemporaneously with the relative uplift of the "Shan Thai Craton" and the onset of the A-subduction under the Petchabun marginal basin. The Benioff-subduction must have been located west of the area of sedimentation of the pebbly mudstones and was directed towards the east.

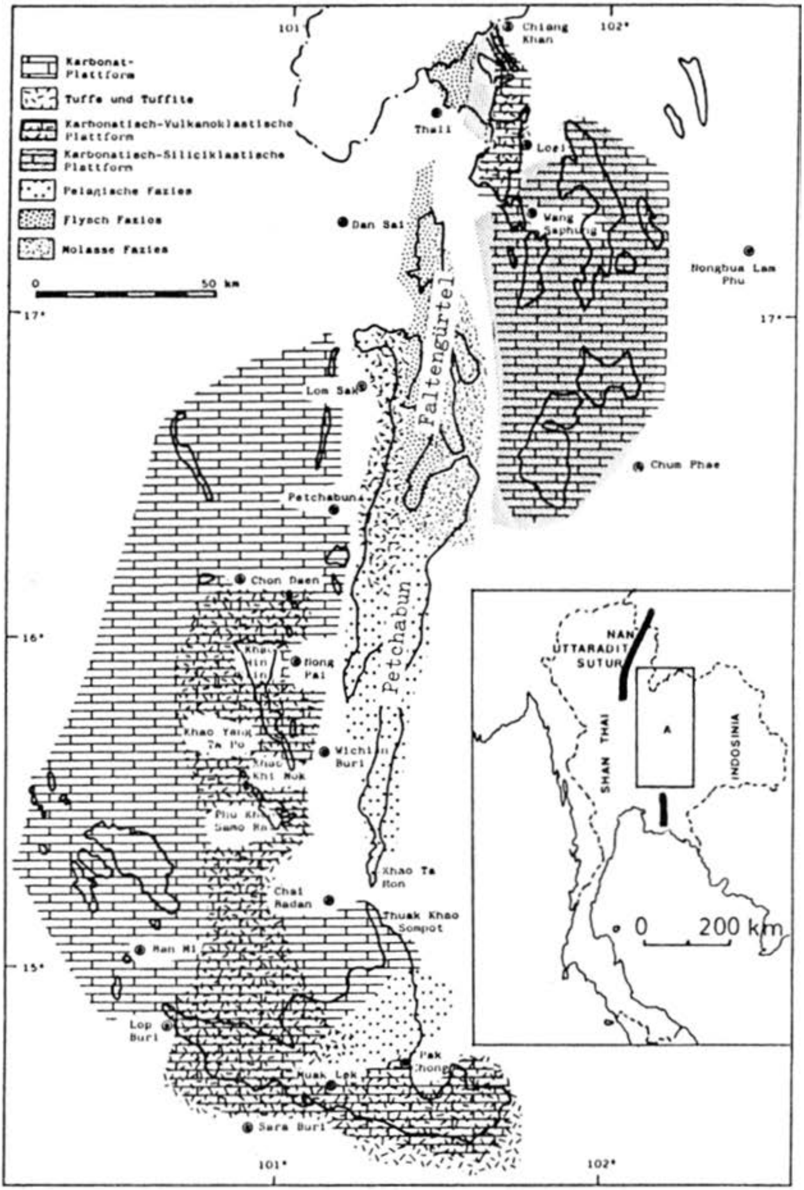


Fig.I: Lage des Arbeitsgebietes (A) und Faziesverteilung während des Perms.
Durchgezogene Linien begrenzen die permischen Gesteine im Arbeitsgebiet (laut Geol. Karte Thailand 1:1000000).

II. ZUSAMMENFASSUNG

Teil I

Bis zu HELMCKEs Arbeiten über den tektonischen Werdegang SE-Asiens (1982; 1983; 1985), galt dieser Teil der Welt als hauptsächlich indosinisch (kimmerisch) gefaltet. Diese Faltung wurde nach BUNOPAS & VELLA (1978), SENGÖR (1985), durch eine Kontinent-Kontinent-Kollision zwischen dem westlich gelegenen Shan Thai-Kraton und dem Indosinia-Kontinent im Osten in der Trias und an der Trias/Jura-Wende vollzogen. Dabei wurde von vielen Autoren ein Abtauchen der Subduktionszone nach Osten angenommen. Der Shan Thai-Kraton soll sich im Oberkarbon von Gondwana losgelöst haben und durch Drift gegen Norden, mit einer gleichzeitigen Drehung im Uhrzeigersinn um 180 Grad die Paläotethys zerstört haben. Gleichzeitig soll im "Rücken" von Shan Thai die Neotethys entstanden sein.

Demgegenüber ist nach HELMCKE (1985), eine Variszische Orogenese für die Prägung dieser Gebiete verantwortlich. Demnach sind alle Suturen im zentralsüdostasiatischen Raum bis zum Ende des Paläozoikums geschlossen worden und der Shan Thai-Kraton ist den jungpaläozoischen Nordkontinenten zugehörig.

Die vorliegende Arbeit behandelt ein östlich der Nan-Uttaradit-Sutur liegendes Gebiet (Petchabun-Faltengürtel, s. Fig. I), das nach HELMCKE & KRAIKHONG (1982) schon im Mittel- bis Oberperm als letzte Phase der Variszischen Orogenese – nach der Meinung anderer Autoren aber während der Indosinischen Orogenese – gefaltet wurde. Die Entwicklung dieses Orogens wird vom Oberkarbon bis ins Oberperm im Spiegel der sedimentären Vorgänge geschildert.

WIELCHOWSKY & YOUNG (1985) haben in diesem Gebiet für das Perm drei Hauptfaziesbereiche auskartiert: Plattformkarbonate und Riffkomplexe, Beckensedimente und flach- und marginalmarine Siliciklastika. Diese Dreiteilung konnte generell bestätigt und verfeinert werden.

Faziesentwicklung

Oberkarbon bis Unterperm.

In dieser Zeit ist die regionale Faziesdifferenzierung des Sedimentationsraumes am ausgeprägtesten.

Westlich der Linie Chai Badan - Lom Sak ist eine breite Karbonatplattform entwickelt. Vom mittleren Karbon (Moscovian) über Asselian, Sakmarian und Yahtashian sind Korallenriffe und beidseitig des Riffs benachbarte Faziesbereiche präsent. Back reef Bereiche, ausgedehnte Karbonatplattformen mit flachmarinen, gut durchlüfteten Milieu sind gut aufgeschlossen. Neben Faunengemeinschaften von Brachiopoden, Krinoiden und Bryozoen, sind Vergesellschaftungen von fusuliniden Foraminiferen und Dasycladaceen (SMF 18; SFB 7-8) weit verbreitet. Ablagerungen geschüzter Lagunen mit Loferiten und spongistromen Kalkmikriten sind häufig. Gelegentlicher siliciklastischer Influx von siltigem Material unterdrückte die Karbonatsedimentation. Kalkhaltige, schräggeschichete Sandsteine dokumentieren ein "bypassing"-Environment in eng begrenzten Sedimentationsräumen (channels).

Der Riffbereich selbst ist nicht aufgeschlossen, jedoch durch gelegentliche Korallen-Funde belegt. Gut belegt sind auch kleinere Vorkommen von Fleckenriffen.

Im gesamten Sedimentationsbereich verbreitete Tuffe und Tuffite, geben Anlaß zu der Vermutung, daß sich die Riffe um die vulkanischen Hochgebiete gebildet haben.

Da die Pyroklastika z.T. sehr grob sind, muß der Vulkanismus in nächster Nähe stattgefunden haben. Anhand der enthaltenen Fossilien konnten die Tuffe als Asselian bis Sakmarian datiert werden.

Bioklastische grainstones der SMF 5 aus dem Hangabfallbereich belegen einen Übergang zu tieferen Zonen.

Im Süden des Untersuchungsgebietes, zwischen Saraburi, Lop Buri, Pak Chong und Chai Badan ist eine ähnliche Faziesentwicklung zu beobachten. Der Unterschied besteht vor allem im Vorkommen wesentlich feinerer, sedimentär umgelagerter Tuffite.

Auch im Norden des Untersuchungsgebietes, etwa 2 km nördlich von Loei, an der Straße nach Chiang Khan sind ähnliche Sedimente aufgeschlossen. Hier wurden Tuffe und Tuffite reich an Strukturen, wie Schrägschichtung, flaserige Schichtung und gelegentliche Gradierung zusammen mit gradierten Krinoidenschuttkalken, die selbst oft Tuffmaterial enthalten abgelagert. Die Bankmächtigkeiten erreichen bis 0.5 m. Diese Karbonate sind proximale Kalkturbidite. Neben wenig segmentierten Krinoiden führen sie auch Foraminiferen und andere Fossilien.

Im Osten des Petchabun-Grabens, vor allem entlang der Straße Lom Sak - Chum Phae, ist eine unterpermische pelagische Fazies aufgeschlossen (HELMCKE & KRAIKHONG 1982). Gebänderte, radiolaritische Chert-Ablagerungen wechseln mit distalen allodapischen Kalken. Seltene turbiditische Tuffite (WINKEL, 1983) sind eingeschaltet. Diese Gesteinsfolge ist stark ostvergent gefaltet und über 1000 m mächtig. Östlich von Petchabun, entlang des Huai Nam Lao Flusses wurde eine Abfolge von Tuffen, Tuffiten und Kieselschiefern gefunden. Die Tuffe und Tuffite sind, wie im gesamten unterem Perm im untersuchten Gebiet, auch hier vorwiegend keratophyrischer Zusammensetzung.

Das noch weiter nach Osten an der Straße Lom Sak - Chum Phae, im Westen von Chum Phae aufgeschlossene Unterperm, ist nur schwach gefaltet. Eine vorwiegend karbonatische Sedimentation erstreckt sich über das gesamte Unterperm. Plattformkarbonate mit organischen "build ups" und Lagunenfazies, ähnlich der im äußersten Westen, sind gut entwickelt. Dominierend sind Dasycladaceen/ Fusulinen-grainstones und wackestones, Mikrite mit ganzen Fossilien, sowie bioklastische Mikrite, die z.T. homogenisiert sind durch die Wühltätigkeit von Sedimentfressern. (SMF 18; 8; 9; 10, SFB 7-8). Die mound- oder mound-Flanken-Fazies mit Krinoiden und Bryozoen-Debris in mikritischer Matrix kommt auch vor.

Mitteleres Perm

Im Westen des Faltengürtels existieren immer noch die Riffe und Flachwasserkarbonate, der Vulkanismus scheint jedoch verklungen. Neben mehreren Ipciphyllum-Korallenfunden (Murgabian) und mächtigen Kalkkonglomeraten der Riffhang-Fazies (Vorriff-Bereich) sind auch Chert-Brekzien, rötlich gefärbte Sandsteine mit mitteldimensionaler Schrägschichtung und in einem Fall Magnetitseifen als Strandschwerminerale gefunden worden.

Die Entwicklung im Süden verläuft wie im Unterperm, aber mit gelegentlicher Einschaltung von strukturlosen Sandsteinen.

Im Süden des Arbeitsgebietes, nördlich von Muak Lek wurden Kalk- und Tuffitturbidite gefunden, die ein Tieferwerden des Beckens belegen.

Im Bereich des Petchabunorogens werden einerseits immer noch bis ins Kubergandian die pelagischen Cherts sedimentiert, andererseits kommt es zur Ablagerung mächtiger Flyschsedimente mit vollständigen BOUMA-Zyklen. Der Flysch ist mindestens 1 km mächtig und wie die Pelagische Fazies streng ostvergent, isoklinal gefaltet. Aufgrund von Ammoniten- und Foraminiferenfunden konnte der Flysch als Murgabian (STROBEL in Vorber.) datiert werden. Die N-S verlaufende Transportrichtung der Flyschsedimente wird als trogparallel interpretiert.

Weiter im Osten, an den Flysch anschließend, kommt es wenig später (ab Murgabian) zur Sedimentation einer Meeresmolasse (Nam Nao Formation, ALTERMANN, 1983). Sie beginnt mit einer nicht mit Fossilien belegten Übergangsfazies von Flysch zu Molasse, in der noch meist turbiditisch abgelagerte Grauwacken vorkommen, die aber keine vollständigen BOUMA-Sequenzen mehr aufweisen (Huai Rahong Schichten, ALTERMANN, 1983). Die Paläoströmungsrichtung in diesen Sedimenten verlief Süd - Nord und Südwest - Nordost.

Danach folgen die Huai Wa Schichten (ALTERMANN, 1983), bestehend aus Feinkonglomeraten, feinkörnigen Grauwacken und autochthonen Kalken (Korallen, Krinoiden, Dasycladaceen und Foraminiferen) in Wechsellagerung mit Silt- und Tonsteinen. Während die Sandsteine sehr reich an Brachiopoden, Foraminiferen und Bryozoen sind, enthalten die Pelite reichlich Pflanzenreste.

Diese Sedimente werden von fossilfreien, monotonen, dunklen Tonsteinen mit wenigen geringmächtigen Sandsteinbänkchen Überlagert. Diese Khao Pha Daeng Schichten (ALTERMANN, 1983) sind wahrscheinlich in einem abgegrenzten, marginalen Becken abgelagert worden.

Die pelagischen-, Flysch- und Molasse-Sedimente sind auch südlich der Straße Lom Sak - Chum Phae (im Osten von Petchabun) aufgeschlossen. Die pelagische Fazies kann noch weiter in den Süden, bis östlich von Wichian Buri verfolgt werden. Hier wurde sie wahrscheinlich auf oberkarbonische Flachmeerkarbonate überschoben.

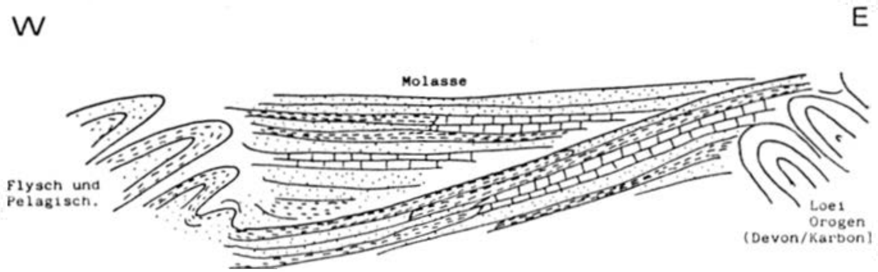
Im Norden kann der Flysch entlang der Laos/Thailand-Grenze, zwischen Chiang Khan und Thali verfolgt werden.

Östlich der Molasse, im Westen von Chum Phae wird die Sedimentation der Karbonate, etwa im Murgabian, durch eine Schüttung von mächtigen Sandsteinen und Tonsteinen abgelöst (Bolorian bis Kubergandian). Stark wechselnde Bankmächtigkeiten, Schräg- und Flaserschichtung neben Laminierung, mitteldimensionalen und großdimensionalen Schrägschichtungskörpern, symmetrischen Rippeln,

Strömungsrippeln und Runzelmarken belegen den marginalmarinen Charakter dieser Sedimente, die aus Südosten geschüttet wurden.
Weiter nördlich dieser Siliciklastika, in der Nähe von Wang Saphung, werden auch Karbonate abgelagert.

Oberes Perm

Belegt ist nur das untere Oberperm - Midian in Flachwasserkarbonat-Fazies mit Fusulinen. Ein Vorkommen gehört der Molasse des Petchabunorogens an. (Huai Wa Schichten).
Das andere Vorkommen ist im äußersten Westen, nördlich von Ban Mi und südöstlich von Chai Badan (Thuak Khao Sompot).



Mittel- bis oberpermischer Molassetrog des Petchabun Orogens
Fortschreitende Faltungsfront von West nach Ost

Fig. II: Schematische Darstellung des Molassetroges im oberen Perm.

Tektonik

Das Mittelperm ist durch das Einsetzen einer starken Orogenese ausgezeichnet, die sich in den Sedimenten des Petchabun-Faltengürtels wiederspiegelt.
Die pelagischen- und Flysch-Sedimente sind isoklinal und ostvergent gefaltet und überschoben. Die Molassesedimente sind wesentlich geringer gefaltet als der Flysch und die pelagische Fazies. Die meisten Falten zeigen keine Vergenz und dort, wo sie vorhanden ist, ist sie meist westlich ausgerichtet.
Die Abfolge von Tuffiten und Kieselschiefern entlang des Huai Nam Lao Flusses, östlich von Petchabun muß in zwei Phasen gefaltet worden sein, da nebst zwei Richtungen der Schieferung auch Falten mit bis zu 70 Grad steilen Faltenachsen entwickelt wurden. Es wird angenommen, daß diese pelagischen Sedimente älter als Asselian sind (?mittleres bis oberes Karbon). Der Metamorphosegrad dieser

Folge reicht bis in die Grünschiefer-Fazies. Auch die westlichsten paläozoischen Aufschlüsse entlang der Straße Lom Sak - Chum Phae weisen zwei Schieferungsrichtungen auf.

Mesozoikum

Eine Winkeldiskordanz trennt die paläozoischen und die mesozoischen Sedimente. Die Trias fängt mit Kissenlaven an, die vom Konglomeraten (Basiskonglomerate) und vorwiegend fluviatilen Sedimenten der Khorat Gruppe abgelöst werden. Die Khoratsedimente bestehen aus Rotserien die vom Karn/Nor bis in die mittlere Kreide reichen.

Diskussion

Die permischen Sedimente Zentral-Thailands belegen die Existenz eines stark differenzierten Petchabun-Beckens und dessen Randbereiche von Oberkarbon bis zum unteren Oberperm (Fig.I).

Um die hier geschilderte Situation zu verstehen, muß man zunächst einen Blick in benachbarte Gebiete werfen.

Die devono-karbonische Nan - Uttaradit Sutur (HELMCKE, 1985) markiert ein präpermisches Orogen, welches während des Oberkarbons und des Perms von einem Flachmeer unter Bildung ausgedehnter Karbonatplattformen weitgehend bedeckt war. Im gesamten Westthailand und auf der Malaischen Halbinsel sind ungefaltete bis schwach gefaltete Plattformkarbonate verbreitet. Die östlichen Ausläufer dieser Kalke und Dolomite mögen den hier dargestellten stabilen Verhältnissen am Westrand des Petchabun Beckens entsprechen.

Das beschriebene östliche Randgebiet stellt das Deckgebirge eines wahrscheinlich devonischen Gebirgszuges dar, welcher etwa NW-SE von Laos über Thailand nach Kampuchea streicht und heute zum größten Teil von den Khorat-Rotsedimenten bedeckt ist (ALTERMANN et al. 1983).

Zwischen den beiden Gebirgen östlich und westlich des Untersuchungsgebietes (Shan Thai und Indosinia) entsteht im ?Mittelkarbon und Mittelperm ein tiefes Becken, das vielleicht 100 bis 200 km breit war und tief genug, um eine pelagische Fazies aufzunehmen.

Ein echter Ozeanboden wurde nicht ausgebildet, die Beckenbildung ist aber vom präorogenen Vulkanismus begleitet. Die aus Dünnschliffen und RF-Analysen (SCHERMERHORN, FU-Berlin) gewonnenen Daten weisen auf quartzkeratophyrische bis spilitische Magmen mit intrakontinantalen Affinitäten hin. Dieser Vulkanismus war offenbar an höhergelegene Gebiete gebunden und zwingt dem Betrachter einen Vergleich mit dem Lahn-Dill-Gebiet auf (FLICK, 1979).

Terrigene Siliciklastika spielen im Unterperm nur eine untergeordnete Rolle.

Im Mittelperm, mit dem Einsetzen der Orogenese im Petchabun- Becken ändert sich das Bild schlagartig. Ein Flysch- und Molassetrog entstehen in die mächtige Grauwacken geschüttet werden.

Das Becken wird ostvergent gefaltet (Fig.III), was auf eine nach Westen abtauchende Subduktionszone hinweist, (HELMCKE & KRAIKHONG, 1982).

Von dieser Faltung nicht sonderlich stark erfaßt wurden die westlichen und östlichen Beckenrandgebiete. Im Westen des Sedimentationsraumes überwiegen vom Moscovian bis ins Midian Karbonate.
Das Fehlen jüngerer Sedimente als Midian kann nur durch die isostatische Heraushebung und teilweise Abtragung des Orogens erklärt werden.
Das Perm wird winkeldiskordant von postorogenen andesitischen Pillowlaven überlagert, gefolgt von triassischen Rotserien, die mit Konglomeraten beginnen. Diese mesozoischen Sedimente sind weitgehend ungefaltet.

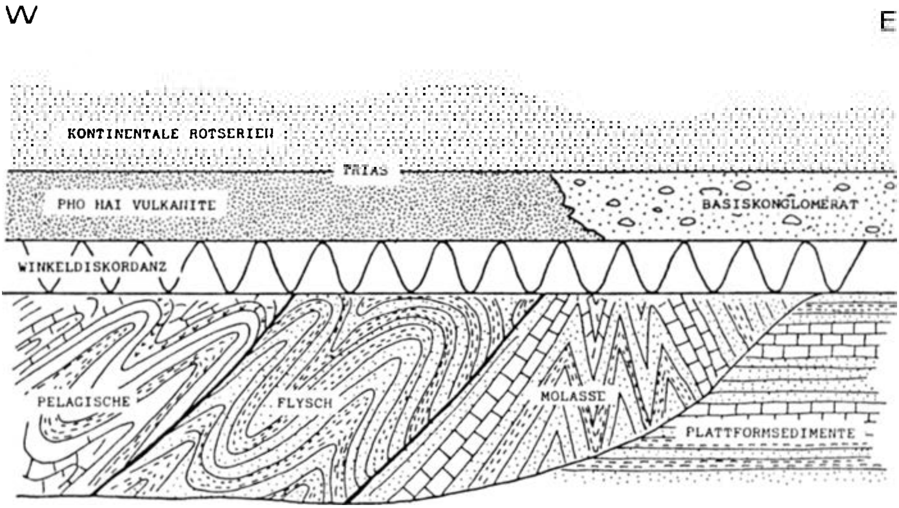


Fig. III: Petchabun Faltengürtel in schematischer Profildarstellung etwa zwischen Lom Sak und Chum Phae. Ohne Maßstab.

Teil II

Der zweite Teil dieser Arbeit befasst sich mit den oberpaläozoischen Ablagerungen am heutigen Westrand des Shan Thai Kratons.

Die Phuket Formation in Thailand und die Singha Formation in Malaysia sind Teile eines Gürtels jungpaläozoischer Mixtite, welcher SE-Asien vom südlichen Tibet bis Sumatra durchzieht. Diese ca. 3000 m mächtigen klastischen Serien wurden von MITCHELL et al. (1970) als Kontinentalhang-Deposita gedeutet.
In neueren Veröffentlichungen wird eine glaziomarine Entstehung dieser Serien vorgeschlagen (BUNOPAS et al., 1978; STAUFFER, 1983). Diese Autoren sind

der Ansicht, daß sich Teile SE-Asiens (Shan Thai Kraton) im unteren Karbon von Gondwana losgelöst hätten und nach Nord-Drift und einer Rotation um 180 Grad in der oberen Trias mit Eurasien kollidiert seien. Die Mixtite sollen als glaziomarine Sedimente die Gondwanazugehörigkeit dieser Region belegen.

Sedimentologie

In ihrer Arbeit unterteilten MITCHELL et al. (1970) die Phuket Formation in die als "flysch-like" beschriebene untere Einheit und die als Delta- und assoziierte Sedimente gedeutete obere Einheit.
Meine sedimentologischen Untersuchungen der unteren Einheit am Kaeng Krachan Dam, auf den Inseln Phuket und Phi Phi in Thailand und den Langkawi Inseln in Malaysia erlauben, sieben Faziesbereiche zu unterscheiden:

1. Dünnbankige, laminierte Tonsteine.
   Die Laminierung und Feinschichtung dieser Tonsteine ist stets parallel und eben. Laterale Veränderungen der Schichtmächtigkeiten wurden nicht beobachtet. Die manchmal zwischengeschalteten Siltsteine sind schräg oder flaserig geschichtet. Diese primären Strukturen sind oft durch Rutschungen überprägt; auch Bioturbation verursacht selten eine teilweise Entschichtung dieser Schelfsedimente.
2. Dünnbankige bis laminierte Silt- und Sandsteine.
   Linsige und Flaserschichtung, die mit Feinschichtung bis Laminierung abwechseln, sind die hervorstechendsten Merkmale dieser Fazies. Die Laminierung hält i.a. nur wenige Dezimeter aus und geht in längliche Linsen über. Die Schichtübergänge sind oft undeutlich. Die Bänke sind stark bioturbat. In diesen Flachwasserablagerungen kommen häufig synsedimentäre Rutschungen vor.
3. Dünn- bis mittelbankige Ton- und Sandsteine mit gestreuten Megaklasten.
   Die Gerölle sind unterschiedlichster Zusammensetzung, meist gut zugerundet und vorwiegend in der Grobsand- bis Feinkiesfraktion. Resedimente wie Tongallen sind häufig. Diese Fazies wechselt oft mit der Fazies 1 – dünnbankigen, laminierten Tonsteinen. Während der Kompaktion entstandene Deformationsstrukturen unter und über den Geröllen führten hier oft zur Fehlinterpretation, daß vom schmelzenden Gletschereis herunterfallende Partikel Impakts verursacht hätten. Der Ablagerungsprozess dieser Sedimente kann unterschiedlicher Natur sein. Neben Auswaschungen kommt auch saisonale Einschüttung gröberen Sediments auf Tone in Frage, wie aus dem Mittelmeerraum bekannt. (GENNESSEAUX, 1962; 1966).
4. Strukturlose, geröllhaltige Tonsteine und Sandsteine.
   Hier sind verschieden große, meist gut zugerundete und sphäroidale Gerölle unterschiedlichster Zusammensetzung in toniger bis sandiger Matrix eingebettet. Tonige Resedimente, Sandsteinlinsen, aber auch Mixtitresedimente gehören ebenso zum Inventar dieser Schichten wie Gerölle von Graniten, Gneisen, Trondhjemiten, Schiefern, Kalken, Grauwacken, Vulkaniten und Quarziten. Die meisten Megaklaste sind in der Grobsand- bis Feinkiesfraktion, jedoch auch wenige Gerölle von 1-2 m Durchmesser wurden beschrieben (TANTIWANIT et al. 1983). Diese Schichten können bis zu mehreren Metern Mächtig-

keit aufweisen. Sie werden als "cohesive debris flows" (LOWE, 1982) interpretiert und gehören somit der "resedimented facies" an (WALKER, 1978).

5. Konglomerate.
   Zwei unterschiedliche Ausbildungen konglomeratischer Sedimente konnten erkannt werden:
   a) Innerhalb der Fazies 3, s.d.
   b) Zusammen mit der Fazies 6, s.d.
6. Gradierte Sandsteine, oft erosiv einsetzend.
   Gelegentlich mit feinkonglomeratischen Ablagerungen beginnend und von Tonen überlagert, zeigen diese Sedimente nebst Gradierung auch andere Merkmale von BOUMA-Zyklen. In den oberen Partien der Schichten kommen oft Schrägschichtung und Laminierung vor. Obwohl es sich nicht um Flysche handelt, sind es eindeutig turbiditische Ablagerungen des Fächerbereichs am Fuß eines Kontinentalhanges.
7. Rutschungshorizonte und "Megakonvoluts". Diese Rutschungen können in bis zu mehreren Zehner Metern mächtigen Paketen vorliegen, der cm- bis dcm-Bereich überwiegt jedoch. Vorwiegend schichtkonform können sie aber auch erosiv auftreten. Die Orientierung der Rutschungen suggeriert eine westlich (Phuket) oder südwestlich (Langkawi) eintauchende Paläo-Neigung des Kontinentalhangs. Pseudorippelmarken und Wasserüberdruckstrukturen wie dish-Marken, Injektionsrisse und sanddikes sind häufig und belegen ein günstiges Environment für großräumige Rutschungen.
   Die oben beschriebene Fazieseinteilung ist der von MITCHELL et al. (1970) sehr ähnlich. Die östlich von Phuket, im Liegenden der Mixtite abgelagerten Thung Song Kalke wurden von diesen Autoren irrtümlich in die Phuket Formation aufgenommen. Die von mir unterschiedenen Faziesbereiche 5 und 6 wurden von ihnen zusammenfassend als channel-Sedimente vorgestellt, obwohl sie oft in unterschiedlichen Situationen auftreten.
   Die obere Einheit der Phuket-Formation wurde von MITCHELL et al. (1970) gegliedert in:
8. Bryozoen-Schichten.
9. Mächtige Sandsteine und Tonsteine.
   Die Bryozoen-Schichten sind feinsandige bis siltige Ablagerungen, die neben Bryozoen vorwiegend Brachiopoden führen. Die sie überlagernde Fazies 9 besteht aus glimmerreichen, oft bimodalen quarzitischen Sandsteinen. Flachwinklige Schrägschichtungskörper mit Amplituden bis zu einem Meter sind hier oft zu beobachten. Mächtige Tonfolgen sind in diesen Schichten eingeschaltet. Die Interpretation dieser Fazies als flachmarin bis delta-top deposita (MITCHELL et al. 1970) wird auch von den Befürwortern der glaziomarinen Entstehung der Phuket Mixtite nicht angezweifelt.

Unter dem Mikroskop erscheinen die Mixtite der Phuket-Formation als strukturell und kompositionell unreife, an toniger Matrix reiche (60-80%) Grauwacken. Der Megaklasten-Detritus (Sand-Fraktion) setzt sich aus ca. 50-60% Quarz, 40-50% Gesteinsfragmente und selten mehr als 10% Feldspat zusammen. Dabei liegt der Plagioklasanteil bei ca. 90%. Die Zusammensetzung der Lithoklasten weist auf einen kontinentalen Ursprung hin.

Eine Silifizierung der Matrix sowie schwacher bis fortgeschrittener Quarzüberwuchs der detritischen Quarzkörner kommt gelegentlich vor.

REM-Untersuchungen

Die rasterelektronenmikroskopische Untersuchung der Quarzoberflächen des Quarz-Detritus der Sandfraktion aus den Faziesbereichen 3 und 4, zeigen keinerlei Strukturen eines glazialen Transports. Soweit nicht überwachsen, sind alle Oberflächen von für Wassertransport typischen, dreieckiegen Ätzfiguren bedeckt. (Untersucht wurden 20 Proben, mindestens je 10 Körner).
Auch makroskopisch wurden an den Megaklasten keine Kritzungen oder andere, vom Eistransport stammende Spuren festgestellt. Solche Kritzungen wurden aber von TANTIWANIT et al. (1983) beobachtet. Fraglich bleibt ob sie wirklich beim Eistransport entstanden sind.

Tektonik und Metamorphose

In vielen Dünnschliffen ist eine leichte Schieferung, manchmal sogar eine Druckschatten-Quarzbildung hinter den Megaklasten sichtbar.
Nebst einer oft vorkommenden Kontaktmetamorphose, aufgrund postpaläozoischer Granitintrusionen (SE-Asiatische Zinnprovinz), sind in zwei Proben, P 10 – Kuan Din Daeng und P 6 – Ko Sire, (beide Lokalitäten auf Phuket), Anzeichen einer Regionalmetamorphose sichtbar. Bei der Probe P 6 ist auch eine kontaktmetamorphe Überprägung feststellbar. Die Schliffe zeigen in einer lithischen Grauwakke – reich an toniger Matrix – Aktinolithporphyroblasten als kontaktmetamorphe Neubildungen eines Ca-reichen Edukts sowie regionalmetamorph entstandenem Serizit, Klinozoisit und – teilweise auch quer zur Schieferung – hellem Biotit neben etwas Chlorit. Obwohl nicht eindeutig fazieskritisch, weist diese Mineralassoziation auf eine Metamorphose der Grünschieferfazies hin (WINKLER, 1979).
Im makroskopischen Bereich ist in den Ko Sire-Aufschlüssen nur gelegentlich eine tektonisch verursachte Ausrichtung der Gerölle in der Schieferung erkennbar. Ansonsten zeigen alle von mir besichtigten Aufschlüsse in Thailand und Malaysia außer der schwachen Schieferung keine Anzeichen einer intensiven Tektonik oder Metamorphose. Dies ist wohl auf eine sehr großräumige Faltung oder Verschuppung, die in dem kleinen Bereich der Aufschlüsse nicht verfolgt werden kann, zurückzuführen.

Diskussion und Interpretation:

Die große laterale Verbreitung der Mixtite und deren zeitliche Erstreckung vom Jungdevon bis Altperm spricht eher für einen ausgedehnten Kontinentalhang als für marin-glaziale Bildung. Abgesehen davon, daß die Stratigraphie dieser Sedimente vor allem in China, Burma und Sumatra noch völlig ungeklärt ist, hat die Gondwana-Vereisung im Bereich Australien, aus dem der Shan Thai Kraton stammen soll, nur etwa 25 mio. Jahre an der Grenze Karbon/Perm gedauert (WOPFNER, 1978).
Trotz weitverbreiteter Flachwassersedimente – TANTIWANIT hat sogar SM-Strandseifen etwas nördlich von Phuket gemeldet (pers. Mitt.) – sind aus dem ge-

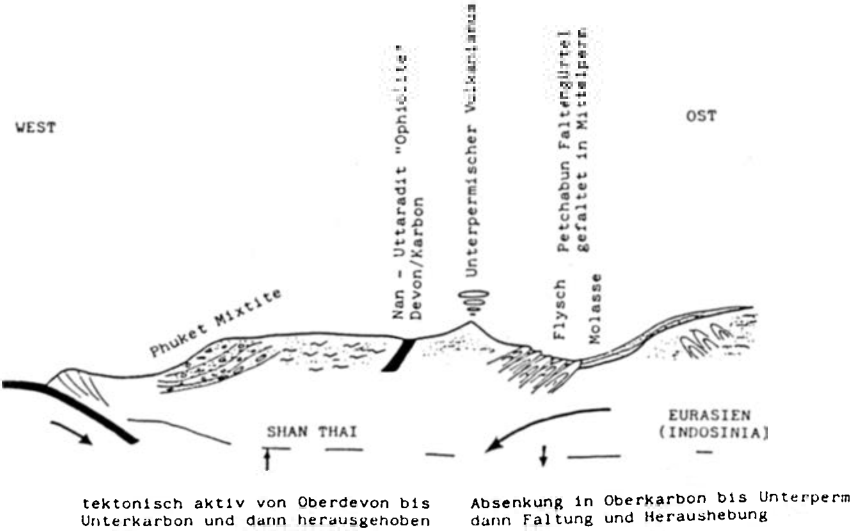


Fig. IV: Ablagerungsraum der Phuket-Mixtite am Westrand des "Shan Thai Kratons". Spekulative Darstellung nach HELMCKE (1985).

samten SE-Asiatischen Raum keine direkten Zeugen einer Vergletscherung bekannt. Weder Moränen, geschrammte Landoberflächen noch andere Zeugen einer Vereisung sind hier aus dem Paläozoikum belegt.

Der glaziogene Ursprung der Mixtite in Süd-Tibet wird von ALLEGRE et al. (1984) bezweifelt und die dortigen Faunen werden als Cathaysia-Faunen beschrieben.

In Sumatra sind im Perm warmwasser-anzeigende Korallen bekannt (FONTAINE, 1984).

Im Gegensatz zu früheren Berichten erwies sich die gesamte Fauna und Flora des jungpaläozoischen Shan Thai-Kratons als eurasischen oder cathasischen Ursprungs (BUNOPAS & VELLA, 1984).

Für eine Vergletscherung des Shan Thai-Kratons gibt es keine Hinweise.

Die geotektonische Position der Phuket/Singha-Mixtite kann, wie folgt, interpretiert werden:

Nach HELMCKE (1985) klang das orogene Geschehen in SE-Asien im Perm aus. Der jüngste Flysch ist mittelpermisch (Petchabun Faltengürtel – Thailand, HELMCKE & KRAIKHONG, 1982), während die Hauptfaltung der internen Zonen im Devon/Karbon stattfand. Weiterhin gibt es Anzeichen, die gegen die Annahme eines ausgedehnten großen "echten" Ozeans zwischen Shan Thai und Paläoeurasia sprechen.

Daraus und aus der geographischen Position muß entnommen werden, daß die Mixtite der Phuket- und Singha-Formationen am damaligen Nordrand der Tethys, respektive südlichen Kontinentalrand von Paläoeurasien, sedimentiert wurden. Weiterhin kann man annehmen, daß die starke tektonische Aktivität im oberen Devon bis unteren Karbon die Sedimentation der Mixtite ausgelöst hat. Eine Entstehung großer Reliefunterschiede durch Heraushebung des Orogens ist anzunehmen. Mit der permischen Faltung des Petchabun-Beckens kam auch die Sedimentation der Mixtite über allmähliche Ausflachung des Ablagerungsraumes bis zum Delta-Stadium und der Bildung ausgedehnter Karbonatplattformen zum Erliegen.

Um das gesamte orogene Geschehen in dieser Region zu erklären, kann man westlich des Ablagerungsraumes der Mixtite eine E-wärts abtauchende Subduktionszone (B-Subduktion) annehmen, die im Perm eine Gegensubduktion (A-Subduktion) hervorruft und zu Schließung des Petchabun Beckens (marginales Meer) mit E-vergenten Faltenbau führt (HELMCKE, 1983).
Somit wäre für das gesamte Untersuchungsgebiet eine variszische Überprägung hinreichend belegt.

III. Preface

The present thesis deals mainly with the facies development of the Permian sedimentary basin in Northeastern and Central Thailand. The pre-Permian history of the region under discussion and its adjacent areas is briefly mentioned.
The work was carried out during two field campaigns, the first one between November 1982 and February 1983 and the second from February to April 1984. The last four-week visit to the field in July/August 1985 helped to check the results. It is a part of the German Research Foundation's (DFG) project "Variszische und Indosinische Prägung am Westrand des Khorat Plateaus" under the supervision of Prof. Dr. D. Helmcke and is based on my M. Sc. thesis (Diplomarbeit, ALTERMANN 1983). Adding all the time together I have spent nearly one year in SE Asia.
I would like to thank to all persons and organisations who helped me to complete this study.

- Prof. Dr. Dietrich HELMCKE, who has been my teacher since 1981, was always helpful and interested in the progress of my work. I am also grateful for his financial contribution to the entire project.
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- Mr. Nikorn NAKORNSRI, DMR Bangkok, assisted me in finding new outcrops and shared with me some of his great knowledge of the local geology.
- Dr. Sangad BUNOPAS, DMR Bangkok, helped to organize most of the field work in central Thailand and was responsible for many interesting discussions concerning the general geology of Thailand and SE Asia.
- Mr. Amnart TANTITAMSOPON, DMR Phuket, helped to coordinate the work in the Phuket area.
- Pater Dr. Henri FONTAINE, Paris analysed several coral specimens.
- Prof. Dr. L. J. G. SCHERMERHORN from the Mineralogical Institute, FU-Berlin, helped with many discussions and the XRF-Analysis.
- My collegues from the Free University of Berlin, Stephan GRAMMEL and Christian STROBEL, accompanied me during a part of field work and helped with discussions and ideas.
- Mr. Holger BERTRAM assisted in the preparation of the most of the thin sections.
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- Last but not least to all my Thai and German friends, without whom this work would never have been finished.

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- The Thai Royal Department of Mineral Resources was always helpful with counterparts and Land Rovers.

My best "danke schön" to all these organisations.

IV. Introduction

Geography and geomorphology.

Thailand is situated right in the center of the Southeast Asian Peninsula, between 5°40′ and 20°30′ northern latitude and the longitude 97°30′ to 105°45′ East of Greenwich. It occupies 518000 square km. The distance from the most northern to the most southern point is 1650 km and the greatest width is 770 km.

Fig.:1. Geopolitical scope of SE-Asia.

Five different geomorphological units are distinguished by LEEMAN (1977).

- Northern folded belt.
  A north-south striking mountain range with an average altitude of 1600 m a.s.l. (highest top is Mt. Doi Inthanon with 2576 m) and several wide intramontane basins at the altitude of 200 m to 400 m.
- The central plain of the Chao Phraya River.
  It is subdivided into the northern part, the transitionary zone flattening towards the south, and the Chao Phraya delta in the south.
- Khorat Plateau.
  This huge plateau, which occupies most of the northeast of Thailand, forms a flat, bowl-shape topography at an altitude of 130 m to 200 m a.s.l. The plateau dips softly towards the Mekong River, which borders it on the north and east. In the south, the Khorat is bordered by the San Kamphaeng and Dong Pak mountains and in the west by the Petchabun Fold Belt.
- The southern mountain range.
  This range extends from the Khorat Plateau to the Gulf of Siam. The NNW striking fold axes are probably the continuation of the northern fold belt in the western part and the Petchabun Fold Belt in the eastern part.
- Peninsular Thailand.
  The peninsula is characterised by N-S striking mountain chains, which are less intensively folded than the northern range and cut by young fault structures. The selective karst weathering of the widespread limestone forms impressive landscapes.

Climate.

Due to the tropical monsoon climate only three seasons are distinguishable in Thailand.

The cold season: November to February.
The hot season: March to May.
The rainy season: June to October.

The annual average of rainfall in some areas on the western flanks of the mountains is up to 5000 mm. The annual average relative humidity in northern and northeastern Thailand is 65% to 75% and in the southern peninsula it is 80%.

The average temperature at sea level is about 24 to 27 degrees centigrade. In the northern mountainous area it can drop during the cold season to 5 degrees centigrade. On the Khorat Plateau in the hot season the temperatures often exceed 40 degrees centigrade.

Infrastructure and industrial development.

Thailand, the rice bowl of SE Asia, is an agriculturally well-developed country, just begining an industrial era. It has a well-organized highway net and transportation system. Nevertheless, large areas are covered by jungle and these are often far away from the modern transportation veins.

The most important export article is rice, but corn, rubber, manioc, and sugar cane are also exported, mainly to Asia. Wood resources are seriously imperilled by the shifting cultivation which is the basis of life for the northern Hill Tribes. Uncontrolled settlements, as well as cutting of timber for export, are limiting the renewal of this resource.

The most important natural mineral resources are tin (10% of the world's production), tungsten and potash salt. Of lesser importance are barite and gems. Zinc, lead and silver are mined from strata-bounded deposits in Kanchanaburi Province (western Thailand). Small deposits of chromite and copper are known in the northern provinces of the country. Some lignite is known to be located in the northern part of the country. In recent years feverish prospecting for hydrocarbons and uranium yielded only minor results. New discoveries of gold on the peninsula are of great importance for Thailand's future.

No real heavy industry as yet has been established in Thailand. Light industrial and home industrial production is the main field of employment apart from agriculture.

PART I

Facies development in the Permian Petchabun Basin, Central Thailand

1. Geology and stratigraphy of Northern and Central Thailand.

The following description is based mainly on the work of the German Geological Mission (1968 - 1971) in Thailand (BAUM et. al. 1970) and more recent papers. It also includes the newest results of HELMCKE (1985). Some principal inconsistencies will be mentioned here, but discussed later.
To make the terminology more understandable three different tectonic zones should be clearly distinguished:

- Sukothai Fold Belt, including the "ophiolite" suture of Nan - Uttaradit (Shan Thai Craton).
- Petchabun Fold Belt - folded and thrusted in Lower to Middle Permian.
- Loei Fold Belt – folded in the Devonian to Carboniferous and extensively covered by Mesozoic red beds.

These zones are not identical with those described by BUNOPAS (1976), who includes the Petchabun Fold Belt into the Loei Fold Belt.
For location see fig.: 2.

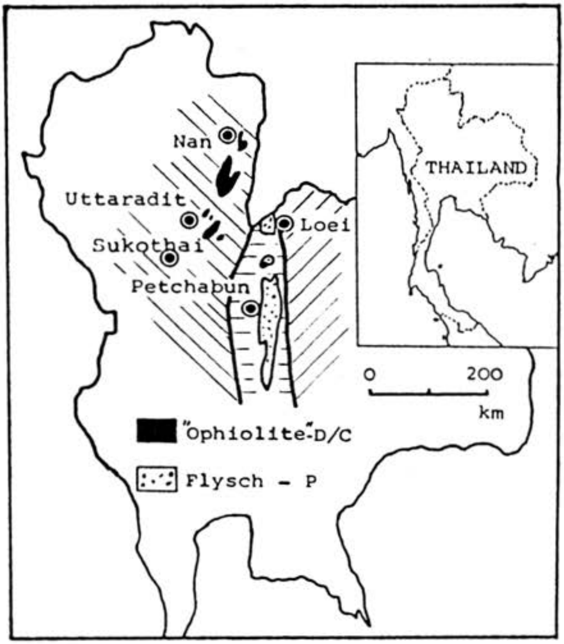


Fig.:2. Sukothai, Petchabun and Loei fold belts as defined in present thesis.

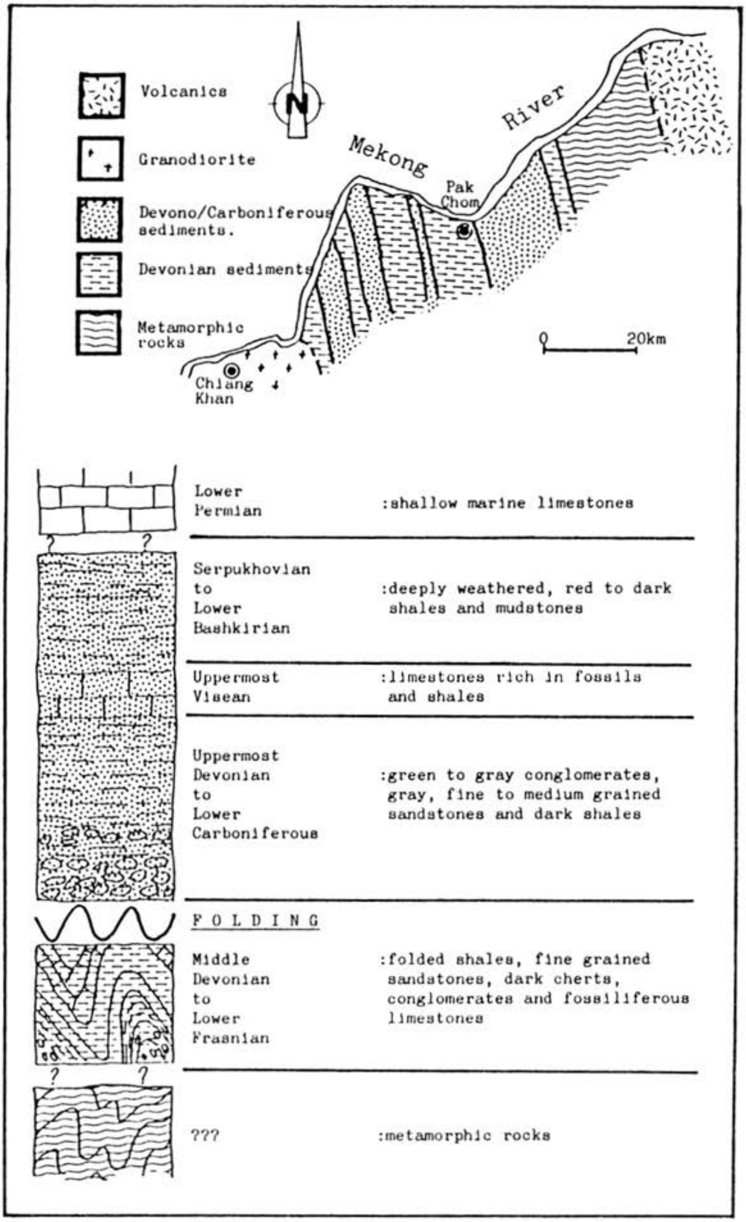


Fig.:3. Loei fold belt - sequence of Chiang Khan - Pak chom area. Ages according to FONTAINE et al. (1981).

Precambrian.

The Precambrian is only exposed north and west of the area surveyed for this thesis. West of the line drawn from Chiang Mai to Kanchanaburi, metamorphic complexes of amphibolite facies, ortho- and paragneisses, augen-bearing marbles, calc- silicate rocks, banded quartzites, and biotite schists crop out. The assignment of Precambrian is based on the unconformably overlying rocks. The Precambrian sedimentary rocks experienced intensive folding, metamorphosis, and partial anatexis before the Cambrian was laid down.

The chief striking direction of the tectonic structures is N-S. BAUM et al. (1970) mentioned also a "roughly east-west direction".

The Precambrian is regarded as an old core of the "Shan Thai Craton", by BUNOPAS (1976) or the "Burman-Thai-Malay-Craton" by WORKMAN (1975) or "Cimmerian Craton" by SENGÖR (1985).

Pre-Permian Paleozoic.

Two pre-Permian Paleozoic strips surround the region under investigation.

The small range east of the Chiang Khan – Wang Saphung line is part of the Loei Fold Belt.

This area has been described by WORKMAN (1975) as the Herzynian Massiv. FONTAINE et al. (1981) and ALTERMANN et al. (1983) gave more precise description of this geology. Middle Devonian to Lower Frasnian folded shales, fine sandstones, dark cherts, conglomerates and fossiliferous limestones are unconformably underlying Uppermost Devonian to Lower Carboniferous green to gray conglomerates, fine to medium grained sandstones and dark shales. They are followed by Uppermost Visean fossiliferous limestones and shales. Serpukhovian to Lower Bashkirian shales and mudstones conformably overlie this sequence. The contact with the Lower Permian shallow marine limestones is not exposed.

The strongest orogenic event is marked by an unconformity at the Devonian/ Carboniferous boundary. SW-vergent, strongly folded and faulted strata crop out along the Mekong River west of Pak Chom. A Frasnian to Middle Devonian age was proven by FONTAINE et al. (1981) on the basis of fossils from limestones. Carboniferous (FONTAINE et al. 1981) sediments east of Pak Chom are only gently folded and include some hundred meters of thick chert conglomerates, which are interpreted as late orogenic sediment (ALTERMANN et al. 1983).

The second, larger area of the pre-Permian Paleozoic is connected with the Precambrian belt described (Shan Thai as well as the Sukothai Fold Belt).

Here, the orogenic activity is dated at the Devonian- Carboniferous boundary (BAUM et al. 1970) and in the Mesozoic (KOCH 1973). The Cambrian and Ordovician sediments were deposited in shallow water conditions. Siliciclastics (quartzites and conglomerates) unconformably overlie the Precambrian. The Ordovician is richer in pelites than the Cambrian and closes up with limestones and algal reef limestones. The Silurian and Devonian are described as geosynclinal deposits, containing approximately 500 m of shales, sandstones, graywackes and cherts (BAUM et al. 1970).

The lower part of the Carboniferous sequence is a distinct flysch. This flysch is probably the sedimentary record of strong tectonic activity. The flysch is followed by basic volcanics (?tectonic contact?). These are represented by gabbro, pyroxenite diabase or andesite and their tuffs and tuffites and were described as "ophiolites". The entire Carboniferous sequence is 300-400 m thick including the "ophiolites" (BAUM et al. 1970).

The description of the Carboniferous sediments as flysch is suspicious. On the one hand, the evidence for continuous siliciclastic sedimentation is present. However, on the other hand, the presence of conglomeratic arkoses, cherts, limestones and erosional features (sometimes down into the Silurian) argues against a deep trough flysch. A more or less shallow, strongly differentiated basin instead of deep marine, uniform trough into which flysch could be deposited is suggested. The term "ophiolite" was used only to describe the basic nature of the volcanics and without any relationship to plate tectonics (v. BRAUN pers. comm.). Nevertheless, they survived in later literature always as an obducted oceanic crust. MACDONALD & BARR, (1984) determined, that they are of island arc composition and high pressure – low temperature metamorphosed. The K/Ar-ages by DAMM et al. (in prep.) show Upper Devonian to Lower Carboniferous age (344 +/- 22 Ma). These volcanics are covered by marine sediments (cherts, conglomerates and fossiliferous shales) and by conglomeratic red beds, sandstones and claystones of nearly 200 m thickness. Some marine limestones are intercalated with the red clastics. The coarse clastics in the red beds contains erosional fragments of all underlying rocks including the "ophiolites".

The upper part of the Carboniferous sequence contains reef and oolitic limestones which pass into Lower Permian.

The western strip of the pre-Permian Paleozoic described here can be followed further to the north up to Yunnan or to the south to Malaya, and can probably be found also in Sumatra and Kalimantan.

Permian.

The Permian seems to be the most controversial Paleozoic sequence in Thailand. On the Geological Map of Northeastern Thailand 1:500000 (SUDASNA & VEERABURUS 1979) the Permian is divided into five units:

P5 -	Upper Permian.
P4 - Nam Duk	Middle Permian.
P3 - Pha Dua	
P2 - Hua Na Kham	
P1 - Phu Tham Nam Maholan	Lower Permian.

This subdivision, based mainly on lithology and not on fossils, disappears on the new Geological Map of Thailand 1:1000000 (CHAKKAPHARAK & VEERABURUS, 1982) where the Permian is not differentiated at all.

Since HELMCKE & KRAIKHONG, (1982) reported a Permian orogenic sequence of pelagic- flysch- and molasse facies from the Petchabun Fold Belt, the Permian is under discussion as to its tectonic importance. (HELMCKE, 1983, 1985; SENGÖR, 1985; ALTERMANN, 1986).

BUNOPAS & VELLA, (1978) wrote in their paper on Paleozoic and Mesozoic structural evolution of Northern Thailand:

> "We know no Permian flysch deposits. The Permian or at least the middle part of the Permian seems to have been an interval of tectonic quiescence in Thailand and the whole of Southeast Asia (...). By Middle Permian the two Cratons (Shan Thai and Indosinia) were close together, and seem to have been separated by only a shallow sea". (BUNOPAS & VELLA, 1978, p. 139).

CHONGLAKMANI & SATTAYARAK, (1978), were the first to describe the Nam Duk Formation of the Petchabun Fold Belt as geosynclinal deposits.

JACOBSON et al. (1969), were the first to propose the Permian to be a principal folding time for Northeastern Thailand. This proposal was based on the indisputably clear observation that in the Loei Fold Belt all strata younger than the Permian are unfolded or only gently folded without dominating vergency.

Mesozoic.

Contrary to HELMCKE (1985) the Mesozoic or more precisely the Triassic/Jurassic boundary is designated by the majority of the geologists as the time of strongest orogenic activity in Thailand and adjacent northern and southern countries.

Mesozoic rocks are the most abundant in Central and Northeastern Thailand. In North Thailand, elongated, N - S trending, Mesozoic sedimentary basins unconformably cover Paleozoic rocks. Some regionally limited outcrops of conformable passing from Permian to Triassic were reported by CHONGLAKMANI (1984) from these basins.

Generally, the Upper Permian (Midian) is followed by an angular unconformity and by marine Triassic starting with pillow lavas. These rhyolitic and andesitic volcanics are followed by conglomerate and finer clastics later passing into continental facies.

PIYASIN (1971) proposed to divide the Mesozoic into the Lampang Group of marine Triassic ranging from the Scythian to Norian and the Khorat Group which consists mainly of non-marine, continental red beds from the Upper Norian to Cretaceous.

The Mesozoic of Khorat Plateau exhibit a total thickness of 4500 m to 5000 m.

The Scythian Hong Hoi Formation in the Lampang area is described by CHONGLAKMANI (1981) as to include flysch-type orogenic sediments. The first observations led to the conclusion that this so-called flysch was laid down in a shallow water environment and does not exhibit any typical flysch properties such as T-sequences (BOUMA, 1962). Apart from this, whole coalified tree stumps, shell beds, mud cracks, and brachiopod-pavements were found in the Hong Hoi Formation (STROBEL, in prep).

HELMCKE (1985) pointed out on the basis of geological maps that the Hong Hoi Formation unconformably overlaps folded Paleozoic strata and is sedimented "under epicontinental conditions in rather rapidly subsiding area (intramontane basins) – much like the Saar - Selke trough of the European Variscides." (HELMCKE, 1985, p. 219).

The continental red beds of the Khorat Plateau, which are said to be "red molasse" of the Indosinian orogeny (BUNOPAS, 1976) were partly investigated by KROKER (1981), HAHN (1982), and the Thai/French team – BUFFTEAU & INGAVAT (1985). The sedimentary conditions during the deposition of these sediments were probably of deltaic and fluvial character. This is not a typical molasse environment. HAHN (1982) measured in the channel sandstones of Sao Khua Formation (middle Upper Jurassic) paleocurrent directions from NE to SW. If this were indeed a molasse, the provenance direction should be from the orogenic uplift in the west.

The Cretaceous tin-bearing S-type granites are according to BECKINSALE (1979) post-orogenic intrusions. This collision closed the Permian marginal basin which occupied the area of Central Thailand. HELMCKE (pers. comm.) related these granites to late or post orogenic magmatism.

Cenozoic.

The Cenozoic of Central and Northern Thailand has, like older epochs, strong parallel development with the whole SE Asian subcontinent.

The most dominant features of the Cenozoic geology are wide N-S trending grabens. These Tertiary grabens were caused by tensional tectonic movements. Tensional forces in the SE Asian continental crust were probably triggered by the strong impact of the Indian Continent into Eurasia. According to MOLNAR & TAPPONIER (1975), the collision of India and Eurasia caused a clockwise rotation of SE Asia. This model explains in a very elegant way the tension and occasional compressional structures in wide areas of the Himalayas and fits with the young SE Asian fault patterns. During the long active tensional movements widespread basaltic flows occurred along the deep faults.

Horst and graben tectonic dominates the present morphology of Thailand and is still active in our times.

1.1. Plate tectonic discussion.

The discussion of the geology of SE Asia has undergone rapid and important changes in the last decade. A short historical description of the various hypotesises of the main authors working in this area will be given with respect to the geology of adjacent parts of Southeast Asia.

KLOMPE's (1962)

model of the geology of SE Asia is not only of historical interest but also has some contemporary validity. According to his classic description, the Southeast Asian Continent grew with time by accreting younger fold ranges to the Precambrian through Paleozoic Eastern Craton (Kontum Massif).

In the first stage the Variscan belt was connected in the north. Later, at the Triassic/Jurassic boundary a new chain was welded on in the west, which extended up to the Gulf of Thailand. At the Jurassic/Cretaceous transition, the East Burman Fold Belt was consolidated and in the Tertiary the rest of the Southeast Asian Peninsula was added. (Mainly west Burma).

This "onion-shaped" geological picture was the basis for later investigations and, was confirmed by later workers in its eastern parts.

WORKMAN's (1975)

model for SE Asia divides the whole region into the areas affected by three main stages of orogenic activity.

1) Hercynian in Middle Carboniferous.
2) Indosinian I in Lower Triassic.
3) Indosinian II at the Triassic/Jurassic boundary.

The Hercynian folding affected the southeastern, northern, and northeastern regions.

The Indosinian I affected the northeastern, central and partly the southern and southeastern regions.

The Indosinian II had only a weak impact, and is today recognizable in the red bed Lower Mesozoic strata.

In its easternmost part, the Kontum Massiv is claimed to be a stable, pre-Hercynian zone.

With the rise of modern plate tectonics theories about the geology of SE Asia become divergent. There are as many opinions as the number of teams which have worked in the area since 1975. In the recent literature two main scientific hypothesises can be distinguished.

The first has been developed by scientists who believe in the Gondwana provenance of mainland Southeast Asia. According to this theory, parts of Burma, Thailand, Malaysia and Sumatra (Sibumasu-Continent, BURRET & STAIT, 1985; Cimmerian Continent, SENGÖR, 1985 or the Shan Thai Craton, BUNOPAS 1981) drifted away most probably from NW Australian part of Gondwanaland in the Upper Paleozoic. After crossing the Tethys Ocean this sub-continent collided with Cathasia or Eurasia in the Triassic to Jurassic. The main arguments in support of this theory are:

I. Angular unconformity between the lower Upper Permian and Triassic and unconformity between the Scythian and Carnian.
II. "Flysch-like" sediments of Anisian-Ladinian age in north Thailand (Hong Hoi Formation).
III. Upper Paleozoic "tillites" (Phuket and Singha, Formations in Thailand and Malaysia and Mergui Group in Burma) which give evidence for the Permian Gondwana glaciation.

The second theory is postulated by scientists who at least deny the Late Paleozoic Gondwana provenance of mainland Southeast Asia. According to their theory, SE Asia was formed during Variscan orogeny, during the Devonian - Carboniferous and Permian times. The flysch character of the Hong Hoi Formation and the tillite origin of the Phuket, Singha, and Mergui pebbly mudstones are disputed. The Triassic unconformities are interpreted as post orogenic uplift and abrasion. The main arguments in support of the Variscan orogeny are:

I. K/Ar metamorphosis ages of the Nan/Uttaradit "ophiolites" (N Thailand) of 344 +/-22 Ma (Devonian/Carboniferous, HELMCKE, 1985).
II. Lack of Mesozoic flysch sediments, but occurrence of folded, faulted and overthrusted Permian pelagic, flysch, and molasse sedimentary orogenic suite.
III. Occurrence of Upper Paleozoic, Cathasian, and Eurasian fossils all over SE Asia.
IV. Mainly unfolded and continental character of Triassic and younger sediments.

MITCHELL (1977),
concluding from his investigations on tin granites, divided SE-Asia into four subduction-related petrographical provinces (fig.:4). The eastward dipping subduction occurred during the Late Carboniferous to Early Triassic and was followed by a continent – continent collision in the Late Triassic, which caused the Indosinian Orogeny.

FONTAINE & WORKMAN (1978),
divided the eastern realms of SE-Asia into two main tectonic blocks:
1) Indochina, including Laos, Thailand and Kambodia.
2) South China, including northern Vietnam.
These two blocks were separated by a NE-diping subduction complex of oceanic terrain. In the Upper Triassic a continent - continent collision between these blocks occurred, building the Indosinian range with the Red River Lineament as a suture.

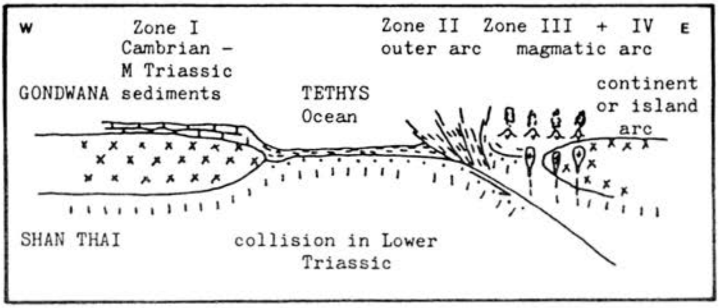


Fig.:4. Indosinian orogeny in Thailand
MITCHELL (1977).

MACDONALD & BARR (1978),
gave a somewhat similar picture for the western realms of SE-Asia. Two blocks (Thai - Burma - Malay in the west and Indochina in the east) collided at the Triassic/Jurassic boundary. The collision was triggered by a westward subduction of

oceanic basement with a developed island arc, which was present since the Upper Carboniferous. With time the island arc volcanism became more felsic and after the collision granites were intruded.

THANASUTIPITAK (1978a),
distinguished three different plates in SE-Asia:

1) Eurasian plate.
2) South China plate.
3) Indosinian plate.

In Permo-Carboniferous times an oceanic basin separated West Thailand, NE Thailand and Indochina. During the movement of Indochina towards the west, the oceanic crust was westwardly subducted. In the Permian, the subduction direction changed to the east and, in the Lower Triassic, the oceanic basin disappeared with a continental collision. The basic rocks of Nan – Uttaradit are interpreted as an ophiolite suture between Eurasia and Indochina. The suture with South China is thought to be located further to the NE and is not described here in detail. In this interpretation Eurasia was located south of Indochina, which was drifting southward from somewhere in the north or northwest. (Comp. MOLNAR & TAPPONIER, 1975).

BUNOPAS and his co-authors (1978, 1983, 1984),
divided Thailand into four N-S trending zones:

1) Western Shan – Thai Craton with thick Paleozoic and Mesozoic sequences, mostly siliciclastics.
2) Shan – Thai Craton – Precambrian metasediments, discordantly overlain by slightly metamorphosed Lower Paleozoic shelf sediments.
3) Central Thailand – Middle Paleozoic to Lower Mesozoic shelf sediments, strongly folded and faulted.
4) Khorat Plateau – Upper Triassic to Cretaceous red beds, interpreted as molasse basin sediments.

According to BUNOPAS & VELLA (1978) (fig.:6), the ophiolites of Nan – Uttaradit mark the suture between the Shan Thai Craton in the west and the Indosinia Craton in the east. These two micro-continents collided in the Norian. In the Permian they were separated only by a shallow sea. The subduction took place westwards under the Shan Thai Craton which drifted away from northwestern Australia in Carboniferous times and crossed the Tethys Ocean with a clockwise rotation of more than 180 degrees.

GATINSKY (1986),
proposed four stages of geological evolution of SE Asia between the Late Proterozoic to Jurassic.

1) Northward drift of the Cathasia Massif (from Gondwana), followed by the Indochina and West Borneo Block during the Early Paleozoic. By the Lower Carboniferous the Indochina Block had already collided with Cathasia.
2) In the Carboniferous the Shan Thai – West Malaya Block drifted away from Gondwanaland and collided with the Indochina/Cathasia in the Upper Triassic.

3) The West Borneo basement rifted away from the Indochina massif and drifted southwards.

4) The "West Burma Platelet" drifted north from Gondwanaland and slid along the Sagaing Fault to attach itself to the Shan Thai Massif.

BEN AVRAHAM (1978),
proposed a model of several microplates or exotic terrains drifting away from Gondwana to the north and colliding one after the other with Eurasia during the Mesozoic.

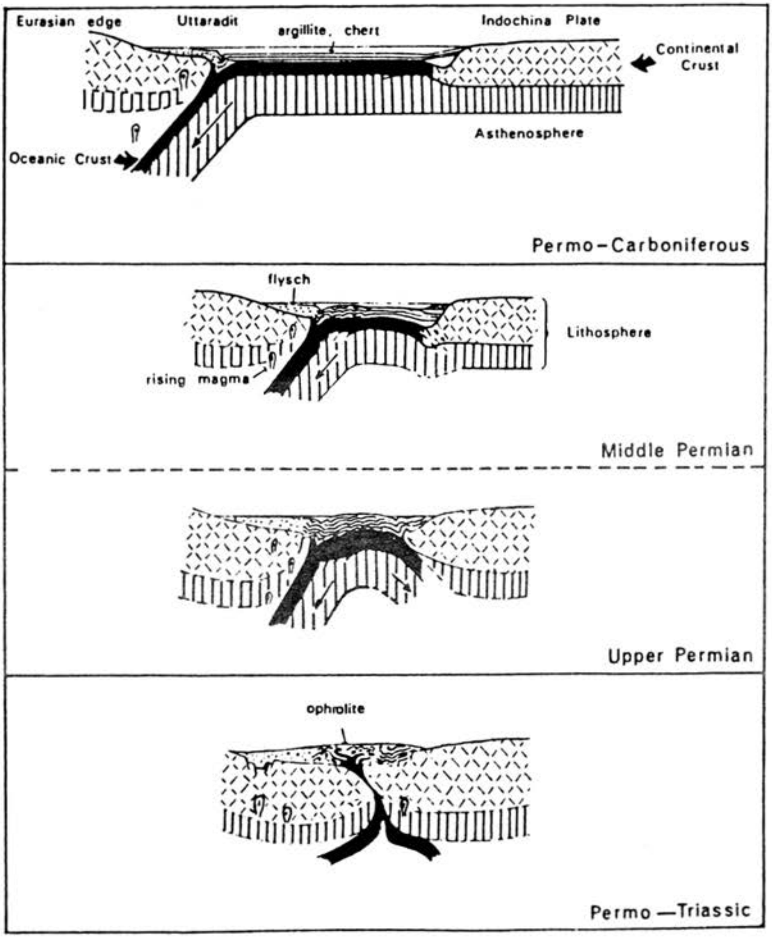


Fig.:5. Plate tectonic model of Thailand THANASUTHIPITAK (1978).

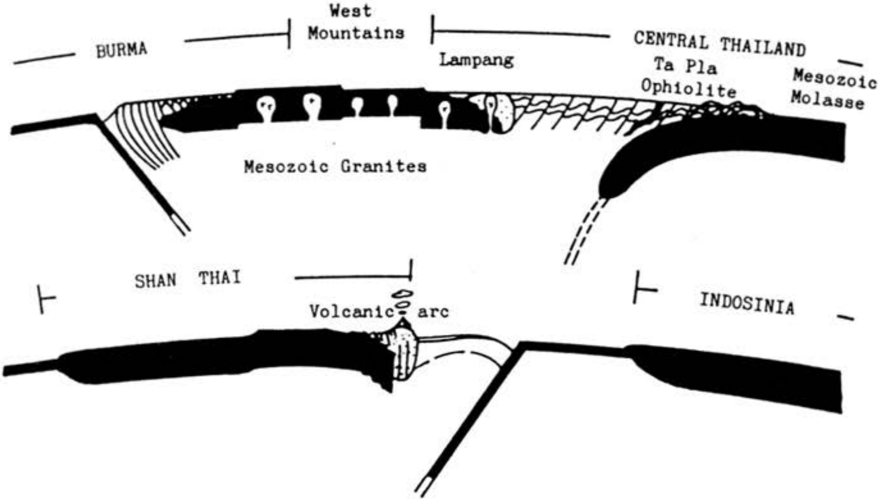


Fig.:6. Plate tectonic model of SE-Asia according to BUNOPAS & VELLA (1978).

SENGÖR (1985),
describing the area from eastern Turkey to Sumatra, proposed also a number of displaced terranes, all together named the "Cimmerian Continent". These microplates rifted away from Gondwana in the Carboniferous and drifted toward the north during Permian and Triassic times, closing the "Paleotethys" and opening the "Neotethys" behind them. The collision with Indochina occurred in his opinion at the Triassic/Jurassic boundary.
There are also theories on the geological evolution of SE Asia that denie a Gondwana or at least a Middle Paleozoic Gondwana origin for western parts of SE Asia. The main tectonic activity is said to be older than Middle Permian.

STÖCKLIN (1984),
based on his experience in the regions west of the Himalayas and adjacent areas and summarizing the literature on SE Asia and Tibet, pointed out that no true Permo - Triassic Tethys Ocean remains are known in the so-called Paleo-Tethys realm.

> "The fact is that not a single sample of a demonstrably Permian or Triassic oceanic sediment nor of an ophiolitic rock datable radiometrically as Permian or Early Triassic has been found by any geologist in any of the Paleo- and Neotethys suture zones of the Alpine – Himalayan mountain ranges"...."Ophiolites and associated deep water sediments are found in what may be a Paleotethys suture in Iran, Afghanistan, the Pamirs, Tibet, Yunnan, Thailand and Malaysia, but wherever these rocks could be dated they have given Late Devonian - Early Carboniferous ages" (STÖCKLIN, 1984, p. 27).

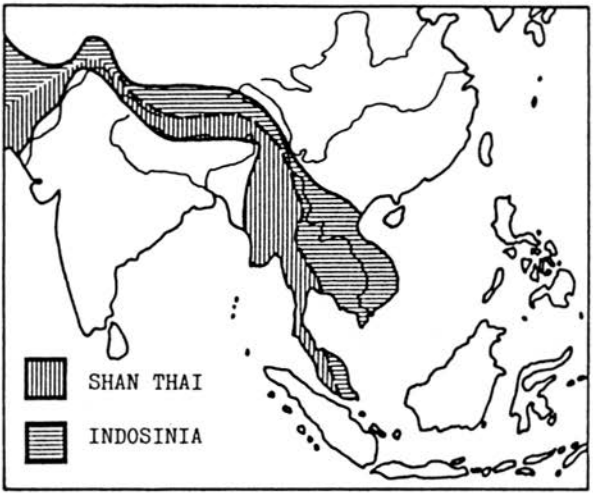


Fig.:7. Plate tectonic reconstruction according to SENGÖR (1985).

For that reason he doubted the existence of the Paleotethys and proposed that the suture closed, at the latest, in the Early Carboniferous. For the Permo - Triassic he admited only the existence of a shallow epicontinental sea.

HELMCKE (1983, 1985) and HELMCKE and co-workers (1982, 1983), after discovering a Permian orogenic sequence of pelagic sediments, flysch and molasse, described the Permian as the last strong orogenic activity before the Himalayan in the area from Pamirs to Sumatra.
Evidence included:

I) the lack of flysch younger than Middle Permian;
II) the unfolded or weakly folded Triassic strata in Thailand;
III) the Carboniferous age of the "ophiolites" of Nan – Uttaradit; and
IV) the lack of true "oceanic floor" or Gondwana fossils in the whole of SE Asia.

HELMCKE (1985) proposed that the closing of the SE Asian suture and the Tibet – Sungpan Kandse sutures occurred in the Middle Permian at the latest or more probably at the Devonian-Carboniferous boundary.

Contrary to other authors he depicted mainland SE Asia as a part of Permian Pangea and Paleoeurasia. In this scenario central SE Asia is build up of the huge Variscan fold belt, and Central Thailand as its eastern external zone (east vergency of the Petchabun Fold and Thrust Belt). The internal zones of this late Variscan orogeny were located more to the west, in Thailand and Burma. During this orogeny, most probably an intracontinental or marginal basin was strongly folded by eastward dipping subduction under Paleoeurasia. This caused a westward anti-movement under the marginal basin. Strong affinities to the European Variscides are suggested.

2. New research.

Purpose and theme of present thesis.

The geological uncertainity in the construction of SE Asia lead me to consider a way to either prove or disprove the various theories. Starting from the principle that different stages of mountain building processes should leave different sedimentary records in the basin neighboring the tectonic activity, an investigation of the the Permian facies development in Central and NE Thailand would answer the question of the origin of the SE Asian plates. The problem also made it necessary to consider the pre- and post-Permian geology of Thailand and to investigate some outcrops in Peninsula Thailand and West Malaysia.

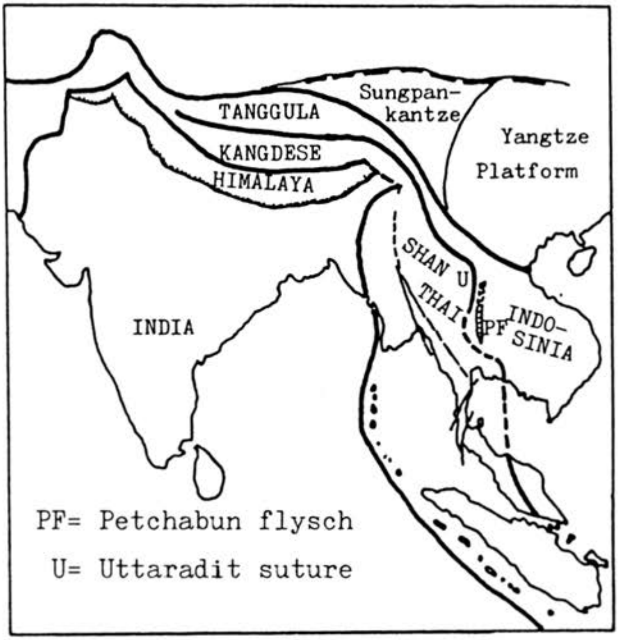


Fig.:8. Plate boundaries according to HELMCKE (1985).

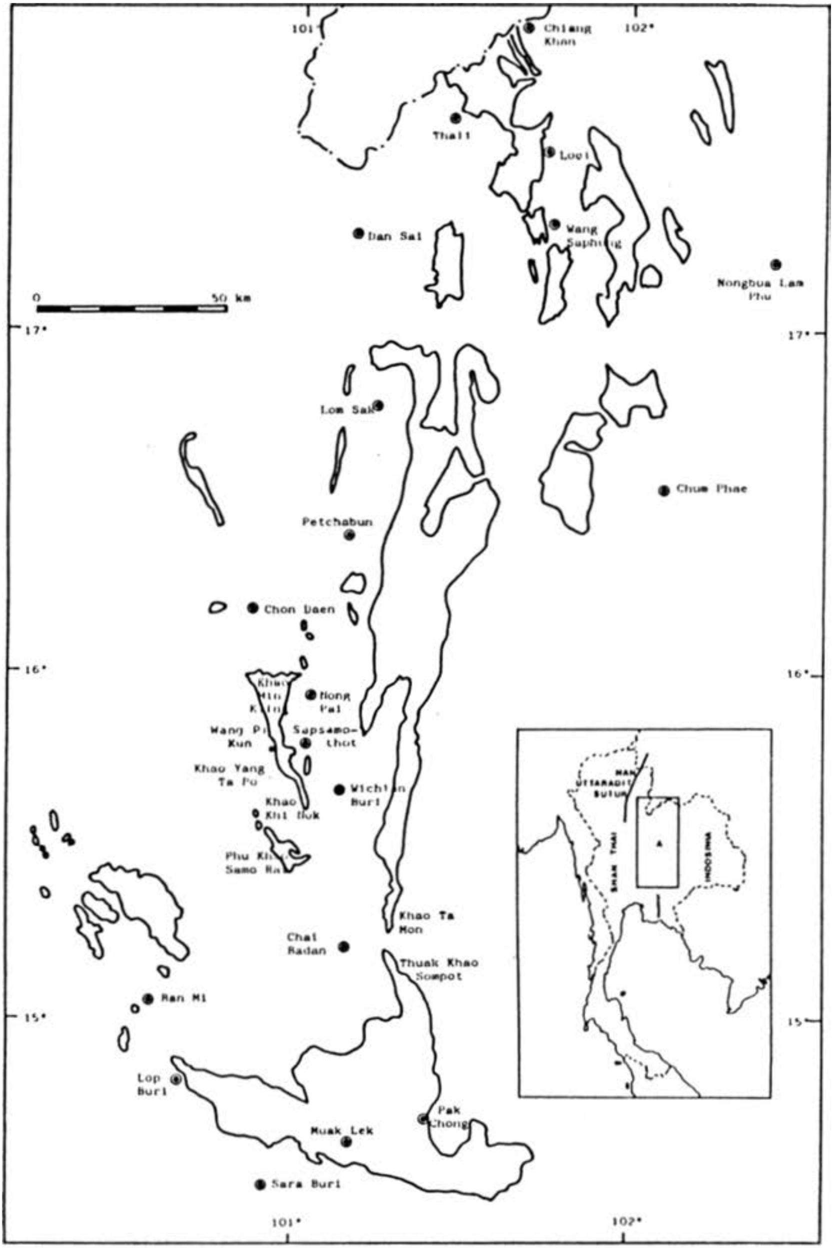


Fig.:9. Permian outcrops in the area under investigation (A) according to geol. map of Thailand 1:1000000.

Location and method of investigation.

The main area under study is located in the N-S striking strip of Permian mapped outcrops between Mekong River (Mae Nam Kong) in the north and the Pak Chong - Saraburi area in the south (fig.:9).

The nature of this area of approximately 70000 square km required the development of special techniques of investigation. Moreover, field and outcrop conditions sometimes did not allow sufficient intensive studies.

The area in the north, along the Laotian boarder, is an off-limits military area. The area at Nam Nao National Park, which was temporarily also a military restricted area, is mainly jungle-covered. Apart from the Lom Sak - Chum Phae highway,

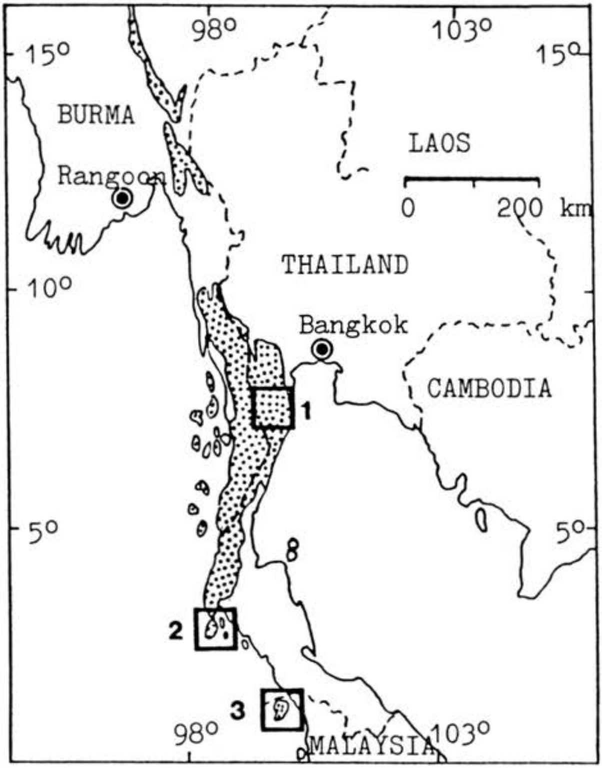


Fig.:10. Distribution of pebbly mudstones in SE-Asia (STAUFFER, 1983) and areas of investigation:
1- Khaeng Krachan Dam.
2- Phuket and Ko Phi Phi.
3- Langkawi.

which shows excellent outcrops, the whole of this region is difficult to enter. As is the case all over the country, offroads follow the crests and exhibit hardly any outcrops. Also, following the streams on foot, the chances of finding outcropping rocks are quite small.

The subtropical vegetation and deep weathering make mapping often difficult. Additionally, the Mesozoic cover sediments and the Tertiary graben fills hide the interesting geology.

Due to the field conditions and the extensive size of the studied area, most of the research was done in the company of a counterpart and with the help of a Land Rover.

Because very little is known about the Permian sedimentary facies in Thailand, it was necessary to work with a help of preliminary simplified basinal models. After the general overview of the exposed facies was developed, more typical and less typical facies were investigated carefully. Some areas were excluded from further investigations because of lack of sufficient outcrops. At that time the general stratigraphy was already worked out by Mrs. R. INGAVAT, based on collected fusulinids.

Special attention was paid to the recording of sedimentological profiles. The only published profiles were by BORAX & STEWART, (1966); WINKEL, (1983); WIELCHOWSKY & YOUNG, (1985) and by the present writer (ALTERMANN 1983, 1984). All these data along with my own new records and data recorded from thin sections and polished sections were the basis for detailed facies subdivisions and their classification within a sedimentary basin model with respect to the stratigraphy, tectonics, and general geological history of the area.

The second area under investigation was the region of the Kaeng Krachan Dam, of Phuket Island, Kho Pi Pi Island (peninsula Thailand) and Langkawi Island (west Malaysia).

245	UPPER PERMIAN	Tatarian	Ochoan		Dorashamian	Dorashamian
					Dzhulfian	Dzhulfian
					Midian	Abadehian
	MIDDLE PERMIAN	Kazanian	Capitanian	Guadalupian	Murgabian	Pamirian
M.Y.					Kubergandian	Murgabian
		Kungurian	Wardian		Bolorian	Kubergandian
	LOWER PERMIAN	Artinskian	Leonardian		Yahtashian	Artinskian
		Sakmarian	Wolfcampian		Sakmarian	Sakmarian
290		Asselian			Asselian	Asselian

Fig.:11. Correlation of Permian stratigraphic stages.

Here most of the outcrops were situated along beaches with tropical karst – weathered Permian limestones, roofing the strata under investigation.

The work was carried out by mapping along the beaches and partly from a boat. Although the outcrops were mostly in good condition, the correlation between particular localities was very difficult because of monotonous sedimentology and lack of fossils.

The following chapter describes the results of my research concerning the lithology, the sedimentology and the stratigraphy of the Upper Paleozoic rocks. Some interpretative aspects will be mentioned, but final interpretation will follow later on, with the final discussion.

At the beginning of every description a summary of previously published data for each region will be given.

My own work is based on field observations, detailed sedimentological profiles, and petrography.

The sandstone classification comes from FOLK (1968) and DOTT (1964). The compositional maturity is after PETTIJOHN (1975). The textural maturity is defined as in FOLK (1956). The limestone classification is after FOLK (1959) and DUNHAM (1962). The diversification of standard micro facies (SMF) and standard facies belts (SFB) is based on WILSON (1975) and FLÜGEL (1978). It was sometimes problematic because of the unique properties of the Permian shallow seas which probably resemble more the ramp model (AHR, 1973; READ, 1985) than WILSON's (1975) model.

Volcanics will be described and discussed in a separate chapter (Volcanic rocks).

All the SCHMIDT'-net diagrams are according to WALLBRECHER, 1979. If no other information is given,

* = the measurement of the sedimentary plane and

1 = the B-axis linear of the fold.

Sedimentological LOGs used in this thesis are from a combination of publications, but especially from BOUMA (1962).

A useful help in the description of rocks was the "Tapeworm-guide for lithological descriptions of sedimentary rocks" by KEMPTER (1966).

Thin sections described here are selected from the total 600 studied and consist of those which are typical for the locality.

The areas treated were determined as exactly as possible by the milestones set up along the highways. Distances between the milestones were measured by the range meter of the Land Rover. Localities along offroads lacking milestones and those which were visited by walking are described by morphological characteristics and with the help of topographic maps. The approximate distance to the next highway junction is always given. As far as possible, map sections showing the places described in the text are drawn.

Fig.:7 shows Permian mapped rocks redrawn from the Geological map of Thailand 1:1000 000 by (CHAKKAPHAK & VEERABURUS, 1982). My work was concentrated on these areas. On the following pages I will describe the lithology of outcrops visited, more or less tracing a line from the south to the north.

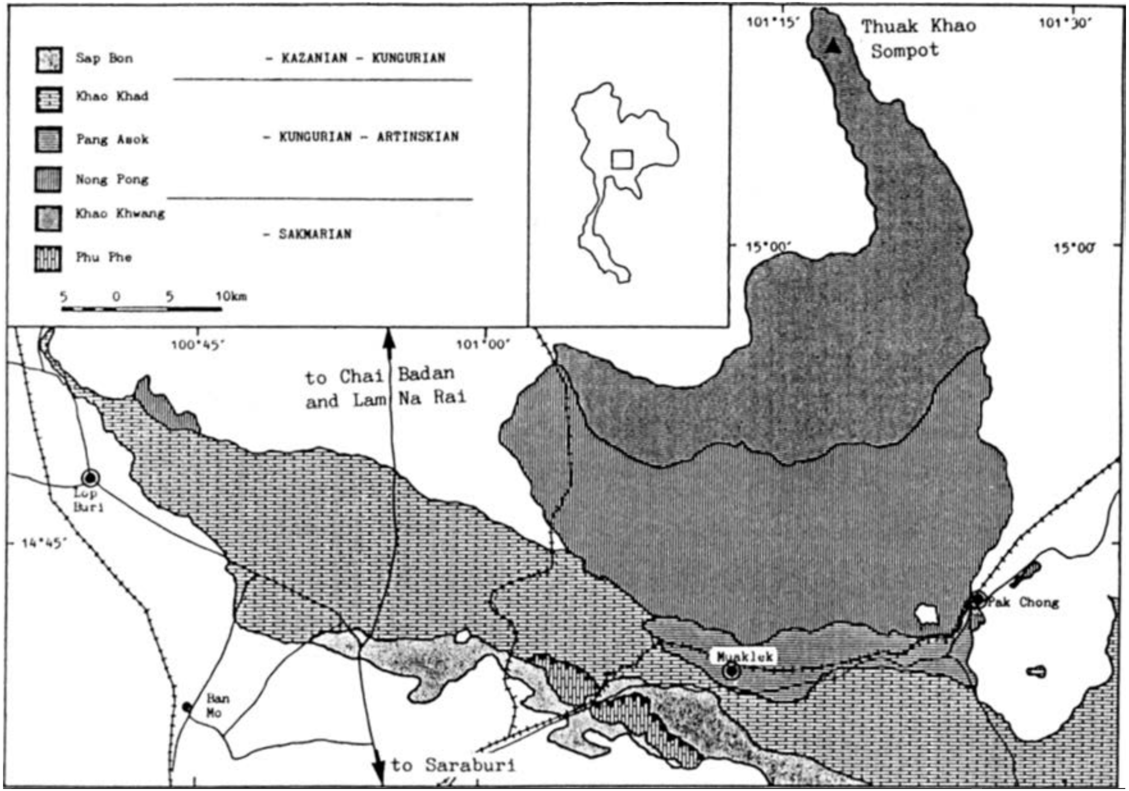


Fig.:12. Geological map of the Permian in Saraburi - Pak Chong - Thuak Khao Sompot area according to SUDASNA & PITAKPAIVAN (1976).

2.1. Saraburi - Pak Chong area

According to the unpublished geological map 1:250 000 – Changwat Phra Nakhon Si Ayutthaya by SUDASNA & PITAKPAIVAN, (1976), the road from Saraburi to Pak Chong crosscuts the following Permian units from west to the east (fig.:12):

- Sap Bon (sb), top:

  "Thin bedded, gray brown, buff sandstone, siltstone, shale and chert intercalated with gray limestone, local phyllite and schist."

  Kazanian to Kungurian (Upper - Middle Permian) age.
- Phu Phae (p):

  "Pinkish gray to very dark gray limestone, nodular and tabular chert bands, partly intercalated slaty shale. Fusulunids and crinoids."

  Sakmarian (Lower Permian) age.
- Sap Bon (sb).
- Khao Khad (kd):

  "Black, very dark to light gray limestone; recrystallined, agrillaceous limestone and dolomite with nodular and bedded cherts; intercalated shale, sandstone and rare volcanics. Local marble and calc-silicate rock. Common fusulines, corals, brachiopods and algae."

  Kungurian to Artinskian (Middle - Lower Permian) age.
- Pang Asok (pa):

  "Thin bedded, gray, bluish - gray, brown, pale reddish, brown shale, slaty shale and slate with lenticular beds of sandstone and limestone; local hornfels."

  Kungurian - Artinskian (Middle - Lower Permian) age.
- Khao Khad (kd).
- Pang Asok (pa).
- Nong Pong (n), bottom:

  Black to dark gray banded and laminated limestone and bedded chert; gray bluish, brownish - gray, grayish - brown and buff shale, tuffaceous sandstone. Local volcanics, hornfels, slate and quartzite. Common crinoids, fusulines and corals.

  Kungurian to Artinskian (Lower - Middle Permian) age.

The description thus far is that given by the geological map.

The westernmost limestone outcrops along this road appear at km 129.000. The outcrops up to km 134.000 (Sap Bon Fm.) show intercalations of siliciclastics (fine-grained sandstones and siltstones) and slightly phyllitic shales with micritic limestones. These limestones are laminated and occur with dark gray, biomicritic to biosparitic rudite limestones of light gray colour with abundant crinoids and rare foraminifera.

Typical lithology in thin section is:

WA84/50: Lithic graywacke. Fine grained, bedded. Cherty to clayish matrix (50%) with some chlorite and goethite. 50% of the clasts are monocrystalline quartz with weak overgrowths, 3-5% are feldspar (plagioclase), more than 40% are rock fragments of mostly polycrystalline quartz grains. Abundant detrital mica, often chloritized. The clasts are angular and moderately sorted.

WA84/51: Fine calcirudite – sorted biosparite (grainstone). Foraminiferal, crinoidal, algal (Phylloidae and red algae) and bryozoan bioclasts in coarse crystalline spar matrix. Abundant silt influx of quartz and plagioclase intraclasts. – Coquina shell hash, SMF 12; SFB 6 or 5. Rim cements evidence influence of brackish water and also "sugar"-granular cements indicate a fresh water influenced environment.

Rapid facies changes in the siliciclastics and carbonates suggest a shelf or platform marginal character for the depositional environment.

The general striking of the strata is east - west (179°/65°; 184°/62°).

At km 134.000 an upright and isoclinal fold with B-linear – 095°/05° was found. Well-developed cleavage, nearly strata parallel and less-developed, secondary cleavage were observed. Foraminifera found at km 134.000 indicate Kubergandian age.

At km 136.000 (Phu Phae Fm.) outcrop light gray, partly spathic limestones, containing foraminifera and crinoids. Thick bedding of these light gray, shallow water carbonates with no siliciclastic intercalations is typical for the stable sedimentary conditions. The limestones are biosparites or biomicrites (grainstones - wackestones) with foraminiferal, crinoidal and minor algal bioclasts. Some of the bioclasts are heavily worn. All standard micro facies of SFB 7 (shelf lagoon, open circulation) are present excluding SMF 8 and 17. The strata are of Kubergandian age.

At km 139.000 (Khao Khad Fm.), an intercalation of fine-grained sandstones with slightly silicified foraminiferal limestones with a micritic matrix, is exhibited. Also some black shales, strongly silicified, appear within the limestones.

Siltstones and sandstones are strongly weathered and contain abundant fossils of foraminifera. The sedimentary environment was of shallow water conditions and periodic quiescence (shales) interrupted by fine-grained siliciclastic influx. The foraminifera tests were probably swept together by wave action. The limestones correspond to those described above (Phu Phae Fm.) but peloidal biomicrites also occur (SMF 19). Rim cements in these limestones are followed by late diagenetic blocky cements.
Stromatactis structures in the limestones indicate subtidal to intertidal areas. Bolorian to Kubergandian foraminifera were found in these beds.
The strata generally strike SSE - NNW (240°/30°- 40°).

At km 141.000 - 142.000 an intercalation of limestones and cherts crop out.
The strata strike generally with 200/50-60 degrees approximately E-W. Bedding thickness ranges from one or two cm to up to twenty cm thickness. The cherts are of light gray colour, partly wavy laminated and contain in some layers abundant foraminifera. The limestones are weakly recrystallized and also contain foraminifera. Some violet weathered shales are present in this sequence.
The cherts are silicified limestones and pelitic siliciclastic rocks which clearly show their previous sedimentary properties. Often lamination or thin bedding could be observed. Some of the layers exhibit burrows 0.5 cm in diameter which vertically penetrate the bedding. Abundant foraminifera and unbroken pieces of crinoidal stems evidence a quiet depositional environment. Replacement of carbonate by SiO_2 and the silicification of the siliciclastics is of diagenetic or late diagenetic origin.
In the thin section could be recognised:

WA84/46: Foraminiferal micrite or sparite completely replaced by chalcedony quartz. The matrix has undergone dolomitization before silification, some dolomite – ghost crystals can be recognized. The structure of former bioclasts is totally destroyed and replaced by "heliolithic" quartz (radial clusters) or chalcedony-quartz and has probably been micritized before silification. The original limestone could be of SMF 9 or 10 or 18.

WA82/222; 223; 224): Foraminiferal and ?algal micrite or sparite are totally replaced by silica. Contacts between the tests of fossils can be recognized as well as internal structures of the tests. Former micro-dolomite rhomboedrons can be recognized from their iron-rich coating – (reddish to opaque). Some dolomite-rhomboedrons of 0.1-0.2 mm are not replaced. In sample 223 abundant quartzose, long needles and spheroidal structures (?spiculae) are present. Here microfractures are calcite-filled and finely dispersed pigmentation of hematite gives the rock a pink - brownish colour. In sample 224 silicified oncoidal fragments are present. Here silica is restricted to the former pore space. The foraminifera found indicate Yahtashian to Bolorian age.

At km 144.300 near to the Muak Lek junction and opposite to the steak house interbedded sandstones and carbonates in up to 50 cm thick layers are poorly exposed. The micritic carbonates (packstones - wackestones) contain some crinoidal fragments and the sandstone layers contain abundant clay galls (rip-up clasts). These sediments could not be studied sufficiently because of lack of fresh samples, but the resediment particles in the sandstones and crinoidal detritus-rich layers in the limestones show local reworking and higher energy conditions.
BORAX & STEWART (1966) described from the vicinity of Thavi Ranch (about 4 km SSE from Muak Lek) a "near reef environment" – possibly a fore reef slope consisting of limestone pebble conglomerate interbedded with limestone, siltstone, claystone and chert. Its age is Lower to Middle Permian.

At km 144.500 (Pang Asok?) no limestones crop out.
The strata are strongly fractured and the microfractures are filled with quartz. The strata consist mainly of fine-grained sandstones in beds of approximately 50 cm thickness, intercalated with minor components of siltstone and shales. Also, the sandstones here contain elongated clay galls, but not so frequently as at the outcrop at the Muak Lek junction. Some of the layers have thin clay flasers in their upper part and on bedding surfaces. The colour of the psammites is gray and yellowish when weathered. The pelites are dark gray to brown.

At km 145.500 (Pang Asok Fm.) the sequence shows similar lithology to the outcrop described above. An intercalation of thin-bedded siltstones with 30-40 cm thick fine-grained sandstones occurs, but rare lenticular limestone layers are also present. These limestones are microsparitic rudites of dark gray colour and do

not contain any macrofossils. The siliciclastics contain a high amount of detrital mica and rare, small clay rip-up clasts, but do not show any layer internal structures.
General strike direction is nearly N-S (SS 258°/45°).

At km 154.500 again limestones crop out. They consist of foraminiferal rudites with micritic or sparitic matrix. SMF 9 of SFB 7 dominates (WA84/37) – those packstones or wackestones contain partly worn foraminiferal and algal (blue-green and Dasycladacea algae) fragments. Rare crinoids and bivalve fragments are also present. Birds eye structures suggest intertidal deposition. Vadose dog tooth cements occur. The strata could be established as Kubergandian to Murgabian. Further to the east clastic sediments prevail.

At km 161.300 to km 161.500 (Pang Asok Fm.) slightly phyllitic, dark gray slates, reddish when weathered, crop out. Rare, thin siltstone layers are intercalated. The mudstones (slates) and siltstones are laminated. Still further to the west, at km 161.500, the siltstones dominate and some fine-grained sandstones rich in mica detritus are also represented. Small current ripples were found. These laminated or crossbedded sandstone layers can reach up to 20 cm thickness.
The general strike is nearly E-W (SS 356°/55°) and the cleavage nearly parallel to the bedding.
In thin section the pelites appear as:
WA82/219: Mudstone. Finely laminated and silty. Weak schistosity is developed and small biotite crystals grow oblique to the schistosity planes. Finely dispersed hematite is enriched along the tectonic planes. Sericite and biotite is locally chloritized and new chlorite is present in the matrix. Low grade metamorphism (WINKLER, 1979) is evident.
Lustrous slates and "slight dynamothermal metamorphism" was also reported by BORAX & STEWART, (1966) in the area south of Muak Lek.

At km 162.100 (Pang Asok Fm.), a thick sequence of some hundred meters, which is overturned, exhibits slightly phyllitic mudstones (slates) with intercalated one to two cm thick fine sandstone layers. The sandstones are crossbedded. The strike is again E - W (SS 180°/78°; 183°/73°) and the cleavage nearly parallel to bedding (Sf 188°/60°).

At km 163.300 - 164.000 (pa), with more or less the same striking direction and also overturned, interbedded weakly phyllitic slates and fine grained sandstones of up to 30 cm thick layers occur. The sandstones are strongly micaceous and the bottom of the layers exhibit flutecasts (SS 190°/45° inverse! – l 280°/03°). This indicates a questionable paleotransport direction of ESE - WNW.

At km 167.000, at the entrance to the Wat Khao Sai Sayan and onto its territory, limestones, siltstones and mudstones of the Nong Pong Fm. are exposed. The crinoidal limestones are partly silicified and of dark gray colour. The crinoidal debris is very fine, some foraminifera and solitary corals in lenticular beds also occur. The foraminifera are aligned parallel to the current but not unidirectional in the different beds. No trend in the direction could be recognized. The whole strata seem to be overthrusted above the Pang Asok Fm. (geol. map SUDASNA & PITAKPAIVAN, 1976). The siliciclastic and carbonatic layers are up to three or four meters thick.
The general strike is as always in this region near to E - W (SS 260°/75°).
The strata could be dated as Yahtashian to Bolorian. In thin section the limestones are:
WA84/34: Intra-biosparrudite (packstone). Foraminiferal and algal bioclasts and volcanic and quartz intraclasts in sparitic matrix. Rare oncoidal fragments are present. Dissolution of calcite and growth of idiomorphic dolomite with fine hematite coating can be observed. Chloritized and glassy volcaniclasts show fluidal textures of small plagioclase crystals. The shallow water biota and oncoids are heavily worn by transportation. Fibrous cements of marine origin (A-cement) are followed by late diagenetic B-cements. There is also late diagenetic dolomitization (coarse crystalline, idiomorphic crystals). Questionable SMF 4 of SFB 2-4?
WA84/32: Strongly chloritized and silicified ?calcisiltite.

Approximately 10 km to the south of Pak Chong, according to the description of WIELCHOWSKY & YOUNG (1985; p.44), basin margin fan deposits occur. These consist of thin to thick bedded, black argillaceous carbonate mudstones through grainstones, dark shales and fine grained sandstones. This description could be also valid for the sequence described from the last outcrops above.

In Pak Chong at the petrol station and opposite to the Wan Chai Hotel (western town entrance) NNW striking (SS 070°/80°) strata crop out. Alternating beds of two to three cm thick strongly silicified limestones, siltstones and mudstones are exposed. The rare limestone layers can be up to 150 cm thick. An andesitic dike crosscuts the outcrop.

WA84/31: Andesite. Saussuritic plagioclase and K-feldspar, phenocrysts of amphibole (actinolite) and some titanite in a glass matrix, partly recrystallized (quartz).

WA84/29-30 (sample from the contact) the limestones underwent strong contact metamorphosis and are rich in chlorite, scapolite, chalcedony and mega quartz.

The Log-profile No.:I was recorded in this outcrop in Pak Chong.

At the altitude of Muak Lek, along the road to the north (via Muak Lek) there are some Permian rocks of the Nong Pong Formation. These Permian strata were laid down in somewhat different conditions from the rocks along the Saraburi - Pak Chong highway. The junction to Muak Lek is located at km 143.700 of this road. From the Muak Lek railroad station one must follow a road 4.8 km to the north. At km 4.8 crinoidal limestones crop out. The light gray crinoidal debris is partly very coarse and is graded. Foraminifera are rare. The rock is recrystallized under stress conditions.

WA84/40: poorly washed biosparrite (grainstone). Mainly crinoidal bioclasts and few foraminifera – bioclastic microbreccia SMF 4?; SFB 3 or 4.

At km 7 on the road north from Muak Lek the same crinoidal microbreccia limestones occur, but here much stronger stressed and recrystallized. Under the microscope they show marble texture (WA84/41).

Approximately 10 km north of Muak Lek to the north, at the small temple and a village school, graded bedded limestones intercalated with calcareous (coarse crystalline) sandy layers and slightly phyllitic, yellowish (weathered) shales are exposed. The strata are folded (fig.:13).

In thin section it appears as:

WA84/43: Intra-biomicrite (packstone) grading to micrite. Intraclasts of limestone and volcanic feldspar partly replaced by calcite (Na-rich, replacement beginning in the center), angular quartz intraclasts in calcitic matrix weakly replaced by chert. Diverse micritized and worn bioclasts of mainly algae and crinoids. Graded bedding. Allodapic limestone, SMF 4; SFB 3 or 4.

At km 11.0 on the road north from Muak Lek very fine crystalline, stressed and silicified gray limestone intercalated with siltstones occur. No fossils were found here.

WA84/44: sparse intramicrite (wackestone). Quartz - silt influx in lime mud. Variety of SMF 3; SFB 3.

The description above makes it clear that the basin becomes deeper towards the north and that the last outcrop represents already a basin plain environment. The sediments are of Yahtashian to Murgabian age. This interpretation is identical to the one given by WIELCHOWSKY & YOUNG (1985).

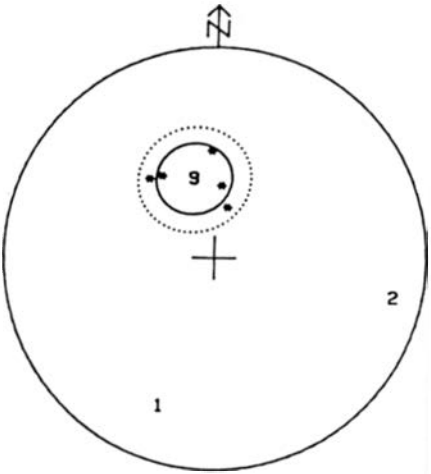


Fig.:13. Fold N'of Muaklek

2.2. Saraburi - Lop Buri area

The highway from Saraburi to Lop Buri also cuts across the Sap Bon Formation and the Khao Khad Formation (fig.:12). In the Khao Khad Formation there are several limestone quarries, which allow detailed studies.

At the junction of the Saraburi - Lop Buri road (No. 1) and the road to the north, to Chai Badan or Lam Narai (No. 21), the outcropping Sap Bon rocks are somewhat different from the Sb Formation described above.

The northward folded strata (two NE-vergent folds with B-axes striking at 248°/05° and 237°/17° are poorly exhibited) are built up mainly from laminated cherts and rare silt- to mudstones. Often cross-lamination could be identified within the chert laminae. The majority of the beds are 5 cm to 10 cm thick, but thicknesses of up to 20-25 cm also occur. Primary carbonates or mudstones and siltstones have been silicified to cherts or cherty siltstones. With a microscope the original texture can be identified.

> The limestones contain spicules and foraminifera while the mudstones contain silt and fine-grained sandstone lenses. Nests of finely dispersed pigmentation of hematite are common. (WA84/52; WA82/217-218).

Some 50 m to the south from the junction, unsilicified limestones occur. The layers are 20 cm to 50 cm thick, light gray coloured and free of macrofossils. In thin section they appear as:

WA84/53. Intramicrite (mudstone) with laminae of sparry calcite and scattered silt-quartz grains. Some calcispheres and abundant dolomite rhombs are present. Wavy lamination can be recognised in thin section scale as well as macroscopically. The dolomitization is caused by compactional water in a late diagenetic stage. This sample is interpreted as a calcisiltite of SMF 2; SFB 1-3.

Also rare lithic graywackes, fine-grained were found in this outcrop. They are composed of 50% sericitic-clayish matrix with a secondary pore filling of dolomite (late diagenetic). The clasts are 60% monocrystalline quartz and 40% lithic fragments which include detrital mica (partly chloritized). Astonishing is the very low volume of feldspar (less than 1%).

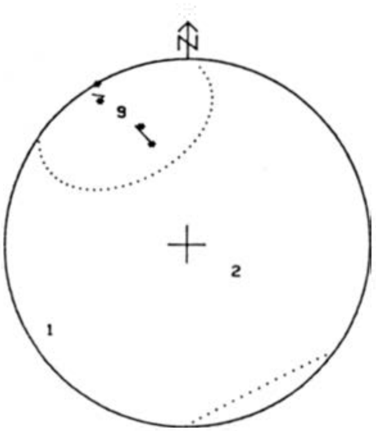


Fig.:14. Fold at the junction of the Saraburi and Lop Buri roads.

The Kd Formation seems to differ from the description given for the Saraburi - Pak Chong road.

Thick to massively bedded conglomerates and breccias which are fine- to medium-grained matrix supported occur together with thin- to thick-bedded limestones. These limestones are algal and foraminiferal wackestones to packstones (packed biomicrites and poorly washed or unsorted, coarse biosparites) associated with shales. WIELCHOWSKY & YOUNG (1985) reported Guadalupian age for these sediments and interpreted the conglomerates as possible rockfalls, debris flows and/or grainflows which were deposited further upslope than the thick bedded limestones and shales, which are likely to be of turbiditic origin. Based on my observations these, latter sediments lack graded bedding or other characteristics of allodapic/turbiditic sedimentation.

2.3. Saraburi - Lam Na Rai area

Along the Saraburi - Lam Narai road No. 21 (fig.:12) there are also outcrops of the Sb Formation in the south and Kd Formation in the north.

The outcrops of the Sb Formation are located between the junction (km 0.0) and km 3.9 where the Kd strata start.

As already described for the Saraburi - Lop Buri highway the lithology is characterised by thin bedded limestones, dark shales and gray-greenish, wavy laminated, fine bedded mudstones or tuffites. Some of the microsparitic limestone layers are graded, indicated by the increase of clay concentration towards the top. The layers are up to 20 cm thick and contain rare clay rip-up clasts. The fine-grained, greenish tuffites are silicified, also some of the limestone beds are highly silicified. The intercalated shales are slightly phyllitic. The strike direction of the strata is always close to E-W.

In thin section the limestones are micrites or microsparites with abundant spiculae and rare filaments of fossils. Rare algal fragments and foraminifera are scattered throughout. These sediments represent standard micro facies 1 to 4 of basin plain to deep shelf margin (SFB 1 to 3). The tuffites are chloritized to a high degree. Rare volcanic intraclasts occur within the limestones. Yahtashian to Bolorian age was established for these sediments.

Log No.:II gives a detailed sedimentological profile through a small, representative part of these outcrops.

The outcrops within the Kd Formation along the highway No. 21 are described by DAWSON (1978). Seven units between km 14 and 6 (latitude 14°41′ N to 14°44′ N; longitude 100°55′ E) are distinguished by DAWSON, (1978):

The units become younger toward the south.

Unit I – oldest stratum of the sequence is located in the very north at km 14.0. It is at least 75 m thick and consists of interbedded 20 to 80 cm thick bands of microcrystalline siliceous limestones and calcareous chert beds intercalated with fusulinid-bearing biosparites. The unit dips southward with an angle of 60 to 80 degrees.

Unit II is located directly south of unit I and its minimum thickness measures 630 m. The limestones are mainly dense, crystalline biosparites of varying grain size and great faunal diversity. The abundance of dasycladacean algae and fusulinid foraminifera is significant for these strata. Well-sorted grainstones of Robustoschwagerina sp. suggest beach sediments; beds of stromatactis indicate shallow, subtidal to intertidal deposition. Towards the top of the unit the limestones have been dolomitized in a supposedly vadose environment.

Unit III, located further to the south, is at least 30m thick. Intercalated beds of biopelmicritic limestones and yellowish, marly, calcareous silt and shale are interpreted to be from a tidal channel environment. This interpretation is supported by the occurrence of abraded coral slabs and foraminifera in a poorly sorted, pelsparitic grainstone.

Unit IV is a 40 m thick sequence, containing thin to thick bedded, medium-grained biomicrites to biosparites. Patches of dolomite and chert nodules are scattered throughout. Algal-fusulinid boundstones with rare corals in growth position lead to the conclusion of a patch reef lagoonal depositional environment.

Unit V is at least 88 m thick and of similar character as unit IV. In its lower part stromatolitic algae, replaced by silica are common. Stromatolites and algal boundstones are partly burrowed by organisms and seemingly destroyed by wave erosion.

Unit VI is a sequence of at least 470 m thickness. It is composed of thin-bedded, coarse-grained biomicrosparites to biomicrites. Three cycles of sedimentation are distinguishable, each starting with mudstone biomicrite, grading to wackestone, packstone, grainstone and partly boundstone and finally fine, dolomitic, microlaminated algal stromatolites. The grainstones and packstones bear Fusulinids. These strata reflect a subtidal depositional environment.

Unit VII is a 67 m thick unit of coarse grained biosparites with layers of stromatolites and laminated layers of pelsparite. It is partly dolomitized and rich in "birds eye" structures and carbonaceous matter. Also mudcracks are reported. The unit reflects intertidal and supratidal depositional conditions.

According to my own observations, the Kd Formation along the Saraburi - Lam Narai highway extends from km 3.95 (southernmost outcrop) to km 14.0 in the north. In the outcrops at km 3.95, light gray to whitish foraminiferal and crinoidal micrites and microsparites (wackestones, packstones, grainstones) of intertidal to supratidal character occur.

WA84/58 – Biomicrite (wackestone) with birds eye structures. Well-preserved foraminifera and diverse fossil fragments are found in micritic matrix. Blocky, granular calcite cements and pores filled in the late diagenetic stage were recognised in this sample of SMF 19? SFB 8.

WA84/58a – Bio-intrasparite (grainstone). Volcanic lithoclasts with fluidal texture of feldspar (partly replaced by calcite) are present in a glassy matrix. Bioclasts of foraminifera, coralline algae, bivalve tests, and oncoidal fragments in microsparitic matrix are slightly replaced by microcrystalline silica. The volcaniclasts are strongly chloritized and hematitized (finely dispersed hematite). Hematite also accumulates along the boundaries of carbonate intraclasts. Some sericite can be found in the matrix. The sample belongs to SMF 14; SFB 6. Marine, fibrous "A" cements are followed by late diagenetic, blocky "B" cements.

These outcrops can be interpreted as a part of DAWSON's unit VII if they are in fact in the same structural and stratigraphical position.

At km 6.0 – (unit VII) a sequence of limestones and cherts is exposed on both sides of the road. The sequence is folded (isoclinal, upright fold). The B-linear of the fold axis measures 052/15 degrees and is NE - SW trending. There is a volcanic sill within the strata. The thickness of the beds ranges from 2 cm to 30 cm. The "cherts" are former carbonates, later partly or totally replaced by silica. These silicified carbonates can be either finely laminated or wavy laminated: (WA82/200; 203; 205) and contain by silica replaced bioclasts (foraminiferal grainstones, SMF 18; SFB 7-8). Chalcedony replacing mainly the fossils (WA82/201; 202; 204; 207) is also present.

The sample WA82/202 contains spiculae. DAWSON (1978) mentions pelagic fauna (spiculae) within unit VII and explains its occurrence in terms of storm action. Since the present author did not find any tempestites in these outcrops, the question of the origin of the spiculae remains open, but they need not necessarily be pelagic.

The occurrence of dolomitic rhomboedrons in association with silica replacement can be found and is also reported by DAWSON (1978). Late diagenetic stylolites and compactionally demolished foraminifera can be observed macro- and microscopically. Hematite surrounds the dolomite rhombohedrons but is also finely dispersed and scattered all over the thin sections, as well as enriched on fractures. Its first occurrence might be characteristic for dolomitization (ghost crystals of dolomite as enrichment centers). The enrichment of hematite in the fractures is related to recent weathering processes.

At km 8.05 to 8.2 on the Khao Khad hill, limestones occur in up to 5 m thick beds and in massive, big lenses. Dominating are pelloidal biomicrites and sparites (wackestones, packstones, grainstones) with abundant foraminifera and diverse bioclasts which are coated and worn. The limestones are of SMF 9, 10, 16-18; SFB 6-7. Fibrous "A" and blocky "B" cements as well as miniscus cements are present and suggest marine, vadose diagenetic processes. Also weak silica replacement of probably late diagenetic origin was observed (WA84/60; WA82/198). These outcrops probably represent the equivalence of unit IV or V.

At km 9.0 occur chertified limestones, as well as original limestones of the same sedimentary properties as one kilometer to the south.

WA84/61: Packed biomicrite (packstone) with abundant agglutinated pellets and worn bioclasts in sparse, micritic matrix. The bioclasts are mainly of foraminifera and Dasycladacean algae origin. The algae are of advanced dolomitization and appear to be partly recrystallized. Fractures are filled by calcite. Some of the fractures crosscut the dolomitized Dasycladacea. SMF 18, SFB 7-8. This sample is very typical for the strata.

Still further to the north, at km 11.5 - 11.6, the thickness of the layers increases to more than 10 m. Chert nodules of various sizes are common within the strata. The sedimentary facies does not change.

Also, at km 14.000 my observations confirm the description given by DAWSON (1978). Addition findings of an intercalation of algal/foraminiferal grainstones of SMF 18 and coquina beds of shell hash and encrinites (SMF 12) with the occurrence of solitary corals can be reported. This lithology within the laminated wackestones and packstones agrees well with the interpretation of a marginal basin slope, but more likely the upper than the lower part of the slope.

DAWSON (1978) dated unit I as Lower Permian (Fenestrella and Pseudofusulina) and ordered the following units in ascending stratigraphic order from the north to the south (from km 14 to km 6). INGAVAT's dating of my samples for unit I (WA84/63 from km 14.0) gives a Bolorian to Kubergandian age. The outcrops at km 9.0 have been dated as Murgabian and at km 8.1 - 8.2 as Kubergandian to Murgabian (WA82/198; WA84/61). The outcrops at km 6.0 have also been dated as Murgabian (WA82/204; 207) and the southernmost outcrops at km 3.9 also as Kubergandian to Murgabian (WA84/58; 59). This shows the whole section to be Middle Permian. No early Permian (Asselian to Yahtashian/Artinskian) could be proved for these outcrops. My data do not contradict the results of DAWSON, who of course did not sample exactly the same beds. Probably the whole sequence is also more discontinuous and interrupted by folds and faults than it has been previously assumed.

2.4. Thuak Khao Sompot and southern areas.

The study area is the northern extension of the Permian outcrops between Pak Chong and Lop Buri. It is mapped on the Amphoe Ban Mi sheet of the Geological Map of Thailand 1:250.000 published by SUDASNA & PITAKPAIVAN (1976) as the Upper Permian Tak Fa (Ptf) Formation. It represents the northern continuation of the Sakmarian (Lower Permian) Khao Kwang Formation from the Phra Nakhon Si Autthaya sheet by the same authors.
Fig.: 12 is redrawn from both map sheets.

WIELCHOWSKY & YOUNG (1985) describe an area lying approximately 30 km SE of Lam Narai (101°17'E). The area is named Khao Khwong and is described as thin- to thick-bedded conglomerates and breccias of reef derived detritus intercalated with graded fusilinid packstones and thin-laminated shales. The authors interpret this to be a fore-reef slope environment and the age is determined to be Sakmarian.

50 km north of Pak Chong, between Phut Khao Heo Ta Bua and Khao Wong (fig.: 12; 15°03'N; 101°22'E), a platform marginal reef was mapped by WIELCHOWSKY & YOUNG (1985). A 520 m thick sequence of coral-algae-sponge boundstone of Lower Guadalupian age is located between basin facies to the east and bedded platform carbonates to the west. This section was not examined, but little to the north of Khao Wong (15°05'N) a somewhat different situation was found.

Here SE-NW striking and NE dipping limestones of massive Verbeekina grainstones and coral boundstones with chert nodules and thin layers form a minimum 500 m thick sequence. This sequence is underlain by massive biomicrites and biosparites and thick-bedded bioclastic grainstones derived from a higher energy environment.

Samples from the lower part of this sequence appear in the thin section as intra-biosparites (grainstones) with rounded and coated clasts in sparse matrix. The bioclasts are of diverse origin and deeply worn, but unbroken crinoid stems also occur. Packed, poorly washed biosparites (packstones) with coated and worn foraminifera, algal, and ooidal fragments, as well as biointramicrites (wackestone - packstone) with abundant pellets and birds eye structures, are common. Syntaxial rim cements of mixing zone origin are frequent. Kubergandian to Murgabian age could be established for these rocks (WA84/82). The facies is interpreted as of inter- to supratidal origin.

At the southwestern flanks of the mountain where these outcrops were found, some small boulders of limestones and siliciclastics were discovered in a corn field.

The siliciclastic sediments are fine to middle grained, reddish brown graywackes with small clay rip-up clasts. They are fractured by a thin net of ?sideritic veins. Their matrix is ferritic - cherty and penetrated by calcite. The detritus is subangular to angular, slightly overgrown with quartz, ?in situ brecciated and calcite-cemented. The feldspar content of the detritus is less than 3%. About 70% of the clasts are monocrystalline quartz grains and the rest are lithic fragments, which are mainly reddish brown, well-rounded "micritic" ?clay fragments.

The limestones are unfossiliferous dismicrites, rich in hematite and with abundant dolomite rhombohedrons. They resemble strongly the standard micro facies 23 of a hypersaline environment - SFB 9 (WA82/151).

Foraminiferal, poorly washed intrabiosparite boulders were also found on the southwestern flank of the mountain. The bioclasts are of fusulinid and dasycladacean origin. Birds eye and meteoric dolomitization are present. "Sugar" calcite cement could be identified and evidence the influence of fresh water diagenesis (WA82/149).

Another interesting boulder (WA82/152) was of pisolitic packstone origin. The pisolites (oncoids) contain cyanoid algae and have a thin tangential, reddish brown colored coating which surrounds coarse, nearly opaque, dark reddish brown nuclei. The pisolites are 0.5 cm to 1.0 cm in diameter and not perfectly spheroidal. The matrix is micritic or micritized, porous, and containing some hematite. Pores are partly filled with spary calcite. The matrix and the pisolites are in situ brecciated and crosscut by a thin net of calcite veins. Chalcedony replaced the matrix along with some of the pisolites and obliterates the original fabric. Remains of indeterminate fibrous and granular cements were traced. An

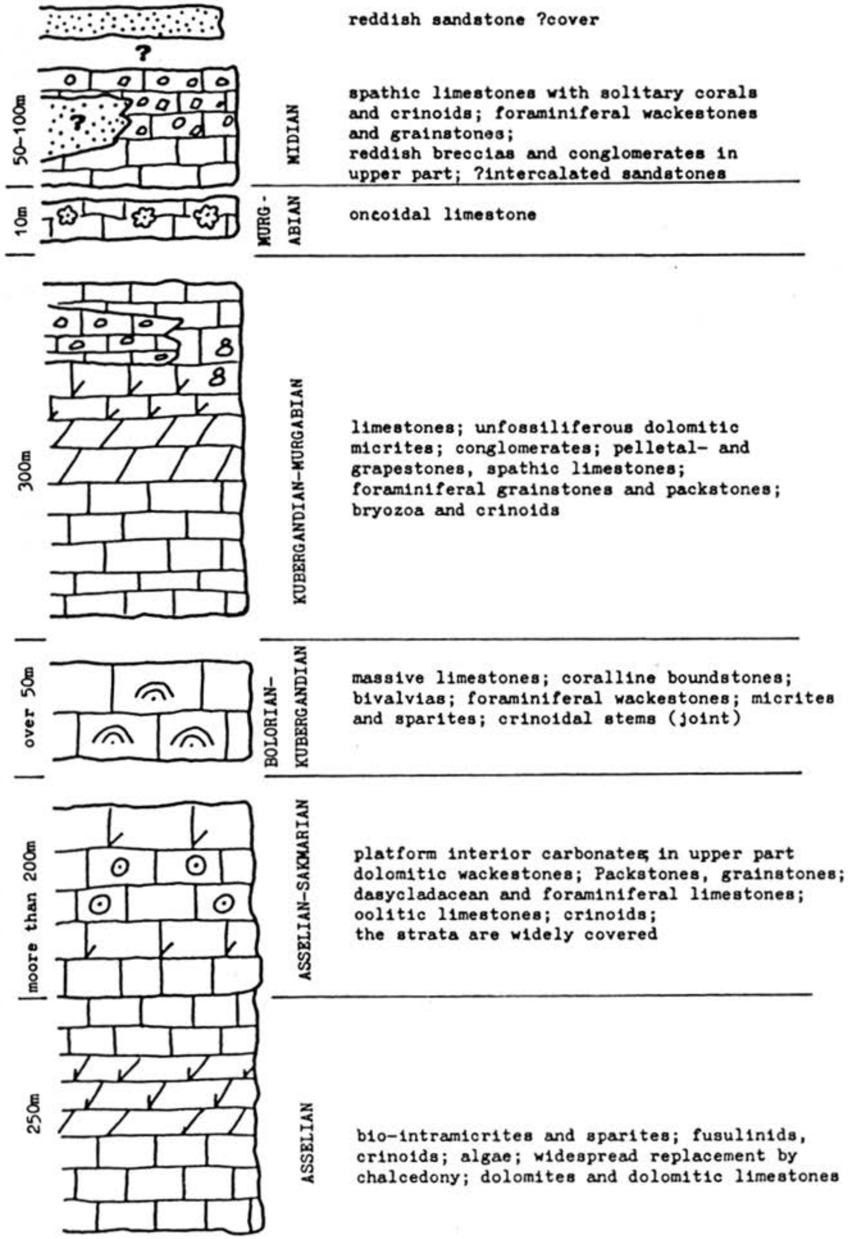


Fig.: 15. Schematical profile of the Thuak Khao Sompot outcrops. Not to scale.

emerged environment with caliche development is suggested. Unfortunately, no outcrops were found to prove this assumption.

The Thuak Khao Sompot mountain exhibits the northernmost Ptf/Kg outcrops in the area under investigation. The extensive outcrops between 15°12'N and 15°06'N are easy to reach. Of course this was not the case when BORAX & STEWART, (1966) examined this area. Nevertheless, they were able to measure a 525.2 m long section of "fine-grained, gray limestones with fusulines" underlain by dolomites of 18.5 m thickness. The strata become younger towards the east.

WIELCHOWSKY & YOUNG (1985) measured a 1260 m thick sequence between 15°06'N - 07'N; 101°18'E - 19'E, ranging from Asselian through Guadalupian. In this section they recognized three subenvironments of a platform interior depositional area, namely

platform interior lagoon,
platform interior mixed mud and sand complex,
platform interior sand shoal.

Since it was not possible to record such continuous profile in the Khao Sompot mountain, the correlation between my description and that of WIELCHOWSKY & YOUNG (1985) can be made only with respect to the lithology and stratigraphy. The description by WIELCHOWSKY & YOUNG (1985) does not seem to support their interpretation, but no closer details on the lithology are given in their paper.

In contradiction to the findings of BORAX & STEWART (1966), a westward dipping strata were also found in the northwestern Khao Sompot outcrops. This complicates the correlation. Evidently the age of the strata does not simply become younger from west to east, as assumed by BORAX & STEWART (1966).

In the eastern, and northeastern outcrops, at the foot of Khao Sompot, light reddish limestone conglomerate is present. It is a matrix-supported, medium-grained (pebble to cobble size) conglomerate, with the clasts embedded in sparitic calcite matrix. The clasts are subangular to rounded and consist mainly of unfossiliferous micrite or microsparite, often with a dark, iron-rich coating. Skeletal fossil fragments are scattered in the matrix. Due to the lack of fossils in the clasts and due to the matrix properties, this conglomerate is associated more probably with a reworked, former supratidal deposition than with a reef slope.

At the same level, some hundred meters to the south, dark, reddish brown dolomitic, spathic and unfossiliferous limestones occur together with gray micritic, unfossiliferous limestones. Also, biosparites (foraminiferal grainstones and packstones) were found. Typical for the latter, is sample:

WA84/68 – poorly washed biosparite (foraminiferal grainstone) with circumference, stylolitic contacts between the foraminifera tests and the beginnings of SiO_2 replacement. Pellets are often grape-like agglutinated. Fibrous cements and late diagenetic cements with granular texture are present, SMF 16? The foraminifera established Kubergandian to Murgabian age.

Along the foot path up to the Thuak Khao Sompot mountain, to the temple Wat Ton Porn Morow, massive limestones with coral boundstones are exhibited. Coral colonies of 0.5 m or 1.0 m in diameter represent small patch reefs environment. Crinoidal limestones of fine debris and up to 10 cm long stems and abundant brachiopod shells and interfinger with the reefal limestones. Also foraminiferal biomicrites and sparites (packstones) and pelletal – foraminiferal wackestones are common. Bolorian to Kubergandian age was established by the foraminifera found (WA84/70). These findings suggest an environment of a shoal shelf with small reefs and mounds, affected by wave action, and protected lagoons. This interpretation corresponds to the one given by WIELCHOWSKY & YOUNG (1985).

To the north, at the lower part of Khao Sompot (15°11'N), oncoidal limestones with up to 2 cm diameter oncoids crop out. The oncoids are composed of cyanoid algae surrounding calcareous or fine siliciclastic nuclei, or organic fragments with irregular, hollow spaces (small cavities). The latter are often compressed and sometimes resettled by algae. In general the oncoids have wavy layers and are of irregular shape and can be treated as sphaeroidal stromatolites of SS-type (LOGAN et al. 1964). These onciodal limestones represent a shallow, intertidal environment.

Going westward from the oncoid outcrop, there occur light gray spathic limestones with solitary corals (overlying the oncoidal limestone?). Reddish, cherty nodules and lenses of 1 or 2 meters length within the limestones form small morphological mounds in the field. Breccias and

conglomerates of reddish colour, matrix-supported and with clasts of pebble to cobble size seem to be interbedded. The matrix is of a siliciclastic, coarse-grained material. About 50% of the clasts are limestone; the other 50% are clasts of reworked, conglomerate. Some layers of foraminiferal wackestones, packstones and grainstones were also found and dated as Midian (lowermost Upper Permian). Those are the youngest Permian outcrops found in this area. In these biosparites SMF 10, 11 and 19 were recognized. Marine, fibrous "A" cements followed by late diagenetic "B" cements are common as well as syntaxial rim cements. The depositional area seems to be a tidal channel and a high energy tidal shelf.
Some sandstone boulders scattered on the surface were found in these fields but not in an original position. The sandstones probably are interbedded within the conglomerates and limestones and derived from the channel infill.

Further to the southwest (15°09'-10'N; 101°17'E), there occur more wackestones, packstones and grainstones. At the outcrop near to the small temple on the western flank of Khao Sompot, the strata (SMF 10-12) are dominated by intrabiosparites (grainstones) with rounded intraclasts and worn bioclasts in sparse matrix. Also present are poorly washed biosparites (packstones) with dasycladacean algae, foraminifera, and worn oolites with marine and rim cements. These Asselian to Sakmarian carbonates (WA84/81) were laid down in an environment of local shoals neighboring deeper areas. This environment was under the influence of constant wave action which winnowed the finer sediment in a platform interior (SFB 6-7).

Some 200-300 meters to the west (the westernmost outcrops at Thuak Khao Sompot), there occur similar biointramicrites and sparites, but with microscopically recognizable, early stages of replacement by length slow chalcedony. These rocks were dated as Asselian (lowermost Permian, WA84/79) and probably deposited in a deeper and lower energy environment on the platform.
Fig.:15 summarizes in an idealized profile the sedimentary conditions found at Thuak Khao Sompot from Asselian to Midian.

2.5. Khok Samrong - Tak Fa area.

Between Amphoe Khok Samrong and Tak Fa, the westernmost Permian strata are drawn on the Amphoe Ban Mi sheet of the Geological Map of Thailand, 1:250000 (SUDASNA & PITAKPAIVAN, 1976). The area is located between 15°10' - 15°25'N and 100°44'E, up to the western sheet border and extends further on the western neighboring sheet up to 100°15'E. The Permian is mapped here as the Ptf – Tak Fa Formation of Upper Permian age and as the P1 – Lower Permian Phu Tham Nam Maholan Formation on the unpublished Geological Map of Northeastern Thailand 1:500000 by SATTAYARAK & VEERABURUS (1979). Only a few outcrops in the area of Ban Chon Saradet and Ban Lam Pa Yom, along the Khok Samrong - Tak Fa highway No.1 were visited.

In Ban Lam Pa Yom village, at km 221.8 (221.0=mile post), a narrow road easily accessible to cars, leads in the N-NE direction after approximately 2 km, to a small quarry within the fields.
Here reddish brown, totally silicified limestones ("cherts") strike SS 112°/28° in a NNE-SSW direction and dip to the east. The strata are wavy laminated and lenticular bedded (beds of ca. 5 cm thickness) and contain abundant foraminifera and brachiopod shells. Rare siltstone and mudstone layers are intercalated and also rich in brachiopod shells. They are slightly silicified, often rich in limonite and show scattered dolomite crystals in a clay matrix.
The foraminifera found in this outcrop were dated as Asselian to Sakmarian.
More typical samples are:

WA82/179 – Foraminiferal "chert". Foraminiferal packstone to grainstone, totally replaced by length slow chalcedony. Stromatactis structures, well-preserved but also silicified exhibit up to 13 generations of fibrous cements, followed by drusy cement or perfectly filling the whole pore space with the last fibrous generation in a miniscus-like structure SMF 19; SFB 8.

WA82/181 – dolomite replaced by chalcedony. Abundant dissolved dolomite "ghost" idiomorphic crystals (near shore-line dolomitisation of lime mud?), often surrounded by hematite concentrations. No primary structures could be traced.

WA82/182 – former spongistromate micrite. Fine crystalline silica with well-preserved, wavy, spongistromate lamination of algal origin. Birds eye structures remain empty. Some small fossil fragments are dissolved (leached)

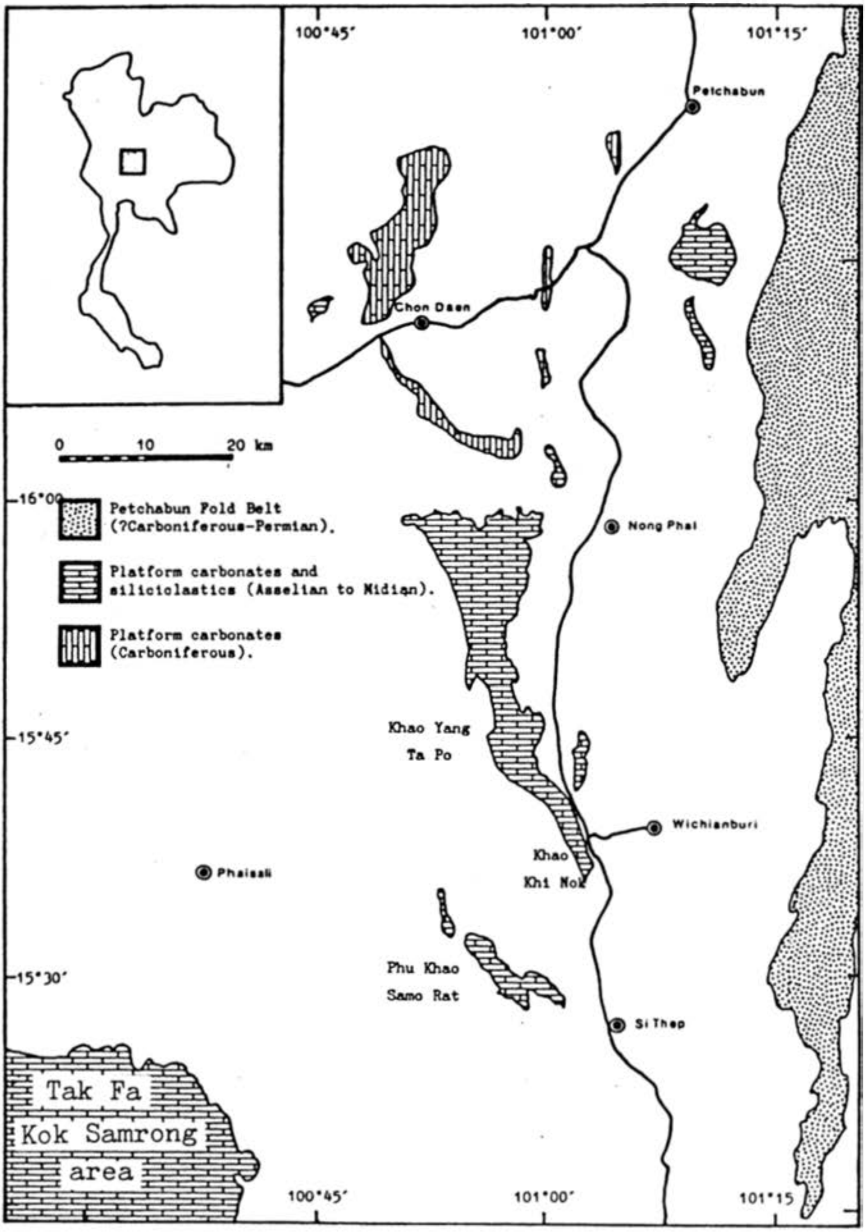


Fig.:16. Investigated outcrops west of the Petchabun Fold and Thrust Belt.

and add moldic porosity to the fenestral porosity. SMF 21; SFB 8.

The lithology described strongly suggests restricted platform interior areas, tidal flats (intertidal environment), and meteoric diagenesis followed by shallow burial silicification before complete lithification of the carbonates (JACKA, 1974).

Some hundred meters to the north from this outcrop, at the hill carbonate layers are exposed, which range from 10 cm to 1 m in thickness. The limestones are medium calcarenites to coarse calcilutites, biomicritic mudstones to wackestones with algal, ooidal, foraminiferal, crinoidal, and bryozooan fragments. Spongistromate mudstones were found as well as bioclastic wackestones of SMF 9 with phylloidal algal fragments. Replacement by chalcedony was observed in some samples. Unfortunately, the foraminifera and other fossils are of neomorphic pseudosparite and could not be classified.

The depositional environment seems to be of similar platform as described above, but with less restricted conditions (SFB 7-8).

The rocks are probably Middle Permian (NAKORNSRI, pers. comm.).

The strata strike NNE-SSW, but dip nearly to the west (SS 250°/32°) in contrast to the eastward dipping strata in the last outcrop.

On the northern flank of this hill were also found very badly exposed, strongly weathered, fine siliciclastic sediments together with carbonate layers. The limestones contain again abundant foraminifera and bryozoan fragments – these strata are also partly silicified. Bolorian age was established by the foraminifera from a sorted, biosparitic grainstone containing codiacean algae, pellets, grapes, and fusulinids.

In Ban Kaset Chai, at the road No.1, near the junction to Phai Sali, coral limestones outcrop behind the Buddhist temple. Corals in growth position interfingering with foraminiferal grainstones and packstones, with abundant brachiopod fragments and gastropod shells are present. These strata are underlain by siliciclastic sediments of red, gray or grayish green claystones, interbedded with lenticular, fine sandstones, coarse sandstones and conglomerates. The siliciclastics are deeply weathered but could be identified under the microscope as being tuffites.

Evidence includes:

1) rich in feldspar (K-feldspar and plagioclase);

2) quartz grains with resorptive border structures;

3) fragments of glass with fluidal texture of plagioclase crystals rich in iron oxide.

All the feldspar crystals are heavily replaced by calcite.

The limestones overlaying these tuffites could be dated as Kubergandian to Murgabian (WA82/188; 190). They are slightly silicified and/or recrystallized limestones of SFB 7 to 8, and coral boundstones of local, small patch reefs.

At km 207 of the road No.1, in Ban Nong Muang, at the Buddhist temple Wat Si Katanaram, red and gray, fossil-rich sparites occur. Foraminifera, gastropods and brachiopods are very common. The limestones are wackestones, packstones and grainstones of mainly SMF 9-10 and SFB 7. Their age could be dated as Murgabian to Midian (WA82/195).

Four kilometers further to the north, approximately at km 203, in Ban Chon Saradet small limestone hills behind the Buddhist temple exhibit veerbekinean grainstones and packstones with small coral reefs. The age is probably again Murgabian to Midian (INGAVAT, pers. comm.).

To summarize, the depositional conditions are similar to the Thuak Khao Sompot sequence, which is also Asselian/Sakmarian and Bolorian to Midian in age.

2.6. Phu Khao Samo Rat area.

The Phu Khao Samo Rat area is located to the west of road No.21 from Lam Narai to Nong Pai (fig.:16). It is a NW - SE trending group of hills with the highest peak at 588 m, also called Khao Amonrat. The geographical coordinates are 15°28'N - 15°32'N and 100°55'E - 101°01'E. It is mapped as Ptf on the map by SUDASNA & PITAKPAIVAN, (1976) and as P1 by SATTARAYAK & SUTEETORN, (1979).

From highway No.21, at km 105.1 a road leads to the west, toward Phu Khao Samo Rat, to the village of Ban Sap Hin Phong. A small Buddhist monastery is located on the eastern flank of the hill and can be reached by a short walk through the fields. Approximately 500 m east of the monastery, an small road passes in the NW direction to the northeastern foot of the hill of Phu Khao Samo Rat. There, medium-grained, red sandstone occur. It is parallel bedded, with parallel lamination or large scale crossbedding. The foresets of the crossbeds can be up to 20 cm thick and dip to the SSW direction (SS 195°/40°). Interbedded with these sandstones are conglomerates with carbonate clasts in a red sand matrix. Rare sandstone clasts also occur but 99% of the clasts are pebble- to cobble-size bioclastic grainstones and packstones with brachipods, crinoids, foraminifera and solitary or colonial corals. The beds average about 50 cm to 1 m thick with some beds more than 2 m thick with clasts up to 30 cm in diameter. Bolorian to Kubergandian age was determined from the foraminifera in the clasts. Some of the red sandstone layers are rich in magnetite detritus, concentrated in thin bands (placer). Cherty, carbonatic and other lithic fragments are present but monocrystalline quartz grains dominate (50%). The matrix is calcitic and in some beds cherty (WA82/135; 136).

The southeastern flank of Phu Khao Samo Rat is of similar lithology. Here the strata are dipping to the west with angles of 20 - 30 degrees. Red sandstones are overlain by identical conglomerates as above. Also, oncoidal limestone clasts were found within the conglomerate. The oncoids are one or two centimeters in diameter with 3-4 mm thick algal coating (SS-R type, randomly stacked hemispheroides, LOGAN et al. 1964) surrounding angular limestone clasts. Dolomite crystals are abundant in the matrix between the oncoids. SMF 13 of SFB 6 dominates these conglomerate clasts.

Further to the southeast, in the outcrops directly east of the monastery, occur breccia and very coarse conglomerate, without much matrix. Boulders up to 1 m in diameter are common. No bedding or imbrication or other sedimentary properties could be observed. Fine siliciclastic influx in the carbonate matrix was seen in thin section. The clasts are carbonates of bioclastic wackestone, packstone and grainstone origin and contain a huge faunal diversity of a shallow water biota. There are also coral boundstones as clasts. Many of the clasts are strongly dolomitized. A subtidal scarp or reef slope could have been the depositional environment.

From the outcrop at the monastery, a cross section of the progressively younger strata could be measured to the west. The easternmost outcrop of the section exhibits fine to coarse pebble conglomerates and are partly breccias with mainly limestone clasts, with carbonate and sand matrix. Also clay rip-up clasts, chert clasts and fine to coarse grained reddish sandstone clasts occur. Such sandstones are also intercalated with the conglomerates. Crossbedded sandstone layers have erosive contacts with upper layers of conglomerates or sandstones. Whole foraminifera, corals, cephalopods, and jointed crinoid stems are present in the clasts and in the matrix. The carbonatic clasts are often dolomitized and silicified. Some of them contain small volcanic intraclasts within the foraminiferal, algal and pelletal grainstones and packstones. Standard facies belt 7 and 8 are represented by all possible SMF in the conglomerate clasts. The conglomerate itself is of SMF 24. The total sequence is more than 100 m thick and has been dated as Yahtashian to Bolorian in age, based on the foraminifera found within the clasts (WA84/83).

Approximately 1500 m to the west, at the western foot of Phu Khao Samo Rat peak, the lithology does not change much but the percentage of foraminiferal, biosparitic grainstones in the clasts increases. Also, no more siliciclastic beds occur in the sequence. Siliciclastics are only represented as rare clasts in the westward dipping conglomerate beds. Bolorian to Kubergandian age was given by the foraminifera from the clasts (WA84/84).

This lithology changes only 1.5 km further towards the west. Here no more conglomerates appear, but massive, fine grained, gray limestones (calcarenitic, biomicrosparitic packstones). No foraminifera were found but abundant unbroken crinoid stems are present.

One kilometer further to the west, again conglomerates crop out. The clasts are medium-grained pebbles (2-3 cm), white, grain -supported and poor in lime-matrix. Some beds of sand-matrix conglomerate with clasts of boulder size are intercalated as well as some red sand and red clay lenses.

These sediments are directly overlain by oncoidal and oolithic limestones of SMF 13 and 15, which contain volcanic intraclasts as nuclei of the spheroides (WA84/92). Very rare glauconite grains were found in these beds.

The layers underlying the oncoidal beds were dated again as Bolorian to Kubergandian with the foraminifera from the clasts (WA84/88).

In the interpretation of the strata of Phu Khao Samo Rat, all the stratigraphical data was worked out from the clasts of the conglomerates which gives the oldest possible age. The clasts seems to be progressivly younger from east to the west as the westward dipping strata become younger in the same direction. The oldest possible age is Yahtashian in the easternmost outcrop and Kubergandian or younger age in the westernmost outcrop. The sequence of deposition and immediate erosion and redeposition is assumed. In the case of erosion of a thick and much older strata, the oldest sediments are eroded last and redeposited on top of the new sequence last.

The deposition of a thick pile of conglomerates and siliciclastic and carbonate strata, with evidently shallow water indicators (heavy mineral placers, shallow water biota, red, coarse siliciclastics with medium size crossbeds and red pelites, oncoidal and oolithic limestones) suggest a transgressive cycle, periodically inactive or perhaps even regressive. The existence of a channeled, supratidal to subtidal regime with rapid environment changes, but always within shallow water limit is well documented. Two transgressive cycles were thus identified:

1) Yahtashian - Bolorian.
2) Bolorian - Kubergandian.

They probably represent much shorter time periods, somewhere in the lower Middle Permian and upper Middle Permian.

Summarising, the transgressive character of the rocks in the Phu Khao Samo Rat area is suggested, as is claimed for the Middle Permian world wide (comp. ROSS & ROSS, 1985).

2.7. Khao Khi Nok area.

The Khao Khi Nok Mount is located between 15°36'N - 15°38'N and 101°02'E to 101°O4'E. It is the southernmost, 441 m high peak of a NNW trending group of hills, which are mapped as the Ptf – Tak Fa Formation on the Amphoe Ban Mi sheet of the Geological Map of Thailand 1:250000 (fig.:16). The same outcrops are mapped as P1 – Phu Tham Nam Maholan Formation of Lower Permian on the 1:500000 map by SATTARAYAK & SUTEETORN (1979).

The location of the outcrops directly west of highway No.21 makes them easily accessible. A side-road leads from highway No.21, at km 118.9, to the west to Khao Khi Nok. The bad outcrop conditions do not allow confident examination and interpretation of the strata. The tectonic and stratigraphic relationships between the particular outcrops in this area were especially difficult to study because of the lack of coherent profiles and significant tectonic structures.

Two main facies were found throughout the surrounding area of Khao Khi Nok. The first consists of massively bedded carbonates; the second consists of decimeters thick beds of matrix-supported chert conglomerates and breccias and/or coarse sandstones composed of angular chert grains. The beds are discontinuous and pinch out over meters distance. These clastic sediments are mainly chert conglomerates and breccias with clasts ranging from 2 mm to 20 cm in diameter, partly very densely packed but still matrix supported and without clear imbrication. They are texturally highly immature but all of chert composition. The matrix is generally silicatic - ferritic and deep reddish brown. Whereas the first facies is restricted to the Khao Khi Nok Mount itself, the second was found only in the surrounding neighborhood, in the flats at the foot of the mount. No direct contact between both lithologic types was found. But, judging from the dip direction of the conglomerate beds and their position relative to the limestones, they seem to cover the carbonates and thus seem to be younger.

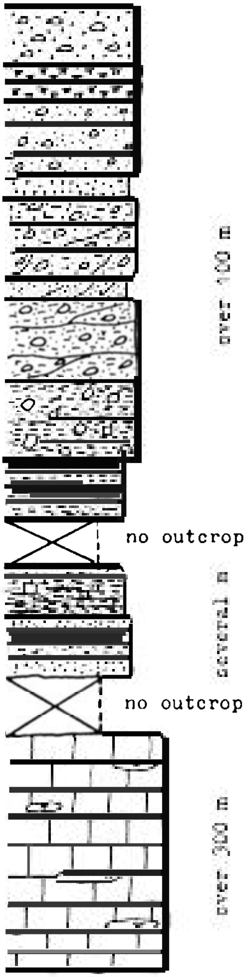
In the outcrops located approximately one km south of the mountain, intensive violet - reddish mudstones and sandstones, only weakly indurated, underlie the conglomerates and breccias described above with conformable, stratiform beds. Intercalated with the conglomerates of this outcrop are chert beds with abundant, relatively unbroken crinoid stems, brachiopods, and colonial coral fragments. These bioclasts are totally replaced by silica and only the crinoids are dissolved and present as molds.

The corals found here are various species of Ipciphyllum (courtesy FONTAINE) of Murgabian age.

WA84/105: Chert. Carbonate replaced by megaquartz. Totally obliterated primary structures, some crinoidal and bivalvia fragments traceable. Rare, very angular, sand-sized chert intraclasts.

The same facies crop out directly at highway No. 21 on the western side, at km 123.0, SE of Khao Khi Nok. Here also the conglomerates are underlain by red clays and sandstones.

On the eastern flank of Khao Khi Nok some boulders of the conglomerate and of red brown,



: Chert conglomerate, red sandstone matrix.

: Chert containing crinoid and brachiopod debris.

: Chert conglomerate, lenticular bedded, pinching out beds are common. Matrix is fine to coarse grained, reddish brown. Clay rib-up clasts and conglomerate and sandstone clasts are common. Coarse sandstone layers occur.

: Reddish, violet breccia of chert clasts, floating in red mudstone matrix.

: Reddish, violet mudstone.

: Violet, marly mudstone.

: Siltstones and shales with plant remains and brachiopods. Occasional sandstone layers.

: Massive limestones and chert beds and nodules. Coral colonies and other fossils are common.

Fig.: 17. Schematical profile of the Khao Khi Nok outcrops.
Not to scale.

coarse grained sandstone were found. Here, in the sample WA84/107 30% of the clasts are of volcanic origin. Lithic clasts of glass with fluidal texture of plagioclase and quartz grains with resorption borders occur together with chert clasts. Abundant chlorite is also present in the volcanic clasts and in the matrix.

Northeast of Khao Khi Nok, conglomerates with red clay or carbonate matrix and with red clay rip-up clasts, red sandstone clasts and fine conglomeratic clasts occur. This indicates repeated reworking. LOG No.III was recorded in this outcrop.

East of Khao Khi Nok black mudstones occur with brachiopod pavement and abundant plant remains on the layer surfaces. Rare, gray siltstones and fine-grained sandstones are intercalated. These evenly bedded rocks are overlain by violet reddish mudstones and marly mudstones which are similar to those found underlying the conglomerates, one km south of Khao Khi Nok.

Mount Khao Khi Nok itself is built up on its eastern side by massive, non-bedded, microsparitic and micritic foraminiferal limestones. Two fine calciruditic biomicrites (mudstone - wackestone) with bioclasts of foraminifera, bryozoa, algae, crinoids and pellets were sampled. Weak SiO_2 replacing of calcite could be recognized in the samples. The samples are of SMF 9 and 19, SFB 7-8 (WA84/106).

At the southern side of the mountain the limestones are stronger silicified but also of SMF 9. Some coral colonies in growth position (coral boundstone) suggest small patch reefs on the platform. The corals are Ipciphyllum genera of Murgabian age (FONTAINE pers. comm.; WA84/108; 110). Samples from this same locality (WA82/120; 122) consist of biomicrosparitic wackestone of SMF 19 (loferite) and poorly washed biosparite (packstone) with pellets and foraminifera – SMF 16. They were determined to be Murgabian or possibly Kubergandian to Murgabian in age (foraminifera). These features suggest a platformal environment with locally restricted and locally open circulation and small patch reefs of corals.

On the base of only unconnected outcrops, an approximate profile throughout this sequence was constructed, based mainly on regional features and stratigraphic data (fig.:17). The assumption that the conglomerates are located concordantly above or interfingering the limestones is strongly supported by findings of Murgabian fossils within the conglomerates and limestones. Whereas in the limestones the corals, are in growth position and the foraminifera autochthonous, the silicified coral fragments in the conglomerates are transported bioclasts and give the oldest possible age. Because these coral fragments are not within the clasts but allochthonous particles themselves, which enrich particular layers together with crinoidal and brachiopod shell debris, they must have been transported more or less directly from their growing position to the depositional area.

The depositional environment of these conglomerates and sandstones is marked by four main features.

1) Rapid changes in facies suggesting rapid changes of high energy conditions with non-depositional areas and/or periods.
2) Red color of the sediment, caused by iron-rich matrix and clasts, suggesting oxidizing conditions. Silicification and dolomitization in the shallowest, hypersaline environment is possible.
3) Mainly angular clasts and immature breccia texture and the occurrence of rip-up clasts do not indicate long distance transportation.
4) The presence of marine fossil debris as an environmental indicator.

These four features within the conglomerate deposition allow only two possibilities: a transgressive or a regressive cycle.

The speculative profile throughout the Khao Khi Nok sequence (fig.:17) suggests a coarsening upward sequence and an increase of hydrodynamic energy towards the top. This is more a regressive than a transgressive characteristic. The problems in recognising such an environment are briefly discussed by JAMES (1979). The non-conglomeratic, pelitic deposits overlying the carbonates can easily be assumed to intertidal flat deposits of a low energy regime.

2.7.1. Silicification processes

It is necessary to explain the silicification of fossiliferous layers within the chert conglomerate with the preservation of corals and brachiopods but the dissolution of crinoid columnals (moldic porosity of crinoidal shape).

Fig.:18 shows the main phases in which silicification, dolomitization, and dedolomitization occur. Silicification is concluded to be an early diagenetic process occurring in a very shallow, hypersaline or even subaerial conditions (HARRIS, 1958; NAMY, 1974). DIETRICH et al. (1963) explained such a silicification process to be contemporaneous or penecontemporaneous with dolomitization of $CaCO_3$.

Whereas the Mesozoic and recent corals are of aragonitic skeleton, the Paleozoic rugosa were made of calcite. Brachiopods could also have had a calcitic shell. Crinoids are throughout the time formed of Mg-calcite skeleton (FLÜGEL 1978). These differences could help us to solve the problem of differential preservation. It is important to notice that the central, axial channel and the crenellae-segments of the columnals, which were probably filled with micrite, are also silicified and preserved. The simplest scheme which can be applied is that of an early diagenetic solution and replacement by silica of the calcite - aragonite mud matrix and bioclasts. This replacement must have been prior to the dissolution of the Mg-calcite, which might be an effect of subaerial or near surface processes. Obviously the Mg content of the crinoids (preferable dolomitization exclusively of the crinoids cannot be ruled out) has prevented the silicification.

It is still unsolved, as to why the clasts of coarse sandstones and the clasts of conglomerates are silicified and/or of chert, while only singular limestone outcrops show partial silicification. Two possible sources for these sediments exist.

I) The clasts are original chert, derived from eroded exposures.

II) The chert clasts were deposited as carbonates and later replaced by silica, or are of precipitative silica origin within the shallowest water conditions, and of diagenetic origin.

According to the composition of the clasts found within the conglomerates and sandstones neither the first nor the second possibility can be ruled out. In all the beds a more or less weak influx of monocrystalline quartz grains occurred and now silica overgrowth evidences the presence of free SiO_2 after deposition. In some beds there is also a small quantity of lapili-volcaniclasts exhibiting the fluidal textures of feldspar crystals in a glass matrix. Possible hydrothermal alteration could aid the silicification process. On the other hand fragments of radiolarian(?), recrystallized chert also occur within the clasts. The great majority of the clasts are probably carbonate replaced by silica. Many of the clasts show their previous pelloidal or bioclastic textures. In addition, scattered, euhedral dolomite-shaped molds often occur within the clasts, which indicates dolomitization prior to, or contemporanous with silicification. The other clasts are of homogenous megaquartz and do not allow any statement on their origin. The angular shape of the clasts suggests short transportation which supports the second possibility described above.

But was the silicification prior to the erosion and redeposition or were carbonate gravels silicified after the deposition? To decide this the petrology must be consulted. The samples WA82/123; 124; 129 and WA84/107 are representative and exhibit best the three main features:

1) The dolomolds occur only in some of the clasts and never in the matrix and suggest dolomitization prior to the deposition within the host gravel layer and prior to silicification. The direct dolomitization of the gravel layers is very unlikely.
2) No carbonate clasts are present in the conglomerate layers, though erosion of carbonates is indicated by the silicified carbonate clasts and by the intercalated fossiliferous layers as discussed above. This suggests silicification of the conglomerate deposits. Otherwise at least a few carbonate clasts should be preserved, since the underlying carbonates are only rarely chertified.
3) Quartz overgrowth of monocrystalline grains and iron (oxide ?) – cherty matrix evidence silica presence after the deposition. A great amount of the clasts also show ferric pigmentation. Clasts which are without iron might be transported and deposited as original chert or as already chertified carbonate. Pores filled by several generations of fibrous cement, megaquartz, and length slow chalcedony indicate post-depositional silicification.

Within this context, an interesting feature is the presence of an algal-like coating of some pores by iron-rich silica, which appears as "negative pisoids" – SS structures (LOGAN et al. 1964). They often exhibit shrinkage fractures which are, together with the remaining pore space, filled by chalcedony (WA82/123 and WA84/107). The genesis of these structures is probably of biogenic origin. Algal or bacterial colonies in the relative large (2-4 mm in diameter) pores probably produced the coating similar to tangential ooid or pisoid structure and were penecontemporaneously silicified. Later subaerial drying of the biogenic matter caused the shrinkage fractures. Repeated submergence led to filling of the remaining empty space with fibrous chalcedony and mega quartz. The subaerial exposure of these sediments, shortly after their deposition, could also cause the dedolomitization of the euhedral dolomite rhombohedric crystals and increase the porosity and permeability. This of course caused preferential penetration by silica.

The remaining guestion is that of the silica sources necessary for the formation of chert. Biogenic silica cannot be considered as the primary silica source because of the prevailing carbonate environment. Volcaniclasts which were found in some of the conglomerate clasts support a hydrothermal origin of the silica. On the other hand a strong hydrothermal activity should leave other records in the strata than only silicification.

According to LASCHET (1984), dissolved silica resulting from continental chemical weathering is the main contributing silica source initiating chert formation. The rate of silica supply is controlled by extensive global palaeoclimate zones with ferralithic weathering. Under the warm Permian climate, which is indicated by the fossils, the solubility of silica was increased. The dissolved silica was supplied to the shallow seas and at the same time the meteoric waters also became enriched in dissolved silica. This may have led to secondary silicification processes, preferentially in the permeable sediments of the coastal regions, on contact with marine phreatic water. Processes as transgression and regression promote the formation of extensive mixing zones of marine phreatic and silica-rich meteoric phreatic water. The precipitation of silica is initiated by the lowering pH, the increase in CO_2 and by salinity changes.

2.8. Khao Yang Ta Po area.

The road to Khao Yang Ta Po branches off to the west on the highway No. 21 at km 132.0. Khao Yang Ta Po or Khao Khat, as it is named on the Amphoe Ban Mi sheet – (Topographic Map of Thailand 1:250000, by the Royal Thai Survey Department, 5/1983), is a 470m high peak within the Permian Ptf Formation.
The exact location of the mountain is 15°36′N and 101°01′E. The general dip of the Permian strata is 30 to 60 degrees to the southwest.

The outcropping rocks have been examined from the east to the west. The easternmost exposures are of thin-bedded mudstones and fine -grained sandstones, in which rare, thin limestone beds are intercalated. The siliciclastic beds are slightly quartzitic, parallel laminated, and contain abundant brachipod shells. Iron oxides are enriched on laminae surfaces. The sample WA84/117 (siltsone) has chlorite in the matrix, together with ferroan (?) dolomite rombohedrons and chert replacing the carbonate. The limestones are calcarenites of biomicrite and biosparite (wackestones to packstones). Foraminiferal and dasycladacean bioclasts were found within these, slightly dolomitized carbonates of SMF 9; SFB 7. Dog tooth and fibrous cements as well as later, sugary cements in pores and fractures are common in these facies. Spongistromate mudstones with abundant fossil fragments on the algal mat surfaces were also found. They caused compactional load -casts within the spongistrome laminae. These SMF 21; SFB 8 carbonates are also slightly dolomitized.

Approximately one km further to the west the fossil debris in the limestones becomes coarser. Brachiopods, bryozoan, and algal fragments are common in those poorly washed or packed intra-biosparites (packstones and grainstones). The bioclasts are worn and coated and some shells are diagenetically (compaction) crushed and show umbrella effects beneath or inside the

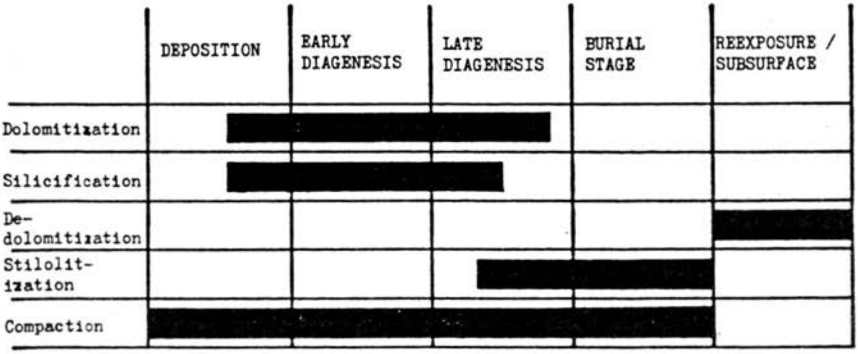


Fig.:18. Compactional and diagenetic processes in carbonates according to DIETRICH et al. (1963), NAMY (1974) and others.

shell. Microsparitic silt infill of shells was observed together with sugar cements. Birds eye structures were found in microbiosparites.
These sediments are followed by reddish yellow, coarse grained lithic arenites with chloritic-cherty matrix rich in iron oxides. About 40% of the grains are of monocrystalline quartz origin and strongly syntaxial overgrown by silica. Approximately 60% are of chert origin. Pores are filled with several generations of chalcedony and mega quartz.
Conglomerates, which strongly resemble those described from Khao Khi Nok were found in the upper part of the outcrops.

Five hundred meters to the west, at the western edge of Permian outcrops, the same clastic sediments were found as boulders along the road. Only limestones crop out here. The limestones contain fine crinoidal debris, abundant corals, and some stromatolithic LLH structures. Large, black chert nodules occur within the carbonates.

WA84/123 is a coral boundstone of Murgabian age (Wencelloides, courtesy of FONTAINE). Samples WA84/121; 122, were also dated as Murgabian on the basis of foraminifera.

WA84/122: Poorly washed intrabiosparite (packstone) with whole brachiopod shells filled by biomicrite or microsparite. Foraminifera, crinoids and dasycladacean algae are present as bioclasts. Coated intracalasts also occur. The beginning of dolomitization and the replacement of calcite by chalcedony quartz points toward another similarity with the Khao Khi Nok limestones.

WA84/121: Biomicrite (wackestone) with foraminifera and diverse other bioclasts. In this sample a stylolite line builds a border of calcite replacement by silica. The replacement affects first the fossils and then later the micrite matrix, with decreasing intensity towards the stylolite (tab.:IVa). This might be an example of late diagenetic silicification.

The suggested depositional conditions are identical with those described at Khao Khi Nok. The same stratigraphical and environmental sequence crops out. The Khao Yang Ta Po section suggests more an interfingering of clastic and carbonate sediments than overlaying of the first upon the latter. The outcrop conditions do not allow estimation of the thickness or the tracing of tectonic structures of the strata.

At the altitude of 132.8 km of highway No. 21, a small road diverges toward the east. A 319 m high hill of Permian (Ptf) outcrops between 15°42'N to 15°46'N and 101°01'E to 101°03'E and has been mapped by SUDASNA & PITAKPAIVAN (1976).
The southern and western outcrops of this unit were visited. Here the strata strike NE-SW and dip to the SE with 30-40 degrees. According to the map of SUDASNA & PITAKPAIVAN (1976), the hill forms an anticlinal structure and the strata on its northern side dip steeply (80 degrees) to the NW.

The lowest unit of the southern outcrops is approximately 30 m thick and consists of 30 cm to 40 cm thick beds of reddish to deeply red brown lime sands which are parallel bedded. They are poorly washed or packed intra-biosparites (packstones and grainstones) in which the coarse arenitic clasts are stained by hematite or limonite. The bioclasts are strongly worn and of rare foraminifera, brachipods, algae (often dasycladacean), crinoids and other fragments. The intraclasts are of diverse origin, but pelletal limestones prevail. Rare syntaxial rim cements surrounding the crinoid fragments evidence fresh water influence during the diagenesis (WA84/98; 100; 101). The standard micro facies is always 14 or possibly 12, of SFB 6 – winnowed edge sands.

Some 500 meters to the south, the overlying strata are exposed. Fine to coarse calcirudites, intrabiosparitic packstones and grainstones are present. The bioclasts are similar to those described above but solitary corals were also found. In thin section pelletal limestone intraclasts, oomicritic intraclasts and spiculitic intraclasts were recognized (WA84/97). Scattered dolomite euhedral crystals and weak SiO_2 replacement of calcite is present. SMF 14 or 12 were found, but also intraformational conglomerates of SMF 24. Unfortunately, no more precise data than Middle Permian could be ascertained from the fossils. The depositional environment is of a winnowed platform edge to tidal flats and channels.
The relationship with the Khao Khi Nok and Yang Ta Po outcrops is not clear, but if contemporary, this area could represent an outer, but shoal shelf depositional area.

2.9. Ban Sapsamothot area.

At the southern entrance to Ban Sapsamothot (Sap Samo Thot), near the Buddhist temple under construction (1984), on the west side of the highway an outcrop in bad conditions is located. At the foot of this hill, tuffs occur. These rocks are strongly weathered and hidden by vegetation but may be bedded. On top of the hill there are badly exposed massive, greenish volcanics and coarse clast-supported conglomerates with green, rounded volcanic clasts (10 cm to 20 cm in diameter).

Two samples were taken from these rocks:

WA84/125 and 127 are doleritic basalts with porphyritic texture of plagioclase and pyroxene (clinopyroxene). The plagioclase is 60% to 70% An, (labradorite). Some phenocrysts contain poikilitic intergrowth of plagioclase and pyroxene. Ca-saussuritic replacement of plagioclase is slightly developed. Chlorite and some epidote is present. Possible carbonate xenoliths were traced in sample 125. Sample 127 is strongly weathered.

Directly above this basalt (not stratigraphically), fine calciruditic limestones crop out. They are bio-intramicritic wackestones to packstones with foraminifera, algae, and brachiopod shell fragments, which are worn and coated. Solitary corals also occur. Undefinable spines are common in the matrix. Partial recrystallization and neomorphism of sparite partly obliterate previous textures.

The samples WA84/124; 125; 126 (SMF 10 and 19, SFB 7) contain lithoclasts of volcanic origin. Though they are strongly chloritized, plagioclase phenocrysts could be recognised in the recrystallized glass matrix. The plagioclase is 20%-30% An (oligoclase) and, therefore, of a different source than the basaltic rocks described above. Blastesis of unidentified, very small, rhombohedric crystals was observed in thin section. Carbonate intraclasts are composed of pelletal limestone. Marine, fibrous cements and syntaxial, rim cements surrounding crinoid fragments are common.

The samples WA84/125; 126, contain whole shells of brachiopods, which are filled with microsparitic silt and small bioclasts. Umbrella effects beneath shell fragments were also observed.

It is assumed by the present author that the doleritic basalt found in Sap Samo Thot (samples WA84/125 and 127) belongs to the Cenozoic basalts described by JUNGYUSUK & SIRINAWIN (1983).

According to the Ban Mi sheet of the geological map of Thailand 1:250000, rhyolite, tuff, agglomerate or andesite of Triassic age unconformably overlie the Tak Fa limestone in the Sap Samo Thot area. According to JUNGYUSUK & SIRINAWIN (1983), in Lam Narai the rhyodacite is intruded by basaltic dikes containing microphenocrysts of labradorite. The same writers describe basaltic flows over the Khao Luak limestones, which are probably equivalent to Ptf – Tak Fa Formation from the Wichian Buri area. The basaltic conglomerates are probably the product of Quaternary, local reworking of the strata.

The volcanoclasts within the limestones are of clearly different origin. Unfortunately no age data could be collected from these limestones but cautious speculation suggests that they might be of Asselian to Sakmarian age because of their volcanic lithoclasts. Keratophyric to spilitic tuffaceous limestones and tuffs occur in this stratigraphic level all over the area of Thailand discussed in this thesis. (s. chapter: Volcanic rocks).

From Ban Sap Samo Thot on, a road to the west, toward Wang Pi Kun crosses Permian Ptf outcrops in two localities. The eastern area at approximately 100°59'E to 101°00'E, 15°46' - 47'N and the western area at the same altitude and 100°56'E longitude. The western outcrops are the northern continuity of the NW-SE trending hills of Khao Khi Nok, Khao Yang Ta Po and Khao Sap Ma Daeng. The area in between these localities is also mapped as Permian Ptf by SUDASNA & PITAKPAIVAN (1976), but is covered by young volcanics, probably of Tertiary age, which are not on this map. Whereas the eastern outcropping strata dip to the west or southwest, the strata in the western outcrops dip in the opposite direction.

The eastern outcrops exhibit strongly weathered, yellowish brown, medium-grained sandstones and mudstones in beds up to 20 cm thick. These rocks may interbed or even underlie limestones located a few hunderd meters to the west. Microscopic examination makes it clear that the sandstones are really coarse crystalline and fine crystalline tuffs, strongly weathered and calcified. Their basic to intermediate origin is evidenced by relict Ca-rich plagioclase which has been altered almost completely into

calcite. Since similar tuffs have been found lying above the western, Permian outcrops, it is concluded that they cover the Paleozoic strata.

Limestones crop out at the western flank of these (eastern) hills. The limestones are of SFB 7 to 8. Intrabiomicrites (packstones) with algal, foraminiferal and crinoidal bioclasts, often worn and coated, are common. Intraclasts and volcanic lithoclasts are present but rare. Authigenic feldspar growth could also be observed in thin section. Loferites with marine, dog tooth, and vadose cements occur. The samples WA82/168; 169 were dated by foraminifera as Upper Carboniferous to Asselian.

The westernmost outcrops in this area are located at the school of Ban Sap May Daeng. Within the area of the school yard, coral reef limestones crop out. The reefs are several meters to tens of meters in diameter and of Murgabian age (WA84/129). Chert nodules and lenses were found in the neighboring biomicritic wackestones of SMF 9. Foraminifera from these limestones have been dated as Bolorian (WA84/128). This discrepancy cannot be explained by any field observations.
At the foot of the hills west - southwest of the school, stromatolitic buildups were also found. Here, replacement by SiO_2 and dolomitization are well developed. Vadose dog tooth cements were found in the chambers of foraminifera.
To the north of the same Ptf area, at Khao Hin Kling limestones also crop out.

At km 167.0 of highway No. 21, a road through the fields leads to the west, toward Wat Khao Tam, which is located NE of Khao Hin Kling (approximately 15°59'N; 100°59'E). Here, massive limestones, partly reddish in color are poorly exposed. SMF 8 – tidal flats and shelf of restricted circulation are suggested by SMF 16 – pelmicrite to sparite, ooids and oncoids and spongistromate and micritic, unfossiliferous clasts in micritic matrix (SMF 24 ?). The age of these strata could not be established.

2.10. West of Nong Pai area.

At kilometer 181.5 (north of Nong Pai) a road leads to the west, to a group of NW-SE trending Permian hills. These hills are located between 16°05'N - 16°10'N and 101°01'E and 101°02'E and are mapped as P1 on the geological map of Northeastern Thailand 1:500000 (SUDASNA & VEERABURUS, 1979).

At the small Buddhist monastery and temple, south of Khao Chon Tho, weathered interbedded limestones, tuffs, and tuffitic limestones are exposed. The outcrop is dissected by basaltic dikes (WA82/173; 178).
The limestones contain biosparitic packstones, often rich in volcanic intraclasts (mostly of SMF 9; SFB 7 with foraminiferal and dasycladacean bioclasts). Also, some coquina packstones of shell and crinoidal fragments were found. Marine, fibrous cements followed by dog tooth cements and/or "B"-cements are common in these limestones.
The entire area of Khao Chon Tho exhibits similar lithology. The best outcrop is the old quarry at the northeastern flank of the hill.
Here the depositional environment of carbonates and tuffs is documented in detail in the Log-profile IV. The peculiarity of this outcrop is the occurrence of shallow water deposits together with graded bedded bioclastic and lithoclastic packstones of SMF 4, whole fossils wackestones, and tuffs and tuffites. Coarse gravel conglomerate beds, several dcm thick are also common. The pebbles of the conglomerate are of diverse carbonate microfacies and of tuff material. The hydrodynamic conditions and sedimentation mechanism seems to change from layer to layer. Very remarkable is the occurrence of long crinoid stem pieces in lime mud matrix near to fine, broken and reworked debris in turbiditic (graded bedded) beds and then again wackestones with brachiopod pavemants on their surfaces. This apparent contradiction can easily be explained by means of two kinds of sedimentation.
One explanation is a continuous, regular sedimentation on a flat shelf, where due to local differences, mainly carbonaceous mudstones to packstones were deposited.
Here, the following standard microfacies prevail:

WA84/17: Packed biomicrite (packestone) with iron-stained intraclasts or algal-boring coated bio- and intraclasts, brachiopod spines and pellets. SMF 14; SFB 6.

WA84/16: Packed biosparite (grainstone) with bioclasts of algae fragments, foraminifera, crinoids, shell fragments, pellets and rare oolites. The clasts are worn and coated. Neomorphism of sparite could be observed. SMF 16; SFB 7-8.

WA84/18 and 24: Foraminiferal biomicrite (wackestone) contains crinoids and brachiopod spines and sparry calcitic intraclasts. Tuff lithoclasts with calcite replacement of feldspar are also present. Fibrous, marine A-cements and dog tooth cements can be seen in the foraminiferal chambers. SMF 9-10; SFB 7.

WA84/26 is also of SMF 9; SFB 7, but contains molds of euhedral dolomite crystals coated by iron oxide, some of them refilled by quartz. In this sample, syntaxial rim cements surrounding rare carbonate clasts (crinoids?) were found.

Spongistromate, wavy laminites were also found in the strata – SMF 21.

The second sedimentation scheme is of "events" interrupting the sedimentation described above and related to the volcanic activity, resulting in deposition of tuffs and tuffites and triggering turbidites and the deposition of conglomerates from a neighbored reefs. Some of the graded carbonate and tuffite layers might be storm deposits which could also be related to nearby volcanic activity.

The volcanic material is of a basic nature, while the feldspar phenocrysts are mostly strongly replaced by calcite. The glass matrix exhibits the fluidal texture of small plagioclase crystals. The abundant chlorite in some samples is of an alteration source.

In the sample WA84/24 the plagioclase crystals in the tuff lithoclasts could be recognized as labradorite to bytownite (65%-75%An). Other tuffites are of albitic plagioclases and trachytic texture of the lapilli.

Grading from tuff to pure limestone is common in different proportions. Sometimes nearly pure tuff material entombs communities of foraminifera and bivalves (plate Va;c).

In other cases the tuff was deposited or redeposited by turbidity currents or storm reworking together with carbonate debris. The grain size of the tuffitic material ranges from lapilli to pelitic particles.

Upper Carboniferous to Asselian and Sakmarian age was established from the foraminifera (WA82/174; 175 and 178).

2.11. Nong Pai - Chon Daen area.

A Lower Carboniferous to Lower Permian section in the vicinity of Chon Daen has been described by CHONGLAKMANI et al.(1983). These authors refer to limestones and siliciclastics ranging from the Lower Visean to Lower Permian. These rocks were previously mapped as the Phu Kradung Formation (Triassic to Jurassic), but not outcropping in a continuous section.

The described outcrops contain:

Pelletal grainstones with foraminifera – of Lower Visean continental shelf of subtidal zone. Middle Visean restricted circulation environment limestones, black and rich in organic matter and pyrite. The following Middle Visean crinoidal limestones are overlain by a few meters of chert (silicified limestone?). The whole sequence is 60 m thick.

In the vicinity and in stratigraphic continuation shale, siliceous shale, siltstone and a few limestone beds and lenses with brachiopods, trilobites and zaphrentid corals occur. These shallow marine sediments seem to be followed by red shales, suggesting emergence and subaerial exposure. The suggestion is supported by gypsum deposits of unknown age, which are mined in this area (CHONGLAKMANI et al. (1983).

Another locality described exhibits packstones, rich in crinoidal fragments and of Upper Visean to Bashkirian (?) age.

The next locality is of massive, pelletal wackestones of Upper Serphukovian to Lower Bashkirian age.

Still further is a locality with calcareous shale, siltstone and sandstone, with fossil molds and preserved fossils of abundant spicules, brachiopods, crinoids and bryozoa of unidentified age.

The easternmost outcrops described exhibit massive and bedded limestones with chert nodules. The fossil assemblage is of gastropods, corals, and foraminifera of Gshelian to probably Lower Permian age and the depositional environment is interpreted as shallow marine with decreasing salinity.

This description by CHONGLAKMANI et al. (1983) leads to two conclusions:

I) The strata become generally younger from west to east.

II) At least two shallowing upward sequences are exhibited, first, in the Visean and, secondly in the Visean to Lower Permian.

The outcrops visited are located south and southeast of the strata described by CHONGLAKMANI et al. (1983).

Approximately five kilometers north of Nong Pai, in the village of Ban Na Chariang a road branching of highway No. 21 leads west, toward Chon Daen. This road crosscuts several outcrops which are mapped as P1 and C2 – Wang Saphung Formation.

The Wang Saphung Formation is described as Middle to Upper Carboniferous grey to greyish black shales, grey sandstones, and grey thin-bedded to massive limestones (SUDASNA & VEERABURUS, 1979).

The first locality visited is located within the V1 – Permo-Triassic rhyolite, tuff, aglomerate, and andesite mapped by SUDASNA & VEERABURUS (1979). It is located west of, and near to the highway No.21, approximately at 16°01'N and 101°02'E. It contains Moscovian (upper Middle Carboniferous) bedded, grey to dark grey limestones which contain small coral colonies embedded in packed biomicrites and pelletal packstones or wackestones with rare dasycladacean algae fragments. (WA84/136). Some limestone breccias were also found. Well-developed dog tooth cements in pores within the coral sceleton, and "B" cements, suggest vadose to meteoric (marine phreatic zone) conditions during diagenesis of these inter- to subtidal sediments.

The second locality is called by the local farmers Khao Ruok and is located approximately 16°01'N and 101°01'E. It is mapped as P1 (SUDASNA & VEERABURUS, 1979). Here, packed biomicrites (packestones) with foraminifera, red algae, crinoids and pellets were dated as Bolorian (WA84/137). Tuff clasts with glass matrix with small crystals in fluidal texture were traced in thin section. Standard facies belt 7 or 8 within the shelf interior is indicated by the collected samples.

Approximately 15 km west of Ban Na Chariang, at Khao Tam Si Son Tam (local name), within the C2-Formation, bedded limestones rich in fossil debris crop out. Coarse calcarenites of biomicrite and biosparite with abundant codiacean and rhodophyta algae and rare dasycladacean fragments were found. Wackestones to packstones, strongly resembling those described above from the Moscovian outcrop are dominant. SFB 7 is indicated by prevailing SMF 9 and 10. Rare geopetal infill of fossils and gravity cements in the fossil shell chambers were found in thin section. Also dog tooth cements are present in intraparticular pores. The strata could not be dated, but the similarity to the Moscovian outcrop and the fact that they have been already mapped as C2 permit a guess that they are at the same stratigraphical level.

The last outcrop visited here is approximately 3 km north of the junction to Chon Daen (2 km west of the last outcrop described) and also within the C2-Formation. Thin bedded limestone with abundant, unbroken and thin crinoidal stems several centimeters long, and foraminiferal, and algal wackestones were dated as Moscovian (WA84/139). Sparite neomorphism was found within thin spongistromate layers. Open circulation shelf environment is suggested.

2.12. Petchabun area.

South of Petchabun, on the east side of the new road from Nong Pai to Petchabun, two areas of P1 are located. The northern area is a hill between 16°14'N - 17'N and 101°08'E - 12'E. The southern area is a long, N-S trending strip between 16°08'N - 12'N and 101°08'E - 11'E. In these P1 outcrops a limestone quarry in Ban Na Yom village (Khao Chaliang Phra Sai hill) was visited. Massive, whitish limestone with abundant crinoids is quarried here. Poorly washed biosparites (grainstone - packstone) to sparse biomicrites (wackestone) prevail. SFB 7 to 8 is indicated by SMF 9; 10; 16. The exact age of these unquestionably Permian strata could not be established.

North of Petchabun, at km 215.5 of highway No.21, similar limestones crop out in a over 100 m thick sequence. Also here limestones of SFB 7 to 8 were found. The bedding is somewhat thinner from the one in Ban Na Yom and additionally small coral colonies and algal debris are present. The age of these strata is probably Middle Permian.

2.13. Petchabun Fold and Thrust Belt.

The Petchabun Fold und Thrust Belt is a north-south trending mountain range. It separates the Loei Fold Belt (BUNOPAS, 1981), folded in the Devonian to Carboniferous (ALTERMANN et al., 1983), and the Sukothai Fold Belt (BUNOPAS, 1981).

The Petchabun Fold and Thrust Belt itself is a part of WORKMAN's (1975) Pak Lay - Luang Prabang, Indosinian folded belt. It includes the Nam Duk Formation of CHONGLAKMANI & SATTAYARAK (1978).

This belt is the subject of a great number of papers discussing the paleogeography and plate tectonics of SE Asia (see 1. - 1.1.). CHONGLAKMANI & SATTAYARAK (1978) were the first to describe geosynclinal deposits from this region. Then HELMCKE

(1983; 1985) with several co-workers published various papers containing detailed descriptions of the lithology, stratigraphy and tectonics of the Petchabun Fold and Thrust Belt. The name "Petchabun Fold and Thrust Belt" was introduced by the American ESSO team – WIELCHOWSKY & YOUNG (1985), which has independently restudied the area discussed by HELMCKE and his co-authors and largely confirmed their results.

HELMCKE & KRAIKHONG (1982), HELMCKE (1983), HELMCKE & LINDENBERG (1983), ALTERMANN et al. (1983), WINKEL et al. (1983) describe a sequence of Permian orogenic rocks containing pelagic, flysch and molasse facies along the Lom Sak - Chum Phae highway. Based mainly on the occurrence of flysch in the Middle Permian and the transgressive gap (angular unconformity) in the Lower Triassic, the folding time is dated as Middle Permian to Upper Permian.

GRAMMEL (1983) has investigated the tectonic style of the folding and came to the conclusion that the strata along the Lom Sak - Chum Phae highway, between km 16.0 and 21.5 (16°44'N; 101°21' - 25'E) were folded and overthrusted in a single act by an east - west deformational front, resulting in E-vergent, isoclinal folds with flat northward or southward dipping fold axes. WINKEL (1983), WINKEL et al. (1983) has done detailed sedimentological work on the pelagic facies (Lom Sak - Chum Phae highway, km 15.95 - 18.5 and km 19.285 - 20.120). His results confirm the interpretation of a pelagic basin and add a great amount of new details, of which the most important are:

- Discovery of tuffs and tuffites within the pelagic sediments.
- Sedimentological subdivision of the section into a pelagic section with cherts, shales, allodapic limestones, tuffs and tuffites and a transitionary section from pelagic to flysch sediments.
- Stratigraphic determination of the sequence, based on foraminifera found in the allodapic limestones and tuffites.

According to WINKEL (1983), the oldest strata of the section probably crop out in the westernmost parts of the section. It is described as "older than Asselian", though no fossils were found here. Its lithology differs significantly from the rest of the pelagic strata. Predominantly light gray siltstones and gray to greenish psammitic beds, up to three meters thick and rather coarse-grained are exhibited. They consist of biogenic clasts (echinod fragments) and siliceous clasts. The clasts are described as dacitic to rhyodacitic rock fragments (WINKEL 1983). Silt and claystones in the westernmost outcrops are also found within the sequence. Several samples were collected from these strata and WINKEL's thin sections were also reexamined. It appears that the volcanic rock fragments are rather of keratophyric or spilitic origin (for detailed information, see on chapter volcanics). For the tuffites WINKEL (1983) assumed turbiditic transportation as well as subaerial ashfall into the pelagic regime. The silt- and claystones in the westernmost outcrops are in stead phyllitic schists which exhibit two directions of schistosity (GRAMMEL, pers. comm.).

A typical pelagic sequence of Lower Asselian to Sakmarian age is for example described from km 16.4 to 17.05. It contains light to medium gray allodapic limestones and black shales and cherts. Tuffites and siltstones are rare.

The most frequent sedimentation of allodapic layers is described for Bolorian to Kubergandian/Murgabian times. Limestones of SMF 4; SFB 3-4 in beds of more than two meters thick were found.

WINKEL's transitionary facies is described from the outcrops along the Tong river and Nam Duk river. It is characterized by a strong influx of detritic quartz into the allodapic limestones, more completely developed BOUMA T-sequences, and the lack of evidence for an euxinic environment. Sole marks indicate transport from the south and the north. This transport direction is interpreted as parallel to the trough axis. The source area for the allodapic limestones is the carbonate platform located east and west of the basin (WINKEL et al. (1983). A minimum thickness of 1000 m for the pelagic sediments and width of 100 - 200 km for the basin was estimated by WINKEL et al. (1983).

The flysch strata crop out between km 18.5 - 19.285 and 20.120 - 21.5 of the Lom Sak - Chum Phae highway. It is one of the main topics of STROBEL's Ph.D. thesis (in prep.). Some main points include the following.

- According to findings of Agathiceras suessi in the pelagic shales between the turbidites (GRAMMEL & INGAVAT, pers. comm.) and Pseudodoliolina (Murgabian) in the T1 intervals (STROBEL, HELMCKE & INGAVAT, pers. comm.), the flysch can be dated as Middle Permian. Though the foraminifera were found on secondary deposit, the abundance of slightly abraded foraminifera - bioclasts, their uniformity and the absence of other, younger species exclude the possibility that the original sedimentation could be younger than Murgabian or even Mesozoic.

- The layers exhibit almost complete BOUMA - sequences.
- The thickness ratio of shale (BOUMA's pelitic interval E or T5 and pelagic interval F or T6) to the turbiditic intervals A to D (T1-T4) is on average 1:1 (50% shale and 50% graywacke).
- Only a few graywacke layers are thicker than 50 cm; the average thickness is 30 cm.
- Turbidites with T1 sequences coarser than 2 mm are very rare and when they occur are mostly composed of carbonate fossil debris.
- Many of the turbiditic layers show carbonate cement. "A" and "B" cements were observed.
- The graywackes are lithic graywackes, interpreted as of the recycled orogenic (on QFLt) regime or quartzose recycled regime on the QmFLt-plot (DICKINSON & SUCZEK, 1979; DICKINSON et al. 1983).
- The transportation of sediment, as concluded from the bottom marks (flute casts) was NNW to SSE (STROBEL, pers. comm.).

The characteristics listed above suggest a north-south trending basin, where distal turbidites were deposited. The deposition depth was above CCD-level (HESSE & BUTT 1976). The main source of the debris were probably basin sediments (pelagic cherts, DICKINSON 1970). The total thickness of these flysch sediments can be estimated to be more than 2000 m. The Log-profile No.:VI was measured in the flysch sediments.

The molasse type strata of the Petchabun Fold and Thrust Belt are the easternmost part of the Nam Duk Formation. The Nam Duk Formation is described as "shale, gray to black, sandstone, yellowish brown, fine graded, limestone, lense and bedded." (Geol. Map of Northeastern Thailand 1:500000). This very incomplete description can only be accepted with difficulty for the rocks between km 34.095 and 42.180 of the Lom Sak - Chum Phae highway. The western border (overthrust) between the Triassic Huai Hin Lat Formation and the Plalezoic rocks was mapped by CHONGLAKMANI & SATTAYARAK (1978) at km 33.980. From my own observations, the Huai Hin Lat Formation crops out up to km 34.02. It is composed of fine grained, friable to moderately hard and reddish brown to violet-brown sandstones. The contact (transgressive and slightly overthrusted) of the Mesozoic to Palaeozoic strata is covered and lies somewhere between km 34.02 and 34.095.

The molasse strata were named the Nam Nao Formation by ALTERMANN (1983) and subdivided into three members with different sedimentological features:

a) Huai Rahong Unit, which represents a transitionary type between flysch and molasse. It is composed of graded graywackes and dark gray shales.
b) Huai Wa Unit, representing marine molasse and containing mainly fine graywackes in alternation with gray shales, siltstones, and autochthonous limestones.
c) Khao Pha Daeng Unit, mainly composed of dark shales and some fine sandstones.

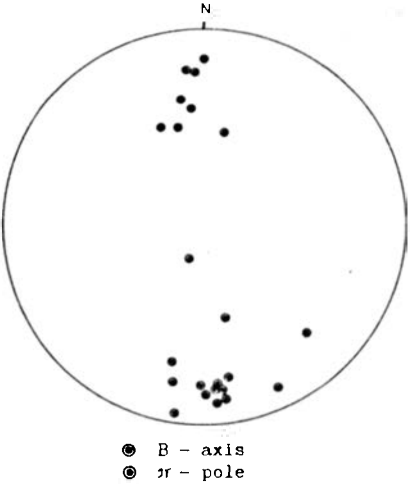


Fig.: 19.

Fold axes in the pelagic sediments along the Lom Sak - Chum Phae highway. GRAMMEL (1983)

The Huai Rahong Unit.

The Huai Rahong Unit starts with graywackes alternating with dark gray shales. The layers vary from 1 cm to 1 m thickness. Only a few layers are thicker than 1 m. The graywackes are moderately hard and of various intensities of gray. Turbidite sedimentation is suggested by BOUMA-intervals, but a complete BOUMA-sequence could not be found. In general only A-B-E sequences are present. Sometimes only A-E or A-B sequences occur. For this reason and because of the unrhythmic alternation of the T-sequences and the total thickness of the unit as no more then a few hundred meters, these graywackes cannot be called flysch. Nevertheless, the transportation by turbidity currents is indicated. Convolute lamination, ripple cross-lamination with flat lee side angles and clay concentration in the trough of the ripples and the sorting pattern, which becomes finer towards the top of the layer are indicative of turbidites. Other layer properties are parallel bedding or lamination, wavy lamination and cross-bedding, small and medium-scale cross-bedding and small and elongated clay galls. The layers show also typical sole marks as flute casts, load casts, and groove casts. The flute casts and groove casts indicate transport direction from SSW to NNE or from south to north. The shale beds are generally not thicker than the graywackes. The shales are of dark gray to black color, moderately hard and slightly silty. The layers are often parallel laminated and contain black, small, elongated clay rip-up clasts. Except for some small plant remains, no fossils were found in the shales and graywackes of this unit. The Log-profiles No VII and VIII show a small cross section of these rocks.

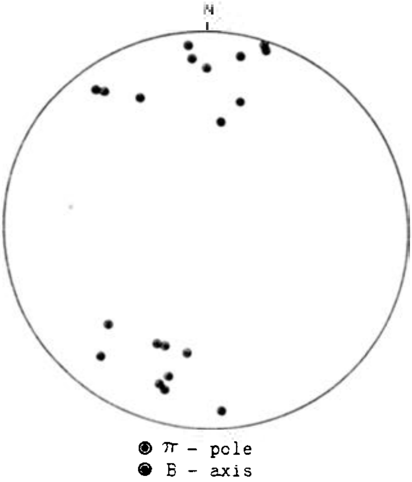


Fig.: 20. Folding in the flysch sediments along the Lom Sak - Chum Phae highway, GRAMMEL (1983).

The thin section petrology of the Huai Rahong graywackes shows that all of them belong to the class "lithic graywackes" of FOLK (1968). They contain 15% to 75% (on average 35%) clayish sericitic - ferritic matrix, no more than 5% feldspar, 10% to 50% quartz (monocrystalline grains), up to 20% rock fragments (including polycrystalline quartz grains) and up to 5% detritic mica (mostly muscovite and only little biotite). Some of the samples contain up to 15% opacoid minerals (mainly pyrite) and rare heavy minerals of green - brown turmaline, green hornblende, rutile and zircon. Only very few of the samples have a limited calcitic matrix. All the graywackes are fine grained, poorly sorted and of immature to submature stage. The particle roundness is angular to subrounded but mainly angular due to the size of the particles.

These sediments were laid down under rapidly changing sedimentary conditions, partly by turbidites and partly during a period of relative quiescence by regular bottom currents and suspension in not very deep water (shelf facies). Plant remains are common in these strata.

The transport direction can be interpreted as parallel to the south - north trending basin trough. The rare occurrence of heavy minerals such as hornblende and biotite indicates metamorphic or igneous source rocks. Nevertheless, the absence of feldspar and the high predominance of quartz are typical for

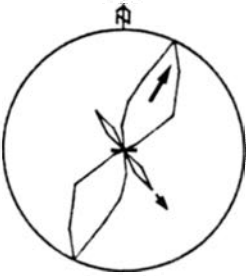


Fig.: 21. Plot of 27 data (bottom marks) from the Huai Rahong Unit, indicating SSW-NNE transport direction.

mainly sedimentary source rocks for the Huai Rahong graywackes. Certainly volcanic rocks were not very important as a supply for these sediments.

The Huai Wa Unit.

This unit, an alternation of limestones, sandstones and shales, was mapped between km 36.7 and km 40.9 of the Lom Sak - Chum Phae highway. The limestones are up to several meters thick, of gray to dark gray color and very fossiliferous. Brachiopods, coral colonies, crinoid stems, unbroken and dismembered, algae and abundant foraminifera were found in the carbonates. Every single outcropping limestone layer or sequence was sampled and dated on the basis of the foraminifera (INGAVAT). The age ranges from Kubergandian to Midian.

All the limestones are biointramicrudites and biosparrudites with a more or less strong influx of fine grained quartzitic clasts. The collected samples represent exclusively standard facies belts 7 and 8 (shelf lagoon, open circulation and restricted circulation shelf and tidal flats). The only exception are small coral colonies (SMF 7; SFB 5) within these facies belts. Dominating the microfacies are burrowed, bioclastic wackestones and coated and worn bioclastic packstones of SMF 9 and 10. Abundant are also pelleted lime mudstones to pelsparites with fenestral fabric (SMF 19) and foraminiferal and algal grainstones (SMF 18). Rare lags with some oolites (SMF 14) and spongistromate mudstones (SMF 21) also occur.

Dolomitization (euhedral dolo-rhombohedrons) was found in several samples and is well-developed predominantly in the grainstones. Stylolitic clast contacts in the grainstones and diagenetic stylolitization are widespread.

In the western outcrops of this sequence, the limestone layers appear lenticular and isolated but become dominant from km 39.3 to the east. Up to km 40.5 they form a big part of the unit. There is no limestone occurrence east of km 40.5 up to the Mesozoic outcrops along the Lom Sak - Chum Phae highway.

The sandstones are mostly fine and rarely medium-grained, of gray to yellowish gray or brown color, and up to one or two meters thick. The layers are often parallel bedded or laminated or ripple cross-bedded. Some of them are very rich in fossils. Beds with dissolved foraminifera tests (extremly high moldic porosity) or with brachiopod pavemants were found as well as beds with abundant plant remains, up to 8 cm long. Bioturbation and distinct burrows with menisci could also be observed in the layers. The few sole loadcasts, sometimes crenulated, do not allow any statement about the stream flow direction. In the Huai Wa Unit all properties of transportation by turbidity currents disappear.

The thin section petrology of these sandstones resemble that of the Huai Rahong psammites. The sandstones belong to the class of lithic graywackes. They are composed mainly of detritic quartz and rock fragments and are very poor in feldspar. The matrix content is about 25% on average and the matrix is generally more ferritic than in the Huai Rahong graywackes. Several layers, especially in the neighborhood of limestones, contain carbonate cement. Many of the sandstone layers have high muscovite concentration on the surfaces of the beds and laminae. Also, in sorting-type, roundness and maturity, these rocks correspond to the Huai Rahong graywackes.

The siltstones and shales of the Huai Wa Unit are mostly of light gray color. They are parallel laminated and rarely exhibit laminae rich in detrital muscovite. Also plant remains and organic matter are common.

Although the carbonates do not correspond to a typical molasse, the prevailing siliciclastic sediments were laid down in a subsiding marine basin that was not very deep and becomes more and more shallow. The foraminifera, corals and unbroken crinoid stems indicate a warm, quiet and shallow marine environment. Plant remains are abundant in the silt layers. Small carbonate platforms were built up in periods when there was an absence of clastic sedimentation (tectonic quiescence?). Such periods were interrupted by sand influx when there existed higher hydrodynamic energy or tectonic uplift. WIELCHOWSKY & YOUNG, (1985) described these rocks as a shallow marine to marginal marine environment.

Khao Pha Daeng Unit.

Typical for the rocks between the km 40.9 and the discordant contact of the Permian with the Triassic Pho Hai Unit of the Huai Hin Lat Formation at km 42.180 is a dominance of dark shales. Ninety percent of the first 500 meters of the outcrops of this unit consist of dark shales. Mostly, the layers are several cm thick, and laminated. They often contain black, elongated clay galls. Only a few unidentified ichnofossils and several millimeters of small plant remains were found in these shales. An irregular network of fine, white quartzitic veins penetrates the shale sequence. It obviously originates from the Triassic dikes. Log No.:XI shows a typical profile of this sequence.

There are no limestones in the Khao Pha Daeng Unit. In the eastern part of the unit more sandstones and siltstones occur. They are of yellowish gray and gray color and well indurated. The layers are often evenly laminated. No fossils were found here.

In thin section the rocks of the Khao Pha Daeng Unit do not appear any different from the clastics of the Huai Wa Unit. Fig.:22 is a plot of the composition of the graywackes from the three units – Huai Rahong, Huai Wa and Khao Pha Daeng, showing their "recycled orogen" provenance from DICKINSON et al. (1983). The Khao Pha Daeng Unit also belongs to the molasse strata. The thick shale sequence is the result of a longer period of very low hydrodynamic conditions, a period of stagnation with dysaerobic (euxinic) facies. This tranquility was interrupted again and again by the short psammitic influx. Later, more sandstone was deposited under conditions of higher hydrodynamic energy and oxygen levels.

It has been suggested by HELMCKE et al. (1985), that the Khao Pha Daeng Unit might be deposited in a lacustrine environment.

Near to the discordant contact with the Triassic Pho Hai Unit, the rocks of the Khao Pha Daeng Unit become reddish. This color might be a weak indicator trace of an erosive paleo land surface. No mudcracks, caliche or other direct signs of subaerial exposure were found here.

The Triassic Pho Hai Unit starts with pillow lavas and locally with conglomerates containing Lower Permian carbonate pebbles.

Age relationship

Besides the facies development, the development of the sedimentary properties and the lateral relationships between these three members of the Nam Nao Fm., the tectonics also show that the Huai Rahong Unit must be the oldest and the Khao Pha Daeng the youngest of the molasse strata.

All of the molasse is much less deformed than the pelagic or flysch sequences. The folds are no longer E-vergent. The vergence disappears altogether or becomes slightly westward directed. The majority of the folds is upright. The force of the folding and faulting decreases in general from the west to the east in the described strata. Also, isoclinal folding decreases eastward. Cleavage is not strongly developed and it even disappears within the strata and is of course highly dependent on the competence of the material.

The only member in the molasse which is dated by fossils is the Huai Wa Unit. The highway from Lom Sak to Chum Phae crosscuts several stratigraphic levels from Upper Kubergandian, Murgabian to Midian. The arguments described

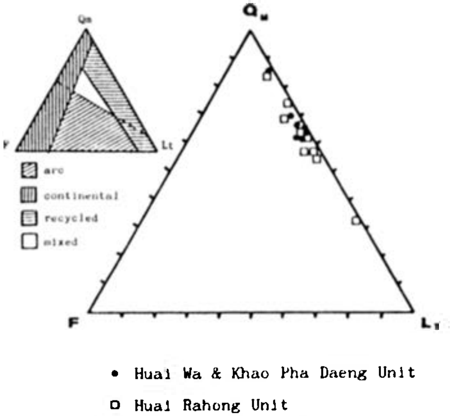


Fig.: 22. Graywackes of the Nam Nao Fm. (molasse) in the QmFLt triangle.

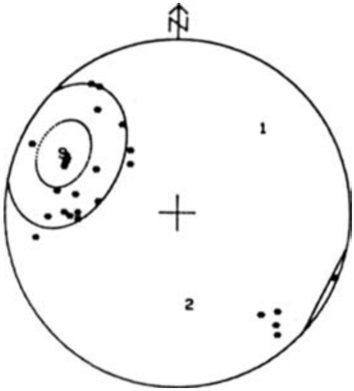


Fig.: 23. Folding of the molasse strata along the Lom Sak – Chum Phae highway (26 data).

above suggest that at least the Huai Raong Unit is older or partly time equivalent to the Huai Wa Unit (i. e. Kubergandian to Murgabian). The Khao Pha Daeng Unit might be only of very limited local distribution and probably not younger than the Midian (regional arguments). In this case it represents a local facies variation of the Huai Wa Unit and should not be referred to as an independent member.

It is still certain, according to foraminifera age determinations, that the pelagic facies is older and contemporaneous with the flysch (Asselian to Murgabian) and the flysch is older and time equivalent to the molasse (Pseudodoliolina and Agathiceras Sussei findings in the flysch – oldest possible age – Middle Permian INGAVAT, GRAMMEL pers. comm.). An increase of virtinite reflectance measured on coalified matter and an increase of illite crystallinity from west to the east along the Lom Sak Chum Phae highway also supports the theory of a general younging of the strata in the eastward direction fig.:24, (HELMCKE et al., 1985).

2.13.1. East of Lom Kao area.

In an effort to trace the pelagic, flysch and molasse facies to the north and to the south, the Petchabun Fold and Thrust Belt was traversed in several places.

East of Lom Kao, between Ban Tad Kloi (17°00'N; 102°22'E) and Ban Hin Lat (approximately 16°57'N; 101°31'E) a sequence of siliciclastic rocks was found. The area is mapped as the Nam Duk Formation (P4) on the Geological Map of NE Thailand 1:500000. Badly exposed siltstones and fine-grained sandstones, rich in mica, crop out. Due to the poor outcrop conditions and deep weathering, bedding properties could not be observed. Wedging of the beds is exhibited in a small outcrop approximately 4 km east of Tad Kloi. Small scale cross-bedding, lamination, graded bedding and clay rip-up clasts were found in some float collected in the freshly cleared jungle and along the road. It is not clear if these rocks belong to the Permian; if so, they could represent the flysch because of the presence of graded bedding.

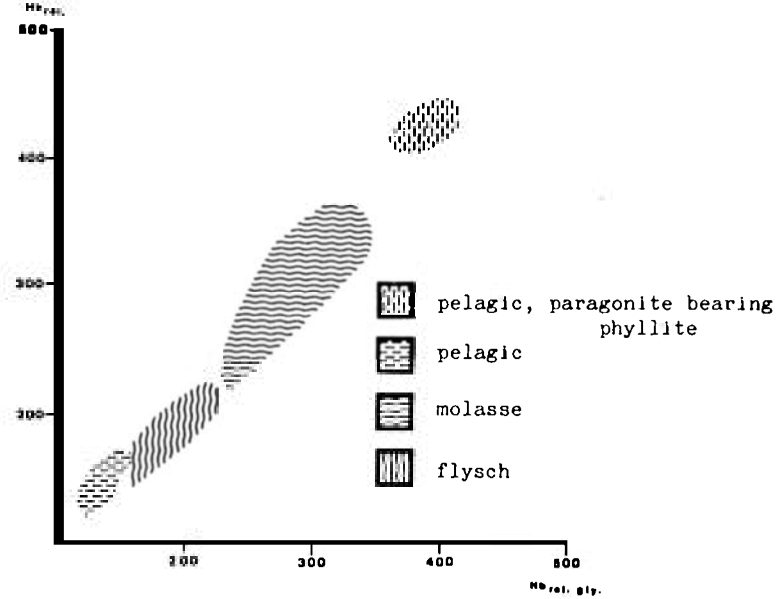


Fig.: 24. Illite crystallinity of the Paleozoic strata along the Lom Sak – Chum Phae highway (HELMCKE et al. 1985).

Volcanic dikes (Mesozoic andesites?) seem to be common in this area. Red beds of the Mesozoic Khorat Formation also crop out in the vicinity.

Southeast of Ban Hin Lat (16°56'N; 101°34'E) several limestone peaks were mapped as P1 (Geol. Map of NE Thailand 1:500000). The limestones are partly conglomeratic with stylolitic contacts between the clasts and carbonate matrix rich in organic matter. The clasts are of packed biomicrite and intramicrite (pelletal and foraminiferal packstones). Algal and crinoidal biomicritic packstones are also common. They represent an intraformational pebble conglomerate (WA84/214; 215).
Other limestones are bedded, poorly washed intra - biomicrites (packstone to grainstone) as represented in the clasts of the conglomerate described above. The bioclasts are often worn and coated and SMF 9 and 10, SFB 7 are indicated. In sample WA84/216 advanced dolomitization (euhedral crystals of dolomite) and weak replacement by SiO_2 were found. Only one bed of a totally silicified spongistromate laminite, was found here. It contains abundant, fine fossil debris of mainly spiculae-like fragments on the laminae surfaces (WA84/217).
Few fine-grained sandstone cobbles were found in the fields between the limestone peaks. In one of them micro cross-bedding was identified. In thin section they show a calcite - clay matrix, in which the calcite is partly poikilotopic. A silicic matrix is also present. The matrix percentage of the entire rock is around 30-40% by volume. When compared with the molasse beds along the Lom Sak - Chum Phae highway, the sandstones (graywackes) show relatively high plagioclase content (10 to 15%). Monocrystalline quartz grains occupy about 50 to 70% and the rest are lithic fragments. The foraminifera found in the limestones are of Middle Permian age. Most probably these sequences are the northern extension of the molasse strata (Huai Wa Unit).

2.13.2. Huai Nam Lao area, (E of Petchabun).

NE of Petchabun, in the vicinity of Ban Huai Yai (16°28'N; 101°18'E), along the creek Huai Yai, flysch outcrops a few kilometers east of the village (HELMCKE, pers. com.). The small outcrops exhibit eastward folded, graded graywackes with completely developed BOUMA sequences.

From Petchabun, the street No.:2211 leads eastward toward Ban Chaliang Lap village. From there, a gravel road to the north, parallel to the Petchabun Fold and Thrust Belt, leads to Ban Nam Lao village at Huai Nam Lao creek (approximately 16°25'N; 101°18'E). The Huai Nam Lao creek flows from east to the west and originates at the SW' foot of Khao Um Nang, a 1310 m high peak, composed of Mesozoic Khorat strata.
The Huai Nam Lao creek was traced from the village Ban Nam Lao to the first Mesozoic outcrops, approximately at 101°23'E latitude. Several Palaeozoic outcrops with different

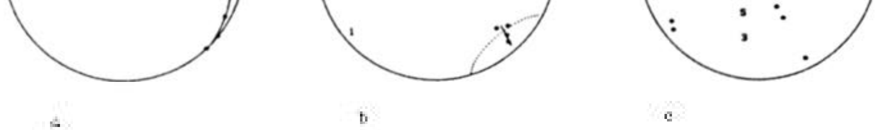


Fig.: 25. Folds along the Huai Nam Lao creek.
a - in the pelagic sediments (6 data)
b - in the molasse facies (8 data)
c - B- axes of 7 folds from both facies

lithologies were found in the stream bed. The outcropping strata start with an intercalation of shales, cherts and greenish tuffs and tuffites. The general striking direction is N - S and the rocks are strongly folded and exhibit steeply dipping fold axes (B-axes) and two well-developed cleavage directions. Along the creek, further to the east some E-vergent folds were also seen (B-axis linears: 008°/20°; 158°/46°; 155°/10°).

The steeply dipping and bi-directional cleavage development indicate two acts of folding. These strongly folded strata are composed mainly of pelagic cherts (ribbon cherts) in beds a few cm thick, with intercalated tuffs and tuffites.

In thin section these cherts (WA85/9-10) show finely dispersed hematite pigmentation and growth of hexagonal, platy biotite crystals. Some of the samples contain small, marmorized, strained calcite patches. Metamorphism of the greenschist facies is evident.

The sample (WA85/9) show volcanic fragments of acidic to intermediate origin. Spilitic to keratophyric fragments with plagioclase (albite-oligoclase), clino-pyroxene, epidote, chlorite and some titanite and hornblende and volcanic shards with trachytic texture are present.

The volcaniclastics are generally thin-bedded but beds can be up to two meters in thickness. They contain fine to coarse lapilli and are often graded. The upper, finer parts of the beds are often cross-bedded or laminated. These beds were laid down by turbiditic currents into a pelagic regime. They strongly resemble the tuffites from the pelagic sequence of the Lom Sak - Chum Phae highway, but their content of carbonate component is much lower. Their generally coarser detritus might indicate relative proximity to the source area.

Further upstream, approximately 7 km east of Ban Nam Lao (101°23'E) a somewhat different rocks crop out. Cross-bedded and laminated sandstones and shales with up to 30 cm thick beds and fine conglomeratic layers are folded in often isoclinal and upright folds. A few W-vergent folds also occur. The tectonic overprint is much weaker than in the lower part of the section. No chert layers occur here but volcanic components were traced in thin sections from the sandstones and fine conglomerates (WA85/12-14). They are of similar but less acidic origin to those described above. 30 - 40% An (andesine plag.) was measured in the feldspar of the volcanic fragments. No mafic components could be found in these samples. The whole rock classification is of lithic graywacke or lithic arenite (FOLK 1968), some of them with carbonate matrix. This siliciclastic sequence seems to be the equivalent of the molasse strata along the Lom Sak - Chum Phae highway.

Since no fossils were found in the Huai Nam Lao outcrops, the age remains unknown. The pelagic part, judged from the tectonic overprint, is probably older than the Asselian, when compared with the outcrops along the Lom Sak - Chum Phae highway. Also the composition and the sedimentological properties are similar to the character of the Huai Nam Lao pelagic sequence.

Apparently, the lower part (pelagic) is overthrusted on the upper sequence (molasse). No flysch sediments were found along the Huai Nam Lao creek.

2.13.3. East of Nong Pai area.

The road from Nong Pai to Ban Tha Duang (15°58'N; 101°18'E) was examined. The only outcrops found are located in the near vicinity of the Huai Klong Nam Kong creek. The outcrops are small and in bad condition. The general striking direction of the strata is N-S and the beds are steeply dipping, mainly to the west. The outcropping shales exhibit well-developed cleavage, more or less parallel to the bedding.

In the outcrops and in the bed of the creek, cherts, greenish-gray tuffites and dark shales were found. Some of the tuffitic beds are graded and contain molds of crinoidal shape. The thickness of the beds ranges up to 50 cm.

In thin section the sampled rocks (WA82/157;158;161) appear as cherts with a weak influx of very small volcanic fragments, rare ?radiolaria and small silicatic needles (?spiculae).

The samples WA82/159 and 160 are tuffites of keratophyric to spilitic composition, with volcanic fragments of trachytic texture, quartz and glass fragments with albite plagioclase crystals, epidote and abundant chlorite in the matrix and in the clasts. Minor constituent pyroxene and finely dispersed hematite are also present.

The sample WA82/159 is of greenschist facies metamorphism (WINKLER, 1979). Blastesis of quartz, epidote, biotite and chlorite was observed. Here the keratophyric tuffite is interlayerd with banded chert.

Other samples are shales and lithic graywackes, containing some chlorite and volcanic fragments and abundant plagioclase.

The age of these rocks could not be estimated by means of fossils. But, on the basis of lithology it is assumed that they are Lower Permian and belonging to the pelagic facies mapped along the Lom Sak - Chum Phae highway and east of Petchabun.

The area of Thiu Khao Kontha (Nam Khan), 15°58'N; 101°15'E was also examined for outcrops. But, apart from some limestone boulders in the corn fields and in the jungle and abundant outcrops of volcanic (doleritic and andesitic) probably Mesozoic rocks, no other rocks were found.

The limestone (WA84/14) is a fine sparite (?neosparite) - fine calcarenite with very low silt (SiO_2) content and no bioclasts or other organic influence. The rock underwent weak strain and recrystallization (slightly aligned texture). The samples could represent SMF 23 of SFB 8 or 9 as well as recrystallized pelagic micrites if they were micritic. Their origin is not understood.

2.13.4. East of Wichian Buri area.

From Wichian Buri a gravel road to the east, to Ban Na Araya was searched for Permian outcrops (fig.:9). Here only a number of very small outcrops were found between 101°20'E and 101°23'E. In these outcrops tuffites and marbles were found. The strata seem to be strongly folded and generally N-S striking. A fold with a steeply dipping fold axis (B-axis) with a strike of 125°/48° could be measured. Since the outcrops are very badly exposed and only the core of the fold is exposed, no more information could be collected. The samples taken from this fold show in thin section (WA82/143; 144) fine crystalline marble with well-developed, folded "schlieren" texture (?relicts of clay lamination?) and weak chert replacement along the laminae. The sample 143 contains two small crinoid columnals (bioclasts) which show strain shadows of coarser crystalline $CaCO_3$.

Other collected samples of uncertain Paleozoic age are:

WA82/142: Medium-grained tuffite with volcanic rock fragments, with abundant replacement of feldspar by calcite and quartz grains with resorptive bay structures. Shale clasts and lithic fragments in clayish - silicatic matrix with abundant chlorite are common. The volcanic fragments show fluidal texture (trachytic).

WA82/140; 141: Shale - mudstone with well-developed schistosity. The samples contain some chlorite and are rich in finely dispersed hematite and of a brownish violet color. Parallel- and wavy lamination can be seen also macroscopically.

WA82/138 and 139: Lithic graywacke with well-developed schistosity and rotated quartz grains with strain shadows of small SiO_2 crystalline texture, which evidence strong stress influence. Sericite, chlorite and hematite predominate in the matrix. Quartz overgrowth is present on the quartz grains. Some of the lithic fragments are of volcanic origin with pyroxene phenocrystals and pyroxene - plagioclase intergrowths.

The lithology and the occurrence of the steeply dipping fold axes in the marble inevitably lead to the assumption that these strata are at least in some part the southern continuation of the pelagic facies traced from the Lom Sak area to the south.

2.14. Khao Ta Mon area.

The Khao Ta Mon or Khao Tambon hill is located directly north of road No. 205 from Lam Narai to Chayaphum (fig.:9). It is the southernmost occurrence of the strata mapped as P4 on the Geol. Map of NE Thailand 1:500000. Four different lithological units were distinguished at this locality.

The lowest unit crops out at the eastern flank of the hill and is composed of siltstone beds with abundant clay rip-up clasts and beds of ferroan - manganese - carbonate breccia conglomerate. The clasts are dark brown to black colored in a brown, carbonate (?sideritic) matrix. Though badly exposed, these beds probably represent a transgression conglomerate. The underlying sediments are not exposed. This unit is less than 10 m thick.

The overlying unit is approximately 40 m thick and consists of siltstone and mudstone beds which do not show any internal sedimentary structures. Since these rocks are strongly and deeply weathered, no information could be obtained from this outcrop.

The third unit is a 60 m thick sequence of limestone, containing coarse crinoidal debris. Some of the stems are up to 10 cm long. The limestone is strongly stressed and recrystallized, which can be measured on the crinoids. This limestone is a packstone or grainstone, but due to its recrystallization, it is impossible to identify the standard microfacies. Possibilities are SMF 12, SMF 14, SMF 9 or 10, or SMF 4. The age of this limestone is probably Lower Permian (NAKORNSRI pers. comm.).

The uppermost unit is again of massive limestone and approximately 100 m in thickness. No clear bedding was observed here. Also, no fossils were found in this unit. The limestone is gray to dark gray and very homogeneous. Under the microscope it shows a very fine crystalline structure of $CaCO_3$. Its primary origin is not clear. Mainly because of the occurrence of the underlying conglomerate, these two limestone units are most likely of rather shallow marine origin and probably within the platform interior environment. WIELCHOWSKY & YOUNG (1985) mapped these outcrops as a basin depositional environment but they did not describe the lithology in their paper.

The gravel road from Ban Bo Nam to Ban Nong Ri crosses the southern end of the Petchabun Fold and Thrust Belt somewhat north of Khao Ta Mon (approximately at latitude of 15°22'N). Along this road fine-grained siliciclastic boulders and a few, small carbonate outcrops were found. The small outcrops are located NE of the westward dipping strata described above. The carbonates are coral, ammonite and foraminifera-bearing. Petrographically they are pelsparites or foraminiferal pelsparites (grainstones to packstones of SMF 16) or bioclastic packstones of SMF 10. They are of Moscovian age (corals and forams).

In facies developement and the tectonic overprint the rocks found in the Khao Ta Mon area strongly differ from those found further to the north within the Petchabun Fold and Thrust Belt. They resemble instead rocks described from the Thuak Khao Sompot or Khao Khi Nok area. Obviously, the fault drawn on the Geological Map of NE Thailand 1:500000 which separates Khao Ta Mon and Thuak Khao Sompot is in fact a group of parallel transverse faults belonging to the Mae Ping fault zone.

2.15. West of Chum Phae area.

The area west of Chum Phae has been described in several papers. BORAX & STEWART (1966) measured several sections in this region. Their section No. 6 extends from the Choen river at lat. 16°38'N and long. 101°47'E for approximately 2 km to the south. Their section No. 7 extends from 16°44'N; 101°47'E to 16°42'N; 101°49'E and their section No. 4 was measured at Phu Pha Daeng (16°52'N; 101°57'E to 16°50'N to 101°57'E). On the basis of their observations, BORAX & STEWART (1966, p. 12) divided the Permian strata into two parts: a "Lower Unit of heavy - bedded to moderately thick - bedded, karst-forming limestone and a conformably (?) overlying Upper Unit of interbedded limestone, shale and siltstone, and quartzitic fine grained sandstone". The age of the units is given as Wolfcampian to Early Wardian (Asselian to Bolorian). The total thickness of the two units was estimated as 8000 m. This estimate seems much too high, judging from the local geological conditions.

In the Lower Unit, which BORAX & STEWART (1966) estimated as 5000m thick, they described large-scale cross-bedding with differences of dip of as much as 10 degrees between units and lentils of cross beds of approximately 100 m in length. These cross-beds were observed only from the air, at the "anti-dip slopes of the hogback ridges" (p.13). This description is very likely a description of the Huai Hin Lat Formation of the Mesozoic Khorat Group. Erroneously, these workers added at least the Triassic sequence (Carnian to Norian) to the Permian strata.

Also the section No. 7, mesured in the "Upper Unit" seems to be within the Khorat Group (comp. CHONGLAKMANI & SATTAYARAK 1978).

WIELCHOWSKY & YOUNG (1985) described from the Nam Prom Dam area and the Lom Sak - Chum Phae highway (approximately 40 km east of the Permian molasse described above), interbedded shales, siltstones, cross-laminated sandstones, and thin limestone beds of shallow marine environment. The intercalated limestones are Artinskian to Early Guadalupian and rest structurally on terrigenous clastic rocks of Early and Middle Guadalupian age, which indicates a major thrust fault. In the same area but structurally in a higher position, WIELCHOWSKY & YOUNG (1985) have mapped also medium- to thick-bedded sandstones, conglomerates and shales and limestones, with channels, burrows, clay rip-up clasts, and plant material. These rocks are also of Artinskian to Early Guadalupian age. They were interpreted as deposited in a marginal marine environment.

Along the Lom Sak - Chum Phae highway at lat. 16°39'N, long. 101°47.5'E the same authors describe a basin margin slope facies with massive limestone conglomerates and breccias, clasts- and matrix-supported. The clasts contain pisolitic grainstones, crinoidal packstones to grainstones, and fusulinid packstones to wackestones with dolomitic matrix. The age of the clasts is Artinskian and older.

The Phu Pha Daeng area was also described by WIELCHOWSKY & YOUNG (1985). They described Asselian, Artinskian and Early through Middle Guadalupian basin margin deposits, consisting of thin- to thick-bedded, black, argillaceous carbonate mudstones through grainstones, dark shales and fine-grained sandstones. Possible channels, graded bedding, convolute bedding and matrix-supported conglomerates are present within this sequence. From these findings, WIELCHOWSKY & YOUNG (1985) interpreted an overall shallowing upward cycle for the Permian strata west of Chum Phae.

ALTERMANN et al. (1983) described shallow marine sediments of Artinskian (Yahtashian) to Kubergandian age. They are located along the Lom Sak - Chum Phae highway, along the road to Nam Prom Dam and along the highway to Wang Saphung (fig.:26). There is a change in sedimentation of limestones (Pha Nok Khao Fm., CHONGLAKMANI & SATTAYARAK, 1978) to the sedimentation of the shallow marine siliciclastics (Hua Na Kham Fm., CHONGLAKMANI & SATTAYARAK, 1978) in the Bolorian to Kubergandian. This change is explained tentatively by orogenic activity.

The lower Pha Nok Khao Formation is only peripherally touched by the road to Nam Prom Dam (see map by CHONGLAKMANI & SATTAYARAK, 1978). The Pha Nok Khao Formation is identical with the Phu Tham Nam Maholan Fm. of SUDASNA & VEERABURUS (1979): Geol. Map of NE Thailand, 1:500000. The Pha Nok Khao limestone is a massive, light to dark gray limestone with chert nodules and rare thin shale or siltstone intercalations. Foraminifera – dasycladacean grainstones of SMF 18 prevail in the strata. This limestone is over 200 m thick and is flat lying. Yahtashian to Bolorian age was proven by foraminifera.

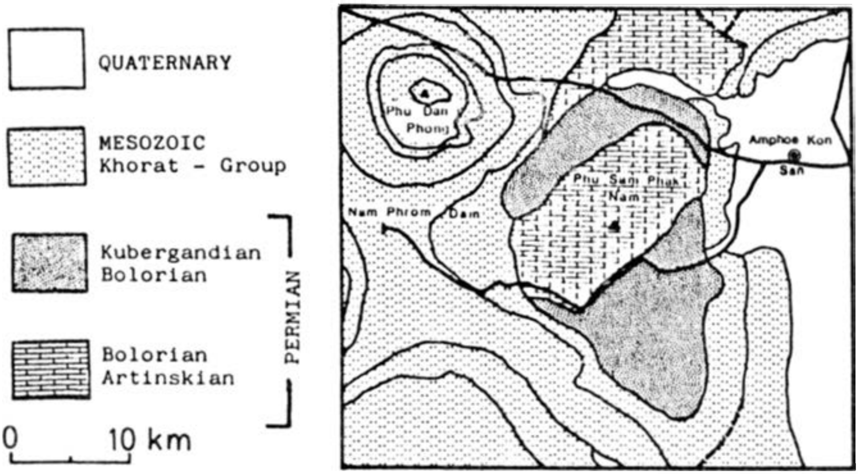


Fig.: 26. Sketch of the geological situation west of Chum Phae, after CHONGLAKMANI & SATTAYARAK (1978).

The section measured in Log No.:XV crops out along the road to Nam Prom Dam, at km 22.800, within the Hua Na Kham Fm. by CHONGLAKMANI & SATTAYARAK (1978). It is a sequence of intercalated sandstones, siltstones, shales and limestones, dipping 50 to 60 degrees SSE and striking NNE-SSW. The beds, which are up to 1 m thick, exhibit ripple cross-lamination containing current and symmetrical ripples; parallel lamination; small clay rip-up clasts; and vertical burrows penetrating the beds, as well as grazing on the bed surfaces. Small plant remains are common on the bedding surfaces of parallel laminated sandstones.
The crossbedding indicates a paleocurrent direction from the SE (fig.:27).

Under the microscope, the psammitic rocks appear as lithic graywackes with 20 to 30% of silicic, slightly carbonatic or also hematite-rich matrix. Carbonate filling in the intergranular pores is common. Also, quartz overgrowth is common. Rare clasts of carbonate, mostly fossil fragments were observed. Approximately 5% - 10% feldspar (plagioclase with 38% An), 30% to 40% lithic fragments and about 50% quartz grains make these rocks identifiable as of recycled orogenic material. On the QmFLt triangle they plot in "mixed" and "quartzose recycled" regime. Detrital biotite and muscovite are common.

The intercalated limestones are bedded in sequences of up to 20 or 30 meters thick. They contain a large faunal diversity of crinoids, foraminifera, algae, brachiopods, and bryozoa, which are only slightly worn.
Wackestones through grainstones are represented by standard micro facies 7 - 12, 14, 16, 18 and 19. Calcedony replacement of matrix and bioclasts is rare. Crystallization of "sugar", blocky dolomite is observed (HE82/27; WA82/92). Fibrous "A" and blocky "B" cements are common in these limestones. The sample WA82/85 is a matrix-supported intra-micrite of medium-grained quartz intraclasts with rare detrital biotite and heavy minerals (zircon) in a micrite matrix with only a few algal and crinoidal bioclasts. It is interpreted as a variety of SMF 24 of SFB 8. The sample WA82/87 is a coral bafflestone with pure lime mudstone and also bioclasts (packed) trapped between the coral frame. The age of these limestones (WA82/86; 87; 91) was established as Bolorian to Kubergandian and Murgabian on the basis of foraminifera.
The depositional area of these rocks is probably a shelf interior region, with partly restricted and partly open circulation, with lagoons and small patch reefs. The coquina beds suggest a winnowed edge environment. Small plant remains are abundant.
The rapidly changing sedimentary conditions distinguish these rocks from the Pha Nok Khao limestone, which was laid down under more or less stable conditions. The whole sequence outcropping along the road to Nam Prom Dam is probably over 1000 m thick. The major fault described by WIELCHOWSKY & YOUNG (1985) was not observed and was probably missed because of insufficient mapping.

The highway from Lom Sak to Chum Phae crosses the area under discussion, notably the Hua Na Kham Formation (P2 on the Geol. Map of NE Thailand 1:500000). The Pha Nok Khao Fm. is crosscut only in the western part, for a short distance. The outcrops are located approximately between km 79.0 and km 86.5 and the first 1000 m are occupied by the Pha Nok Khao limestone. These Pha Nok Khao outcrops are of an identical nature as those along the Nam Prom Dam road. Foraminiferal grainstones are abundant, often with long crinoidal stems, worn oncolites and pelletal grains. The bioclastic grainstones and packstones contain fragments of spongistromatoid and phylloid algae. Standard facies belts 6 and 7 are evident by SMF 12, 13, 18, and 19. Meteoric dolomitization of lime mud (uniform, equi-sized dolomite rhombohedrons) evidence a near shore environment and very shallow conditions. Artinskian to Bolorian and Bolorian to Kubergandian age was established on the basis of foraminifera (HE81/51; WA82/102).

The Hua Na Kham Fm. along the Lom Sak - Chum Phae highway also strongly resembles the outcrops along the road to Nam Prom Dam. The Logs No.:XII; XIII & XIV depict the sedimentation patterns of these outcrops. Interbedded siliciclastic rocks and rare limestone beds form the northern flank of the gentle anticlinal structure of the Phu Sam Phak Nam. The most significant properties of these rocks are the rapid facies changes; pinching out of the beds; cross-beds of up to 50 cm amplitude; repeated rapid change from pelitic to coarse psammitic sedimentation; large (20 cm) clay galls; and rip-up clasts. The crossbeds have NW-ward dipping lee sides.
Brachiopods, crinoid and ammonoid fragments evidence a marine environment also for the

siliciclastics. Beds with abundant plant remains several cm long are common. Commonly the pelitic layers are strongly bioturbated by large, burrows up to 1 cm wide. Symmetrical ripples were found on the thin, fine psammitic beds. Under the microscope the psammitic rocks appear on the QFL plot as lithic graywackes of the recycled orogenic composition and within the mixed, quartzose recycled and transitional recycled regime on the QmFLt triangle (DICKINSON et al. 1983). In particular cases they contain 20% to 50% matrix of mostly silicic - clay origin. Rarely the matrix is carbonate of ferritic.

The sample WA84/104 exhibits poikilotopic calcite matrix. Quartz overgrowth is common in many samples. The content of the monocrystalline quartz grains is always around 40% to 60%. The content of feldspar ranges from 3% to 20% but is mostly between 5% and 10% (plagioclase and K-feldspar are present). The lithic fragments represent 40% to 60% of the clasts and the ratio of polycrystalline quartz to other fragments is about 1:1 to 1:2. Some "granitic" fragments of intergrowing quartz, feldspar and mica were found within the lithic fragments. The content of detrital mica seldom exceeds 5% and detrital carbonate was found only in a few samples, but there it is common. Rare heavy mineral grains of zircon and tourmaline were found. Structurally, these sediments are moderately sorted (mature); the grains are of subangular to subrounded roundness and mainly of (elongated) – 0.65 sphericity.

The carbonates interlayered with the siliciclastics are thin-bedded, biogenic carbonates with common chert nodules. A great diversity of relatively intact fossils was found in these beds. Solitary and colony corals, crinoids, bivalvia tests, foraminifera, diverse algae and other fragments were observed. Micrites of laminated lime - dolomite mudstone, containing small lime mud rip-up clasts but no bioclasts and with small-scale truncation of laminae and weak silt influx on some laminae (SMF 19 - 20; SFB 8) are evidence for tidal flats environment. There is an abundance of lags of poorly washed biosparite (packstone to grainstone) with foraminifera tests and diverse algae and often goethite-rich matrix as well as of pelletal wackestones and packstones.

The carbonate and siliciclastic properties indicate a marginal marine environment of inter- and subtidal character for the deposition of the Hua Na Kham Fm. along the Lom Sak - Chum Phae highway, between km 81.0 and 86.5. This is the identical and the neighboring (landward) depositional regime of the Hua Na Kham sediments, which are exhibited along the Nam Prom Dam road. The sediment source judged from the crossbeds was SE of these deposits, which is in agreement with WIELCHOWSKY & YOUNG (1985). The age established on the basis of foraminifera found in the limestones is Bolorian to Kubergandian and Kubergandian to Murgabian (WA82/83; 98; 110; HE81/52).

The comparison of the stratigraphy of P1 and P2 shows that the Pha Nok Khao and the Hua Na

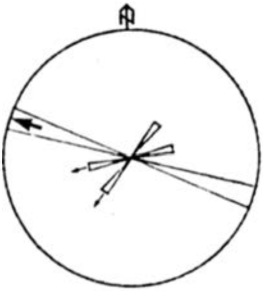


Fig.: 27. Paleocurrent direction based on crossbed foresets of six sandstone layers west of Chum Phae

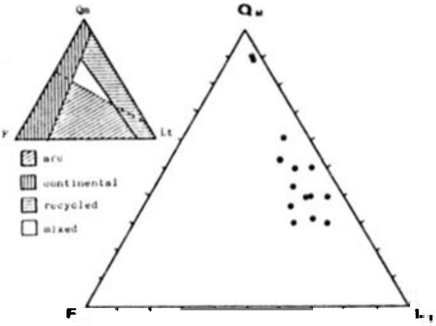


Fig.: 28. Graywackes from the Nam Prom dam area in the QmFLt triangle.

Kham Formations are partly contemporary and therefore lateral facies variations, and not necessarily two vertical units. The remarkable change of the sedimentation from the thick, massive carbonate sequence of the Pha Nok Khao limestones to the sudden prevailing siliciclastic deposition as claimed by ALTERMANN et al. (1983) probably occurred more continuously and less violently, somewhere between Bolorian and Kubergandian times.

In the area of Phu Pha Daeng (16°52'N; 101°57'E) a section of thin- to thick-bedded (10 cm to 1 m range) crinoidal, slightly recrystallized limestone, underlain by massive nonbedded limestone was measured.
The area is mapped as P1 on the Geol. Map of NE Thailand 1:500000. The basin margin fan deposits of WIELCHOWSKY & YOUNG (1985) were not found. According to my own observations the limestones are of an open circulation platform regime and are represented mainly by fine calciruditic, biomicritic wackestones to packstones of SMF 9 and 10, with weak replacement by SiO_2 of fossils and weak dolomitization (euhedral dolomite crystals). The bioclasts are mainly foraminifera and crinoids, commonly with long and intact stems. Dismicritic limestones with pellets and calcispheres also occur. The sample WA84/141 yields Asselian and WA84/142 Murgabian foraminifera.

2.16. The Wang Saphung area.

In the vicinity of Wang Saphung several outcrops were visited. Fig.:29 is a skech redrawn from the Geol. Map of NE Thailand 1:500000, showing the Paleozoic outcrops in NE-Thailand.

1). Approximately 6 km west of Wang Saphung, in the area mapped as P2, some very small outcrops of light gray, banded limestone; fine breccious, stressed limestone; cherts and fine quartzites are found. No fossils were discovered in the finely recrystallized limestones or in the other rocks. It is not known whether these rocks are Permian. Their depositional environment was also not fully understood. Nevertheless, they represent shallow marine deposits. Since igneous rocks are mapped in the vicinity, a contact metamorphic overprint cannot be ruled out.
2). Southwest of Wang Saphung, near to Ban Om Lao (17°15'N; 101°44'E), within the P2, a sequence of intercalated shales, siltstones, rare fine-grained sandstone beds, and limestones was found. The strata strike NNW-SSE and dip 70 degrees to WSW. The beds are up to 20 cm thick. The siliciclastic sediments contain abundant clay rip-up clasts and are strongly penetrated by well-preserved trace fossils. The feeding burrows are up to 0.5 cm in diameter. Plant remains are concentrated on bedding surfaces. Also, the limestones are bioturbated and often strongly silicified. There, laminites with ?ostracod fragments on the laminae and fossiliferous micrites (lime mudstones) with abundant calcispheres prevail. A lagoonal mud paleoenvironment is suggested. Few Agathiceras fragments were found in the siliciclastic beds and evidence Middle Permian (Guadalupian) age.
3). At km 319.9 (milestone 320) of the Wang Saphung - Chum Phae highway No.201, NNW-SSE striking strata of thin-bedded siltstones, shales and rare, chertified limestones crop out. Brachipods and crinoids are present in these bioturbated rocks. Further to the east (approximately 400 m), these rocks are underlain by light gray, massive limestones with solitary corals and abundant phylloid algae fragments. The sample WA 84/156 is a biomicrite (packstone) of the phylloid platy algal mud facies (lagoonal facies) with abundant dolomite euhedral rhombohedrons in the matrix. It is the most typical facies of this outcrop. The foraminifera found in this limestone evidence Asselian age (WA84/155).
4). At Ban Na Kae somewhat different types of rocks crop out. Here also thin-bedded siltstones, shales, sandstones, and limestones are exposed as in the upper part of outcrop 3, but the siltstones and shales are often wavy laminated. Rare graded bedding was observed in the medium-grained sandstone beds. Graded sandstone beds were also found in the vicinity of Ban Kok Klaeng (at the schoolyard). These beds are micro crossbedded and parallel laminated in their upper part. Lenses of foraminifera-bearing limestone were found within these strata. Sakmarian age was established for the sample WA82/80. The limestones are poorly washed bio-intramicrites to sparites (packstones) with clasts of volcanic origin, quartz and feldspar grains, and stromatolitic fragments. Obviously, the facies change from platform interior lagoon regime to basin margin environment. A few km to the east, at Phu Khi Khai (Phu Khao Khong) WIELCHOWSKY & YOUNG (1985) describe again platform interior, supratidal flats and sub-

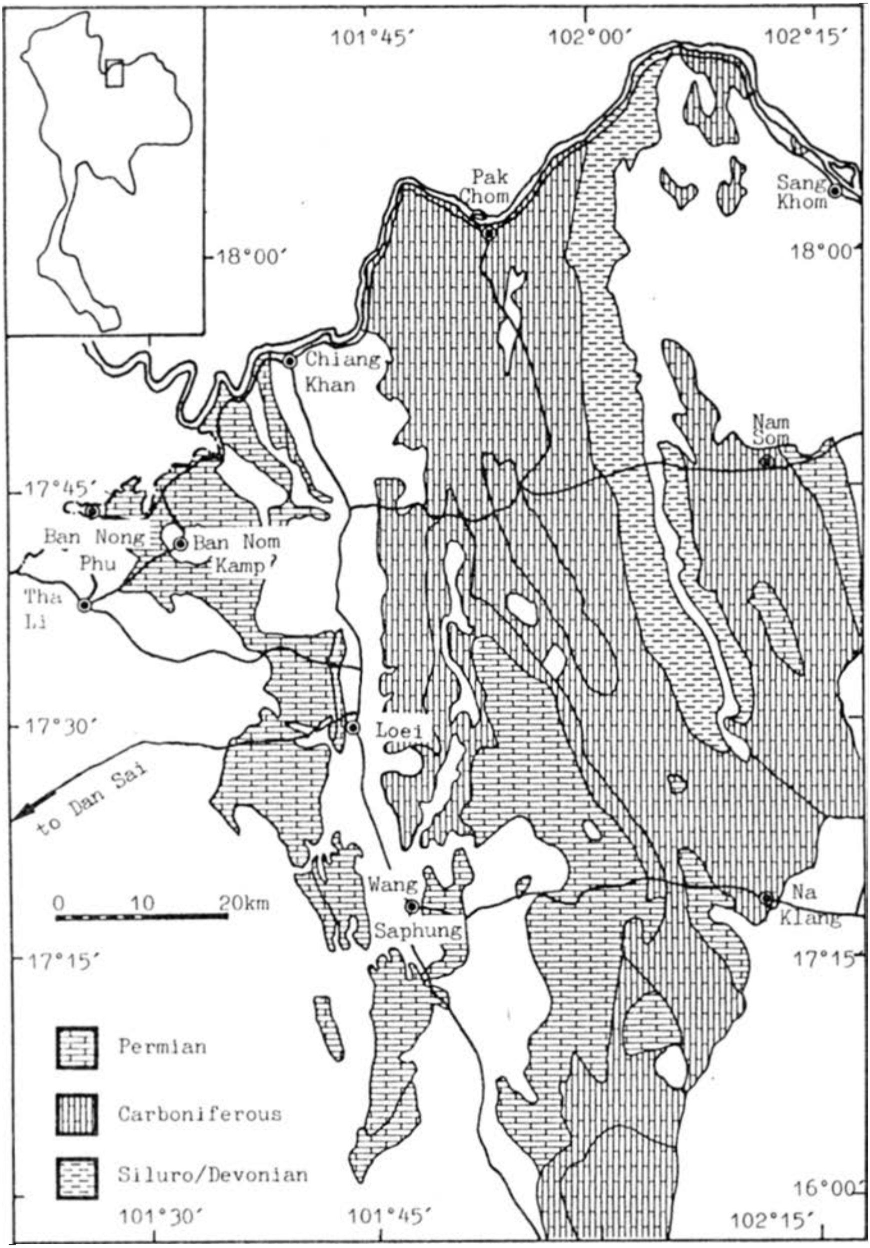


Fig.: 29. Simplified map of Paleozoic strata in Northeastern Thailand (SUDASNA & VEERABURUS, 1979).

tidal lagoon facies of an early Permian age. It appears that regional facies variations are more responsible than stratigraphical reasons for the subdivision into the P1 and P2 on the Geol. Map of NE Thailand 1:500000.

Along the road No. 210 from Wang Saphung to Na Klang and Udon Thani several outcrops were visited. At km 2.1 and 3.5 east of Wang Saphung (17°17' - 17°18'N; 101°48' - 101°49'E), badly exposed fine-grained sandstones, siltstones, and limestones were found. The area was mapped by SUDASNA & VEERABURUS (1979) as C2 – Middle to Upper Carboniferous Wang Saphung Formation on the Geol. Map of NE Thailand 1:500000. Judging from the limestones, a subtidal lagoon can be claimed for the depositional environment of these rocks. The siliciclastic sediments, which appear west of the limestones, are thin-bedded and represent tidal flats.

At km 6.0 a chain of NNW-SSE striking and ENE steeply dipping limestones (SS 066°/78°) crop out. The hills south of the highway are named Phu Pha Sing. Massive limestones are exposed in the upper part; thin-bedded limestones in the lower part. The limestones are gray or red-yellowish micrites through sparites, which are partly dolomitized and/or silicified. In the upper part, lenticular bedded limestones with intercalations of thin, very fine (pelitic), greenish tuffites were found. One bed with fine ?intraformational breccia was observed, as well as a few thin graded layers (medium calcirudite grading upwards to calcilutite). These graded beds contain mainly crinoidal debris, together with bivalvia, algae, and coral fragments and lime mudstone rip-up clasts in their lower part. Ostracod fragments, spiculae, and small, dark, clayish intraclasts are concentrated in the upper part of the layers. The beds are bioturbated. Replacement of fossils by SiO_2 is common. These beds are interpreted to be tempestites – storm deposits (AIGNER, 1982). Characteristic for the lower, massive limestone are micrites with dasycladacean algae fragments and other shallow water biota debris. Birds eye structures and bioturbation were observed. The limestones are slightly recrystallized. SMF 9; 19 and 23 were identified and suggest an intertidal depositional environment. Bolorian to Kubergandian age was established for these rocks (HE82/25).

The next outcrops are located at km 15.5 east of Wang Saphung and were mapped as P1 by SUDASNA & VEERABURUS (1979). The stratum is composed of massive limestone with scattered fossils of ammonites, crinoids, and solitary corals. The fossils are intact and imbedded in micrite and/or sparite matrix.
Thin algal crusts (LLH-laminites) were found in some layers. Phylloidal platy algal mud facies are also present. Abundant chert nodules occur in the stratum. The sample WA84/197, which is a sparse biomicrite (wackestone) with algal fragments and small ammonites, yields Upper Carboniferous foraminifera.

Approximately two km further to the east, medium-bedded, flat-lying limestones crop out. Some thin breccia conglomerate layers were found. They are clast-supported, badly sorted, and bearing mainly clasts of unfossiliferous, gray or reddish, dolomitic carbonate. Some fine sandstone and chert clasts also occur. The clasts are up to 10 cm in diameter. Most probably this conglomerate is of intraformational origin (SMF 24). Other layers are of foraminiferal dasycladacean packstones, pelsparites or intrasparites with chert intraclasts. Ammonites are also common in these beds. Some layers of algal laminites (LLH structure) were found. Rare beds are of cross-bedded biosparites (grainstones). The limestones are bioturbated and the vertical burrows are filled with silt and sand. In rare cases thin beds of wavy laminated siltstone are interlayered with the limestones.
Yahtashian to Bolorian foraminifera were found in these intertidal and supratidal deposits (SFB 8 and 9). Similar rocks, but containing more reddish brown, fine siliciclastics, are exposed at km 19.5 east of Wang Saphung. Dolomites, together with unfossiliferous lime muds, breccias and other burrowed carbonates, represent intertidal flats of Bolorian age.

Approximately at km 30.0 to km 31.1 (17°11'N; 101°59' - 102°00'E), gently ENE-dipping, medium-bedded limestones are exhibited. Foraminifera, crinoids, ammonites, bivalvia, solitary corals, and spiral gastropods are preserved in the carbonate rocks. Dasycladacean and foraminiferal grainstones and packstones, stromatactis limestones, unfossiliferous dolomitic mudstones, abundant burrows, chert nodules and various stages of chert replacement of the carbonate are evidence for a subtidal through intertidal depositional regime. The prevailing standard microfacies is SMF 9 (SFB 7). In thin section phylloid algae and ostracods were also recognized. Yahtashian to Bolorian age was proved on foraminifera in the samples WA84/204-206. WIELCHOWSKY & YOUNG (1985) recognized a subtidal restricted lagoon of early Guadalupian age in this area, which was mapped as P1 on the Geol. Map of NE Thailand 1:500000.

The easternmost Paleozoic outcrops along the Wang Saphung - Udon Tani road are located 40 km east of Wang Saphung and are also mapped as P1 by SUDASNA & VEERABURUS (1979). These exposures consist of dark gray, generally massive biomicrites and biosparites (packstone through grainstone), but also carbonaceous mudstones, which are lighter colored. The fossils found here are only crinoids and do not allow the determination of the stage within the Permian. Fine grained and well-sorted conglomerate with lime-matrix-supported limestone clasts are found in the vicinity. SFB 8 of restricted circulation shelf to lagoonal environments are determined for these deposits because of the prevalence of non-laminated, dolomitic micrites and crinoidal packstones and grainstones. The conglomerates could represent tidal channel sediment.

2.17. The Loei area.

North, northwest and northeast of Loei, a large area was mapped as Permian on the Geological Map of NE Thaialand 1:500000 by SUDASNA & VEERABURUS (1979). From Loei a road, No.201, leads to the north to Chiang Khan on the Mekong river (Mae Nam Kong). Along this road Permian rocks were found. North of Loei two other roads branch off from this road to the west. The southern road leads to Dan Sai (No.203) and joins road No.201 approximately one km north of Loei. It crosscuts Permian rocks. Approximately 7 km north of Loei, the second road to the west joins road No. 201. This road No. 2115 leads to Amphoe Tha Li and also crosses Permian rocks. These exposures were examined.

2.17.1. Loei - Dan Sai road.

The road to Dan Sai crosses the P2 – Hua Na Kham Formation for a short distance. Further to the west it crosses the P3 – Pha Dua Formation of "shale, gray sandstones, sandy shale, micaceous sandy siltstone" (SUDASNA & VEERABURUS, 1979). The easternmost outcrops are located at km 2.5 from the junction to Loei and Chiang Khan and are within the P2 area. These outcrops continue for approximately 1 km and are represented mainly by dark gray to blackish shales in which thin, fine sandstone beds are intercalated. The strata are N-S striking and dip 60°-70° to the east. Weak cleavage is developed and is more or less parallel to the bedding. According to NAKORNSRI (pers. comm.) Agathiceras was found in these outcrops by Mr. WORAWUT from DMR/Bangkok. The shale and silt through fine sandstone is partly micro cross-bedded, wavy laminated, or lenticular bedded. Rare biogenic structures were observed. The burrows are mostly about 3 mm in diameter with the maximum of 1 cm. Most of them are filled with silty material and pyrite-enriched at the burrows margin.

In the eastern part of these outcrops (km 2.7) gray and sometimes reddish violet psammites occur. Small plant remains were found here. Log No.:XVII shows a typical section through these rocks.

The thin section petrology of these silt and fine sandstones shows well-sorted, angular, monocrystalline and undulatory quartz grains (60%-80%), less than 1% feldspar, over 10% lithic fragments and 3%-5% detrital mica. The matrix occupies 20%-60% of the rock and is mainly sericitic - cherty, in some samples hematite rich. In sample WA82/4 50% of the matrix is chlorite concentrated in nests and "patches" and especially strongly enriched on micro fractures, which suggests secondary processes.

The mudstones petrographically exhibit small idiomorphic pyrite crystals which might suggest euxinic conditions of sedimentation.

The outcrops between km 7.0 and km 10.0 exhibit somewhat similar lithology. The strata are still N-S striking and dip with angles of 30° to 90°. The beds of silty, fine sandstones and shales are one or two centimeters to over 50 cm thick. Often, the pelitic layers are significantly thicker than the psammites. In rare cases pinching out of the beds was observed. Small-scale cross-bedding, parallel lamination and up to 5 cm long clay rip-up clasts are common. In many beds abundant plant remains of 1 cm and smaller cover bedding surfaces. Also in rare cases burrows are found. In the psammitic beds there is a high content of detrital muscovite in up to two or three millimeter long platelets. This strongly suggests the absence of turbulent currents or winnowing in the depositional area, but also indicates short transport distance. The sediments are strongly weathered and of yellow to reddish color. No truly fresh samples could be collected.

Under the microscope abundant chlorite was found in one sample (WA82/76). In general, both psammites and pelites strongly resemble the rocks from the eastern outcrops described above. They contain less pyrite but more limonite which might come from the pyrite through weathering. The matrix is mainly silicatic - sericitic and weak quartz overgrowth is common. Monocrystalline quartz grains compose over 50% of the clasts, lithic fragments about 40%. The content of feldspar is less than 1% and of detritic mica over 5%. Very rare grains of green hornblende, zircon, and tourmaline represent the heavy mineral spectrum of these lithic graywackes.

Log No.:XVIII is an example for the sedimentation patterns of these deposits. The log No.:XIX was measured at km 13.7 west of Loei. With the exception of the increasing content of arenite beds, no significant change in sedimentation as compared with the rocks described above was observed. The fine sandstone beds can reach up to 1 m in thickness.

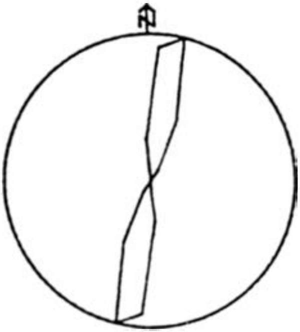


Fig.: 30.

Paleocurrent direction calculated from 16 measurements at km 18.5 of the Loei - Dan Sai road.

Further to the west, the strata are often crosscut by thick volcanic dikes, probably of Mesozoic age. They are up to 20 m thick and deeply weathered, so that the rock appears very soft and friable. They are of dark red brown color.

West of km 16.5 Permian siliciclastic rocks again crop out. Log No.:XX was measured at km 17.9, Log No.:XXI at km 18.5 and Log No.:XXII at km 20.7. They show very similar features as compared to those from the eastern outcrops.

At km 18.5 small groove casts on the bottom of the overturned beds are exhibited. Rotated back to the original position they indicate questionable a NNE - SSW paleotransport direction (fig.:30).

In the same manner the Permian strata continue approximately up to km 21.0 west of Loei.

2.17.2. Loei - Tha Li road.

The road No. 2115 to Tha Li runs more or less parallel to the Loei – Dan Sai road. For a short distance it also crosses the P2 Formation in the east and then the P3 Formation in the west (SUDASNA & VEERABURUS, 1979). For that reason the sedimentological properties of the strata along the Tha Li road do not differ much from those along the Dan Sai road. Only the P2 Formation is very different from the dark shales described from road No. 203.

The P2 Formation crops out approximately between km 2.0 and 2.8 west of the junction to Loei and Chiang Khan. At km 2.0 a small gravel road leads a short distance to the north, to a Buddhist temple located at the foot of the limestone hill. The limestones here are medium-bedded to massive. Asselian to ?Kubergandian foraminifera were found in these limestones (HE82/46). Partly dolomitized (idiomorphic dolomite crystals in the matrix) pelleted biomicrites (wackestones), intrasparites and loferites prevail. In one sample, small idiomorphic needles of apatite are found. They are of diagenetic neomorphic origin and evidence a restricted platform regime of periodically higher salinity. Vadose miniscus cements and "sugary" cements are common.

At km 2.8 thin-bedded, fine grained siliciclastic rocks also crop out. Log No.:XXIII was measured here. The strata dip to the SSE (SS 155°/35°) and are overturned. In the strata, thin chertified limestone beds are intercalated. They contain abundant foraminifera and crinoids. Bioturbated, parallel- and wavy laminated layers with ?ostracod fragments and ?spiculae, foraminiferal grainstones or packstones of SMF 18 and SMF 10 are present. The fossils are totally replaced by chalcedony quartz with small iron-surrounded dolomite crystal molds (dedolomitization). The depositional environment of these rocks is of restricted shelf environment but often interrupted by fine siliciclastic influx. In one of the beds the foraminifera tests are aligned by water current and indicate a SW - NE transport direction (three measurements). The foraminifera are of Lower Permian (HE82/45), Yahtashian (WA82/14; 16; 26) age.

West of km 2.8 siliciclastic sedimentats replace the carbonates and the P3 Formation is exhibited. Volcanic dikes often dissect the generally N-S striking strata.

At km 3.3 small current ripples indicate a westward paleocurrent direction. In the shales of the strata bioturbation, plant remains and a fragment of Agathiceras ammonite (M. Permian) were found. Several siltstone beds exhibit small groove casts indicating NW - SE paleotransport direction (16 measurements). Log No.:XXIV was measured across this outcrop.

The Logs No.:XXV and XXVI were measured at km 7.5 to km 7.6. Fragments of Middle Permian ammonites (Agathiceras) were found here. Six to seven centimeter long plant remains are common in these beds. In a few cases wavy lamination and bedding occur as well as rapid lateral changes in the fine sandstone beds. A N-S paleocurrent direction is again indicated by small groove casts.

At km 8.8 to 9.0 the fine sandstone beds become thicker and can reach up to 1 meter. Abundant clay rip-up clasts are present in the beds. Detrital muscovite is common.

In thin section the psammites of the Loei - Tha Li road exhibit 30% to 40% of sericitic - silicic matrix. Quartz overgrowth is common. 60% to 70% of the clasts are monocrystalline quartz grains and the rest are lithic fragments. Less than 3% feldspar and 3%-5% detrital mica, partly chloritized, are present. Heavy mineral grains of green hornblende, zircon, and tourmaline are present in the samples.

At km 13.1, abundant limestone boulders, but no outcrop, were found in the forest north of the road. Their shape, size and abundance, together with their position quite far from the road, make it likely that they are in place. These limestones contain abundant fossils of large crinoidal stems and foraminifera and algal fragments. They are of a coquina facies (grainstones) and exhibit vadose dog tooth cements in the foraminifera chambers. The depositional environment of these Yahtashian (HE82/43) carbonates was a winnowed edge of an organic buildup on platform margin or in a platform interior.

The clastic sediments outcropping along the roads from Loei to Dan Sai and from Loei to Tha Li are of marginal marine character. A tidal flat environment, with small, shallow washout channels and channel casts, is strongly indicated. The easternmost outcrops at the Dan Sai road, which contain mainly dark shales represent most probably a lateral facies variation and not a separate formation as claimed by SUDASNA & VEERABURUS (1979). The siliciclastics overlie the P2 limestones found at the eastern exposures of the Tha Li road, but probably also the limestones found in the westernmost outcrops of this road. The change of carbonate sedimentation to siliciclastic deposition occured during or after Yahtashian period and could be contemporaneous with the flysch onset in the Petchabun Fold and Thrust Belt (comp. Nam Prom Dam area). The suggestion of Kubergandian age for sample HE82/46 is questionable (INGAVAT, pers. comm.).

Presumably, sedimentary rocks, acid magmatites and/or metamorphites were the source rocks for these sediments. The transport distances were probably not very long in view of the occurrence of sometimes rather big plant remains, muscovite platelets, and quite unstable heavy mineral grains of hornblende.

2.17.3. Loei - Chiang Khan area.

Road No.201 from Loei to Chiang Khan runs parallel to the P2 strata which have been already described because it outcrops at the Tha Li road. Nevertheless, outcrops exhibiting new and interesting features were found along the road to Chiang Khan. The outcrops are in a quarry located west of the road, approximately two kilometers north of Loei, in the vicinity of the Catholic church. The strata exhibited here strike more or less N-S, dip steeply to the east, and are overturned. The outcrops are composed of interbedded, light gray limestones, light green tuffs and tuffitic limestones. Log No.:XVI was measured in the northern part of the quarry as

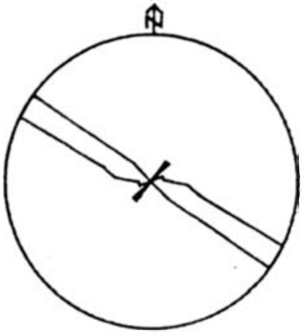


Fig.: 31.

Paleocurrent direction calculated from 21 measurements at km 2.8 - 3.3 of the Loei - Tha Li road.

far as non-faulted strata are exposed. The thin- to medium-bedded sediments are often graded; some beds are also inversely graded in the upper part and build beds which become finer and then coarser upwards. Rare beds pinch or even completely pinch out. The limestones and lime – tuffites contain abundant fossils of crinoid stems, foraminifera, solitary corals, and algae. The fossil debris generally fines upwards within the beds and its sorting becomes better towards the top of the layer. The bioclast size varies from medium calcirudite (gravel) to lutite (pelitic) grains. Rare fossiliferous limestone cobbles to boulders up to 30 cm in diameter were found within the limestones. The volcaniclasts in the tuff and tuffite are never coarser than fine sand size (0.2 mm).

Above the graded bed interval, cross-bedding and/or wavy bedding and parallel lamination are rare. Some non-graded, cross-bedded or evenly bedded layers occur. Also, the pelitic tuff and tuffite layers are mostly wavy or lenticular laminated. The foraminifera from these beds evidence Asselian to Sakmarian age (WA82/33; 35; 39).

In the SW part of the quarry the layers consist of dark gray to black shales and calcacerous shales and gray - greenish fine sandstones which are often graded but appear only in thin beds. Some of the shale layers are bioturbated, the burrows are 1-2 milimeters thin and mainly on the bedding surfaces.

Under the microscope, the limestones could be identified as intra-biomicrites and intra-biosparites with mainly crinoidal and foraminiferal bioclasts, often strongly replaced by calcedony quartz. The matrix also underwent strong silicification. Volcanic intraclasts are common. In some of the bioclasts dedolomitization was observed, which is probably post-redepositional and contemporaneous or prior to the silicification since the dolomite molds are filled by chalcedony SiO_2 (WA82/35). The clasts are worn and coated. Some crinoidal bioclasts are syntaxially cemented (rim cements). In so far as they were not obliterated by the replacement, SMF 4 and rare SMF 9 were recognised. Pelagic lime mudstones of SMF 3 and microbioclastic calcisiltites (SMF 2), with small volcaniclasts are also present.

The tuffs are of keratophyric and quartzkeratophyric origin and are strongly chloritized. The volcaniclastic grains are of glass with plagioclase phenocrysts (albite - oligoclase - andesine), partly replaced by calcite. Calcite and chlorite fill small cavities and epidote, magnetite and titanite minerals are common.

The fine sandstones from the SW part of the quarry are lithic graywackes, which are matrix poor (15%-20%) and commonly with quartz overgrowth. The matrix is silicic with abundant sericite and chlorite. 50% of the clasts are lithic fragments, mainly of chert origin. Over 40% quartz monocrystalline grains, 5% detrital muscovite and less than 3% feldspar grains on average are typical for these graywackes. Some samples contain volcaniclastic lithic fragments. Carbonate fragments are rare. The compositional maturity of these rocks is low.

All the graded layers represent turbiditic deposition as described by MEISCHNER (1964), Mc ILLREATH & JONES (1979) and WALKER (1979). As common in carbonate turbidites, mainly the A-division of BOUMA sequences dominates these layers. The triggering mechanism for the turbiditic flows could of course be related to the volcanic activity.

2.17.4. West of Chiang Khan area.

From Chiang Khan a gravel road to the SW, to Tha Li, runs parallel to the Thai-Laotian border, and along the Mekong and Huai Nam Huang rivers. The Permian outcrops from Chiang Khan to Ban Nong Phu at this road and

along the southern road from Ban Na Yan through Ban Nom Kamp to Ban Nong Phu were examined (fig.:29). Since no milestones were set along this road the locations are described by the distance from the main junction of Chiang Khan - Loei roads.
According to the Geological Map of NE Thailand prepared by SUDASNA & VEERABURUS (1979), P2 and P3 Formations are exhibited west of Chiang Khan and are intruded by Permo-Triassic granitoid rocks.

The easternmost outcrops up to approximately 4 km west of Chiang Khan represent the P2 Formation. This is a N-S striking sequence of fine-grained sandstones, siltstones, and mudstones in beds ranging from a few centimeters to up to two meters thickness. The beds contain abundant plant remains, are strongly micaceous, and seldom graded bedded. Small clay rip-up clasts are common in the strata.
The psammites are matrix rich and under the microscope show high chlorite content in the matrix and angular, badly sorted clasts of quartz (30%-40%), 5%-20% feldspar and approximately 40% of lithic fragments. Volcanic lithic fragments were recognized in sample WA82/20. The sample WA84/195 exhibits weak quartz overgrowth and calcite-replacing feldspar.

The easternmost outcrops of the P3 Formations are in such bad condition that no fresh samples could be collected. As far as could be determined, it is an interbedding of pelites and psammites, which does not differ from the P2 rocks.

Approximately at km 19.0 west of Chiang Khan the interbedded fine sandstones and shales exhibit two well-developed cleavage directions (SS 200°/90°; Sf1 350°/88°; Sf2 315°/85°). The strata are fine- to medium-bedded and some siltstone beds exhibit small-scale cross-bedding and lenticular bedding.

Three to five kilometers to the west, along the Huai Nam Huang river, the rocks are strongly contact-metamorphosed and in thin section show diopside and feldspar growing together with clinozoisite (epidote) and magnetite. The rock is silicified and very indurated. The mica is strongly chloritized. The educt of this metamorphism was a fine grained graywacke, probably with a weak carbonate matrix. The primary siliciclastic texture, the detrital quartz grains and the lithic fragments can easily be recognized (WA84/192; 193). The direct contact with the granite is not exposed.

Approximately 30 km west of Chiang Khan the rocks along the border to Laos exhibit again yellowish-gray fine sandstone, siltstone and dark mudstone. The strata are folded and N-S striking. Abundant plant remains were found, primarily in the mudstones; some beds are also rich in clay rip-up clasts. The psammites are mica rich. The thickness of the bedding ranges from a few centimeters to over one meter. Wavy lamination and parallel bedding are common. Rare small- and medium-scale cross-bedding was also found. Some beds change their thickness rapidly over a few meters. Other beds are graded. Syndepositional deformation structures

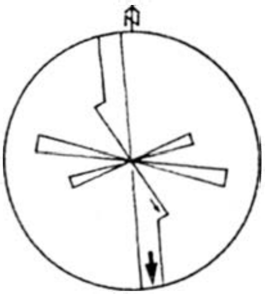


Fig.: 32. paleotransport direction based on 12 measurements of bottommarks west of Chiang Khan.

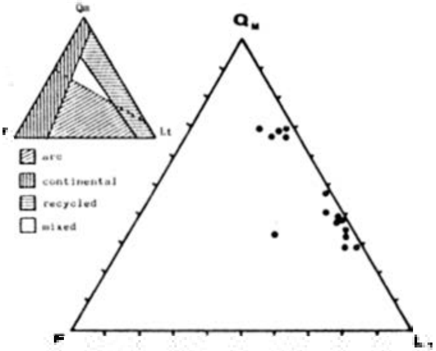


Fig.: 33. Graywackes west of Chiang Khan in the QmFLt triangle.

(convolution) are also observed in a few beds. Some of the dark, laminated mudstone beds are superficially bioturbated. Log No.:XXVIII was measured 31 km west of Chiang Khan and is typical for the sedimentation patterns prevailing in this section of the outcrops.

The rocks remain the same for at least 10 km to the west. In some outcrops the pelitic content increases and the beds become up to 2-3 m thick. In rare cases, thin conglomeratic beds with mainly chert and minor volcanic clasts are also found here.

In rocks of a similar lithology, at km 42.9 west of Chiang Khan, ripple mark crests and crossbed foresets were measured indicating paleocurrent direction from north to south. In these beds up to 15 cm long clay galls occur.

Under the microscope the arenites appear as lithic graywackes with 30%-60% of mainly clayish, but also carbonate matrix. The quartz grains occupy about 30%-50% of the clasts and the feldspar content is under 10%. Lithic fragments range from 30% to 60%. The clasts are mainly angular and moderately sorted. Quartz overgrowth has been observed in some of the samples. Chlorite in small quantities is common in the matrix. Zircon, hornblende, tourmaline, and very rare biotite appear as heavy minerals.

Fig. No.:33 is a plot of 16 samples from this area in a QmFLt triangle.

P3 outcrops of identical character are also exposed along the southern road from Ban Na Yan to Ban Nong Phu. Logs No.:XXIX & XXX were measured here. The age of these siliciclastics remains unknown because of lack of identifiable fossils. WIELCHOWSKY & YOUNG (1985) describe the rocks W of Chiang Khan as shallow to marginal marine siliciclastic sediments of Asselian to late Guadalupian age. The writer suggests that these sediments were deposited in a shallow marine environment in the eastern part and a deeper shelf environment in the western part. In their eastern part these sediments strongly resemble the siliciclastics of the P3 Formation described from the Loei - Tha Li and Loei - Dan Sai roads where Agathiceras ammonites were found.

Approximately 50 km west of Chiang Khan and 3 km east of Ban Nong Phu there is a junction of the roads Chiang Khan - Tha Li and Ban Nong Phu - Tha Li. In the area around this junction and near the military camp 500 m south of this junction, flysch sediments are exposed.

This is a more than 500 m thick sequence of N-S or NNE-SSW striking, W to NW dipping graywackes interbedded with dark shales. The graywacke layers have sharp-based, erosive beds, which are graded and exhibit, in their upper part small-scale cross-bedding, parallel lamination, and convolute bedding. Complete Bouma T-sequences are common. Flute casts indicate a SSE-ward paleocurrent direction. The thickness of the graywacke layers ranges from 10 cm to 80 cm, but is mostly of about 40-50 cm. The pelitic intervals are on average 20 cm thick. Log No.:XXXI was measured 500 m east of the junction to Ban Nong Phu.

Under the microscope these graywackes appear as fine-grained lithic graywackes with up to 60%, mainly sericitic-chloritic but also carbonate matrix. The clasts are of angular shape

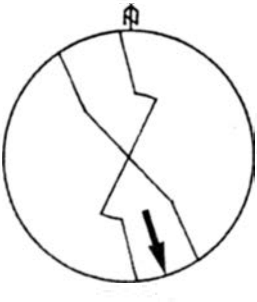


Fig.: 34. Paleocurrent direction based on bottommarks in the flysch west of Chiang Khan (7 data).

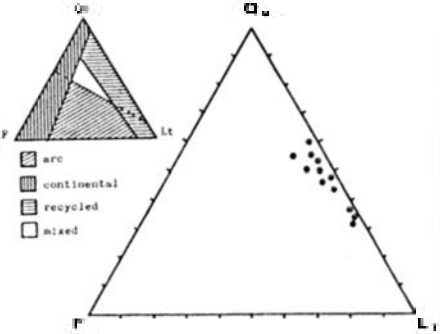


Fig.: 35. The flysch graywackes plot in the QmFLt diagram within the transitional recycled regime.

and texturally immature. Abundant detrital muscovite and some biotite are present. The feldspar content of these rocks is about 10% (10% An – Oligoclase could be measured in one case). Some 40% to 60% of mainly monocrystalline quartz and 30% to 60% of lithic fragments identify these graywackes as from a recycled orogenic regime source (fig.:35).

No fossils were found in the flysch sediments west of Chiang Khan. The flysch seems to be overthrusted above the P3 Formation, which crops out to the east. It is assumed that this flysch is contemporaneous with the flysch from the Petchabun Fold and Thrust Belt and marks the northern continuation of this orogenic belt. In this case the Permian flysch in Thailand is traced for a distance longer than 150 km in a N-S direction.

The ratio of arenite to pelite or T1-4:T5 is 1.6:1, which when compared with the flysch outcrops from the Lom Sak - Chum Phae highway, where this ratio is 1:1, suggests a more proximal character for the northern flysch occurrence. Nevertheless, both exposures are classical turbidites deposited on a lower fan. No pelagic sediments were found west of Chiang Khan.

2.17.5. East of Chiang Khan area.

East of Chiang Khan, outcrops along two roads were visited. The northern road is a highway to Si Chiang Mai and Sang Khom, running along the Mekong River (fig.:29). This road crosscuts Paleozoic rocks of Siluro-Devonian and Carboniferous age between 101°44'E and 102°14'E longitude. These rocks belong to the Variscan Loei Fold Belt (see 1. - 1.1.). The rocks consist of pre-Frasnian metamorphics, Lower Frasnian to Middle Devonian strongly folded dark ribbon cherts, shales, fine graywackes, conglomerates, and fossiliferous limestones. These SW-vergent folded and cleavaged strata are covered unconformably by gently folded Uppermost Devonian to Carboniferous conglomerates with clasts of chert, shales, graywackes, and fossiliferous limestones. The Upper Paleozoic sediments are interpreted as late orogenic to postorogenic deposits (ALTERMANN et al. 1983).

The southern road running from Ban Huai Phot (approximately 20 km south of Chiang Khan, at road No.: 201 to Loei) to Nam Som (17°46'N; 102°11'E) crosses similar lithology to the road along the Mekong (fig.:29). Between Nam Som and Suwan Khu Ha (17°34'N; 102°17'E), two NNW-SSE striking sequences are mapped by SUDASNA & VEERABURUS (1979) as P1 – Lower Permian Phu Tham Nam Maholan Fm. WIELCHOWSKY & YOUNG (1985) mapped these areas as a massive to bedded reef complex and well-bedded platform carbonates of Asselian to Early Guadalupian age.

The present author visited the outcrops east of Nam Som and found mainly ?Mesozoic volcanic rocks, which are missing on the geological map by SUDASNA & VEERABURUS (1979). The volcanics create a mountainous landscape, resembling lime karst mountains. The limestones mapped by WIELCHOWSKY & YOUNG (1985) are located a few kilometer south of the volcanics. These limestones probably belong to the postorogenic cover of the Devono-Carboniferous Loei Fold Belt. They represent the same environment as the limestones from the area of Wang Saphung or Nam Prom Dam.

3. Volcanic rocks.

The abundance of volcanic rocks associated with the sedimentary rocks described makes it necessary to consider the aspect of volcanism and its effects in Thailand. Several writers have already investigated the problem of Paleozoic to Mesozoic volcanism and magmatism in Thailand. The scope of the present chapter is to mainly discuss the Lower Permian volcanics of the areas described in chapter 2. Nevertheless the results of previous authors have to be first summarized.

BUNOPAS & VELLA (1978), gave an overview of Paleozoic to Mesozoic volcanic belts of Thailand, which is shown in fig.:36. Of course these volcanic belts are a part of the geotectonic model proposed by these authors (see 1.1.). The belts represent a stationary volcanic arc (Silurian to Mesozoic), related to a westward subduction of oceanic crust beneath the Shan Thai Craton. In this case volcanism of an intracontinental rifting character should be followed by ocean spreading volcanics, then by subduction, and later, by collision related volcanism and, finally, by post-collisional volcanism and magmatism.

MACDONALD & BARR (1978) have analysed the Late Carboniferous "volcanic arc" of N Thailand between Chang Rai and Chiang Mai. They come to the conclusion, that these volcanics are of tholeiitic magma origin, similar to island arc – low potassium tholeiites. The thin section petrology is described to "... consist essentially of clinopyroxene (augite or titanite) and plagioclase (andesine - labradorite), commonly accompanied by forsteritic olivine" and the rocks are termed as basaltic (MACDONALD & BARR, 1978; p.152).

BARR et al. (1985) describe from the San Kampaeng area (ca. 25 km E of Chiang Mai), from the southern outcrops described above as Late Carboniferous "volcanic arc", apparently Permian volcanics. It is suggested by these authors that all of the Late Carboniferous arc is Permian.

A drill core of an exploration well GTE-1, consisting of mainly porphyritic and amygdaloidal basalts, with subordinate crystal- and lithic-crystal tuffs and basaltic dikes and pillowed units is described. Within these volcanic rocks a Permian limestone is intercalated. It seems not to be clear whether the contact is of a tectonic origin or not. Both, limestone and volcanics are complexly deformed and metamorphosed to sub-greenschist facies. The volcanics are said to consist mainly of clinopyroxene and altered plagioclase. Questionable olivine phenocrysts, completely pseudomorphosed by chlorite are also mentioned. Contrary to MACDONALD & BARR (1978) the rocks were identified on the basis of immobile trace elements as of continental tholeiitic affinities. High TiO_2 (2-3%), Nb/Y less than 1, high Ti/Y (600 to 700) and high zircon (average 166 ppm) are most characteristic for these rocks and consistent with those previously reported from the surface outcrops from the southern part of the Late Carboniferous "volcanic arc". Though, BARR et al. (1985), try to apply the westward subduction model of BUNOPAS & VELLA (1978), they interpret the belt as giving no evidence for a paleosuture. They believe it more likely to be an interplate rift volcanism, probably located west of the Permian subduction zone.

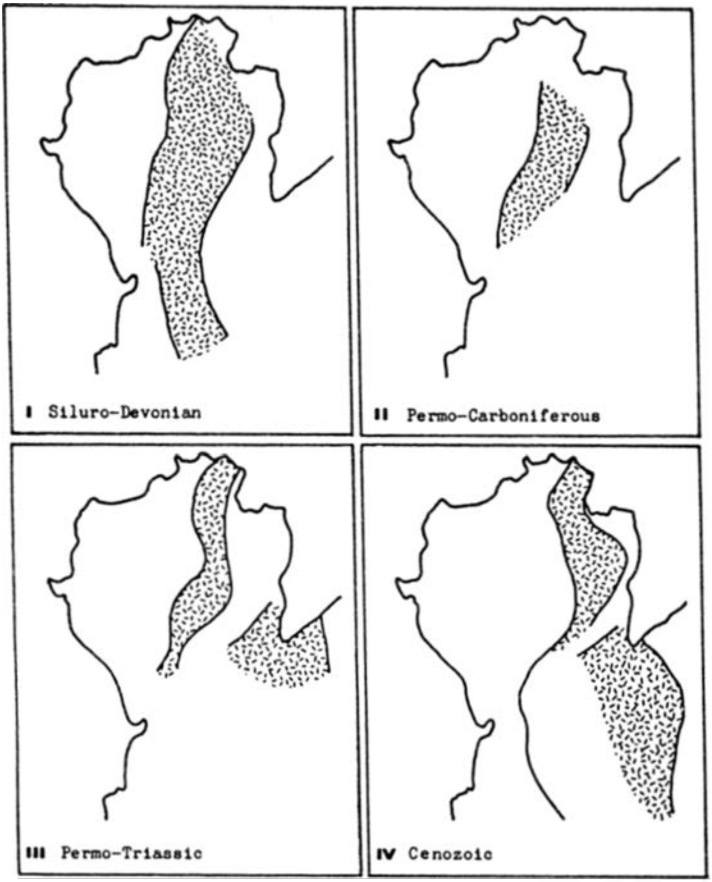


Fig.: 36. Volcanic belts of Northern Thailand (BUNOPAS & VELLA, 1978).

The Nan Uttaradit "ophiolites" which lies east of the Permian or Late Carboniferous belt described above were investigated by MACDONALD & BARR (1984). In this paper the authors report for the first time crossite bearing blue schists in SE Asia. Metagabbros, epidote amphibolites, metabasalts and ultramafic rocks, which elsewhere in the literature are regarded as true ophiolites, are described in this paper as of closer affinities to a volcanic arc setting than with MORB. A close relation to calcalkali basalts is stressed, as well as a relationship to the volcanic belt between Chiang Rai and Chiang Mai. Again the Nan River belt is claimed to be more proximal and the Chiang Rai - Chiang Mai belt more distal to the Permo-Carboniferous westward subduction complex.

MACDONALD et al. (1985; p. 25) use more powerful words for this Nan mafic-ultramafic belt: "The apparent lack of oceanic geochemical characteristics in the mafic rocks, as well as the apparent absence of pillowed basalts and sheeted dike sequences, suggests that the mafic-ultramafic sequence does not represent true ophiolites and that significant obduction of ophiolite did not occur during the closure of any ocean basin originally separating the two cratons", (Shan Thai and Indosinia).

Independently from MACDONALD, BARR and their co-workers, DAMM & HELMCKE (1985) has investigated the Nan Uttaradit belt. Their geochemical results confirm largely those of MACDONALD & BARR (1984). Additionally for the first time, radiometric ages were obtained from these mafic-ultramafic rocks. The K/Ar ages give an average 344 +/-22 Ma and are interpreted as the age of the orogenic metamorphic event i.e. the youngest possible age of these rocks.

BUNOPAS (1981) describes also Lower Permian, Upper Permian to Lower Triassic and younger volcanism. The Lower Permian volcanics are only described as tuffs and fine agglomerates of acidic composition restricted only to a small area N of Lam Pang (N Thailand).
In this paper the Devono-Carboniferous Nan Uttaradit belt seems to be dated as Upper Permian.
From SE Thailand, (Sra Kaeo Province) spilitic pillow lavas are described. According to BUNOPAS (1981) these spilites are unconformably overlain by limestone of Upper Permian age. They are regarded to be the southern continuation of the Nan Uttaradit belt.

The Upper Triassic to Lower Cretaceous volcanics are described by BUNOPAS (1981) and HAHN (1976) as rhyolites, (alkali rhyolites) which are the extrusive pendant of the S-type granites, widespread in SE Asia.

The youngest volcanism in Thailand is Cenozoic. It has been widely researched by several workers because of its abundance and its gem content (mainly sapphires and rubies). All the authors agree on the intracontinental, basaltic nature of these young volcanic rocks.

The writer has investigated only the volcanics of the Upper Carboniferous to Lower Permian in Loei and Petchabun areas. Contrary to BUNOPAS (1981), not only a small area of Lower Permian volcanics, but a strip from the Saraburi - Pak Chom highway in the south up to the outcrops N of Loei, could be traced. Though the volcanics found are tuffs and tuffites interbedded with carbonates, they could be dated by the foraminifera. All the occurrences are of Permian or Upper Carboniferous age.
To clarify the nomenclature in the description of these rocks there is a need to specify at least three terms:
According to SCHERMERHORN (1973),

A) quartzkeratophyres are leucocratic sodic felsic volcanic rocks which are divided into two types:
   I. quartz-albite phyric (quartz phenocrysts bearing).
   II. albite phyric (quartz present only in the vesicles and matrix).

B) Keratophyre is a leucocratic sodic intermediate albitephyric volcanic rock. In both, quartzkeratophyre and keratophyre, mafic components are generally absent or rare.

C) Spilite is a mafic volcanic rock which is generally amygdaloidal and containing albite (to oligoclase), epidote, hematite and chlorite. Quartz is generally only present in the matrix. Pyroxene and olivine are always absent. Characteristic is the low K_2 and high Na_2 content (AMSTUTZ, 1974).

The "spilite problem" and the origin of quartzkeratophyres, keratophyres or spilites will not be discussed here. Neither the opinion that they are of primary or differentiated magma origin, nor their partial melting origin or the point of few that they represent altered or metamorphosed alkalirhyolites, alkalitrachytes and basalts can be supported or denied by the present investigation. Nevertheless their roll in Paleozoic fold belts is seen as initial magmatites and volcanics, predating the flysch sedimentation and the onset of folding. This feature of the quartzkeratophyre – spilite suite has been sufficiently shown by several scientists in describing the European Variscides (LEHMANN, 1974; SCHERMERHORN, 1970; RÖSLER & WERNER, 1979; SCHÜTZ, 1985).

The thin sections descriptions and the analysis of the samples with an X-ray fluorescence spectrometer (XRF-Phillips, courtesy Prof. Dr. L.J.G. SCHERMERHORN) were complicated by the fact, that the samples are pyroclastic (and epiclastic) volcanic rocks. The volcanic particles in the tuffs and tuffites seldom reach the size of fine lapilli (2mm) and the rocks are "contaminated" by sedimentary, mainly carbonatic influx. For that reason the Ca-content could not be used in the diagrams and is not diagnostic. For the same reason the Sr value is probably too high in the samples. Since no dolomite was found in the thin sections, the MgO content has been plotted in the AFM-triangle. The contamination by the sedimentary $CaCO_3$ also explains the relatively high percentage loss on ignition in many samples. During the preparation for the XRF-analysis the samples were probably contaminated with chromium and nickel.
Before handling with the XRF-results additional remarks on some samples have to be made.
The sample WA82/173 is a basaltic dike, which crosscuts the Lower Permian carbonates and tuffites and exhibits a narrow zone of contact metamorphism.
The sample WA82/163 is a sill folded within probably Upper Carboniferous to Asselian strata (regional arguments).
The sample Ru82/51 has been also described by WINKEL (1983) as taken from a sill folded within Middle Permian strata.
The sample WA84/18 and WA85/14 are tuffites, which contain-an extremely high value of sedimentary carbonate. For this reason the total amount of the major elements is substantially decreased relative to CaO and the loss on ignition.

3.1. XRF - Analysis and discussion.

The aim of the XRF - Analysis was mainly to render a possible comparison of the Upper Paleozoic volcanism in Thailand with the volcanism and magmatism in the Variscan mountain chains of Europe. The difficulty in this discussion is founded in

Sample No.	WA 82/29	WA 82/31	WA 82/36	WA 82/70	WA 82/72	WA 84/18	WA 82/159	WA 82/160	WA 82/163	WA 82/173	WA 85/11	WA 85/14	Ru 82/13	Ru 82/18	Ru 82/19	Ru 82/21b	Ru 82/35	Ru 82/51
Locality & age	N'Loei Ass-Sak	N'Loei Ass-Sak	N'Loei Ass-Sak	N'Loei Ass-Sak	N'Loei Ass-Sak	Nong Pai Asselian	E'Nong P UC-Ass	E'Nong P UC-Ass	E'Nong P UC-Ass	Nong Pai ?R-??	E'Pet'bun UC-Ass	E'Pet'bun UC-Ass	LM-CP rd UC-Ass	LM-CP rd Asselian	LM-CP rd Asselian	LM-CP rd Ass-Sak	LM-CP rd Bol-Mur	H.N.Duk Bol-Mur
Rock name & symbol	Tuffite ■	Tuffite ■	Tuffite ■	Tuffite ■	Tuffite ■	Tuffite ○	Tuffite □	Tuffite □	Sill □	Dyke ◆	Tuffite ◨	Tuffite ◑	Tuffite ◨	Tuffite ◨	Tuffite ◨	Tuffite ◨	Tuffite ◨	Sill ◨
% SiO_2	57.67	55.70	54.87	60.00	56.19	45.93	68.28	55.97	57.74	49.98	60.11	51.72	63.64	70.83	71.38	62.65	60.69	62.05
Al_2O_3	14.72	17.50	16.31	13.86	14.33	15.56	13.12	16.81	14.98	18.90	15.73	8.50	15.20	18.45	15.40	17.07	16.38	15.31
Fe_2O_3 tot.	6.63	4.90	5.68	5.95	6.02	7.53	4.61	11.05	5.93	11.80	9.83	3.51	6.70	2.30	4.62	3.72	3.50	4.96
MgO	4.73	4.10	4.62	4.18	4.13	6.29	1.08	3.42	2.70	3.53	3.26	0.75	2.24	0.82	1.63	1.07	1.08	1.53
CaO	4.70	4.60	5.43	4.67	6.52	9.34	5.55	3.50	8.14	9.42	2.11	17.64	2.05	0.23	0.20	4.72	4.88	4.45
Na_2O	0.94	3.00	3.56	1.09	0.98	4.36	4.84	3.24	8.19	2.53	3.80	2.60	5.31	2.02	1.31	1.41	8.47	3.33
K_2O	2.20	2.51	1.41	2.28	2.45	0.37	0.68	0.84	0.08	0.96	0.48	0.69	0.49	1.19	0.97	1.37	0.43	1.74
TiO_2	0.96	0.87	0.76	1.02	0.95	0.59	0.59	0.95	1.39	0.90	1.21	0.33	0.80	0.41	0.45	0.69	0.67	0.34
P_2O_5	0.32	0.38	0.33	0.32	0.32	0.13	0.16	0.10	0.24	0.30	0.13	0.11	0.18	0.04	0.06	0.08	0.14	0.15
MnO	0.05	0.04	0.05	0.05	0.06	0.04	0.11	0.30	0.12	0.19	0.04	0.16	0.13	0.07	0.10	0.14	0.03	0.11
Loss on ignit.	7.25	6.57	7.11	6.85	8.32	9.98	0.52	4.00	0.61	1.83	3.03	14.34	2.70	3.35	3.29	6.51	3.38	5.38
Σ	100.17	100.17	100.13	100.27	100.37	100.12	99.50	100.18	100.12	100.33	99.83	100.35	100.44	99.71	99.41	99.45	99.65	99.08
ppm Sc	18	20	20	17	16	20	21	29	35	29	21	12	20	8	9	18	13	10
V	88	135	114	92	81	110	99	208	313	300	202	51	102	45	54	79	75	72
Cr	32	31	47	32	25	21	212	55	30	28	129	37	60	8	34	36	180	50
Co	18	12	12	16	14	20	8	26	11	31	22	8	15	4	7	9	8	10
Ni	14	8	9	14	12	6	15	34	1	9	13	7	4	3	6	10	28	3
Cu	12	156	13	9	11	10	10	34	1	116	33	8	16	7	16	14	36	•3
Zn	119	81	88	100	90	82	18	89	14	85	86	30	70	36	49	60	20	44
Ga	18	17	15	16	15	13	12	20	16	20	16	9	17	17	14	18	14	16
Rb	63	73	39	64	62	5	7	12	•1	12	8	13	7	25	20	33	5	48
Sr	79	105	116	79	95	358	520	194	288	543	166	419	211	593	357	439	408	439
Y	39	40	40	39	38	35	24	22	36	27	21	22	31	25	22	26	15	20
Zr	185	138	113	179	167	74	55	76	87	68	103	69	142	166	130	175	137	92
Nb	7	4	4	7	6	2	3	2	3	2	4	3	4	5	3	5	4	3
Sn	2	3	2	2	1	2	2	1	3	2	3	2	1	1	3	1	2	2
Ba	246	167	108	256	187	61	305	263	139	590	114	120	305	249	181	151	47	667
Hf	4	1	3	5	4	1	•0	2	0	1	1	1	2	6	2	5	4	3
Ta	1	2	•1	2	2	1	1	•0	0	3	2	0	•0	1	1	1	3	1
W	3	5	5	5	3	2	7	1	1	•0	5	5	6	1	3	3	4	3
Pb	8	6	8	9	5	5	4	8	4	6	5	10	10	12	10	14	5	7
Th	8	7	4	7	6	2	3	3	3	2	1	2	4	7	4	4	3	5
U	3	6	6	1	4	1	1	1	1	1	1	1	1	3	1	3	1	1

Fig.: 37. XFA-results of the volcanites. The symbols remain identical in all the following figures the fact that the descriptions of the European Variscides concentrate on the geochemical investigations of lavas and normally do not treat tuffs and tuffites.

Fig.:37 shows the measured values for the 18 samples from Thailand. In all the diagrams, the symbols used to distinguish the samples from different areas remain identical. Sample WA82/173 – post-Paleozoic basaltic dike, and the samples WA84/18 and WA85/14 – tuffites, which are most strongly contaminated by sedimentary calcite, have varying symbols from the other samples because of their unigueness. Reading the diagrams one should keep in mind, that when reading absolute values, contaminated samples usually have lower absolute values than samples uncontaminated by sediment.

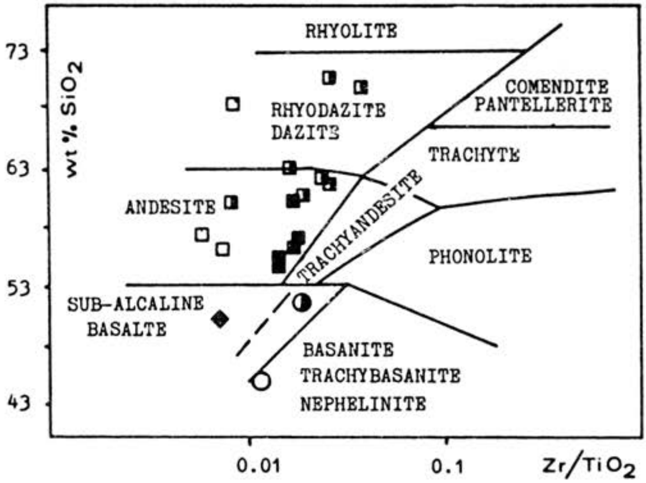


Fig.: 38. Volcanic samples in the SiO_2-Zr/TiO_2 diagram (WINCHESTER & FLOYD, 1977).

Using the SiO_2-Zr/TiO_2 diagram of WINCHESTER & FLOYD (1977), the samples plot in the sub-alkaline basalte, andesite and rhyodacite-dacite fields. Here, when recalculating the contamination by carbonate, only the SiO_2 values would increase and than the samples would plot between the andesitic and rhyolitic field. In this diagram WA82/173 shows a subalkaline trend (fig.:38).

Using the TAS-diagram (Total Alkali Silica), as proposed by ZANETTIN (1984), the samples plot in the basaltic-andesite, andesite, dacite and trachyandesite fields. Only WA84/18; WA85/14 and WA82/173 are in the basalt field. Only WA82/173 is truly basaltic, WA82/163 is a true trachyandesite, and Ru82/51 is a true andesite. All the other samples should plot in the andesite - dacite - trachyte field, if they were not more or less strong contaminated by sedimentary carbonate.

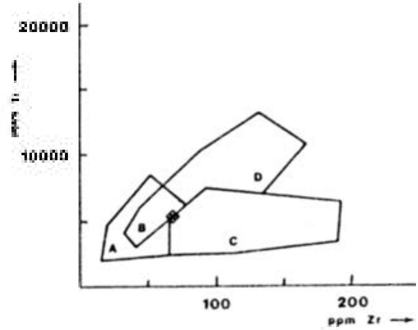


Fig.: 39. WA82/173 - basaltic dike, in the Ti/Zr diagram (PEARCE & CANN, 1973).

A+B = island arc tholeiites.
B+C = calcalkali basalts.
B+D = ocean floor basalts.

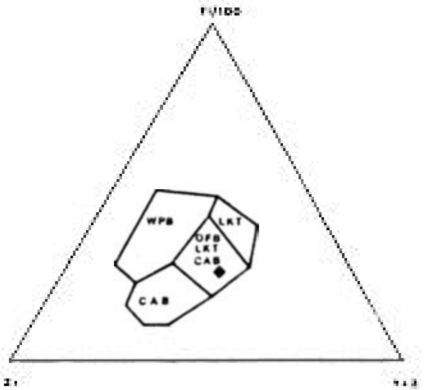
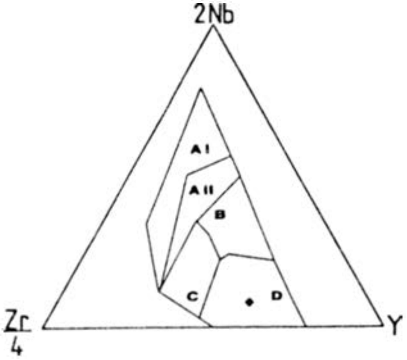


Fig.: 40. WA82/173- basaltic dike, in the Ti/Zr/Y diagram (PEARCE & CANN, 1973).

CAB = calcalkali basalts.
WPB = within plate basalts.
LKT = low K tholeiites.
OFB = ocean floor basalts.



AI = WP alkali basalt.
AII = WP alkali basalts & WPT.
B = P-type MORB (plum influenced).
C = WPT & VAB.
D = VAB & N-type MORB.

Fig.: 41. WA82/173 - basaltic dike, in a Nb/Zr/Y diagram (MESCHEDE, 1986).

In the TAS diagram the Hawaii composition line (MACDONALD & KATSURA, 1964) is added to differentiate the alkalic and tholeiitic magmas. Only the WA84/18 – tuffite, the Ru82/35 – tuffite, and the WA82/163 – subvulcanite plot in the alkaline field. Even when recalculating the sedimentary carbonate content, a number of samples would not reach the alkaline field, because the SiO_2 values would also increase. This feature is significantly different from the Middle European Variscan initial magmatites. Similarly, when we compare the volcanism of Thailand with the European Variscides in the same diagram but using KUNO's (1968) differentiation of alkaline and tholeiitic series, the result is the same. In that diagram (fig.:42) the samples plot closer to the alkaline field and three of them are even in the field of Lahn-Dill quartzkeratophyres (FLICK, 1978).

The sample WA82/173, from the post-Paleozoic basaltic dike was put on the Ti/Zr diagram and on the Ti/100 - Zr - Y×3 diagram (PEARCE & CANN, 1973). In both diagrams it plots in the calcalkaline basalt area (fig.:39 & 40).

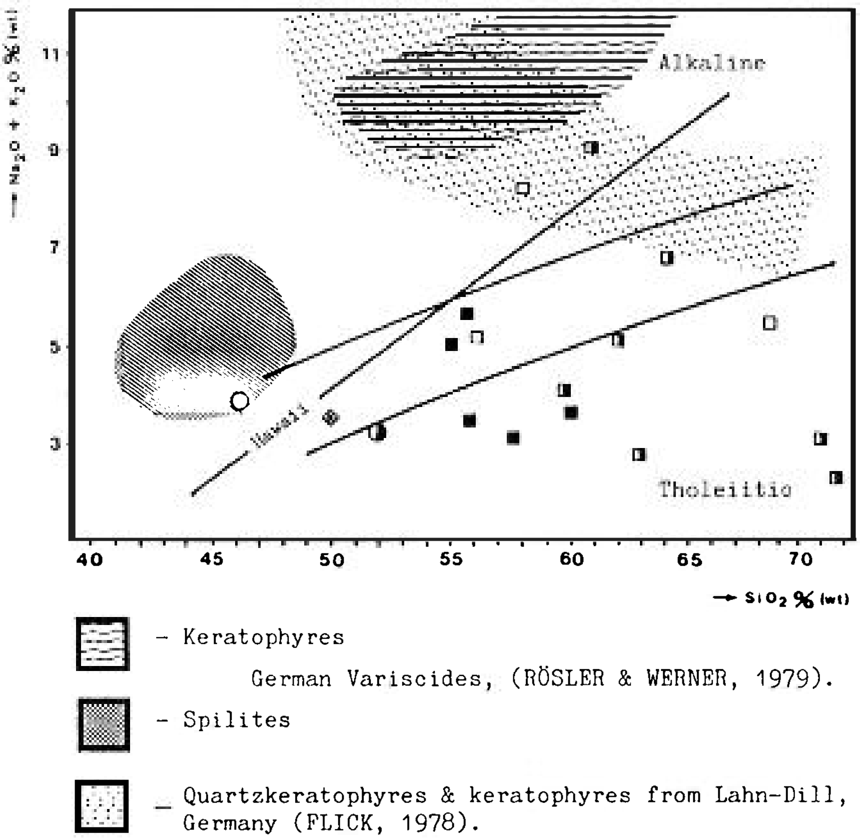


Fig.: 42. Comparison of the samples from Thailand with the lavas of the European Variscides. Alkaline and tholeiitic fields after KUNO (1968); ZANETTIN (1984).

In the recently published Nb-Zr-Y discrimination diagram (MESCHEDE, 1986) the same sample plots in the N-type MORB and island arc field (fig.:41).

The main reason for the significantly lower alkali content of the volcanics of Thailand, when compered with those from Europe, might be based on the fact that the values for the European rocks are from lavas, which are more resistent to alterati on than tuffites. SCHÜTZ (1985) has compared the K_2O-Na_2O values for the quartzkeratophyric lavas and tuffs from the SW-Iberian Pyrite Belt and pointed out that the lavas contain on average double the values of alkalies than the tuffs. In fig.:43 the samples from Thailand are plotted against the lava and tuff fields in a Na_2O-K_2O diagram of SCHÜTZ (1985). The resulting agreement is highly correlative. Two samples do not plot in the field of tuff (Ru82/35 and WA82/163). The

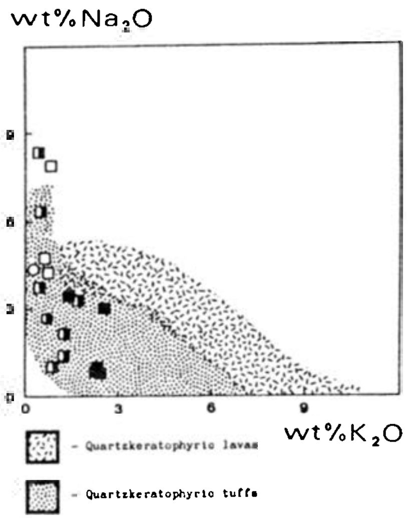


Fig.: 43. Tuffites from Thailand and Variscan quartzkeratophyres from Spain (SCHÜTZ, 1985).

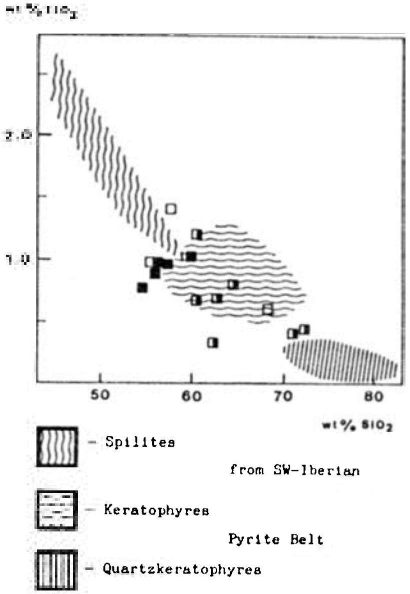


Fig.: 44. In this TiO_2/SiO_2 diagram, the tuffites from Thailand plot between the spilite and quartzkeratophyre field of SCHÜTZ (1985).

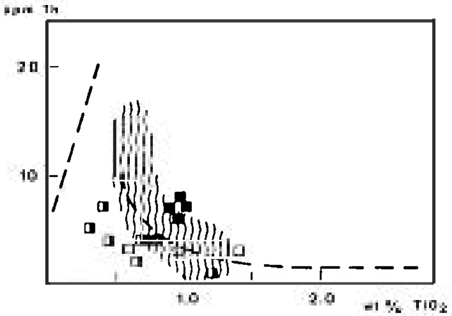


Fig.: 45. The tuffites from Thailand exhibit similarities with the keratophyres from the Pyrite Belt.

latter one is taken from a sill and not a tuffite. The other sample from the sill (Ru82/51) plots in the tuff area but on the border of the lava field. The decreasing values of the alkalies from lavas to tuffs can also be seen in thin section. The feldspars in the tuffites are generally more strongly altered than in the two samples from the sills.

The similarity of Thailands Paleozoic keratophyres to the volcanism of the SW-Iberian Pyrite Belt can also be shown on diagrams depicting the modality of the magma origin. The quartzkeratophyre – spilite association of the European Variscides,

Sample No.:	WA 82/173	WA 85/11	WA 85/14	Ru 82/13	Ru 82/18	Ru 82/19	Ru 82/21 b	Ru 82/35	Ru 82/51
Locality & age	Nong Pai ?R-T?	E' Pet'bun UC-Ass	E' Pet'bun UC-Ass	LM-CP rd. UC-Ass	LM-CP rd. Asselian	LM-CP rd. Asselian	LM-CP rd. Ass-Sak.	LM-CP rd. Bol-Mur	H. N. Duk Bol-Mur
Rock name & symbol	Dyke ◈	Tuffite ◨	Tuffite ◑	Tuffite ◨	Tuffite ◨	Tuffite ◨	Tuffite ◨	Tuffite ◨	Sill ◨
$\tau=\frac{Al_2O_3-Na_2O}{TiO_2}$	18.19	9.14	17.78	11.09	40.00	31.26	22.64	11.80	35.14
$\sigma=\frac{(K_2O-Na_2O)^2}{SiO_2-43}$	1.73	1.07	7.62	2.24	0.37	0.18	0.40	4.48	1.35

Sample No.:	WA 82/29	WA 82/31	WA 82/36	WA 82/70	WA 82/72	WA 84/18	WA 82/159	WA 82/160	WA 82/163
Locality & age	N' Loei Ass.-Sak.	N' Loei Ass.-Sak	N' Loei Ass-Sak.	N' Loei Ass-Sak.	N' Loei Ass-Sak	Nong Pai Asselian	E' Nong P. UC-Ass	E' Nong P. UC-Ass.	E' Nong P. UC-Ass
Rock name & symbol	Tuffite ■	Tuffite ■	Tuffite ■	Tuffite ■	Tuffite ■	Tuffite ○	Tuffite □	Tuffite □	Sill □
$\tau=\frac{Al_2O_3-Na_2O}{TiO_2}$	14.32	16.63	16.75	12.70	14.03	18.96	14.03	14.25	18.19
$\sigma=\frac{(K_2O-Na_2O)^2}{SiO_2-43}$	0.67	2.38	2.08	0.67	0.89	7.62	1.20	1.28	4.63

Fig.: 46. RITTMANN's σ & τ values of the tuffites from Thailand. See text for explanation.

has often been described as a bimodal magmatism, which is typical for intracontinantal rifting, when it is alkali accentuated.
SCHÜTZ (1985) pointed out that for the SW-Iberian rocks the SiO_2 bimodality is not unequivocal but the spilites, keratophyres and quartzkeratophyres plot in separate fields on the TiO_2 - SiO_2 diagram. A better bimodal distribution results in a Th - TiO_2 diagram. The Paleozoic volcanic samples from Thailand, excluding the highly contaminated tuffites WA84/18 and WA85/14, were applied to the same diagrams. In both figures (fig.:44 & 45) the tuffites follow the trend of the volcanics from Spain and plot within or close to the keratophyre field of SCHÜTZ (1985).

GOTTINI GRASSO (1968) and RITTMANN (1968) have introduced the τ-quotient to differentiate the simatic and the sialic magmas.

$$\tau = (Al_2O_3 - Na_2O)/TiO_2 \text{ (wt\%)}$$

According to these authors, simatic, mantle-related magmas have values of $\tau < 10$. Values higher than 10 are typical for crustal contaminated or sialic – palingenic magmas.
According to RÖSLER & WERNER (1979), the Rhenoherzynian quartzkeratophyres have on average $\tau=25.8$ and the Saxothuringian quartzkeratophyres on average $\tau=22.2$. The keratophyres from the Rhenoherzynian zone have $\tau=14.6$ on average and the Rhenoherzynian spilites a $\tau=4.5$. The spi-

lites from the Saxothuringian zone have on average a volue of $\tau=3.9$. Following these values an "oceanization" in time of the magma types can be postulated for the European Variscides.

The τ-values of the volcanics from Thailand are given in fig.:46.

Their average of $\tau=17.15$ (WA82/173 not considered) is in between the values of the keratophyres and quartzkeratophyres from Europe. Only two values are lower than 10, most represent crust-contaminated magma. Indeed most of them are contaminated by sediment. The reliability of the τ-quotient as a selector of crustal and mantle material is not discussed here. RÖSLER & WERNER (1979) claim for the volcanics of Saxothuringian zone an intracontinental magma character and for the Rhenoherzynian zone intracontinantal or island arc magma origin.

Fig.:47 is a diagram, in which the τ-index (log) is plotted against the log of RITTMANN's (1973) relativity index-σ.

$$\sigma = (K_2O + Na_2O)^2/SiO_2 - 43$$

In this diagram the A-field represents lavas of volcanoes in non-orogenic zones. The B-field represents lavas of volcanoes in orogenic zones and island arcs. C-field is a mixed area of both types, where the Na-accentuated alkalivolcanics generally plot near A and the K-accentuated are located closer to B.

According to RÖSLER & WERNER (1979) the Mid-European quartzkeratophyres plot in the orogenic field, whereas the keratophyres plot in orogenic and mixed field, and the spilites mainly in the mixed field. The volcanics from Thailand, plot nearly exclusively in the orogenic field. Only two samples are in the mixed and one in the non-orogenic area, but near the ABC-triple point. The latter sample is the WA82/163 – subvulcanite. It is suprising that the post-Paleozoic basalt sample (WA82/173) also plots in the B-area.

The orogenic series or the "basalt - andesite - dacite - rhyolite suite" of RINGWOOD (1974) are a calcalkaline series. On the AFM diagram (fig.:49) the samples from Thailand plot in the calcalkaline field. Only the sample WA82/173, post-Paleozoic dike and the sample WA82/160 are in the tholeiitic field. The first sample, is in good agreement with RINGWOOD (1974) as to the gabbroic to basaltic magmatite crustal environment. The keratophyres and quartzkeratophyres from the Lahn-Dill mountains plot generally as calcalkalines and the spilites as tholeiites (FLICK, 1978).

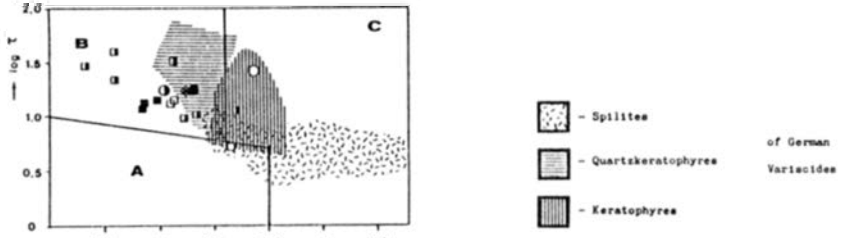


Fig.: 47. Comparison of the tuffites from Thailand with the German Variscides (RÖSLER & WERNER, 1979).

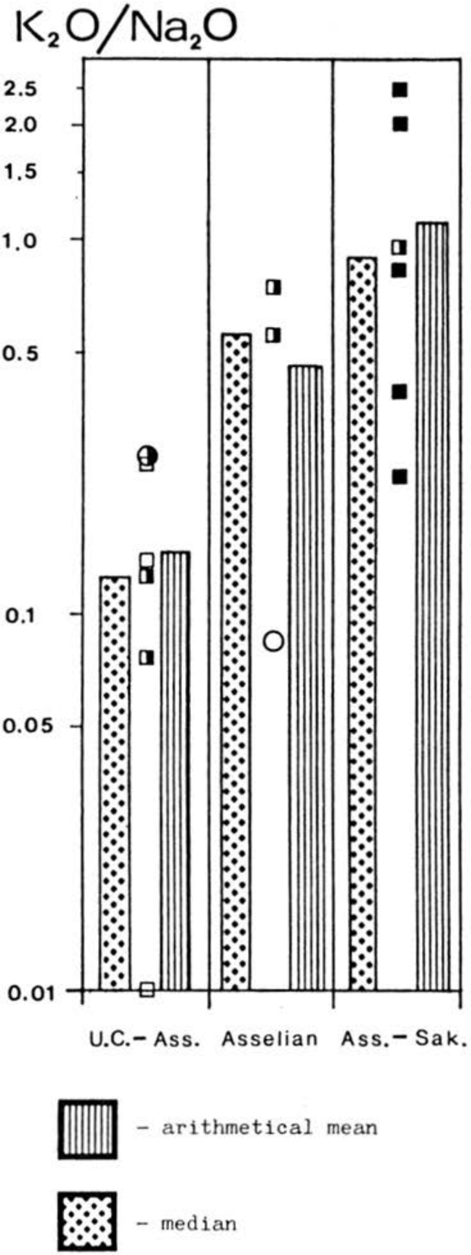


Fig.: 48. Increase of the K_2O/Na_2O ratios of the tuffites from Thailand with time. Compare with RINGWOOD, 1984.

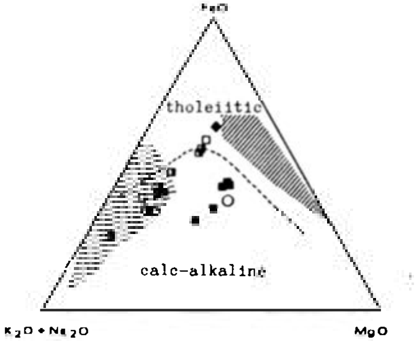


Fig.: 49. Samples from Thailand in the AFM diagram compared with the spilites and keratophyres from the Lahn-Dill, Germany (FLICK, 1978).

The increase of the K_2O content with the maturing of island arcs has been described by many authors. From the European Variscides a similar behaviour of the magmatism is well documented, though the Variscan orogeny in Europe is generally interpreted as "intracontinental". Less conservative interpretations also admit the possibility of an island arc collision or accretion.

Young island arcs are, according to RINGWOOD (1974), characterized by low K/Na ratios whereas evolved arc volcanism has high K/Na ratios. The orogenic magmas becomes more alkalic with increasing distance from the trench, e.g. with the increasing distance from the Benioff zone. As can be seen in fig.:37 a general incre-

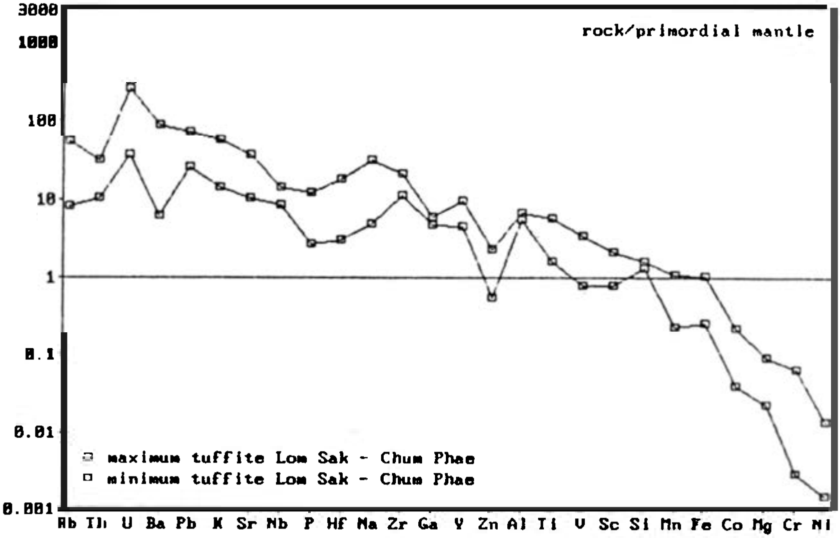


Fig.: 50. Rock/primordial mantle diagram (SCHERMERHORN, pers. comm.) of the tuffites from the Lom Sak - Chum Phae highway. The enrichment of incompatible elements suggests continental input.

ase in K_2O content with time is valid for the samples from Thailand. To visualize this behavior, the K_2O/Na_2O ratios were plotted against the time table in fig.:48. The two samples of Bolorian - Murgabian (Ru82/35 and 51) plot on the same level as the Asselian samples, but the significance of only two samples is not strong enough. Furthermore it must be added that the age of Ru82/35 is the youngest possible age (secondary deposit of turbidite into a pelagic basin) and the age of Ru82/51 is the oldest possible one (sill within the pelagic strata). This must be also considered for the other turbiditic and sill samples. Also the Upper Carboniferous ages are not based on fossils but on regional arguments. Fig.:48 illustrates the evidence for the maturing of the orgeny.

The geochemical data of the samples investigated here do not allow any serious discussion of the source and petrogenetic synthesis of the magma. This problem still remains unsolved for the better investigated European Variscides. Only one statement is allowed: there is no evidence for oceanic (MORB) volcanism found in the area under investigation in Thailand. A strong indication for continental influenced magma is given by the standardization diagram of the Thailand rocks against the primitive mantle (SCHERMERHORN, pers. comm.). In fig.:50-52 the enrichment of incompatible elements is shown. Also the semi-incompatible elements (Nb, P, Ti, Zr, Hf) are enriched. The sharp turn towards the compatible elements is very distinct.
The fractionation patterns of the Lower Permian samples from Loei, of the samples from the Petchabun Fold and Thrust Belt, and of the post-Paleozoic dike from the vicinity of Nong Pai follow the same trend. Both, the Upper and post Paleozoic volcanism seems to be congeneric.

The geochemical characteristics of the volcanics from Thailand and those of the European Variscides show many similarities, which indicate parallel evolution. Two more points about the volcanic activity of Paleozoic Zentral Thailand resemble the European developement.

I) The volcanism in Europe, the quartzkeratophyre – spilite suite, and the volcanism in Thailand is initial. It predates the folding and the sedimentation of the flysch. It is than followed by calcalkaline volcanism and later K-rich intrusions.

II) Thailand's tuffites, when judged from the fossils and the SMF of the interbedded limestones, are closely associated with shallow water deposits. Either they were directly deposited on the shallow carbonate platform or redeposited into the deeper basin by turbidites from the platform. A paleogeographic high position for the keratophyres and quartzkeratophyres from the Lahn-Dill area is described by FLICK (1979). According to this author the Middle Devonian to Lower Carboniferous intermediate to acidic volcanism of the Lahn-Dill "geosyncline" was related to volcanic islands. These islands were intensively eroded by the sea and deposited as "keratophyre tuff" or "Schalstein".

The description of the paleogeographic position of the Lahn-Dill keratophyres by FLICK (1979) strongly resembles an island arc.

SCHÜTZ (1985) has found the evolution of the magmatism in the South Portugese Zone, as parallel to an island arc evolution and collision. The parallelism of the igneous evolution of the Paleozoic and Mesozoic of Thailand to the Variscan orogeni-

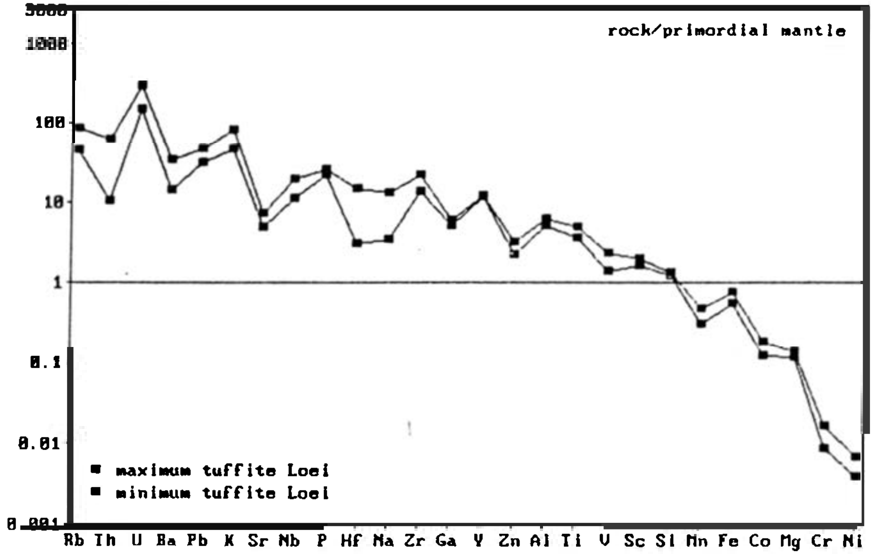


Fig.: 51. Rock/primordial mantle diagram (SCHERMERHORN, pers.comm.) of the samples from the Loei area. The enrichment of incompatible elements suggests continental influence.

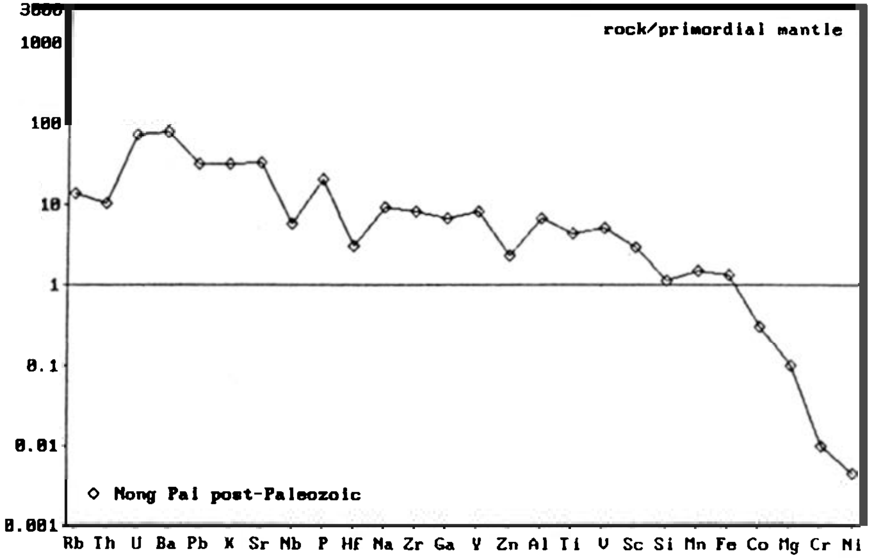


Fig.: 52. Rock/primordial mantle diagram (SCHERMERHORN, pers.comm.) of the sample WA82/173- basaltic dike. Also here continental influence is evident.

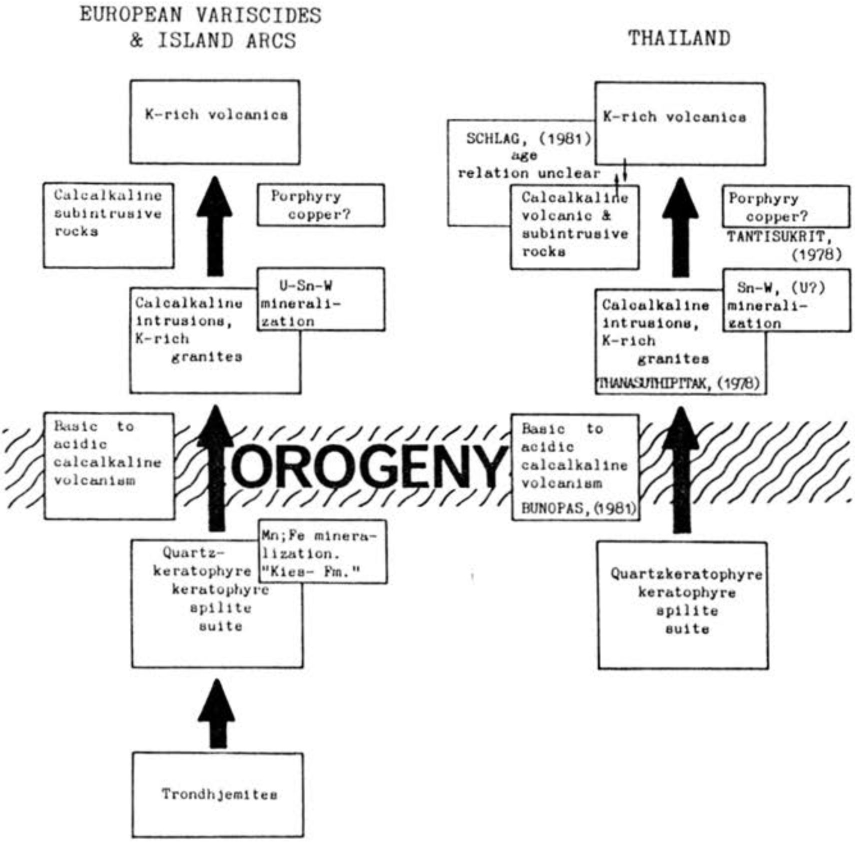


Fig.: 53. Volcanism and orogenies: left side European Variscides and island arcs after SCHÜTZ, (1985). Right hand side: Thailand – present thesis and from diverse literature.

es of Europe and to general island arc development can be postulated on the basis of the collected data and published information (summarized by THANASUTHIPITAK, 1978; TANTISUKRIT, 1978).

Fig.:53 is a speculative interpretation in which the unreliable age and geochemistry data for Thailand's post-Paleozoic igneous rocks are of course problematic.

Trondhjemites are not reported from mainland of SE Asia, but the West Thailand "Precambrian complex" seems to be favorable for trondhjemitic rocks. Precambrian has never been proven to be in this area and is only established by the degree of metamorphism and the intensity of folding.

The existence of quartzkeratophyre – spilite – suite is till now only proven by the occurrence of pyroclastites and sills. The Fe-Mn-Kies-formation is not known or does not exist in Thailand. However, the parallelism shown in fig.:53 make its existence highly probable.

The K-rich granitic intrusions and the tin belt are discussed in many papers. The age of many of the intrusions remains uncertain. At least four intrusive periods were postulated for the Peninsular Thailand (THANASUTHIPITAK, 1978), and are most probably valid for all SE Asia.

1) Late Carboniferous
2) Triassic
3) Late Triassic - Early Jurassic
4) Cretaceous

The final magmatism in fig.:53 (K-rich volcanics and calcalkalic volcanic and subintrusive rocks) is based mainly on SCHLAG's (1981) work. The age relationships of these two groups are questionable. They might even be contemporanous with the granites. SCHLAG's (1981) age dating is constructed only on geochemical characteristics and fitted into the Indosinian orogeny model.

3.2. Description of thin sections.

Before the XRF-analysis a thin section of every sample was made. All the Ru-samples were collected and already described by WINKEL (1983). Their description given here is based on WINKEL's and my own observations. The rocks has been renamed from dacitic or rhyodacitic in accordance to the nomenclature used for the European Paleozoic rocks.

Ru82/13: Keratophyric or quartzkeratophyric tuffite.
Lom Sak - Chum Phae highway, km 16.0
From a graded layer within the pelagic strata of the Petchabun Fold Belt.
Upper Carboniferous to Asselian age.
The sample contains silicic-chloritic matrix and angular to subrounded grains, poorly sorted and up to one mm in diameter. The grains consist of monocrystalline quartz, rich in inclusions, plagioclase (albite-oligoclase), K-feldspar and volcaniclasts. The volcaniclasts are of very fine crystalline quartz in vesicles and glass matrix with micro-trachytic feldspar texture (fluidal texture). They are partly chloritized. The sample shows carbonate-filled secondary veins.

Ru82/18: Keratophyric tuffite.
Lom Sak - Chum Phae highway, km 16.21.
Graded layer within the pelagic strata of the Petchabun Fold Belt.
Asselian.
In clayish-silicic matrix with sericite, chlorite and some light biotite, monocrystalline quartz grains and volcaniclasts and rare biotite clasts are present. The percentage and the size of the volcaniclasts increases rapidly towards the bottom and the matrix becomes a minor constituent. The volcaniclasts are chloritized and sericitized and exhibit both, pilotaxitic and porphyroblastic texture in the acidic plagioclase crystals in a glass matrix.

Ru82/19: Quartzkeratophyric to keratophyric tuffite.
Lom Sak - Chum Phae highway, km 16.21.
Graded layer within the pelagic facies of the Petchabun Fold Belt.
Asselian age.
The sample is very poor in silicic matrix with some limonite in clusters. Monocrystalline angular quartz grains with abundant inclusions and some "cherty" – polycrystalline quartz grains, mainly subangular, together with grains of volcaniclasts which are strongly chloritized, are present. The micro-fluidal texture of plagioclase crystals in recrystallized glass matrix resemble trachyte. Rare biotite detritus was found.

Ru82/21b: Keratophyric crystal-tuffite.
Lom Sak - Chum Phae highway, km 16.28.
Pelagic facies of the Petchabun Fold Belt.
Asselian - Sakmarian age.
Poor in matrix and strongly sericitized psammitic tuffite with detrital carbonate grains and fine, angular quartz grains. Volcanic grains with feldspar porphyroblasts or platy feldspar grains (10-20% An) are abundant. Biotite and some hematite is also present in the matrix.

Ru82/35: Quartzkeratophyric to keratophyric tuffite.
Lom Sak - Chum Phae highway, km 17.30.
Pelagic strata of the Petchabun Fold Belt.
Bolorian - Murgabian age.
The coarse psammitic tuffite is poor in silicic matrix and contains abundant volcanoclastic grains and plagioclase grains of oligoclase-albite, rare K-feldspar detritus and detrital carbonate. The volcaniclasts are of a slightly chloritized glass matrix, with some quartz in the vesicles and small feldspar crystals in aphanitic fluidal texture. The feldspar is partly sercitized and partly replaced by calcite. Zonation of plagioclase with oligoclase in the center surrounded by albite is common.

Ru82/51: Quartzkeratophyre.
Huai Nam Duk
Sill folded within the Bolorian pelagic strata of the Petchabun Fold Belt.
Youngest possible age – Murgabian on regional arguments.
An aphanitic matrix of quartz and chlorite is present with up to 6 mm large idiomorphic – blastic crystals of chloritized and sercitized plagioclase, together with idiomorphic biotite, which is also chloritized and rich in opacoide ore-minerals. Quartz is present in vesicles as well as in small, porphyroblastic crystals in between acicular chlorite and sercite. Hematite is also present in the matrix.

WA85/11: Keratophyric - quartzkeratophyric tuffite.
Huai Nam Lao.
Pelagic facies of the Petchabun Fold Belt.
U. Carboniferous - Asselian?

The sample contains volcaniclasts of trachytic and micro-porphyritic texture with albitic feldspar crystals in glass matrix, which is partly recrystallized and contains some chlorite. Some of the volcaniclasts contain Ti-minerals. The glass matrix contains some quartz. Other clasts are K-feldspar and more abundant albite or oligoclase fragments. Epidote replaces the feldspar and rare clinopyroxene has been also found. Sedimentary carbonate grains, quartz grains, and altered biotite are rare.

WA85/14: ?Keratophyric tuffite.
Huai Nam Lao.
Pelagic facies of the Petchabun Fold Belt.
U. Carboniferous - Asselian?
The sample is strongly "contaminated" by sedimentary carbonate and carbonate cement. Volcaniclastic grains are floating together with some well-rounded quartz grains and chert grains in the carbonate matrix. Two different kinds of magmatic clasts are present. The one is of a trachytic or porphyritic texture with small albite plagioclase crystals in a recrystallized glass matrix. The other one is of a granoblastic texture of quartz and plagioclase (38% An) intergrown with rare muscovite. Monocrystalline quartz grains and plagioclase and K-feldspar grains are also present. The plagioclase is partly replaced by calcite.

WA84/18: Keratophyric - ?spilitic tuffite.
Nong Pai, km 181.5.
Western platform.
Asselian age.
The sample contains mainly clasts of recrystallized glass with a very fine fluidal texture of albite crystals. The clasts are cemented by calcite and rare bioclasts exhibit narrow syntaxial rim cements. Albitized plagioclase is also present as monocrystalline, very angular grains. Chlorite is abundant and no quartz has been observed in thin section.

WA82/159: Keratophyric - quartzkeratophyric tuffite.
E' Nong Pai
Pelagic facies of the Petchabun Fold Belt.
U. Carboniferous - Asselian?
The thin section contains two layers. The coarser, psammitic layer contains volcaniclasts of a trachytic and porphyritic texture of albite or oligoclase in a recrystallized glass matrix with small quartz crystals as rare porphyroblasts and in vesicles. Rare K-feldspar grains and acidic plagioclase grains are also present as well as chloritized mica detritus. Chlorite and hematite are common in the matrix. Epidote replaces plagioclase and the matrix, and is concentrated especially along the border with the upper, pelitic layer, in which also some carbonate occurs.

WA82/160: Keratophyric tuffite.
E' Nong Pai
Pelagic facies of the Petchabun Fold Belt.
U. Carboniferous - Asselian?
The coarse psammitic tuffite, contains mainly shards of aphanitic - trachytic keratophyre which are chloritized and epidotized. Very angular clasts of porphyritic keratophyre and very angular fragments of K-feldspar and plagioclase crystals are also present. The matrix is rich in epidote and chlorite and contains additionally rare opaque ore-minerals, hematite, and goethite. Epidote also replaces most of the feldspar clasts.

WA82/163: ?Keratophyre.
E' Nong Pai.
Sill folded within the pelagic facies of the Petchabun Fold Belt.
Oldest possible age ? U. Carboniferous - Asselian.
Youngest possible age - Murgabian on regional arguments.
Doleritic texture of plagioclase, rare K-feldspar and abundant epidote and common titanite. The epidote occurs in two generations, first as crystals lobed within the plagioclase texture and replacing feldspar and the second in clusters intergrown with titanite. Light, Fe-poor biotite in small rare crystals and some chlorite also occur.

WA82/173: Basalt.
Nong Pai, km 181.5.
Dike.
Triassic - Tertiary?
Porphyritic texture of zonal plagioclase porphyroblasts in microcrystalline, plagioclase-rich matrix with ore-minerals, epidote and some chlorite, mainly in clusters. The plagioclase porphyroblasts are of bytownite and saussuritic.

WA82/29; 31; 36; 70 and 72: Keratophyric tuffite.
N' Loei.
Western platform edge.
Asselian - Sakmarian age.
These thin sections are very similar and can be summarized with one description. The samp-

les are strongly chloritized and of green a color. They are keratophyric tuffites of pelitic to coarse psammitic grain size. WA82/31 is graded. The samples contain volcaniclasts and shards of volcanic material of mainly two kinds. The first one is of an aphanitic-trachyte texture with plagioclase (albite) crystals in a glass matrix. The matrix is recrystallized and chloritized and contains often epidote and Fe-minerals. The other kind is of porphyrytic texture of plagioclase in recrystallized and also chloritized matrix. Other clasts are fragments of acidic plagioclase and some K-feldspar, rare, angular, polycrystalline quartz grains, sedimentary carbonate clasts, and rare fossil fragments. The matrix surrounding the clasts is mainly chlorite with finely scattered hematite and opaque ore-minerals. Idiomorphic pyrite also occurs. Epidote is often present in the matrix and replacing the plagioclase, which is saussurutized and exhibits replacement by calcite, sericitization and albitization.

4. Upper Paleozoic facies development in Central Thailand.

Upper Paleozoic sediments of Moscovian to Midian age were found in the study area.

4.1. Carboniferous.

West and east of the area discussed, FONTAINE et al. (1981) and FONTAINE & INGAVAT (1983) have described Lower Carboniferous deposits. West of Chon Daen, Upper Tournaisian to Visean rocks of a shallow marine facies outcrop. Periods of emergence in the Visean have been suggested. The sequence can be followed with similar facies development into the Bashkirian. On the eastern side, in Loei Province, the lowermost Tournaisian starts with conglomerates which are probably conformably overlying Devonian sandstones and shales. The Visean, Serpukhovian and Bashkirian in this region are represented by shales, limestones, and interbedded thin cherts. A sub-reefal paleo-environment is suggested (FONTAINE & INGAVAT, 1983). Moscovian is not reported from this area.
The author has found Moscovian to Upper Carboniferous outcrops in the area of Chon Daen, where the strata seem to conformably overlie the Bashkirian described by FONTAINE & INGAVAT (1983). Furthermore, previously undiscovered Carboniferous outcrops have been found by the writer between Sapsamothot and Wang Pi Kun, NW of Nong Pai, in Ban Lam Pa Yom (Khok Samrong - Tak Fa road), and ca. 23 km NNE of Khao Ta Mon. The facies indicated by the limestones found NNE of Khao Tha Mon are of inter- to subtidal conditions within the carbonate platform. Sediments of shelf lagoon of restricted and open circulation and diagenetic conditions of marine phreatic zone could be diagnosed from the petrography.
In the outcrops at Khao Chon Tho the Upper Carboniferous age is evidenced only by the sample WA82/175. All the other samples indicate Asselian age and are mainly from a subtidal shelf environment with the influence of tidal flats, barrier bars, and channels.
At Ban Lam Payom, the Upper Carboniferous is also determined from one sample only (WA82/185). Restricted platform areas to an intertidal environment are the postulated paleoconditions. Middle to Upper Carboniferous limestones crop out NE of Khao Ta Mon. Solitary corals, foraminifera and ammonites have been found in limited, badly exposed outcrops. Most probably they represent a subtidal environment in a shelf interior area.

In the Petchabun Fold Belt the author has found outcrops which are most likely Middle to Upper Carboniferous, but represent quiet different paleo-conditions than the outcrops described above. Though not proven by fossils, WINKEL (1983) has suggested an age "older than Asselian" for the westernmost exposures of the pelagic facies outcropping along the Lom Sak - Chum Phae highway. The age determination might be also strongly supported by findings of a lithologically similar pelagic sequence along the Huai Nam Lao creek – E of Petchabun.
Regional arguments suggest an age older than Asselian for these westernmost outcrops of the Petchabun Fold Belt. The strata become in general younger towards the east.

WINKEL (1983) has described the pre Asselian pelagic sediments as consisting of ribbon cherts, phyllites and tuffites, which were deposited in a deep marine regime.

Summarizing the observations of former workers and the present results, three main depositional regimes have been recognised for the Carboniferous in Central Thailand: East and west of the Petchabun Fold Belt shallow marine carbonates are located. The western carbonate platform contains some intercalated tuffites. The two shallow marine areas are separated by a deep marine basin into which turbidites transported carbonate and tuff debris from the platforms interrupting the pelagic mud and chert sedimentation.

4.2. Early Permian.

WIELCHOWSKY & YOUNG (1985) established for the Permian in Central Thailand similar facies diversification as described above for the Carboniferous. They mapped west of the study area the shallow marine, carbonate Khao Khwang Platform, and in the east, the Pha Nok Khao platform of marginal marine siliciclastic sediments and carbonates. The two platforms are separated by the Nam Duk deep marine basin. This subdivision has been widely confirmed.

For Lower Permian a wide carbonate platform (ramp) has been traced west of the line connecting Lam Na Rai with Lom Sak. During Asselian, Sakmarian and Yahtashian reefal buildups, patch reefs and associated facies belts existed on this ramp. Typical faunal communities of algae and fusulinid foraminifera, brachiopods, crinoids and bryozoa dominated the depositional area. Loferites and spongistromate, micritic limestones were deposited in restricted lagoons and on a tidal-influenced shelf.

In Ban Lam Payom area, Asselian to Sakmarian tidal flats and shelf of restricted circulation conditions are suggested by the micro-facies.

At Phu Khao Samo Rat only Yahtashian, passing into Middle Permian outcrops were found. The Yahtashian appears as conglomerate facies. The age is based on foraminifera within the clasts. The conglomerates, interpreted as intraformational breccias and transgressive conglomerates are interbedded with red siliciclastic psammites and pelites. They are most probably of Upper Yahtashian or Lower Bolorian age.

At the southern entrance to Sapsamothot, limestones containing keratophyric lithoclasts suggest Asselian age, which is not proven by fossils. This facies represents probably a shelf with open circulation conditions (outer shelf).

Asselian upper shelf to tidal flats carbonates were found somewhat west of Sapsamothot, along the road to Wang Pi Kun. Here no volcanic intraclasts were found.

NW of Nong Pai, at km 181.5 in the direction of Petchabun, mainly Asselian strata were discovered. Two samples also indicate Upper Carboniferous and Sakmarian age. Subtidal to intertidal shelf carbonates are intercalated with tuffites and tuffs of keratophyric composition. Storm or turbiditic layers and reef slope deposits are also present within the strata.

Carboniferous to Sakmarian strata have been also found south of Chon Daen, and interpreted as originated in a shallow marine carbonate environment.

The southern regions of the investigated area exhibit similar, shallow marine conditions for the Lower Permian.
Along the Saraburi - Pak Chong road only uppermost Lower Permian was found. The fossils indicate Yahtashian to Bolorian and younger age. The rocks are predominantly limestones with rare sandstones arranged in beds and lenses. They are interpreted as a platform to bypass environment. Along this road, Sakmarian was mapped by SUDASNA & PITAKPAIVAN (1976) as the Phu Phae Fm. It also represents platform carbonates.
At Thuak Khao Sompot, Asselian and Sakmarian foraminifera and algae were found in the westernmost outcrops. Again platform interior carbonates were recognized in this area. Asselian and Sakmarian platform interior carbonates were found by WIELCHOWSKY & YOUNG (1985) in the area of Thuak Khao Sompot.

The Lower Permian of the Nam Duk Basin of the Petchabun Fold and Thrust Belt (WIELCHOWSKY & YOUNG, 1985) appears to have been deposited in completely different sedimentary conditions. A pelagic basin is documented by the sediments of the Nam Duk Fm. (CHONGLAKMANI & SATTAYARAK, 1978). In this basin a thick pile of mainly ribbon cherts and black shales punctuated with distal allodapic limestones and tuffites was deposited. The limestones yield Asselian and Sakmarian foraminifera as bio-clasts. The tuffs are of keratophyric composition as already described from the western platform. WINKEL (1983) has reported a N-S, turbidite transportation parallel to the basin edge.

In the Loei - Chiang Khan area, few kilometers north of Loei, Asselian and Sakmarian rocks were found. They might represent the more proximal turbidites associated with the pelagic facies of the Petchabun Fold Belt. Fine lapilli to ash tuffs, often graded, are intercalated with ruditic to lutitic, graded, fossil debris-rich limestones. The interbedding is arranged in beds of up to several dcm thickness. Some graywackes are also interbedded. The volcaniclastic and the carbonate debris is equivalent to the strata found on the western platform (Nong Pai) and within the Nam Duk basin.

The Lower Permian east of the Nam Duk basin exhibits mixed siliciclastic and carbonate sediments. In the area west of Chum Phae and in the Nam Prom Dam area (Phu Sam Phak Nam), ALTERMANN et al. (1983) have described Yahtashian to Kubergandian strata of carbonates and siliciclastic sediments. The Yahtashian along the Chum Phae - Lom Sak road (km 79) and Chum Phae - Nam Prom Dam road is within the Pha Nok Khao Fm. of CHONGLAKMANI & SATTAYARAK (1978). The strata have been deposited in a very shallow platform regime and a near shore, restricted environment. Oncoidal and stromatolitic algae are evidence of an intertidal environment.
Along the road from Chum Phae to Loei and at Phu Pha Daeng, Asselian limestones interbedded with thin sandstone and shale beds crop out. This sequence is interpreted to be from an interior shelf regime and lagoon.
At Ban Khok Klaeng, SW of Wang Saphung, outcrops of Sakmarian age evidence marginal marine environment in which mainly carbonates, but also thin-bedded siliciclastic sediments, were deposited.

East of Wang Saphung, Yahtashian intertidal and supratidal deposits were found. The sediments are mainly of burrowed, algal and foraminiferal limestones, cross-bedded biosparites, and wavy laminated, thin-bedded siltstones.

North of Loei, along the Loei - Tha Li road and west of Chiang Khan, Asselian and Yahtashian restricted platform carbonates, and marginal marine, fine siliciclastic sediments are located. The dating of the sediments west of Chiang Khan is based on fossils found in a limestone lense within an exclusively siliciclastic strata. The data given by the fossils range from Asselian to Kubergandian.

The facies distribution for the Lower Permian in the investigated area is not significantly different than that in the Upper Carboniferous.
Outstanding is the occurrence of the Asselian - Sakmarian keratophyric volcanics, which form a perfect marker horizon. These green tuffs and tuffites are intercalated with typical platform carbonates and can be traced in similar facies probably from the Saraburi - Lop Buri junction in the south up to Loei in the north. It is proposed to group them under one name, as the Hin Kiew Unit (Asselian - Sakmarian). In Thai language, "hin kiew" means green rock, in accordance with the light green color of the tuffites. The Hin Kiew Unit has served the pelagic Nam Duk Basin as a source area for the turbidites within the pelagic sediments.
On the eastern side of the Nam Duk Basin, on the Lower Permian Pha Nok Khao shelf, no keratophyres or other volcanics were found. The tuffite strata N of Loei might be overthrusted towards the east (see below). On this side of the basin siliciclastic strata occur and the provenance direction is predominantly from the east or east-southeast. Another outstanding difference between the Khao Khwang and the Pha Nok Khao platform is the widespread absence of Yahtashian strata on the western platform.

4.3. Middle Permian.

The Middle Permian (Guadalupian or Bolorian, Kubergandian and Murgabian) heralds a new situation in Central Thailand.
In the most western outcrops, between Khok Samrong and Tak Fa, Bolorian through Murgabian reefal limestones and associated facies are exposed and cover Asselian and Sakmarian strata of a similar environment. Yahtashian strata have not been found. This Middle Permian sequence starts with ?Bolorian/Kubergandian conglomerates, sandstones and tuffites and passes into thin-bedded limestones. The Murgabian is composed of widespread coralline patch reefs which extend up to the lowermost Upper Permian.
On the Lower Permian Khao Kwang platform the onset of Bolorian seems to be marked by transgression.
In the area of Phu Khao Samo Rat probably two cycles of transgressive sediments are present, Yahtashian-Bolorian and Bolorian-Kubergandian. These cycles exhibit a westward advancing coast line. Reddish, cross-bedded sandstones with magnetite strand placers are followed by mainly carbonate conglomerate of reef debris and oncoidal and oolitic limestones. The limestone conglomerates contain dolomitized and silicified matrix and less abundant reddish sandy matrix. A very weak volcanic influx and some glauconite has been found in these rocks.

At Khao Khi Nok the outcrops are of Kubergandian to Murgabian age.
The lower part of the sequence is represented by thick-bedded carbonates of platform interior character. They are covered by partly red-colored mudstones and sandstones and silicified and dedolomitized conglomerate. The Khao Khi Nok outcrops are interpreted as shallowing upwards or regressive cycle with the regression peak in the Murgabian.
At Khao Yang Ta Po, similar conditions are exposed, but the Murgabian also contains algal and coral patch reefs. In the area of Wang Pi Kun, west of Sapsamothot, Murgabian reefal carbonates seem to rest upon Bolorian limestones.

The southern part of the study area, between Pak Chong - Saraburi and Lam Na Rai, exhibits also predominantly shallow marine conditions for the Middle Permian. Along the road from Saraburi to Lam Na Rai, the beds seem to become generally older from west to east, between km 129.0 and 142.0 (Murgabian to Yahtashian). In this area the limestones prevail, but fine-grained sandstones, siltstones, and slightly phyllitized shales are also present. The environment through the Middle Permian is of an upper shelf with lagoons, organic build-ups, winnowed edge sands, and restricted circulation areas.
Further to the east, siliciclastic sediments prevail up to km 146.0 of this road. The fine- to medium-bedded sandstones and shales lack sedimentary structures. Rare gray limestone lenses and beds, poor in fossils, are interlayered with the siliciclastic strata. These beds are interpreted as Middle Permian shelf and shelf margin deposits.
Yahtashian to Murgabian foreslope and deep shelf margin limestones have been found north of Muaklek.
The Kubergandian to Murgabian limestones between km 154 and 155 of the Saraburi - Pak Chong road are of intertidal character. Further to the east, probably basin margin fan deposits (sandstones and shales) are metamorphosed into the low grade facies.
In the Saraburi - Lop Buri area Middle Permian basin margin slope deposits of limestone, limestone conglomerate, and rare graywackes are found.
Along the Saraburi - Lam Na Rai road a thick sequence of bedded limestones of Kubergandian to Murgabian age are present. Nearly all facies variations of shallow, subtidal to supratidal environment are documented in these beds.
From the Thuak Khao Sompot area WIELCHOWSKY & YOUNG (1985) reported Asselian through Murgabian platform interior deposits. The author did not found Yahtashian in this area, but discovered Midian rocks. The middle Permian limestones represent a subtidal and intertidal environment. In the Kubergandian and Murgabian conglomerates were also formed at Khao Sompot.

The Nam Duk Basin experienced three different mechanisms of sedimentation in the Middle Permian.
During nearly the whole of the Middle Permian pelagic sedimentation of ribbon cherts and dark shales with minor punctuation of allodapic limestones occurred in a part of the basin.
At the close of Middle Permian, a thick pile of turbidites, often exhibiting complete BOUMA-cycles was deposited. This flysch sediment was dated as Murgabian on

the basis of foraminifera-clasts and ammonites (STROBEL, INGAVAT-HELMCKE & HELMCKE, pers. comm.). It is suggested, that the flysch sedimentation began in the Murgabian, at the latest, or already in the Kubergandian. The flysch can be traced from the latitude of Petchabun in the south (16°28'N) up to the Thai-Laotian border, 50 km west of Chiang Khan.
In the eastern, external parts of the basin, molasse sediments from the rising, young orogenic belt in the west, accumulated in a rapidly subsiding marine trough. This sedimentation occurred mainly in Murgabian, but started in the Kubergandian and came to an end in the Midian.

East of the molasse basin (Nam Nao Fm., ALTERMANN, 1983), on WIELCHOWSKY & YOUNG's (1985) Pha Nok Khao platform siliciclastics and carbonates of mainly marginal marine character were deposited in the Middle Permian. The environment is not much different from the one described from the same area for the Lower Permian.
Marginal marine siliciclastic sedimentation and sub- to intertidal limestones of Middle Permian age were discovered in the area of Phu Sam Phak Nam. The sedimentation pattern changes in the Bolorian - Kubergandian from predominantly carbonate to siliciclastic (ALTERMANN et al. 1983).
Similar facies development occurred in the area of Wang Saphung, where platform interior and supratidal sediments were found. East of Wang Saphung, Bolorian and Kubergandian tidal flat deposits with tempestites occur.
Probably Middle Permian siliciclastic sediments crop out along the Loei - Dan Sai road. The same strata are exposed along the Loei - Tha Li road and west of Chiang Khan, at the Mekong river. The strata are of shallow marine and marginal marine character and overlie Lower Permian limestones.

4.4. Late Permian.

Only the lowest Upper Permian (Midian) was found in the study area. Over all of Central Thailand the Midian represents shallow marine conditions and is followed by the Triassic with an angular unconformity. The few Midian outcrops west of the Petchabun Fold and Thrust Belt are located south of Ban Nong Muang, in the Khok Samrong - Tak Fa area. Red and gray, fossil rich, sparitic limestones and gray coralline boundstones evidence platform interior environment.
The Midian limestones at Thuak Khao Sompot probably represent a tidal flat depositional area.
Midian shallow marine to marginal marine deposits are part of the molasse strata of the Petchabun Fold Belt (Nam Nao Fm.) Here the Midian age is evidenced by samples from km 40.3; 40.0; 39.7; 39.29; 39.18 and 36.8 of the Lom Sak - Chum Phae highway. On the eastern (Pha Nok Khao) platform no Midian was found.

4.5. Discussion.

The Permo-Carboniferous facies development in Central Thailand proves the existence of a N-S trending marine basin and basin marginal areas. The Nam Duk Basin (CHONGLAKMANI & SATTAYARAK, 1978) was folded in Middle Permian and in the Upper Permian only a remnant shallow marine sea existed.

The Devono-Carboniferous Nan-Uttaradit suture most probably marks a pre-Permian orogeny, formed at a continental edge or by an arc – continent collision. This suture was probably closed at the latest 344 +/-22 Ma ago (HELMCKE, 1985). The suture does not contain MOR-basalts but high pressure – low temperature metamorpic, glaucophane-bearing schists typical of subduction zones (MACDONALD et al., 1985). The occurrence of volcanic (mainly andesitic?) belts in this area suggests the existence of a subduction zone from Siluro - Devonian to the end of the Paleozoic or even Triassic.
The Shan Thai orogenic realm was widely covered by mainly shallow marine carbonates during the Middle Carboniferous to Upper Permian. All over West Thailand and the Malay Peninsula, gently folded platform carbonates, not younger than lower Upper Permian, are widespread. They are clearly post-orogenic sediments.

The eastern edge of this Carboniferous to Permian platform is represented by the Khao Khwang carbonates in the area west of the Petchabun Fold and Thrust Belt. Periods of emergence in the Visean and transgressive cycles in the Yahtashian/ Bolorian and Bolorian/ Kubergandian are suggested. The volcanic activity in the Lower Permian has no oceanic character. The volcanism was limited to structural highs, which were surrounded by shallow marine platforms. Continental fractionation patterns for the keratophyres and quartzkeratophyres have been demonstrated and the similarity to an volcanic arc developement has been suggested.
The area between Thuak Khao Sompot, Lop Buri, Saraburi and Pak Chong, as already suggested by WIELCHOWSKY & YOUNG (1985), belongs to the Khao Khwang platform and was probably thrusted along the Cenozoic Mae Ping Fault Zone (KNOX & WAKEFIELD, 1983) towards the southeast. The same is true for the Khao Ta Mon outcrops. Judging from the comparison of the Permo-Carboniferous facies of the Khao Tha Mon, Thuak Khao Sompot, the area west of the Petchabun Fold Belt, and the fold and thrust belt itself, the Mae Ping Fault Zone must cross the Upper Paleozoic strata somewhere between Phu Khao Samo Rat and Khao Khi Nok and N of Khao Tha Mon as well as between Khao Tha Mon and Thuak Khao Sompot.
Limestone sedimentation was dominate on the Khao Khwang platform, but the tuffites of the Lower Permian, and rare psammitic and pelitic siliciclastic sedimentation occurred. This siliciclastic influx is more frequent in the southern part of the platform and mainly of marginal marine character. In the northern parts of the platform the siliciclastics are often in red-bed facies and mainly Visean and Middle Permian.

At least in the Upper Carboniferous a pelagic basin (Nam Duk Basin) existed. The E-W extension of the N-S trending Nam Duk Basin was probably not greater than 100 or 200 kilometers (WINKEL, 1983; WIELCHOWSKY & YOUNG, 1985). This assumption is supported by the lack of oceanic crust under the radiolarites and by the occurrence of turbidites with the pelagic sediments. The thickness of the pelagic sediments, which can be estimated as 2000 m +/-1000 m and the width of the non-restored E-W extension of the the Petchabun Fold and Thrust Belt, which is 40 to 50 kilometers, also support this calculation.

Pelagic sedimentation, interrupted by limestone and tuffitic turbidites, continued through the Lower and Middle Permian. The strongest activity of the allodapic sedimentation was in the Middle Permian (WINKEL, 1983).

In the Middle Permian (Kubergandian - Murgabian) the flysch sedimentation started, marking a strong convergent and uplift movement of the basin floor. This E-W directed tectonic activity led to an E-vergent, isoclinal folding of the basin. The westernmost parts of the Petchabun Fold and Thrust Belt are metamorphosed to greenschist facies and affected by two acts of folding (Huai Nam Lao, present thesis and HELMCKE et al. 1985).

In the eastern, marginal part of the basin, beginning in Kubergandian - Murgabian, molasse sediments were deposited as a result of the new rising mountain belt. The eastward prograding folding front affected in a less spectacular manner also the molasse sediments. The intensity of the folding in the molasse decreased toward the east and toward the younger strata. In the Midian carbonate sedimentation become dominant in the molasse.

The sedimentary sequence of pelagic, flysch, and the molasse strata represents a thick pile of coarsening-upwards sediments typical of subduction related sutures. According to LASH (1985), this coarsening-upwards arrangement of marine litofacies is even more diagnostic for convergent plate movements than the discrimination triangles of DICKINSON & SUCZEK (1979).

The western Khao Khwang platform is not strongly affected by the closure of the Nam Duk Basin and the sedimentation patterns there remained the same from the Carboniferous to Midian. Also, the eastern Pha Nok Khao platform does not show the effects of strong tectonic activity. The Pha Nok Khao platform is interpreted as the post-tectonic cover of the older Variscan orogeny located further east and now covered by the Khorat Mesozoic red beds (ALTERMANN et al., 1983). On the Pha Nok Khao platform, as far as can be proved, platform interior and marginal marine environments prevail from Asselian to Murgabian. No Midian was found in the area of the Pha Nok Khao platform.

In the area west of Chiang Khan the flysch is overthrusted on the foreland strata of the eastern older Variscan fold belt (Loei Fold Belt). This is not the only indication for the existence of huge overthrusts (napes?) in the Petchabun Fold Belt. Overthrusting on a large scale was observed by WINKEL (1983), WIELCHOWSKY & YOUNG (1985) and was strongly implied by HELMCKE et al. (1985) on the basis of illite crystallinity and vitrinite reflectance measurements. Overthrusting is also indicated by the outcrops along Huai Nam Lao, where the pelagic facies is overthrusted on the molasse sediments and the flysch is missing.

It seems possible, that the whole sequence of the pelagic, flysch and molasse sediments has been tectonically transported from the west to its present position.

The deformation style of the Petchabun Fold and Thrust Belt can be listed as follows:

- ?Pre-Asselian, metamorphosed to a greenschist facies. The suitable sediments are phyllitized. Rocks are folded to isoclinal folds with steeply dipping B-axes and show two well-developed cleavage directions.

- Lower and Middle Permian pelagic and flysch strata, low grade – sub greenschist facies metamorphosed, are single act folded into E-vergent, isoclinal folds. Slaty cleavage is well-developed. Kink bands are inclined towards the west. The strata are overthrusted.
- Kubergandian to Midian molasse strata are folded to mainly upright and tight folds. Some folds are slightly inclined towards the west. Cleavage and kink bands are generally not developed. Steep faults are frequent.

The E-vergent folds prove that the crustal shortening (subduction) was westwardly directed. This activity continued into the Upper Permian. The youngest deformed strata are Midian.

The Midian is followed by the Triassic (Carnian - Norian) with an angular unconformity. The Mesozoic starts with andesitic pillow lavas and local basal conglomerates containig Asselian pebbles. These sediments and volcanics are conformably followed by red beds for nearly the entire Mesozoic. The red bed sediments had been originally sedimented from a NE direction (KROKER, 1981; HAHN, 1982) and cannot represent a molasse of an west-lying mountain belt. Fluviatile, continental red beds usually do not represent orogenic sediments. The Mesozoic is only slightly folded into a gentle synclinal and anticlinal structures.

In some places the Paleozoic is overthrusted onto the Mesozoic. The situation described above is by no way compatible with any continent – continent collision in the Triassic or Jurassic times. It only fits with the late Variscan orogenic event, as described by HELMCKE (1983; 1985).

To understand the mechanism which led to the closure of the Nam Duk Basin, several points have to be taken into the acount:

- The Nam Duk Basin separated the Shan Thai "Craton" and the Indosinia Craton in the Carboniferous and Permian. No younger than Permian pelagic sediments are known in Thailand.
- These two cratons were separated only by a basin, which did not exceed 200 km in width. Oceanic crust cannot be detected there. The Lower Permian volcanites

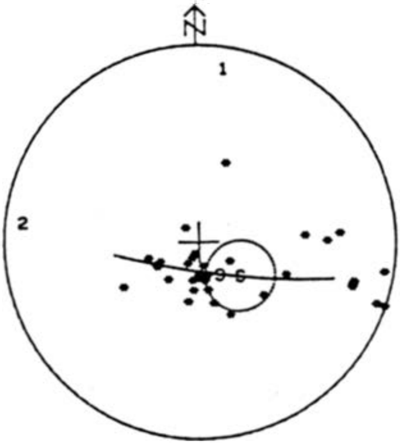


Fig.: 54.

The Khorat strata have not been affected by a strong folding and exhibit only gentle folds between km 21.5 - 34.0 of the Lom Sak - Chum Phae highway. (36 data).

do not indicate the existence of MOR-basalts. The Upper Paleozoic faunas found on both sides of this basin are of an identical paleogeographic source.

- A volcanic belt or belts, active from ?Silurian to Permian, were located always west of the Nam Duk Basin. While the western border of these volcanic belts remained stable through time, the eastern border migrated eastwards (fig.:36).
- The Nam Duk Basin had been E-vergent folded and the pre-flysch, flysch, and molasse sediments are arranged in this order from west to east. According to HELMCKE (1985), the Petchabun Fold and Thrust Belt is an eastern external zone of a huge Variscan orogeny, of which the internal parts are represented by the Nan - Uttaradit suture.

The conclusion, that the Nam Duk Basin is of a marginal sea character (?back-arc basin?), is supported by the facts listed above. This marginal basin was closed by a westward dipping subduction. Because the main continental mass was located to the east ("Indosinia Craton") and the volcanic arc was in the west ("Shan Thai Craton"), the westward subduction can only be represented by an "A"-subduction. The Benioff zone – "B"-subduction had to be directed towards the east and had to be located west of the volcanic belts (see HELMCKE's 1985 – Paleotethys discussion).

The Nan - Uttaradit suture represents most probably the collision boundary of continent with island or volcanic arc or arcs. The question over how far these arcs were underlain by continental crust or if the back-arc basin temporarily developed

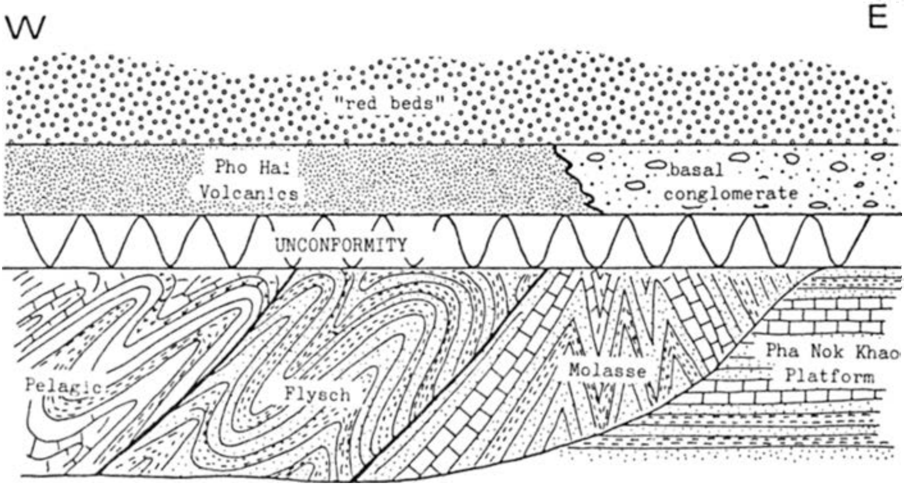


Fig.: 55. Schematical profile through the non-restored Petchabun Fold and Thrust Belt, between Lom Sak and Chum Phae (not to scale).

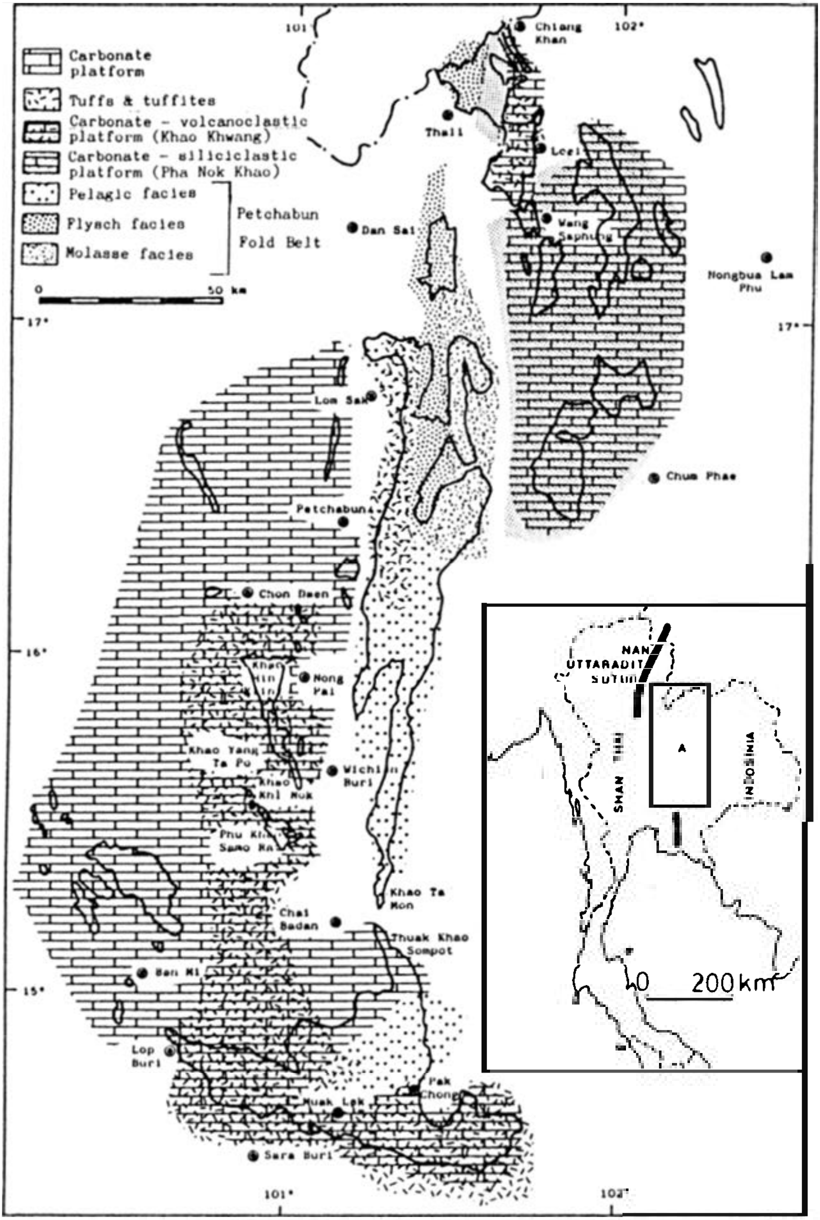


Fig.: 56. Non-restored facies distribution in the Petchabun Fold and Thrust Belt (Upper-Carboniferous to Midian).

oceanic crust demand further investigation. A situation similar to Japan – island arc as developed today seem possible. To answer this question, much more work is needed.
Of interest is the fact that if the model described above is correct, the direction of the subduction has not changed since Paleozoic to recent times, when we restore the Cenozoic clockwise rotation of SE-Asia.

Models explaining the interaction of Benioff and Ampferer subduction zones has been widely introduced in the last decade. Most of them deals with plate convergence rates and the gradient of inclination of the plunging oceanic crust. Especially ZIEGLER (1984) applied such a model to the European Variscides. In this model an "A"-subduction is triggered by a high convergence rate when flat subduction angle is present in a "B"-zone. The back-arc rifting occurs during a low convergence rate and a steep subduction angle in the "B"-zone. Such a model can be applied also to the Paleozoic of Thailand.

Part II

The pebbly mudstone facies in peninsular Thailand and western Malaysia

1. Introduction.

To make the interpretation of the Upper Paleozoic rocks in Thailand more complete and to allow a better paleotectonic reconstruction, the famous pebbly mudstones of the Phuket Group in Thailand and the Singha Formation in Malaysia were investigated (fig. :8). The Phuket Group and the Singha Formation are part of the SE-Asian pebbly mudstone belt, stretching from southern Tibet to Sumatra. Due to limited acces and outcrop conditions, the state of knowledge on these rocks does not permit correlation even between neighbouring outcrops.

The pebbly mudstones were investigated by many authors since the fifties.
They figure as "Phuket Series", "Kanchanaburi Series", "Kaeng Krachan Formation" or "Tanaosi Group" due to their local distribution in Thailand. In Malaysia and Burma also various names for these sediments are common. BURTON (1983) gave an extensive review on the development of the knowledge on these rocks. The Phuket and Singha series were thought to be Cambrian after the questionable findings of Eophyton (BROWN et al. 1951).

HUMMEL & PHAWANDON (1967) distinguished in the "less metamorphosed part" of the Phuket Series three litho-sedimentary facies:
conglomeratic shale
laminated shale
thin bedded siltstone and shale
The metamorphic features in the "more metamorphosed part" are described as well-developed schistosity and foliation and thermal metamorphosis of nearly all grades. All the metamorphic changes are, according to these authors, related to the granitic plutons. The metasediments are described as folded in an unknown size and character.

BAUM & KOCH (1968) divided the Phuket series into separate units of the Cambrian Tarutao Formation (quartzites); the Ordovician to Devonian Thung Song Formation (limestones); and the i.e. Phuket Group, probably not older than Carboniferous.

MITCHELL et al. (1970) constructed a more detailed facies subdivision of the Phuket Group. These authors divided the Phuket Group into the Lower Formation and the Upper Formation. The Lower Formation contains:
Facies A: laminated mudstones.
Facies B: sharp based sandstones and mudstones.
Facies C: slump units.
Facies D: pebbly mudstones.
Facies E: limestone.
Facies F: well-sorted sandstones and conglomerates.
The Upper Formation consists of:
Facies G: bryozoan bed.
Facies H: thick-bedded sandstones and shales.

In their facies D, these authors found rugose corals and the trilobite Cyrtoymbole (Waribole) perlisensis and estimated this fauna to be late Devonian.

Since MITCHELL et al. (1970) do not accept the subdivision by BAUM & KOCH (1968), the Devonian Thung Song limestone is also included in their Phuket Group. Their facies "E" – limestone is not identical with the Thung Song limestone. It is described as very rarely occurring, unfossiliferous, grey clay rich rocks up to 5 m thick and apparently restricted to the top of the Lower Formation.
The fauna from their facies "G" – bryozoan bed suggest warm water conditions and has an early Permian age. The investigations led MITCHELL et al. (1970) to an interpretation of the Phuket Group as sediments derived from the east and deposited on a prograding delta or deltas (Upper Formation) and on a continental margin (Lower Formation). Since the work by MITCHELL et al. (1970) no significant progress has been made in the investigation of the Phuket Group.

SAWATA et al. (1975), investigating the Kaeng Krachan Formation in the Khao Phra area, Petchaburi province, came to a similar conclusions as MITCHEL et al. (1970). These authors also found rugose corals in the pebbly mudstone and defined the paleotransport direction as from northeast/east to southwest/east to southwest/west or reverse (mainly on the basis of symmetrical ripples, some interference ripple marks and a few sole marks).

With the entrance of modern plate tectonics into SE Asian geology in the seventies, the Shan Thai Craton was assigned to be a part of the Paleozoic Gondwanaland. Because of this several writers still interpreted the pebbly strata as glaciomarine tilltes or dropstones. In this interpretation, the Gondwana relationship of the Shan Thai Craton shall be supported.

STAUFFER & SNELLING (1977) dated with K/Ar a trondhjemite boulder from the pebbly mudstones of Langkawi island – Singha Formation. A Precambrian age was given. The source for this boulder is unknown, since no Precambrian is found in the area.

STAUFFER, (1983) and BUNOPAS and his co-authors (1978, 1981, 1983, 1984) are the main advocates of the theory that the "Shan Thai Microcontinent" rifted away from Gondwana (most probably from northwestern Australia) in Carboniferous times and collided with Indosinia in late Triassic times and caused the Indosinian Orogeny. The rifting occurred with a clockwise rotation of more than 180 degrees which became more rapid with time. In this interpretation the Cenozoic rotation of SE Asia (MOLNAR & TAPPONIER, 1975; BUNOPAS & VELLA, 1983) is not regarded.
Of course with this theory also a puzzeling of paleomagnetic data began. Two contrary results were curried out by different working groups.

McELHINNY et al. (1974) published paleomagnetic results from Malay Peninsula, which showed that this part of SE Asia was positioned at 15°N during the Paleozoic. Their results for the Cretaceous supprisingly suggest that the Peninsula was not welded to the mainland of Eurasia.
The Paleozoic data has been criticized by several authors as being influenced by plutonic intrusions during the Triassic to Cretaceous and not showing the Paleozoic position.

BUNOPAS (1981) sampled the Phuket and Kaeng Krachan Groups and also took one sample from the Ordovician Thung Song Fm. and two samples from the Permian limestone overlying the pebbly mudstones.
The results gave a Carboniferous position of the Shan Thai Craton as 13°S and for the Permian a paleoaltitude of 19°S. According to BUNOPAS (1981), the Ordovician sample does not gave reliable results.
It seems to be necessary to point out that BUNOPAS (1981) claimed a clockwise rotation of more than 180° for the Shan Thai - Craton while crossing the Paleotethys.
In their paper BUNOPAS & VELLA (1984), followed diverse publications by SENGÖR, (1985) that the Shan Thai - Craton is traceable to the west, as far as Turkey.
Considering, that such a movement cannot be explained in the light of plate tectonics or global tectonic theory some principal critical points must be added.

- Since the age of the pebbly mudstones has been estimated as early Devonian to early Permian by the overlying and underlying strata and by the occurrence of Devonian fossils in the pebbly mudstones, it is an oversimplification to establish any sample from the pebbly mudstones as Carboniferous.
- It is in the nature of the pebbly mudstones, which often lack any sedimentary structures or bedding, that it is impossible to decide the correct orientation in the outcrop. Graded bedding is not always diagnostic for orientation of beds in these sediments.
- Another complication is the impossibility of tracing the paleolongitude by the method of paleomagnetism. The paleomagnetic data from the pebbly mudstones are certainly unreliable.

Good evidence for or against the Gondwana relationship of the Shan Thai - Craton can be obtained from the paleofauna and flora. Unfortunately the evidence given by the fossils are equivocable. For example the often cited Glossopteris flora found in the vicinity of Phuket turned out to be Walchia Piniformis Schlotheim (BUNOPAS & VELLA, 1984), common in the northern hemisphere, but a plant can migrate for long distances. Also the Permian fauna described by WATERHOUSE (1982) does not give clear results and has already been contrarily interpreted by GRANT (1976).
Since neither the paleomagnetics nor the fossils allow a final determination of the original position of the Shan Thai - Craton, a careful analysis of the pebbly mudstones might lead to a useful clue.

As for the glaciation theory, only two origins for the SE-Asian pebbly mudstone belt seem possible.
The first, one is preferred by BUNOPAS & VELLA (1984). According to these authors the pebbly mudstones are bimodal sediments transported and derived from different directions and sources. It is suggested that the pelites were transported from the present east and the pebbles from the present west. This suggestion is supported by the generally increasing size and abundance of the megaclasts towards the west. Despite the lack of any statistical investigations on the size or abundance of the clasts, transport on floating icebergs should not cause any sorting of the clasts. Typical for dropstones is the lack of sorting (see later discussion). The pictu-

re drawn by BUNOPAS & VELLA (1984) postulates deposition of the pebbles on the Permo-Carboniferous northern margin of Shan Thai Craton (in respect to the 180° clockwise rotation and the Cenozoic clockwise rotation (BUNOPAS & VELLA, 1983). The pebbles were transported northward from Gondwana on floating icebergs. These icebergs had to have crossed the initial "Neo-Tethys" and also the Shan Thai - Continent! This continent had already rifted away from Gondwanaland producing the "Neo-Tethys" and acting as a barrier to the northward floating icebergs (the main part of the 180° rotation is claimed for the Permo-Triassic, BUNOPAS & VELLA, 1984). In this case tillites should be present on the Paleo- and Neotethys margins of the Shan Thai Continent and it is difficult to explain why the pebbly mudstones are not located also on the present eastern margin of the Shan Thai Continent.

The second possibility for the origin of the SE Asian pebbly mudstone belt is that of deposition during the Permo-Carboniferous glaciation of Gondwana, while the Shan Thai Continent was connected to Gondwanaland. The ice migrating northward entered the continental margin or shelf. In this case the mudstone and the megaclasts came from the southward lying landmass and one should also expect records of grounded ice in the shallow marine Permo-Carboniferous deposits of the Phuket or Singha sediments.

In order to solve this problem the sedimentary facies of the pebbly mudstones on Langkawie Islands, Ko Phi Phi Island, Phuket Island and Kaeng Krachan area were studied.

To avoid any genetic interpretation of the pebbly mudstones the term "mixtite" often is used in the following text. According to SCHERMERHORN (1966), mixtite is a descriptive name without any regard to origin for ill-sorted, disperse megaclastic sediments of rudite - arenite - lutite composition.

2. Pebbly mudstones investigation

2.1. Langkawi area.

On the Langkawi Island the Upper Paleozoic Singha Formation rests unconformably on the Lower Paleozoic rocks and is covered conformably by the Chuping Limestone.

Outcrops of the Singha Formation are found along the S-SW coast of Langkawi, on Pulau Ular, Pulau Tepor, and Pulau Singha Besar. These outcrops exhibit mainly structureless mixtites, which are partly sandy with scattered clasts up to fine gravel size. Bedded pebbly sandstones were also observed and are involved in large scale folds of soft sediment deformation. The strata dip slightly to the SE.

Pulau Ular

On Pulau Ular some several tens of meters of thin-bedded siltstones, which are cross-bedded or lenticular bedded crop out. The strata contain small clay rip-up clasts and abundant, scattered coarse sand-sized grains (bimodal distribution). The beds are highly bioturbated but the burrows are chiefly only horizontal and are up to 1 cm wide. Slump structures, mega-convolutes, and convolute lamination are common in this unit. When followed eastward, the sequence becomes coarser (fine sandstone). In the eastern scarps of Pulau Ular, gray pebbly mudstones and pebbly sandstones crop out. A few thin sandstone beds and lenses are included in the strata and show synsedimentary disturbance of bedding. The pebbles in the gray, fine sandy matrix are mainly of fine gravel size, and elongated, angular to subrounded. When bedding or lamination was apparent, some convoluted structures and slumps could be observed. Very rare, stressed crinoid stem pieces were found in the mixtites. Thick burrows long, straight and perpendicular to bedding were also observed.

The pebbly strata are slightly schistose. Because the cleavage planes dip at a lower angle than the bedding, it is assumed that the strata are overturned. No folds were observed. Since the beds are dipping eastward, the siltstones probably cover the mixtites.

Petrographically, the siltstones and silty sandstones (WAL84/1-3) show rare detrital mica and feldspar at approximately 10% of the volume. The matrix is serizite to clayish.

Pulau Singha

On Pulau Singha the siltstone and mudstone layers are organized in wavy and lenticular bedding with rare flasers. Feeding and crowling (repichnial) burrows, similar to those on Pulau Ular were also found. These beds probably represent tidal flat deposits. They pass upward into the Chuping - Limestone, which starts with thin- to medium-bedded calcarenites (intramicritic wackestones to packstones) with high clay content, pellets and rare bioclasts. Umbrella effects beneath the shell fragments were observed. Further upwards the limestone beds become thicker.

The pebbly mudstones underlie this entire sequence and contain also limestone megaclasts of boulder size.

Pulau Tepor

On Pulau Tepor, the extensive outcrops exhibit diverse water injection structures as sand dikes and sills. Contored bedding and sedimentary boudinage were observed in the mudstone/sandstone beds. Convolute structures and synsedimentary folds, which do not exhibit any cleavage but are sometimes sheared parallel or along the B-axis and sand intrusions in the axis plane, evidence deformation of metaconsolidated sediment.

The cleavage in these mixtites is obviously independent of these fold structures and crosses the strata without change in dip or strike direction. Large, up to 30 cm long burrows, perpendicular to the bedding were found in the sandstone and mudstone beds. Some of these burrows pass through the fold and slump structures. The burrows are over 1 cm in diameter, filled with sandy material and with no internal structures, but contain abundant pyrite crystals (WAL.84/4+5). Some of the sandstone and mudstone beds are slightly carbonatic and some contain rarely scattered megaclasts of fine gravel size. A few compactional loadcasts beneath and above the clasts were observed. These structures were probably interpreted as dropstone structures by the advocates of the glacial origin of these mixtites.

2.2. Ko Phi Phi area.

In Thailand, on the Ko Phi Phi Khon Island, the mixtites of the Lower Formation of the Phuket Group are widely exposed.

The southeastern cap of the island exhibits along its eastern beaches pebbly sandstones which are wavy bedded and containing clay clasts. The pebbles are up to 5 cm in diameter and mainly subrounded to rounded. Some several meters thick intervals of structureless, non-bedded pebbly sandstones to mudstones with sandstone lenses occur. Upwards fine-bedded, fine-grained sandstones are intercalated with densely packed, but still matrix-supported fine-grained conglomeratic layers. The conglomerate clasts are mostly of quartz and well-rounded.

These strata are overlain by quartzose, fine-grained sandstones and siltstone beds with thin layers of very fine conglomerate. Some of the sandstone beds exhibit bidirectional small scale cross-bedding or are laminated. The Upper Formation of the Phuket Group is probably exposed at the whole hill and its western flanks extending to the village of Ban Phi Phi. It is flat-lying (SS 205°/11°). The diagnostic bryozoan bed was not found.

In Thong Lay Bay, medium-grained, quartzose sandstones in 20-40 cm thick beds occur. Large-scale cross-bedding is the dominant sedimentary structure with some small-scale cross-bedding and thin layers to laminae of coarse sand quartz grains. Up the hill, the sandstone layers can become over 1 m thick and also the cross-sets increase in size. Coarse sandstone and fine conglomerate layers became common. The conglomerate and sandstone grains are well-rounded. The bedding is generally lensoidal in character.

These strata belong to the Upper Phuket Formation and have probably been deposited in a deltaic regime.

Under the microscope the sandstones (WAP84/37-43), appear as sublithic arenites and quartz arenites, with strong quartz overgrowths and a very poor silicic matrix. The feldspar content is very low and the content of the lithic fragments is 15-25%. The lithic fragments are mainly composed of polycrystalline quartz grains. Heavy minerals of well-rounded zircon and tourmaline are present. The content of detrital mica is very low. The samples are moderately sorted and the grains are rounded to subangular and mainly of spheroidal shape.

The Ratburi - Limestone which overlies the Upper Formation crop out in the western part of Ko Phi Phi Khon island. They are bedded and become massive towards the top. In these limestones abundant Permian fossils of brachiopods, crinoids, and corals are present and are described also from other localities by GRANT (1976) and WATERHOUSE et al. (1982). In the lower layers of the limestone bioturbation, and chert nodules, and silt to sandstone lenses can be found.

2.3. Phuket area.

On Phuket island, which gave the name to the Phuket Group several localities were visited.

Laem Hin

At Laem Hin a thick sequence of gray mudstones with indistinct bedding and scattered, rare pebbles of 5 cm in diameter crop out. Some clayish, black rip-up clasts have been found in the strata, normally in the slightly sandy layers. The bigger clasts can exhibit structures similar to "current flow marks" . Such marks are mainly described from olisthostromes. The strata dip 10°-15° to SE.

The thin sections from the fine sandstone layers of these outcrops are lithic graywackes with over 50% silicic-serizitic matrix. The grains are structurally non-sorted and contain over 60% quartz grains (Qm) and about 40% lithic fragments of Qp, shale, and rare ?dacitic volcaniclasts. The feldspar content is very low.

Beneath these mudstones pebbly sandstones in beds of 1-2 m in thickness with elongated pebbles up to 3 cm in length are exposed. The pebbles are of quartzite, granite, and gneiss origin and seem to all point in one direction, but no true imbrication in this matrix-supported mixtite could be proven. Some long axis linears of the pebbles were measured on a SS 130°/10° bed surface. Their strike direction is on average SE-NW, but since the transportation mechanism is unclear and no three dimensional observations were made, no statement on the paleocurrent direction is possible (fig. :57).

Structureless pebbly sandstones were also found in these outcrops. The abundant pebbles are of various origin, but mainly of sandstone. They are in general smaller than 2 cm in diameter. Gray colored, fine-bedded mudstones without megaclasts are intercalated.

Ko Sire

At Ko Sire gently NE dipping strata are exposed. The extensive outcrops show gray, indistinct laminated mudstones at the top of the sequence. They are underlain by 1 m thick layer of mixtite with mainly quartzitic pebbles in a pelitic matrix. The pebbles are mainly 3-6 cm in diameter, well-rounded, and spheroidal. Dark clay rip-up clasts of flaky, angular shape are also present. Outstanding is the extreme enrichment in pyrite idiomorphic crystals which are up to 1 cm long. The mixtite layer is again underlain by bedded mudstone, which also contains abundant pyrite. Within the mudstone some fine sandstone layers occur and a 2 m long and 20 cm high lense of sandy mixtite with small, mainly coarse sand sized clasts is present.

Than a squence of pebbly mudstones follows and is underlain by bedded sandstones with siltstone lenses. Some sandstone layers grade upwards into mudstone. In one case a pebbly sandstone layer contain inverse graded bedding. This entire sequence contains slumps and convoluted bedding.

The sequence at Ko Sire with detailed sedimentary structures is illustrated in log No.:XXXII. Without statistical analysis it is still evident that fine-grained, quartzose or sandstone clasts prevail in the mixtites of Ko Sire. Coarse-grained sandstone clasts are also present. The majority of the clasts are 3-5 cm in diameter, well-rounded, and elongated to spheroidal. No clasts bigger than coarse-gravel size were found.

In thin section low grade metamorphism could be recognized. The mudstones exhibit weak slaty cleavage, and small light biotite crystals grow perpendicular to the cleavage direction. Abundant chlorite is present (WAP84/10-21).

In WAP84/15 quartz neomorphism in strain protected areas behind clasts can be seen. Serizite crystallization along the cleavage plains is common.

The sandstones show abundant quartz overgrowth.

The sample WAP84/17 exhibits also small, lepidoblastic actinolite crystals, grown oblique to the cleavage planes. Also chlorite and neomorphe biotite are common.

Quartz grains are most common in thin sections. Carbonate grains and volcaniclasts were rarely found. Feldspar or feldspar/quartz intergrown with mica are also present but not abundant.

Some thin sections exhibit several tourmaline (green) grains as heavy minerals. They are small and well rounded.

Laem Nga

On the way to Laem Nga, which is the northernmost point of Ko Sire, pebbly mudstones of several tens of meters thickness are also exposed. They are structureless, sometimes of slightly sandy matrix, and contain clasts of mainly fine gravel size.

Very similar strata outcrop along the beach west of Laem Khao Khat. The pebbles can be up to 5 cm in diameter, but mainly are about 1 cm in diameter and mostly rounded. "Current flow" marks, surrounding the bigger pebbles were observed. Sandy and clayish lenses and rip-up clasts are common. The strata contain slump-structures.

In thin section these mixtites appear as structurally and compositionally immature lithic graywackes, which are rich in matrix (60-75%). The matrix is mainly unstratified and does not exhibit any lamination or other layering. Contrary to the matrix, some of the rip-up clasts clearly show lamination of phyllosilicates.

Laem Phan Wa

Laem Phan Wa is the southernmost occurrence of pebbly mudstones on the main Phuket Island. The strata which outcrop here are also of mixtite origin. The layers dip 10°-30° towards N-NE. The matrix of the mixtite is pelite with fine psammitic lenses and laminae. Slumps and convolute bedding are common also in these outcrops. An unique property of these outcrops is the occurrence of cobble-sized clasts of pebbly sandstone and pebbly mudstone within the mixtite strata.

Compactional load casts resembling impacts occur. It is important to note that these load casts also occur above the clasts and never break through the laminae or bedding. The majority of the clasts are less than 3 cm in diameter and in general very rare within these outcrops.

Ban Pak Thai Sako

At Ban Pak Thai Sako the strata dip E-NE. Gray mudstones outcrop and are intercalated with fine beds of yellowish, fine-grained sandstones.

The fine beds range from one to five centimeters in thickness. Wavy bedding also occurs and some of the sandstone bed surfaces exhibit current ripples indicating paleotransport direction from E-SE to W-NW.

No megaclasts were found in these beds. A 20 cm thick fine-grained sandstone layer contains brachiopods and molds of dissolved crinoidal stem pieces. Further upward in the sequence the bedding becomes lenticular and the fine psammitic fraction increases. Bioturbation is also present. Slump folds, convolute structures and water injection structures, such as sand dikes and sills are common. Pseudoripples caused by tilting of the sandy layers by slumping are present and indicate together with the majority of the slumps a northwestward dipping paleoslope (fig.:57).

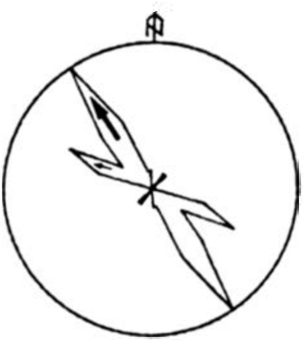


Fig.: 57.

Paleocurrent direction measured on current ripples (E-W), slumps (SE-NW) and pebble long axes (NE-SW) in Phuket area (16 data).

2.4. Khaeng Krachan area.

Around Khaeng Krachan Dam (also called Phet Dam, 12°55'N; 99°44'E) the upper part of the Lower Formation of the Phuket Group crops out. The sequence contains reddish, fine-grained quartzose sandstone layers intercalated with mudstones. Rare pebbly sandstone beds also occur. Lateral changes in bed thickness occur rapidly. Cross-bedding and lenticular bedding are common. Wave ripples of symmetrical shape containing chevron structures are common. A near-shore paleoenvironment is suggested.

These sequence is underlain by schistose pebbly sandstones and siltstones. The mixtites of this area, which may be associated with a shallow water sequence, have a sandy matrix scattered with abundant clasts up to fine gravel size. The clast shape is mostly angular to subrounded. Beds and sequences of fine-bedded, wavy bedded, or lenticular bedded mudstones are intercalated with the mixtites. No slumps or convolute structures were found in these outcrops.

On the top of the sequence at Kaeng Krachan Dam, there seems to be a reddish to white quartzose sandstone in beds of several cm to a few dcm thick. This sandstone is a bimodal sediment with coarse grains and predominantly fine-grained psammite. It represents probably the Upper Formation of the Phuket Group and the quartzites on Ko Phi Phi.

TANTIWANIT has found in the vicinity of Khaeng Krachan Dam, in the upper part of the pebbly mudstones, heavy mineral strand placers (pers. comm.), which strongly supports the interpretation of a nearshore environment.

3. Facies description and discussion.

The Upper Devonian to Lower Permian, 3000 m thick, clastic strata of the Phuket Group and the equivalent Singha Formation were described in the sixties and seventies as continental margin sediments. (JONES, 1961; KOOPMANS, 1965; MITCHELL et al., 1970; GARSON et al., 1975). At the same time a great amount of literature on sedimentary processes on continental margins was published. The literature on the Phuket and Singha pebbly mudstones and that on other continental margin deposits, exhibit similar trends in facies development and sedimentary features.

The pebbly mudstone deposits of SE Asia form the western margin of the Paleozoic outcrops from southern Tibet to Sumatra. To my knowledge the only throughly studied deposits are those of peninsular Thailand and western Malaysia.
The following facies types could be distinguished during my fieldwork in Thailand and Malaysia:
Lower Formation:
1) Thin-bedded or laminated mudstones.
2) Thin-bedded or laminated siltstones and sandstones.
3) Thin-bedded mudstones to sandstones with scattered pebbles.
4) Structureless pebbly mudstones to pebbly sandstones.
5) Conglomeratic layers.
6) Sharp based, graded sandstones.
7) Slumped units.
Upper Formation:
8) Bryozoan bed.
9) Thick-bedded sandstones and shales.

Since my observations correspond with the description given by MITCHELL et al., (1970), only a brief description and discussion of the facies will be given:

1) Thin-bedded or laminated mudstones.
Bedding planes of these layers are flat and sharp. Lateral variations in layer thickness have not been found. Locally, the intercalated siltstones and fine sandstones exhibit flaser bedding or small-scale cross-bedding. Rare bioturbation has been found in this facies. The depositional area is shelf to continental slope. These sediments are often involved in slumping.

2) Thin-bedded or laminated siltstones and sandstones.
The thickest unit of this facies crops out on Pulau Ular, Langkawi. Here several tens of meters of silty sandstones without mudstone intercalation are exhibited. Lenticular bedding of isolated siltstone lenses and some flaser bedding occur. The laminae and beds are not very sharply based, and the bases and tops do not remain parallel for lateral distances longer than a few decimeters. This facies is strongly bioturbated. The burrows penetrate the bedding and destroy the surfaces. Convolute structures, slumps, and erosive boundaries are abundant. The sedimentation took place in a very shallow depositional environment.

3) Thin- to medium-bedded mudstones to sandstones with scattered pebbles.

This facies is associated with facies (1) and is quite widespread. The pebbles are commonly of fine gravel size, but smaller clasts are dominant. They are of various composition and shape but mostly rounded. Some clay galls and intraclasts also occur.

Seasonal influx of gravel on the mud surface in a depth of about 20 to 30 meters has been described, for example, by GENNESSEAUX (1962a; b; 1966). Furthermore, several possibilities for transportation of gravels on mud are described in the literature (STANLEY & SWIFT, 1976). Rare compactional load casts beneath, and sometimes above, the clasts have been misinterpreted as dropstone impacts. The occurrence of both normally oriented and up-side-down "impacts" in thin sandy layers in the same outcrops, where the possibility of overturned strata can be excluded, is incompatible with dropstone origin. Furthermore, the clasts do not penetrate the layers or laminae, but are always concentrated on surfaces. This should not be the case with glaciomarine tilloids. Additionally, no true varvites are described from the SE-Asian pebbly mudstone belt.

This facies contains slumping and soft sediment deformation and often exhibits various water overpressure structures.

4) Structureless pebbly mudstone to pebbly sandstone.

This is the most abundant facies in the Lower Formation. Individual units can reach up to several tens of meters thickness. The bases are erosional, as far as exposed. Isolated clasts of different shapes are scattered in a structureless matrix. The clasts are usually smaller than fine gravel. A few clasts up to one or two meters in diameter were reported by TANTIWANIT et al. (1983). This resedimented facies (WALKER, 1978) was deposited by cohesive debris flows (LOWE, 1982). The facies also includes lenses of deformed, bedded sediments of facies (1) and (3) and resedimented pebbly sandstones and pebbly mudstones as clasts. These clasts were eroded and again redeposited further downslope by the gravity flow.

5) Conglomeratic layers.

Two different settings of conglomeratic layers are distinguishable. In one case – within facies (3) – thin conglomeratic layers of small gravel size are superimposed on laminated mudstone to sandstone. The origin can be explained by deposition of gravel on the surface of pelitic or psammitic layers and/or concentration by winnowing of finer sediment by bottom currents.

In the other case conglomerates are associated with sandstones which can be cross-bedded or pebbly. They also contain mudstone clasts. The thickness seldom exceeds 10 meters. The layers usually have erosional bases with conglomerates followed by sandstones. These sediments could have been deposited in a upper fan to suprafan area (WALKER, 1978).

6) Sharp based, graded sandstones.

These sediments, commonly intercalated with mudstones, have parallel bases and tops and do not show lateral changes in layer thickness. The sandstones are graded and show, in their upper parts, cross- and/or parallel lamination. According to BOUMA (1962) they can be interpreted as having been deposited by turbidity currents.

7) Slumped units.
   Slumps and soft sediment folding of several tens of meters thick units are common in the outcrops on Phuket and Langkawi. Rarely the upper part of the slumps is eroded or the base is erosional. Similarity to the facies described by DOTT (1963) was noted by MITCHELL et al. (1970). Preferred orientation of the slumps could be determined and indicate a northwestward (on Phuket) or southwestward (on Langkawi) dip direction for the paleoslope (Cenozoic rotation of SE Asia not considered, comp. MOLNAR & TAPPONIER, 1975). Westward gradation from shallow to deeper water was also suggested by GARSON et al. (1975).
   Pseudoripples caused by lateral pressure resulting from slump folds were observed in some places on Phuket. Overloading of water-saturated alternations of coarser (more permeable) and pelitic (minor permeable) sediments by sudden deposition of a gravity-flow layer etc. is well documented within this facies. Clastic dikes, small injection structures, and dish structures can be seen in many outcrops, especially on Langkawi Islands. It is obvious that gravity flows can be easily triggered in such an environment.

In the Upper Formation, the author examined only the facies of thick-bedded sandstones and shales.

8) Bryozoan bed. (Not studied.)

9) Thick-bedded sandstones and shales.
   Laminated or cross-bedded, micaceous, gray shales or silty shales separate sandstone units whose individual layers are up to two meters thick. The layers change rapidly in thickness laterally. The sandstones are mostly quartzose, well-sorted, and rarely contain minor components of coarse grains which are always concentrated in thin laminae or as cross-beds within sandstone layers. The grains are well-rounded. Some layers exhibit low angle cross-bedding in a scale of up to one meter. The interpretation of this facies is of delta top deposits (MITCHELL et al. 1970).

The Upper Formation clearly shows shallowing upward conditions in the depositional area during Lower Permian times.
There is a remarkable similarity of the olisthostrome facies described by GÖRLER & REUTTER (1967) from the Appenine Mountains to facies 3 nad 4. This similarity is not suprising because of the genetic relationships of olisthostrome, gravitative mudflows, and slumps. Olisthostromes can pass into gravitative mudflows. The degree of destruction of the primary sedimentary bedding most probably depends not only on the distance of transportation, but more on the degree of consolidation before the triggering of the sediment movement and on the viscosity of the moving mass, i.e. on its water content and the amount of pelite in the matrix.

SEM-investigation of grain surfaces.

From the above description it is evident that, from the sedimentological point of view, the pebbly mudstones are not glaciomarine tillites but submarine deposits from a continental slope.

In a search for further evidence, surface textures of the sand-sized quartz grains from the pebbly mudstones were studied. Thirty samples, with a minimum of ten grains each were examined under a Scanning Electron Microscope. On all surfaces without silica overgrowth, V - shaped patterns or irregular pitting typical of aqueous abraded grains are common. No "glacial" textures can be reported, which, even if found, would be questionable (comp. WHALLEY & KRINSLEY, 1974 and SETLOW & KARPOVICH, 1972).

Discussion

The supporters of the Gondwana origin of the "Shan-Thai Craton" use various arguments to advocate the glaciomarine dropstone genesis of the SE-Asian "pebbly mudstone belt". Their main arguments (STAUFFER & LEE, 1984) will be discussed here.

1) Distribution: Great lateral extent of the pebbly mudstones of at least 2000 km.
   – Neither the glaciation nor the continental slope can be disproved by this long lateral extent. If the pebbly mudstones were continental slope deposits, they must have been deposited by different submarine fans along the continental margin. The thickness of the sequence and the long time interval (Devonian to Lower Permian) are clear evidence against glacial origin.
   According to WOPFNER (1978) the Gondwana glaciation occurred over the Carboniferous - Permian boundary in Australia. This is commonly believed to be the former "neighboring" craton. This gives a maximum time of 25 m. y. for deposition. Furthermore the glaciogenic origin of the south Tibetian pebbly mudstones ("Damxung - Linzhu tillites") is also very doubtful (comp. ALLEGRE et al. 1984).

2) Character of megaclasts: the gneissic and granitic clasts must be regarded as exotic, since they cannot be tied to any probable source in SE Asia. Furthermore the "dropstone impacts" and the angular, blocky and facetted shapes of the clasts are most consistent with ice-rafted debris.
   – The composition of the megaclasts (quartzites, sandstones, limestones, granites, gneisses, conglomerates, and pebbly mudstone resediments) are evidence for a cratonic source of these sediments. Continental granites and gneisses were exposed during Devonian to Lower Permian times. Today these might be eroded away or covered by younger sediments.
   Up to now statistical analysis on the shapes of the megaclasts is lacking. Naturally, the larger clasts are better rounded than the smaller. However, the degree of roundness depends not only on the distance of transportation but also on the time the individual clast spent in areas of wave action. Both angular and well-rounded clasts occur in the pebbly mudstones from Thailand and Malaysia. Typical for glacial gravels is a pentagonal outline and a tabular, subrounded to angular shape (WENTWORTH, 1936; CAILLEUX, 1952). Pentagonal, tabular shapes are very rare in the pebbly mudstones of Thailand and Malaysia. The "dropstone impacts" are – as shown above – clearly load casts. Although no striated or faceted clasts were found by the author, they are reported by TANTIWANIT et al. (1983). Striations on clast surfaces can also be produced by processes other

than ice transport (comp. STANLEY & SWIFT, 1976; GÖRLER & REUTTER, 1967). For example, striated clasts occur in glaciogenic tillites as well as in olisthostromes. However, striated clasts are rare in olisthostromes and common in tillites.
The resedimented clasts of pebbly mudstone in the pebbly mudstone sequence are incompatible with dropstone origin.

3) Depositional environment: Evidence of deposition in shallow water makes an origin by mixing during redeposition unlikely.
– Paleobathymetrical studies are often problematic. The ichnofacies depends not on bathymetry but on hydrodynamic energy conditions and sedimentary processes (WETZEL, 1983).
There is no doubt that some of the pebbly mudstones (especially on Langkawi Islands and in the Kaeng Krachan area) were deposited in rather shallow water. If these sediments were laid down during a glaciation period, we should expect records of grounded ice. VISSER et al. (1985) recently published convincing photographs of such conditions in the Dwyka Formation (S Africa). On the other hand, there is no doubt that some of the pebbly mudstones (especially on Phuket Island) were deposited in rather deep water. The neighboring shelf and slope deposits are usually not far from one other.
Deposition of pebbly mudstones has also been reported from the Mediterranean coast of France in a depth of about 25 m. Here gravels are deposited seasonally on sands and muds (GENNESSEAUX, 1962a, b, 1966). Metastable structures which induce gravity failures are known on 0.5 degrees slopes (DOTT, 1963).

4) Fauna: Descriptions of faunas in the upper part of the pebbly mudstone sequence of peninsular Thailand evidence cold water.
– WATERHOUSE's (1982) paper on the Permian fauna has often been cited by the supporters of a glaciogenic origin of these sediments. The conclusions of his paper should be cited here:
"In summary the fauna cannot be regarded as unreservedly cool-water, because some genera with paleotropical affinities are found... they indicate a temperature much cooler than prevailed for later Permian times in Thailand. However, the temperature, to judge from the fossils, was not as cold as for faunas associated with glacial sediment over much of Gondwana during the late Asselian Kumarian substage." (WATERHOUSE, 1982 p. 352).
Also incompatible with Gondwana/glaciogenic origin are finds of Walchia piniformis SCHLOTHEIM in the Phuket Group (BUNOPAS & VELLA, 1984). Furthermore, FONTAINE (1984) reported middle late Asselian warm water corals from Sumatra (Djambi).

5) Diamonds: Small numbers of gem quality diamonds were recovered in Quaternary sediments in South Thailand and Sumatra.
– No diamonds were found in the pebbly mudstones. They may or may not have been derived from the Paleozoic sediments. However, diamonds are not fossils which depend on temperature, age or paleo-latitude but rather minerals which also occur in the northern hemisphere. Additionaly many of the diamon-

diferous Kimberlite-pipes are not older than Cretaceous. Though the diamonds themselves are, of course older, how could they derive into Paleozoic sediments?

4. Conclusions and interpretation.

Since no single phenomenon alone distinguishes normal continental slope deposits from those associated with glaciers, all facies and their relationships must be carefully investigated. These problems were discussed extensively by SCHERMERHORN (1974) and GRAVENOR et al. (1984). For example, the classic Gowganda Formation – a world famous glacial unit – is mainly a product of submarine sedimentation on a continental margin (MIALL, 1983).

The Phuket and Singha Formations do not exhibit any evidence to support a glaciomarine origin. The depositional area of these sediments required a high paleorelief and tectonic uplift or other activity. This would allow the accumulation of gravel in the marine environment and the triggering of gravity flows. Throughout time similar sediments are known from continental margins which are associated with orogenic belts.

As for the paleogeography of these deposits, according to HELMCKE & KRAIKHONG (1982) and HELMCKE (1983), the main tectonic activity in SE Asia subsided during the Middle to lowermost Upper Permian (data from the Petchabun Fold and Thrust Belt). This activity most probably affected a basin floored by thinned continental crust or a marginal oceanic basin (HELMCKE, 1985; ALTERMANN, 1985; this thesis).

Considering the facts that

- no evidence for strong folding younger than Permian has been found elsewhere in central SE Asia (latest flysch is upper Middle Permian),
- no true remains of "oceanic floor" younger than Carboniferous are known in the area under discussion (DAMM, HELMCKE & TODT, in prep.),
- no paleontological evidence for a Gondwana provenance, but for Cathaysian and Eurasian, has been found in this area,

we have to agree that during the deposition of the pebbly mudstones the "Shan Thai Craton" was closely connected with Paleoeurasia. If we accept this conclusion, than the pebbly mudstones must have been deposited on the former southern (present western) slope of this continent.

Furthermore, we can speculate that at the Devonian - Carboniferous boundary, the tectonic activity (Nan Uttaradit "ophiolites") caused the beginning of the pebbly mudstone sedimentation. Later, with the folding of the Petchabun Marginal Basin between the "Shan Thai Craton" and mainland Paleoeurasia ("Indosinia"), the depositional area of the pebbly mudstones was up-lifted. The sedimentation turned to shallow marine sandstones and later to limestones. Such an evolution could be caused by eastward subduction which took place somewhere in the present western area of these continental slope deposits (comp. HELMCKE, 1985).

As the pebbly mudstones are not affected by strong tectonic activity but often exhibit weak slaty cleavage and are only ?gently folded, this scenario might seem dispu-

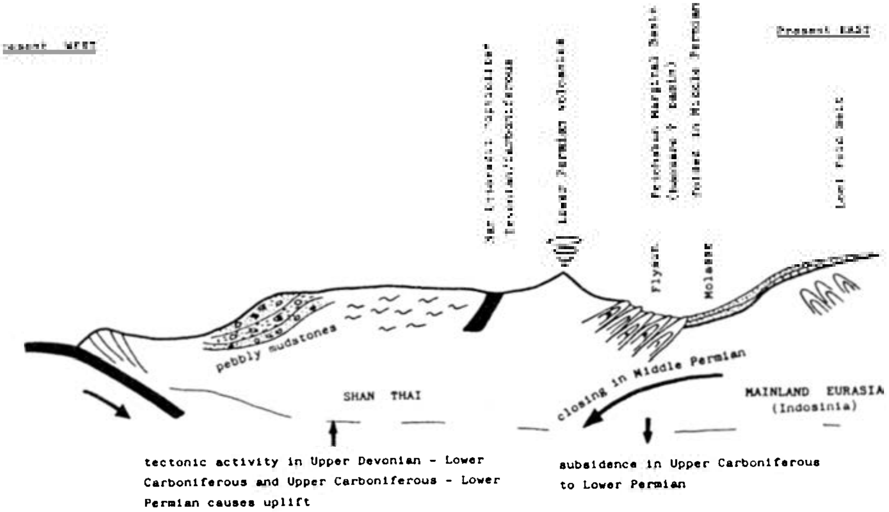


Fig.: 58. Speculative paleogeographical interpretation of Upper Paleozoic SE Asia (comp. HELMCKE,1985). Deposition of pebbly mudstones on the active continental margin of Paleoeurasia. Beginning of the deposition contemporaneous to the Nan-Uttaradit "ophiolite" post-metamorphic uplift. End of the deposition contemporaneous to the beginning of folding of the Petchabun Marginal Basin.

table. Recently v.HUENE (1986) presented a model of an unfolded but overthrusted subduction zone complex which may explain this inconsistency. This explanation is the best way to understand the geotectonic structures and regional geology of SE Asia according to modern plate tectonic models. Most importantly this model is incompatible with the "Indosinian orogeny". It fits perfectly with the final assemblage of Pangaea (TRÜMPY, 1982), as discussed by HELMCKE, (1986).

5. Last word.

The weakest point in applying a model of an arc-continent collision for Late Paleozoic Thailand is the difficulty in exactly defining this volcanic arc on the "Shan Thai Continent". The development over time of the arc through island arc to volcanic arc and continental edge and vice versa has to be explained using geological patterns which are not yet fully researched, especially in SE Asia. The problem might be also grounded in the assumption, that the plate tectonics in Paleozoic times obeyed different rules than it is the case today. Operating with microcontinents, though very modern, seems often sheer reality. Neither Upper Paleozoic spreading zones (origin of MORBs) nor true collisional belts and folding for the Lower and Middle Mesozoic can be claimed for Thailand and adjacent areas.

The speculative scenario described above in Part I and Part II excludes the possibility of global changes of sea level being exclusively responsible for the major facies changes in the Petchabun Fold and Thrust Belt and the Phuket Group.

WIELCHOWSKY & YOUNG, (1985) compared the relative costal onlap chart of VAIL et al. (1977) with the development of the carbonate platforms in Central Thailand. They pointed out that the change of the carbonate to siliciclastic sedimentation on the Pha Nok Khao platform is contemporaneous with the decrease of carbonate accumulation on the Khao Khwang platform, and that both events can be correlated with the global low sea level. The high sea level in the Kubergandian and Murgabian is the time of the major carbonate accumulation on the Khao Khwang platform. This is, according to HELMCKE (1983; 1985); ALTERMANN, et al. (1983) and WIELCHOWSKY & YOUNG, (1985) the time of the major tectonic activity in the Nam Duk Basin.

In the present thesis transgressive cycles in Yahtashian/Bolorian and Bolorian/Kubergandian on the Khao Khwang platform were suggested. These cycles are in good agreement with the curve of VAIL et al. (1977) where a slow rise of sea level is indicated for the Yahtashian to Upper Bolorian. At the end of the Bolorian this rise becomes more rapid. It has been noted by CLOETHINGH et al. (1985) that the most characteristic feature of VAIL's curves is the occurrence of slow increases in relative sea level followed by periods of rapid falls on time scales of less than 10^6 years.

A regressive cycle has been found in the Murgabian of the Khao Khwang platform. A strong decrease in sea level has been advocated by VAIL et al. (1977) for the Murgabian and Midian. Also the relative sea level drop recorded in the Carboniferous of the Khao Khwang platform (Visean near Chon Daen, CHONGLAKMANI et al., 1983) is most probably correlatable with the global Carboniferous eustatic events (ROSS & ROSS, 1985).

In order to correlate the facies development of the Phuket Group with the global relative sea level changes, more precise age data from the mixtites are needed. On the other hand this shallowing has often been regarded as the sea level drop caused by the Permo-Carboniferous Gondwana glaciation.

Continental glaciation certainly should have a strong impact on global sea levels on the order of tens of meters. Transgressive and regressive cycles can be traced worldwide in the shelf sediments. Nevertheless these sea level changes can never turn a deep marine basin into a shallow sea or marginal marine environment into a "geosynclinal" one.

INGAVAT-HELMCKE & HELMCKE (1986) attempt to relate global sea level changes to orogenic events and to the evolution of fusulinid foraminifera. They correlate rapid drops in sea level with the rizing of orogenic belts in the Permian. For example, the Ural Orogeny is correlated to rapid, worldwide regression in the Yahtashian and the latest Variscan orogenic event in SE Asia (Petchabun Fold and Thrust Belt) is correlated to the sea level drop at the Murgabian-Midian boundary.

Another example is the mid-Carboniferous eustatic event (SAUNDERS & RAMSBOTTOM 1986), which is predated by the Culm flysch facies in Europe.

Moreover, INGAVAT-HELMCKE & HELMCKE (1986) relate these events to the extinction of certain foraminifera species. This idea of correlating orogeny and sea level changes with the extinction of shallow sea biota has long reaching consequences. This implies that endogenic earth processes are responsible for the evolution of life.

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APPENDIX

sample locality			Carboniferous		L. Permian			M. Permian			U. Perm.	
			m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
N' of Muaklek	WA84/40	Colania sp. Thailandina sp. (?) crinoidal fragments joint							—	—		
	HE82/52	Geinitzina sp. Bradyina sp. ? Ammodiscus sp. Tubiphytes sp.					—	—				
Thuak Khao Sompot, E' to SE' of Chai Badan	WA84/68	Colania donvillei Sumatrina annae Verbeekina verbeeki Chusenella sp. Kamurana sp. Climacammina sp. Calcitornalla sp.							—	—		
	WA84/70	Parafusulina gigantea Pseudodoliolina sp. Chusenella sp. Climacammina sp. Tetrataxis sp. Pachyphloia sp. Paleotextularia sp.						—	—			
	WA84/78	Lepidolina multiseptata Verbeekina verbeeki Chusenella sp. Cribrogenerina sp. Paleotextularia sp. Deckerella sp. Climacammina sp.									—	
	WA84/79	Triticites cf. samaricus Bradyina nana Paleotextularia sp. Tetrataxis sp. Deckerella sp. Paradagmarita sp. Tubiphytes sp. algal fragments			—							
	WA84/81	Eoparafusulina sp. Chalaroschwagerina sp. Calcitornitella sp. Tetrataxis sp. Eotuberitina sp. Pseudovermiporella sp. Epimastopora sp. Anthracoporella sp. Tubiphytes sp. algal fragments			—	—						

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
S'of Pak Chong HE82/51	Parafusulina sp. Verbeekina (Paraverbeekina) sp. Pseudodoliolina sp. Nankinella sp. Eotuberitina sp.					—	—				
Saraburi - Pak Chong road km 160.0 WA84/34	Pseudofusulina sp. Schubertella sp. Mizzia sp. Anthracoporella sp.					—	—				
km 154.0 WA84/37	Parafusulina cf. kaerimizensis Parafusulina cf granumannae Chusunella chihsiaensis Afghanella sp. Verbeekina verbeeki Nankinella sp.							—	—		
km 141.0 WA 82/222	Maklaya sp.						—				
WA82/224	Misselina sp. Ungdarella sp.					—	—				
km 139.0 WA84/48	Parafusulina sp. cancellina sp. Geinitzina sp. crinoidal and algal fragments						—	—			
km 138.0 HE82/54	Pseudodoliolina sp. Afghanella sp. Parafusulina sp. Yangchienia sp. Pachyphloia sp. Tubiphytes sp. bryozoa							—	—		
km 136.5 WA84/47	Armenia sp. Afghanella sp. Parafusulina sp. Neoschwagerina sp.							—	—		
km 134.0 WA84/51	Pseudodoliolina sp. Sumatrina sp. Chusunella sp. Agathammina sp. Tubiphytes sp.							—			

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
km 14.0 WA84/63	Maklaya (?) recrystallised						—	—			
km 9.0 WA84/61	Afghanella sp. Schbertella sp. Verbeekina sp. Neofusulinella sp. Agathammina sp. Pachyphloia sp. Mizzia sp. algal fragments								—		
km 8,5 WA84/60	Afghanella sp. Chusenella cf. schwagerinaeformis Paraverbeekina sp. Parafusulina sp. Agathammina sp. Climacammina sp. Mizzia sp. Eotuberitina sp.							—	—		
Saraburi - Lam Na Rai road km 8.0 WA82/198	Parafusulina gigantea Pseudodoliolina sp. Hemigordius sp. Tubiphytes sp.							—			
WA82/204	Lepidolina sp. Verbeekina sp. Chusenella sp.								—		
km 6.0 WA82/207	Sumatrina sp. Verbeekina sp. Lepidolina sp. Deckerella sp. Mizzia sp.								—		
km 5.9 WA84/58	Parafusulina sp. Pseudodoliolina sp. Yangchienia tobleri THOMPSON Neoschwagerina sp. Sumatrina sp. Reichelina sp. Paleotextularia sp. Hemigordius sp. Geinitzina sp. Climacammina sp. Ostracod and oncoliths							—	—		
km 2.3 WA 84/57	Girvanella					? —	? —				

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Lam Na Rai - Chayaphum road S' of Thuak Khao Sompot WA84/82	Pseudodoliolina pseudolepida Neoschwagerina sp. Colania sp. Khalerina sp. Globivalvulina sp. Paleotextularia sp. Pachyphloia sp. Paradagmarita sp. Eotuberitina sp. Ichtyolaria sp. Ungdarella sp.							—	—		
WA82/149	Pseudoschwagerina sp. Rugosofusulina sp. Schubertella sp. Endothyrid sp. Cribrogenerina sp. Textularia sp.			—	—						
Ban Bo Nam - Ban Nong Ri NE' of Khao Ta Mon WA82/155	Staffellid Bradyina sp. Eotuberitina sp. Tubiphytes sp.	—	—								
WA82/156	Pseudostaffella sp. Hemifusulina sp. Textularia sp. Bradyina sp. Tubiphytes sp.	—	—								

sample locality			Carboniferous		L. Permian			M. Permian			U. Perm.	
			m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Khao Yang Ta Po, western outcrops	WA 84/123	Wentzelloides (Battambangina, close to Multimurinus) Nov.sp.								—		
	WA84/121	Nankinella sp. Codonofusiella sp. Deckerella sp. Climacammina sp. Cribrogenerina sp. Bradyina sp. Globivalvulina sp. Paleotextularia sp. Pachyphloia sp. Umbellina sp. Hikorokodium sp. Epimastopora sp. Ungdarella sp.								—		
	WA84/122	Nankinalla sp. Codonofusiella sp. Cribrogenerina sp. Deckerella sp. Climacammina sp. Tubiphytes sp. Anthracoporella sp.								—		
Phu Khao Samo Rat	WA82/134	Parafusulina sp. Sennbertella sp. Globivalvulina sp. Endothyrid sp. Hemigordius sp. Tetrataxis sp. Pachyphloia sp. Mizzia sp. Tubiphytes sp.						—	—			
	WA 84/83	Pseudofusulina sp. (in pebble)					—	—				
	WA84/84	Parafusulina cf. yunanica Misselina ovalis Pseudofusulina sp. Neoschwagerina sp. Minojapanella sp. Agathammina sp. Cribrogenerina sp. Deckerella sp. Tubiphytes sp.						—	—			
	WA84/88	Parafusulina cf. hainanica Parafusulina gigantica Misellina sp. Minojapanella sp. Neofusulinella sp. Neoendothyra sp. Paleotextularia sp. Cribrogenerina sp. Deckerella sp. Ungdarella sp.						—	—			

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Ban Lam Pa Yom WA82/184	Colania sp. Armenia sp. Schubertella sp. Cribrogenerina sp.							—			
WA82/185	Endothyrida Pachaphloia sp. Eotuberitina sp.	—	—	—							
WA82/183	Parafusulina cf. kaerimizensis Geinitzina sp. Neoendothyra sp. Eotuberitina sp. Disphaera sp. Lassiodiscus sp. Protonodosaria sp. Tetrataxis sp. Epimastopora sp.						—				
WA 82/179	Schwagerinid Girvanella sp.			—	— ?						
Khok Samrong - Tak Fa road S'Ban Nong Muang WA82/195	Chusenella sp. Neoendothyra sp. Lepidolina sp. Codonofusiella sp. Reichelina sp. Globivalvulina sp. Textularia sp. Lasiodiscus sp. Langella sp.								—	—	
Ban Kaset Chai - Phai Sali WA82/188	Fusulinid gen.et sp. indet. (schwerinid wall struct.) Nankinella sp. Globivalvulina sp. Pachaphloiy sp. Geinitzina sp. Eotuberitina sp. Bisphaera sp. Hikorocodium sp. Ungdarella sp. Epimastopora sp.							—	—		
WA82/190	Neoschwagerina sp. Nankinella sp. Nautiloid with strait shell							—	—		

sample locality			Carboniferous		L. Permian			M. Permian			U. Perm.	
			m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Khao Ruok	WA84/138	Pseudoschwagerina sp. Rugosofusulina sp. Pseudofusulina sp. Cribrogeneria sp. Ungdarella sp.			—							
S'Chon Daen Ban Na Chariang - Chon Daen road	WA84/139	Eostafella sp. Ozavinella sp. Bradyina nana. Bradyina sp. Tetrataxis sp. Paleotextularia sp. Eotuberitina sp. Deckerella sp. Bigenerina sp. Eolassiodiscus sp. Erlandia sp. Girvanella sp. sponge spiculae.	—	—								
SE' of	WA84/100	Nankinella sp. Paleotextularia sp. Eotuberitina sp. Glomospira sp.							—	—		
Sapsamothot (Temple)	WA84/124	Triticites sp. Rugosofusulina sp. Tubiphytes sp. Permocalcurus algal and bryozoan fragments			—							
	84/125	Rugosofusulina sp.				—						
Wang Pi Kun	WA84/130	Paraschwagerina sp. Cribrogenerina sp. Paleotextularia sp. Globivalvulina sp.			—							
	WA84/128	Eoverbeekina sp. Chusenella sp. Neofusulinella sp. Deckerella sp. Climacammina sp. Cribrogenerina sp. Paleotextularia sp. Globivalvulina sp. Neoendothyra sp. Pachyphloia sp.						—				

sample locality			Carboniferous		L. Permian			M. Permian			U. Perm.	
			m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Khao Khi Nok	WA 84/102	Ipciphyllum nov. sp.?								—		
	WA84/108/110/112	Ipciphyllum laosense PATTE								—		
		Ipciphyllum laosense PATTE								—		
		Ipciphyllum laosense PATTE								—		
	WA 82/120	Globivalvulina sp. Pachyphloia sp. Tuberitina sp.							? —	—		
	WA82/122	Sumatrina longissima Verbeekina verbeeki Verbeekina (Armenia) sp.								—		
	WA84/106	Pachaphloia sp. Calcisphera sp. Ungdarella sp.							—			
	WA84/109	Chusenella sp. Deckerella sp. Climacammina sp. Mizzia sp.							—			
Sapsamothot - Wang Pi Kun rd. E'Wang Pi Kun	82/168	Hemifusulina sp. (?)		—	—							
	WA82/169	Hemifusulina sp. Bradyina sp. Tubiphytes sp.		—	—							
	WA84/129	Ipciphyllum minor FONTAINE								—		

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Lom Sak - Chum Phae road, pelagic facies of the Petchabun Fold Belt km 16.42 Ru82/22a	Schwagerina sp. Endothyria sp. Hemigordius sp. dasycladacean algae and crinoidal fragments				—						
82/22b	Pseudofusulina (Daixina) sp. Hemigordius sp.			—	—						
km 16.63 Ru82/23	Pseudofusulina (Daixina) sp.			—	—						
km 16.95 Ru82/29	Pseudoschwagerina sp. Bultonia sp. Fenestella			—							
km 17.01 Ru82/30	Parafusulina sp. Pseudofusulina (Daixina) sp. Boultonia sp.(?) Endothyria sp. Hemigordius sp. Umbellina sp. Fenestella sp.			—	—						
km 17.22 Ru82/34	Parafusulina sp. Sumatrina sp. Yangchienia sp. Neoschwagerinida sp. Pachyphloia sp. Hemigordius sp. Kamurana sp.						—	—			
17.63 /41	Pseudodoliolina sp. Parafusulina sp.						—	—	—		
km 17.67; Ru82/38	Pseudodoliolina sp. Parafusulina sp.						—	—	—		
km 17.72 Ru82/42	Parafusulina gigantea DEPRAT Pseudodoliolina sp. Yangchienia sp. Sumatrina sp. Sphaerulina sp. (?) Hemigordius sp. Neoendothyria sp. Aquathammina sp Tubiphytes cf. obscurus MASLOV							—	—		
km 18.12 Ru82/7	Parafusulina sp. Parafusulina sp. cf. gigantea DEPRAT Sphaerulina							—	—		
km 18.43 Ru82/43	Parafusulina gigantea DEPRAT Pseudodoliolina sp. Sumatrina sp. Yangchienia sp. Hemigordius sp. Qenitzena sp. Tubiphytes obscurus MASLOV						—	—			

sample locality			Carboniferous		L. Permian			M. Permian			U. Perm.	
			m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Nong Pai - Petchabun road, W'km 181.5	WA84/16	Schwagerinid fusulinae Umbellina sp. Deckerella sp. Lassiodiscus sp. (in oncolith) Algal and bryozoan fragments			—	—	—	—	—	—		
	WA84/18	Pseudoschwagerina sp. Quasifusulina sp. Cribrogenerina sp. Bisphaera sp Epimastopora sp. Tubiphytes corynthiacus (FLÜGEL)			—							
	WA84/24	Pseudoschwagerina sp. Quasifusulina sp. Eotuberitina sp.			—							
	WA82/174	Pseudoschwagerina sp. Rugosofusulina sp. Bradyina sp. Climacammina sp. Bisphaera sp. Eotuberitina sp. Tubiphytes sp.			—							
	WA82/175	Endothyra sp. Textularia sp. Lassiodiscus sp. Frondina sp. Bisphaera sp. Deckerella sp. Eotuberitina sp. Girvanella sp. blastoid plate.		—	—							
	WA82/178	Rugosofusulina sp. Bigenerina sp. Bisphaera sp. Tubiphites sp.			—	—						
Ban Na Chariang - Chon Daen road.	WA84/136	Favosites coral Stafella sp. Baisalina sp.	—	—								
	WA84/137	Pseudofusulina vulgaris SCHELLWIEN crinoidal and algal fragments				—						

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Lom Sak - Chum Phae road, molasse facies km 36.80 HE80/15	Sumatrina sp. Codonofusiella sp. Ozawainella sp. Pachyphloia sp. Tetrataxis sp. Tubiphytes sp. algal fragments								—	—	
km 37.55 WA82/17	Parafusulina sp. Codonofusiella sp. Rauserella sp. Khalerina sp. Neoendothyra sp. Climacammina sp. Tetrataxis sp. Bigenerina sp. Pachyphloia sp. Agathammina sp.								—		
km 38.40 WA82/18	Pseudodoliolina pseudolepida DEPRAT Schwagerina sp. Cribrogenerina sp.								—		
km 38.70 HE84/21	Verbeekina verbeeki Pseudodoliolina sp. Sumatrina longissima Chusenella cf. shengi Kahlerina sp. Minojapanella sp. Russiella sp. Dunbarulla sp. Codonofusiella sp. Tetrataxis sp. Agathammina sp. Ungdarella sp.							—			
km 39.00 HE84/20	Chusenella sp. Tetrataxis sp. Pachyphloia sp. Neoendothyra sp. Deckerella sp. Langella sp. Umbellina sp. Fotuberitina sp. Iuberitina sp.							—			

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Lom Sak - Chum Phae road, molasse facies km 39.18 HE84/18	Codonofusiella cf. gubleri TIEN Schwagerina crassa DEPRAT Kahlerina sp. Climacammina elegant MÖLLER Cribrogenerina sumatrana LANGE Pachyphloia Paleotextularia Girvanella Fenstellid Oncolith								—	—	
km 39.21 HE84/17	Chusenella sp. Reichelina sp. Neoendothyra parva LANGE Deckerella sp. Tetrataxis sp. Textularia sp. Lagena sp. Nodosaria sp. Cribrogenerina sp.								—		
km 39.25 HE84/16	Chusenella shengi TORIYAMA & KANMERA Rauserella sp. Pachyphloia sp. Agathammina sp. Hemigordius sp. Paleotextularia sp. Neoendothyra parva LANGE Tetrataxis sp. Antharacoporella sp. Epimastopora sp. algal fragments								—	—	
km 39.30 HE84/15	Codonofusiella sp. Chusenella sp. Agathammina sp. Anthracoporella sp. Epimastoporella sp. Tubiphytes sp. bryozoan and algal fragments crinoidal stem joint								—		
km 39.40 HE84/13	Bryozoa - Fenestelid polypora Girvanella sp. Climacammina sp. Bigenerina sp. Langella sp. Crusted algae, crinoidal stem joint								—		

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Lom Sak - Chum Phae road, molasse facies km 39.40 HE84/14	Agathammina sp.										
	Textularia sp.										
	Neoendothyra sp.										
	Anthracoporella sp.								—		
	Anchicodium sp.										
	Uermiporella sp.										
	Girvanella sp.										
	crinoidal stem joint										
km 39.70 HE84/12	Pseudodoliolina										
	Minojapanella										
	Reichelina										
	Tetrataxis cf. conica								—	—	
	Agathammina sp.										
	Pachyphloia sp.										
	Endothyra sp.										
km 39.85 HE84/11	Codonofusiella sp.										
	Chusenella sp.										
	Reichelina sp.										
	Endothyra sp.										
	Tetrataxis sp.										
	Paleotextularia sp.										
	Abadahella sp.								—	—	
	Pachyphloia sp.										
	Climacammina sp.										
	Umbellina sp.										
	Bigenerina sp.										
	Eotuberitina sp.										
km 39.92 HE84/10	Codonofusiella sp.										
	Minojapanella sp.										
	Neoendothyra sp.										
	Globivalvulina sp.										
	Paleotextularia sp.										
	Climacammina sp.										
	Cribrogenerina sp.										
	Pachyphloia sp.										
	Tetrataxis sp.								—	—	
	Protonodosaria sp.										
	Hemigordius sp.										
	Frondina sp.										
	Eotuberitina sp.										
	Tubiphytes sp.										
	algal and crinoidal fragments										
	Stellate radiolaria										
	Sponge										

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Lom Sak - Chum Phae road, molasse facies. km 39.99 HE84/9	Verbeekina verbeeki Pseudodoliolina Codonofusiella sp. Dembarula sp. Pachyphloia sp. Eotuberitina sp. Ungdarella and other algae								——	—	
km 40.02 WA82/19	Pseudodoliolina pseudolepida DEPRAT Ungdarella sp. unidentifiable fragments of fusulinacean foraminifera								——		
HE84/8	Verbeekina verbeeki GEINITZ Chusenella sp. Pseudodoliolina sp. Khalerina sp. Tetrataxis sp. Agathammina sp. Pachyphloia sp.								——	—	
km 40.05 WA82/20	Verbeekina verbeeki GEINITZ Pseudodoliolina pseudolepida DEPRAT Chusenella sp. Codonofusiella sp. Rauserella sp. Minojapanella sp. Gribrogenerina sp. Bigenerina sp. Dagenerina sp. Tubiphytes sp. Ungdarella sp.								——	—	
km 40.+? HE84/7	Verbeekina verbeeki GEINITZ Verbeekina sp. Pseudodoliolina sp. Geinitzina sp. Frondina sp. Mizzia sp. Tubiphytes sp. Ungdarella sp.								——	—	
km 40.18 WA82/22	Pseudodoliolina sp. Chusenella cf. compacta WHITE Reichelina sp. Tuberitina sp. Ungdarella sp.								——		

sample locality			Carboniferous		L. Permian			M. Permian			U. Perm.	
			m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Nam Nao National Park, E' of Ban Huai Lat	WA84/214	Presumatrina sp. Khalerina sp. Rauserella sp. Nankinella sp. Neoschwagerina sp. Minojaponella sp. Tetrataxis sp. Geinitzina sp. Tubiphytes sp.						—	—			
	WA84/215	Afghanella sp. Chusenella sp. Deckerella sp. Streblascopora sp. Multithecopora Tubiphytes sp.							—			
	WA84/216a	Colaniella sp. Sumatrina sp. Hikkorocodium sp. crinoidal stem joint							—	—		
	WA84/216b	Neoschwagerina sp. Sumatrina sp. Chusunella sp. Umbellina sp. Tubiphytes corynthiacus echinoid spine, bryozoa and algal fragments							—	—		
Lom Sak - Chum Phae road	km 86.5 WA82/102	Parafusulina japonica Parafusulina gigantea Sumatrina sp. Yangchienia sp. Minojapanella sp. Cribrogenerina sumatrana Hemigordius sp. Tetrataxis sp. Globivalvulina sp. Lagena sp. Permacalcurus sp. Tubiphytes sp. Epimastopora sp.						—	—			
	km 84.5 WA82/110	Hemigordius sp. Hikorocodium sp. Bryozoa gen. et sp. indet. Tubiphytes sp.						—	—			

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Lom Sak - Chum Phae road, molasse facies km 40.+? HE80/17	Pseudodoliolina pseudolepida Chusenella sp. Afghanella sp. Verbeekina cf. verbeeki (destructive form) ? Minojapanella sp. Geinitzina sp. Pachyphloia sp. Tetrataxis sp.								—		
km 40.19 HE84/4	Pseudodoliolina cf. gracilis TORIYAMA & KANMERA Schwagerina sp. Sumatrina sp. Minojapanella sp. Dunbarula sp. Pachyphloia sp. Tetrataxis conica EHRENBERG Agathammina sp. Endothyrid Geinitzina sp. Ungdarella sp. algal fragments								—		
km 40.22 HE84/5	Schwagerina crassa DEPRAT Minojapanella sp. Reichelina sp. Dunbarula sp. Neoendothyra sp. Glomospira sp. Globivalvulina sp. Lagella sp. Geinitzina sp. Textularia sp. Eotuberitina sp. Ichtyolaria sp. Tubiphytes sp. Girvanella sp.								—		
km 40.30 WA84/112	Verbeekina verbeeki Ungdarella sp.								—	—	
km 40.35 HE84/6	Pseudodoliolina cf. gracilis TORIYAMA & KANMERA Schwagerina sp. Ozawainella sp. Minojapanella sp. Endothyra sp. Tetrataxis sp. Tubiphytes sp. Mizzia sp. Ungdarella sp.								—		

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
km 79.0 HE81/51	Toriyama sp. Armenia karinae (KOCHANSKY - DEVIDE & RAMOVS) Pseudofusulina cf. regularis (SCHELLWIEN) Pseudofusulina sp. Parafusulina sp. or Nagatoella sp. Cuniculinella sp. Neofusulinella sp. Climacammina sp. Globivalvulina sp. Pachyphloia sp. Geinitzina sp. Tubiphytes sp. Stromatolithes					—	—				
Lom Sak - Chum Phae road km 81.5 HE81/52+HE82/25	Parafusulina sp. cf. japonica GÜMBEL Parafusulina gigantea DEPRAT Parafusulina parva PITAKPAIVAN Parafusulina cf. grupensis (?) Yangchienia tobleri THOMPSON Nankinella sp. Tetrataxis sp. Cribrogenerina sp. Neoendothyra sp. Pachyphloia sp. Deckerella sp.						—	—			
km 81.2 WA82/83	Parafusulina Neoendothyra sp. Umbellina sp. Epimastopora sp. Tuberitina sp.							—	—		
km 87.5 WA82/98	Parafusulina gigantea DEPRAT Nankinalla sp. Minojapanella sp. Cribrogenerina sp. Textularia sp. Parmacalcurus sp.						—	—			

sample locality			Carboniferous		L. Permian			M. Permian			U. Perm.	
			m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Chum Phae - Nam Prom Dam road	HB82/26	Misellina claudiae DEPRAT Globivalvulina sp. Eotuberitina sp. Permocalculus sp.					—	—				
	HB82/27	Parafusulina gigantea DEPRAT Parafusulina japonica GÜMBEL Parafusulina sp. Yangchienia thompsoni SKINNER WILDE Eotuberitina sp. Girvanella sp.					—	—				
	WA82/93	Presumatrina sp. Parafusulina cf. gigantea Yangchienia cf. tobleri Chusenella sp. Cribrogenerina sp. Paleotextularia sp. Protonodosaria sp. Tubiphytes sp. Ungdarella sp.							—	—		
	WA82/86	Hemigordius sp. Pachyphloia sp. Abadehella sp. Tubiphytes sp. Permocalcurus sp. crinoidal fragments							—	—		
	WA82/87	Polythecalis sp. Hemigordius sp. bryozoan and crinoidal fragments							—	—		
	WA82/91	Parafusulina cf. parva Geinitzina sp. Globivalvulina sp. Eotuberitina sp. Climacammina sphaerica Dasycladacean algae						—	—			

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Ban Dong Noi 14km S'Wang Saphung WA82/82	Parafusulina sp. Pseudodoliolina sp. Yangchienia sp. Pachyphloia sp. Paleotextularia sp. Eotuberitina sp. Ungdarella sp. Epimastopora sp. Permocalcurus sp.							—	—		
Ban Kok Klaeng SW'of Wang Saphung WA82/80	Pseudofusulina valida Eoparafusulina sp. Staffelid Rugosofusulina sp. (?) Boultonia sp. Globivalvulina sp. Hemigordius sp. Pachyphloia sp. Tetrataxis sp. Tubiphytes sp.				—						
Chum Phae - Loei road km 265.0 WA84/141	Pseudoschwagerina sp. Triticites sp. Rugosofusulina sp. Eoschubertella sp. Bradyina sp. Paleotextularia sp. Globivalvulina sp.			—							
km 271.0 WA84/142	Lepidodoliolina cf. gracilis Parafusulina sp. Yangchienia cf. tobleri Armenia sp. Afghanella sp. algal fragments							—			
km 319.9 WA84/155	Triticites ozawai Quasifusulina tenuissima Tubiphytes algal fragments and oncoliths			—							

sample locality			Carboniferous		L. Permian			M. Permian			U. Perm.	
			m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Loei - Chiang Khan road, quarry, 2km N' of Loei	WA82/39	Pseudofusulina sp. Pseudofusulina sp. (thick wall) Tetrataxis sp. Lassiodiscus sp. Tubiphytes sp.			—	—						
	WA82/35	Pseudofusulina sp. Triticites sp. Ozawinella sp. Tubiphytes obscurus Tubiphytes g. corynthaicus			—	—						
	WA82/33	Schubertella sp.(?) Tetrataxis sp. Globivalvulina sp. Eotuberitina sp. Bradyina sp. Tubiphytes sp. bryozoa, shell and crinoidal stem fragments			—	—						
km 2.0	HE 46/82	Pseudofusulina sp. ? Triticites sp.			? —	? —	—					
Loei - Tha Li road km 2.7-2.8	82/14	Pseudofusulina sp.					—					
	82/16	Pseudofusulina sp.					—					
	82/26	Tetrataxis sp. Geinitzina sp.				? —	? —					
km 3.3	82/12	Agathiceras sp.						—	—	—		
	82/10	Agathiceras sp.						—	—	—		
km 13.0-13.1	HB82/43	Pseudofusulina sp. Cribrogenerina sp. Pachyphloia sp. Textularia sp. Eotuberitina sp. Tubiphytes sp.					—					
35km W' of Chiang Khan	WA84/185	Endothyrid Eotuberitina sp. Pachyphloia sp. Ostracod			—	—	—	—	—			

sample locality		Carboniferous		L. Permian			M. Permian			U. Perm.	
		m.	u.	Ass.	Sak.	Yah.	Bol.	Kub.	Mur.	Mid.	
Wang Saphung - Na Klang road km 15.5 WA84/197	Nankinella sp. Endothyrid sp. Kanmurana sp. (?) Paleotextularia sp. Glomospira sp. Tuberitina sp. Globivalvulina sp. Vermiporell cf. nipponia						—	—			
km 17.2 WA84/198	Pravitoschwagerina thailandensis TORIYAMA Misellina cf. termieri Ozawinella sp. Kamurana sp. Calcitornitella sp. Pachyphloia sp. Pseudovermiporella sp.					—					
km 17.8 84/199	Pseudofusulina sp.				—	—	—				
km 30.0 WA84/204	Eoverbeekina sp. Globivalvulina sp. Pachyphloia sp. Eotuberitina sp. Girvanella sp. Ostracod					—	—				
WA84/206	Eoverbeekina sp. Globivalvulina sp. Pachyphloia sp. Eotuberitina sp. Pseudovermiporella sp. (?)					—	—				

GUIDE FOR LOG-PROFILES

Rock type:

▩	claystone, mudstone, shale
⛆	sandstone, graywacke
⊞	limestone
⊞	dolomitic limestone
⊞	tuffaceous limestone
⊞	chertified limestone
▦	tuff, tuffite
▼	chert
°	conglomerate
▒	siltstone
≈	marl

Bedding plane properties:

⊟	sharp, flat contact
⊟	distinct, flat contact
∼	undulating contact

Structures:

⊡	flute cast
⊡	striation cast
⊡	load cast
⊡	prod cast, bounce cast

Current direction:

⧄	line of flow pointing and distinct (SW to NE)
⧄	line of folw distinct, pointing doubtful (SW-NE)

Color:

wh - white
rd - red
blk - black
yel - yellow

gy - grey
gn - green
brn - brown
prp - purple

Intensity:

lt - light
md - medium
dk - dark

Layer properties - sedimentary structures:

═	bedding, dcm range
≡	bedding, cm range
☰	bedding, mm range (lamination)
≋	wavy bedding
∾	lenticular - wavy bedding < 1m
⬭	lenses of beds > 1m
≠	no apparent bedding
∠	cross-bedding
Y	cross-bedding, multi-directional
••••	graded bedding
••••	inverse graded bedding
~	casts under megaclasts
⊙	casts surrounding megaclasts
⬭	rip-up clasts, nodules
⊓	convolute bedding
⊐⊏	pull-apart
⌊	pull over, flame structure
@	contored bedded, slump
>	wedging, pinching out
∿	asymmetrical ripples
∧∨	symmetrical ripples
≈	parting lineation
-=-	streaming lineation
-0-	burrows
-0- v	vertical
-0- h	horizontal
♠	plant fragments lineation

Texture:
(In carbonates applied for allochthonous particles.)

Clay, silt: 0.062 mm
f.S. - fine sand size: 0.2 - 0.062 mm
m.S. - medium sand size: 0.2 - 0.62 mm
c.S. - coarse sand size: 0.62 - 2.0 mm
f.G. - fine gravel size: 2.0 - 6.2 mm
m.G. - medium gravel size (and coarse gravel size): > 6.2 mm

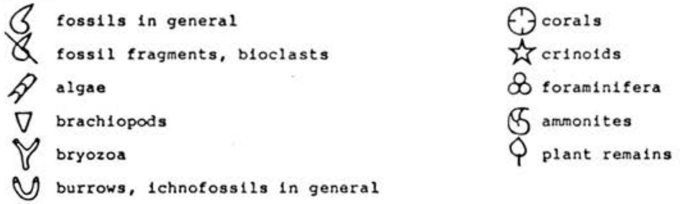
Cement:

T	clay cement	TT	chert, quartz cement
▤	carbonate cement	▤	ferritic cement

Induration:

1 - friable, rock crumbles between fingers.
2 - moderately hard, grains can be detached using knife, small chips can be easily brocken by hand.
3 - hard, chips are difficult to break by hand, fractures go between sand grains.
4 - very hard, fractures pass through grains.

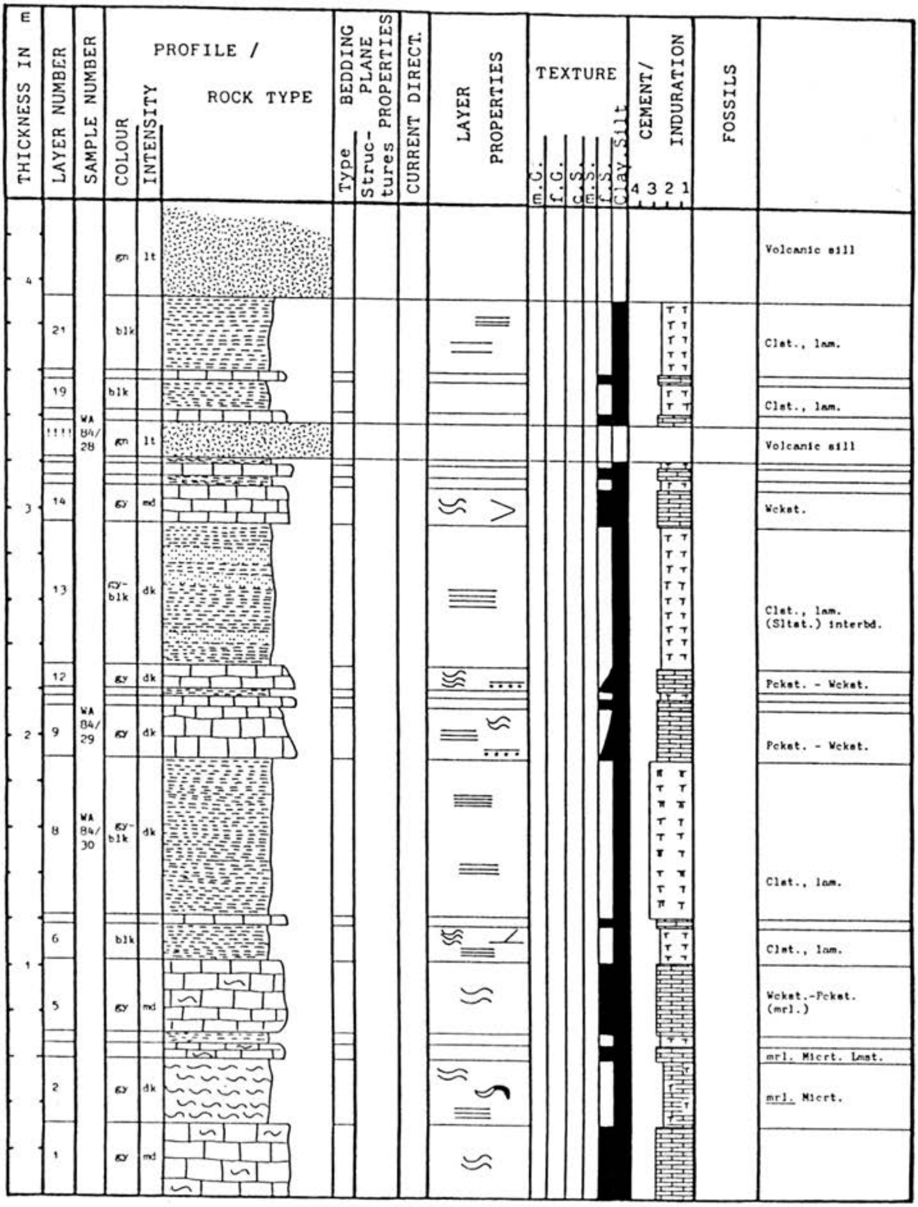
Fossils:



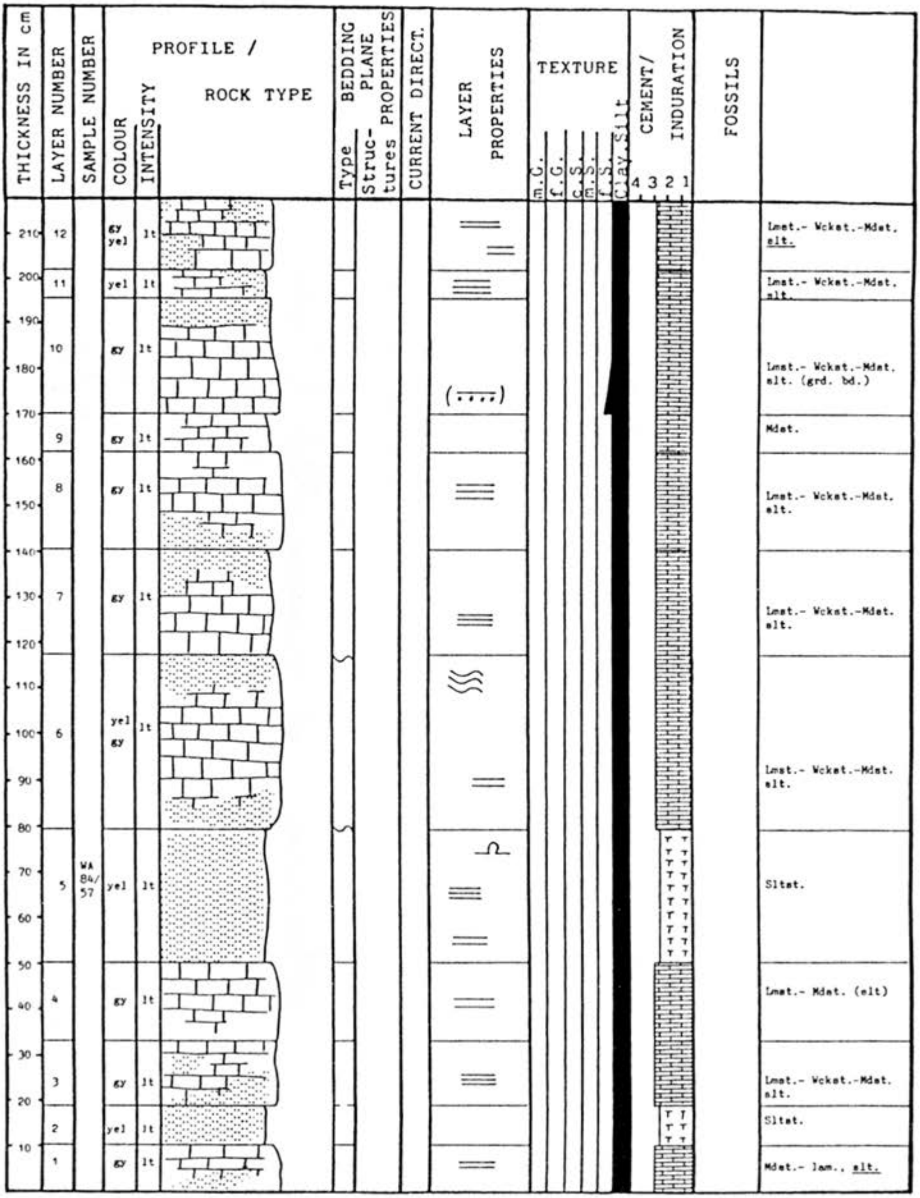
Description and adjectives:

(...) - slightly, weak, rare
<u>XY</u> - strong, abundant, very
abd - abundant
aggl - agglomerate
alt - alternation
ang - angulare
Bc - breccia
bc - breccious
bd - bedded
biocl - bioclasts
Bld - boulder (> 256 mm)
carb - carbonaceous
Cbl - cobble (64-256 mm)
Cgl - conglomerate
cgl - conglomeratic
Chlt - chlorite
Cht - chert
cht - cherty
Clst - claystone
clst - clayish
cmt - cemented
crs - coarse
Dol - dolomite
dol - dolomitic
elong - elongated
f - fine
grd - graded
Grst - grainstone
inv - inverse
lam - laminated
lent - lenticular
Lmst - limestone
Mdst - mudstone
Mic - mica
micr - micro
Mrl - marl
mrl - marly
nod - nodules
Pb - pebble, pebbly (2-64 mm)
Pckst - packstone
Py - pyrite
Qz - quartz
rnd - rounded
Sdst - sandstone
sdst - sandy
Sh - shale
Slt - siltstone
slt - silty
sph - spherical
spr - sparritic
Tf - tuff, tuffite
tf - tuffaceous
Wckst - wackestone
wdg - wedge
wv - wavy
xln - crystalline

LOG PROFILE I
Pak Chong, at the gasoline station.

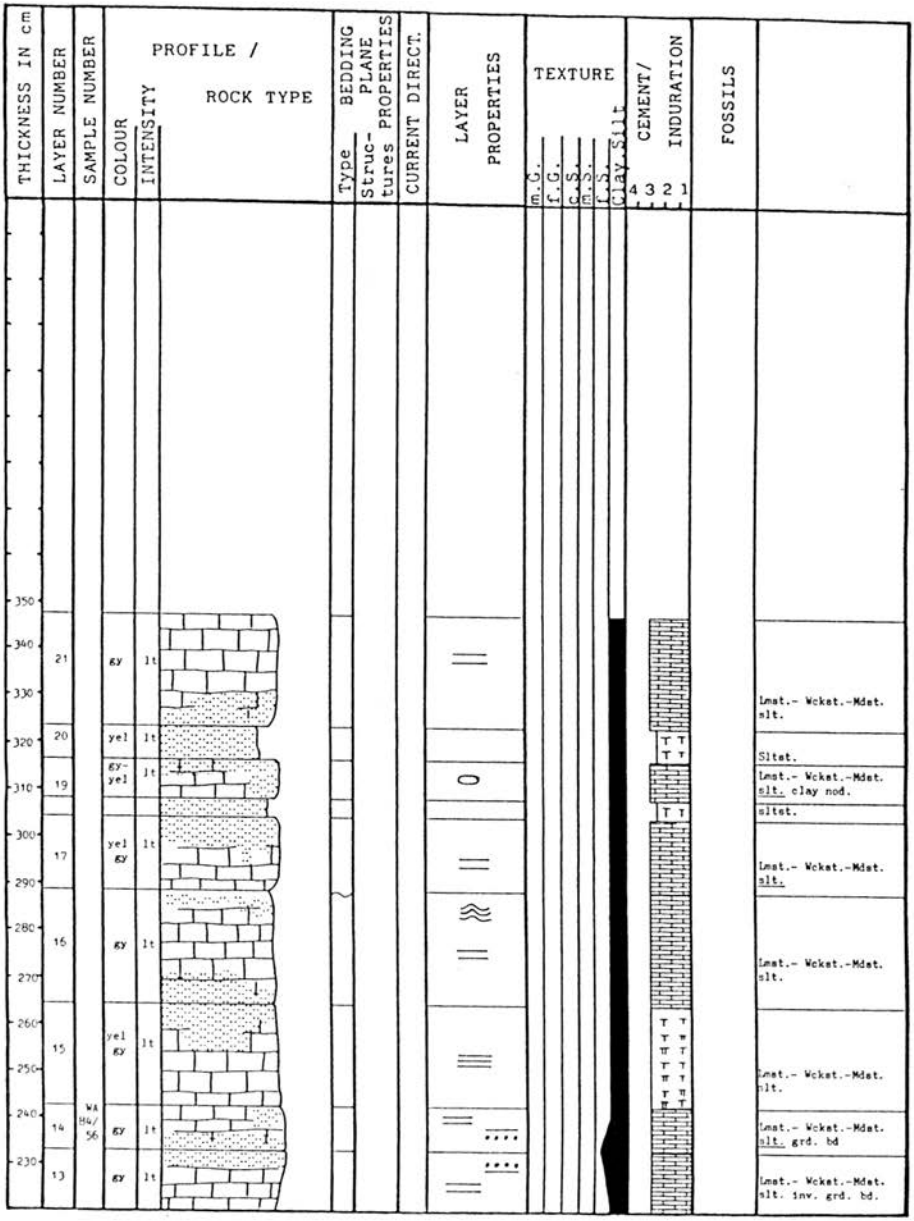


LOG PROFILE II (a)
Saraburi-Lam Na Rai road, km 2.3.

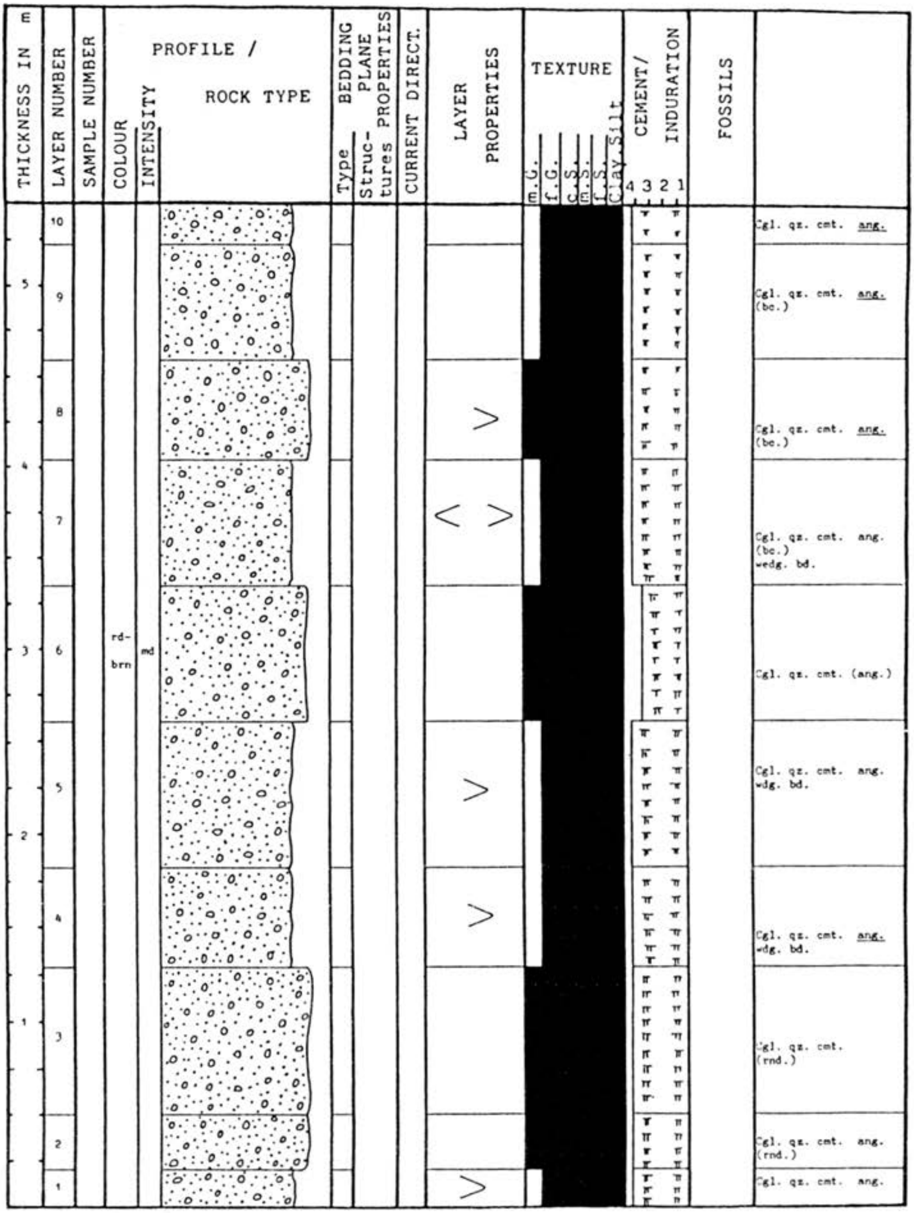


LAYER NUMBER	SAMPLE NUMBER	COLOUR	INTENSITY	
12		gy yel	lt	Lmst.- Wckst.-Mdst, slt.
11		yel	lt	Lmst.- Wckst.-Mdst, slt.
10		gy	lt	Lmst.- Wckst.-Mdst, slt. (grd. bd.)
9		gy	lt	Mdst.
8		gy	lt	Lmst.- Wckst.-Mdst, slt.
7		gy	lt	Lmst.- Wckst.-Mdst. slt.
6		yel gy	lt	Lmst.- Wckst.-Mdst. slt.
5	WA 84/57	yel	lt	Sltst.
4		gy	lt	Lmst.- Mdst. (slt)
3		gy	lt	Lmst.- Wckst.-Mdst. slt.
2		yel	lt	Sltst.
1		gy	lt	Mdst.- lam., slt.

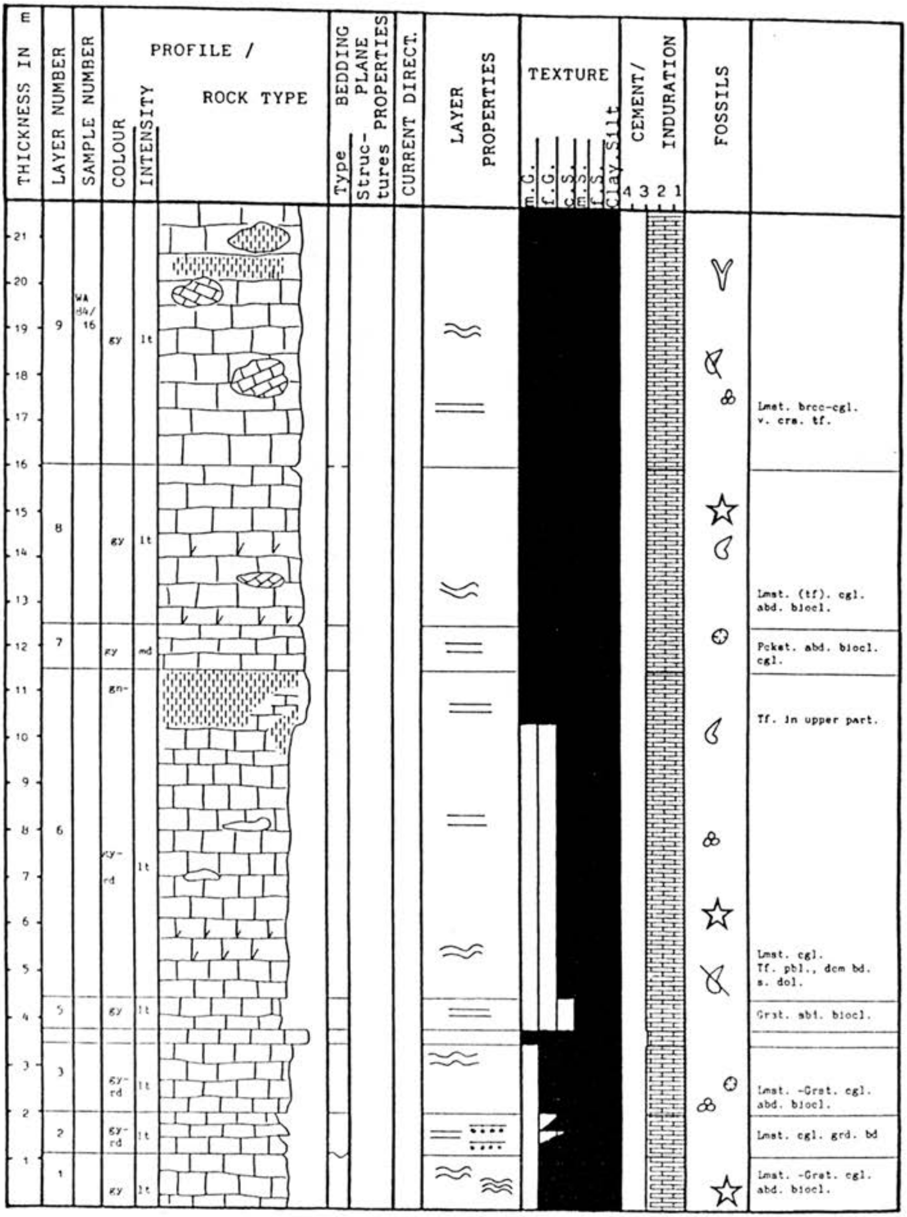
LOG PROFILE II (b)
Saraburi-Lam Na Rai road, km 2.3.



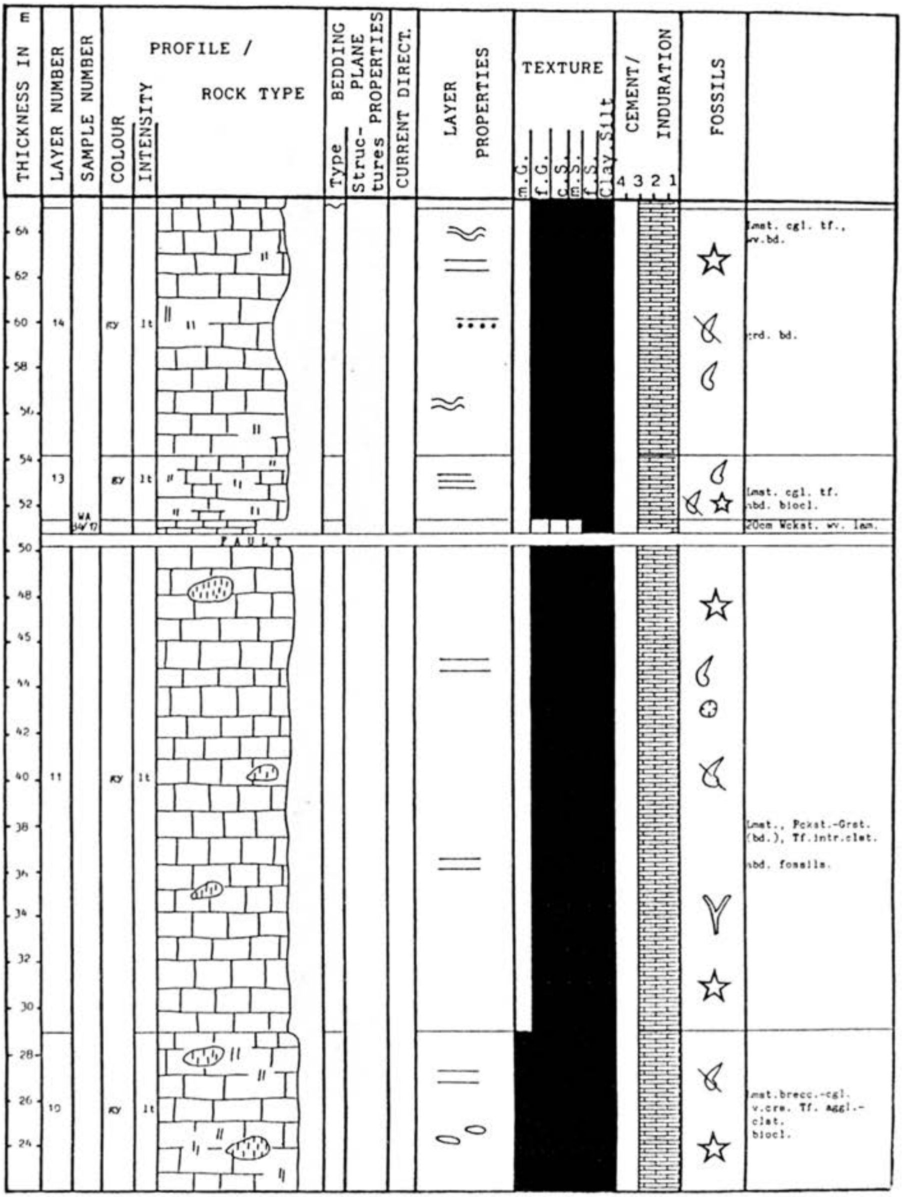
LOG PROFILE III
Wichian Buri- Lam Na Rai road, km 118.9



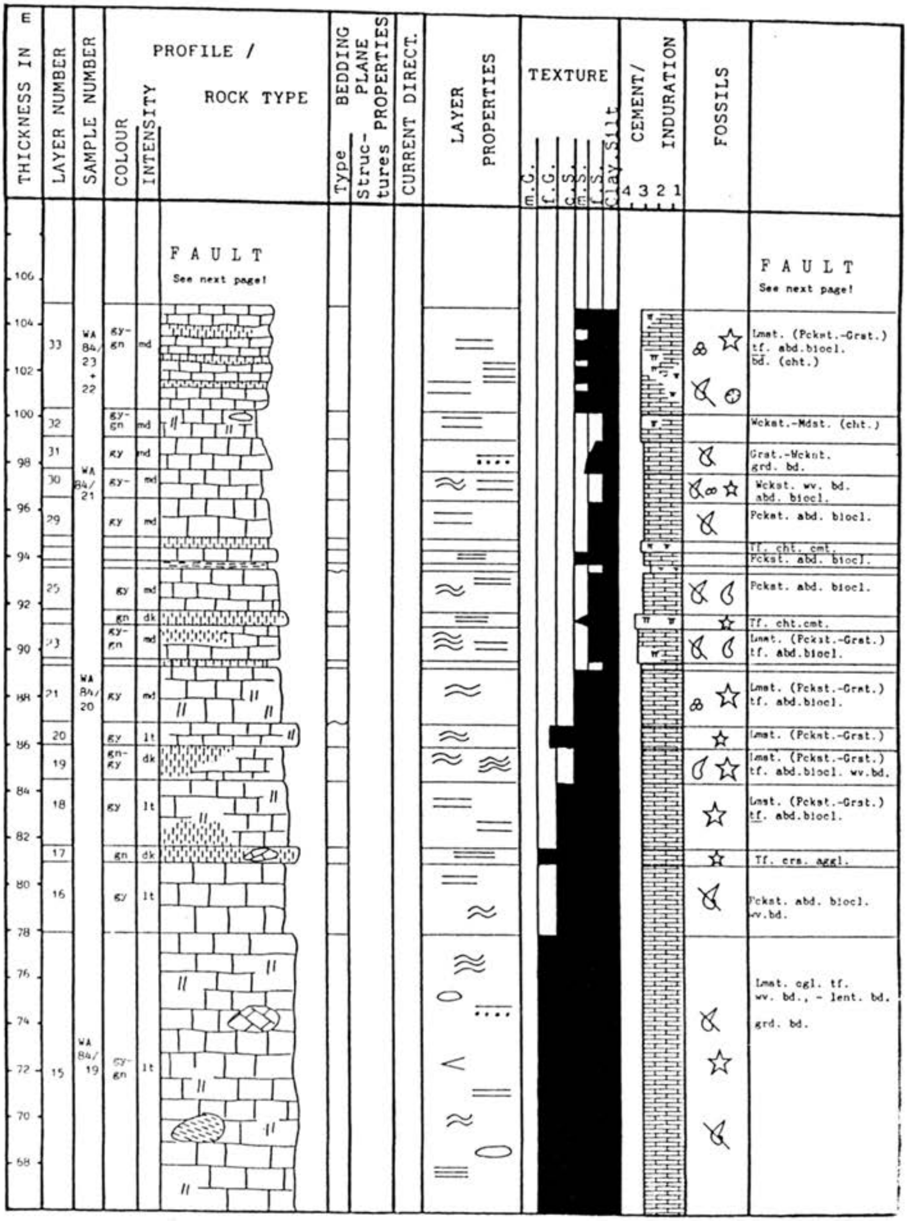
LOG PROFILE IV (a)
N of Nong Pai, km 181.5.



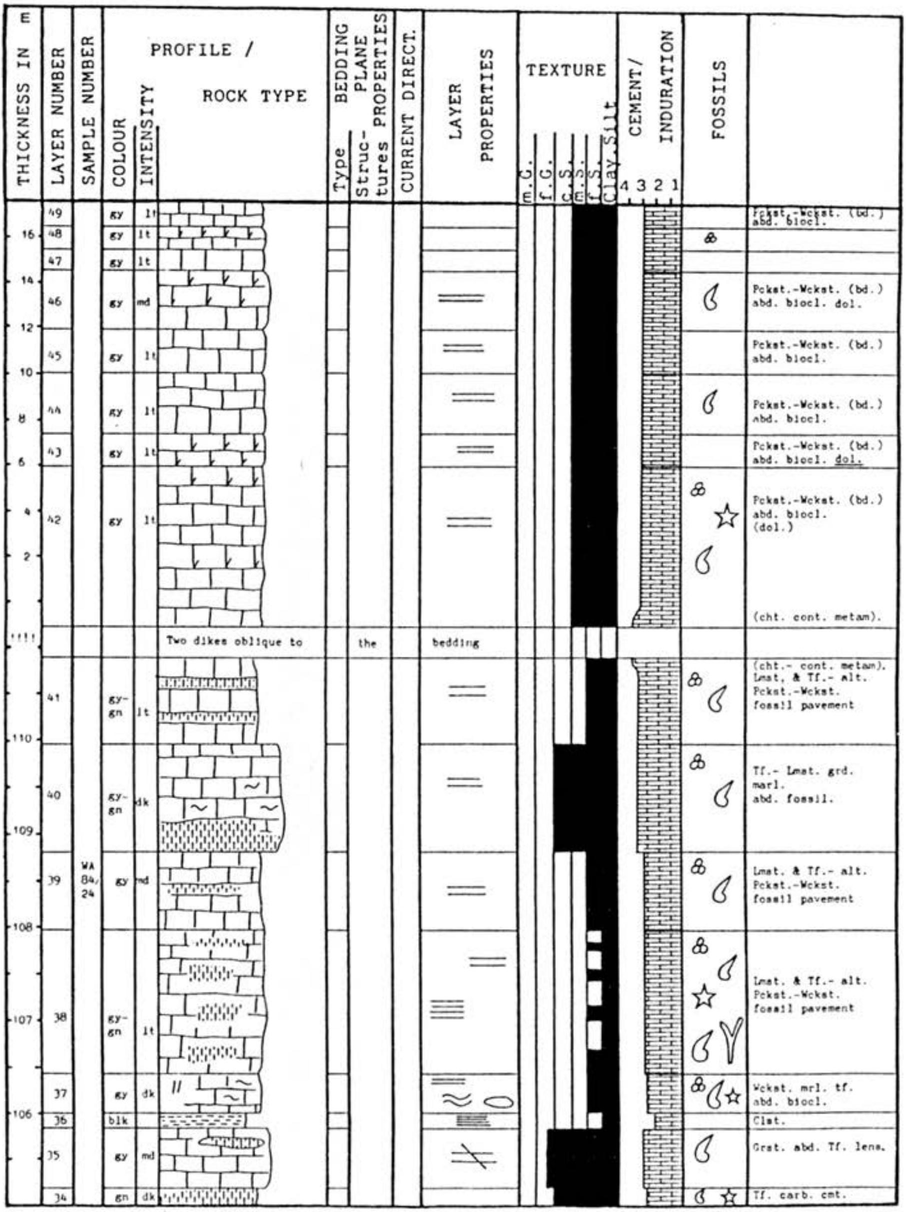
LOG PROFILE IV (b)
N of Nong Pai, km 181.5.



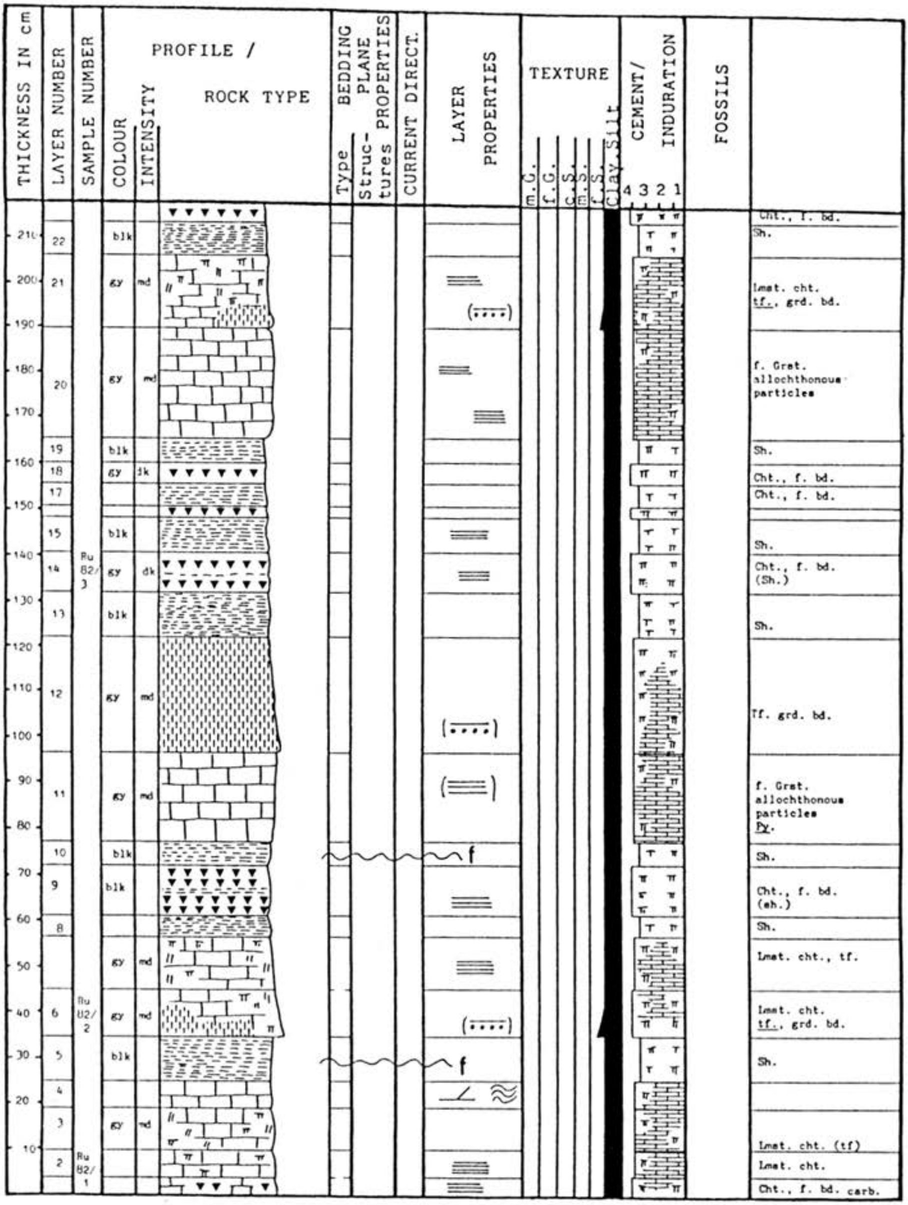
LOG PROFILE IV (c)
N of Nong Pai, km 181.5.



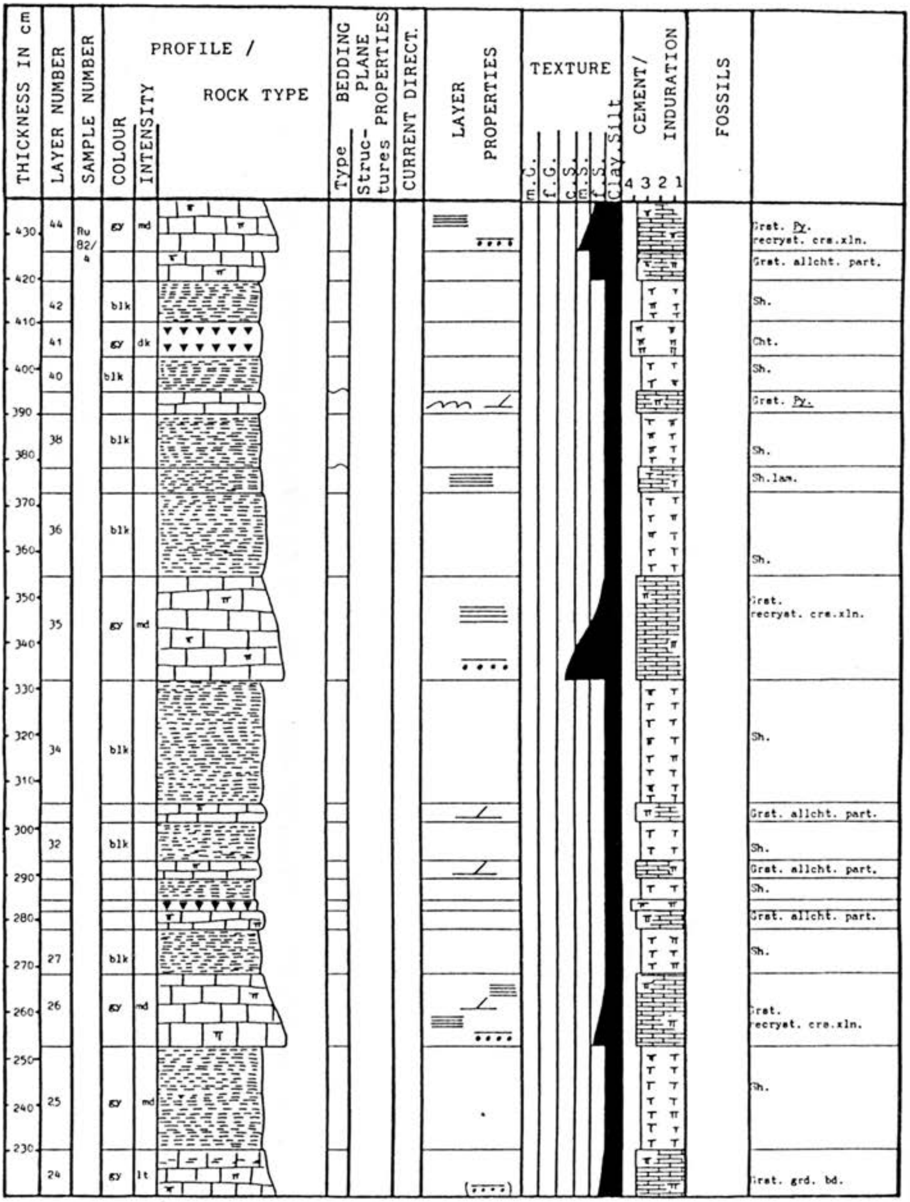
LOG PROFILE IV (d)
N of Nong Pai, km 181.5



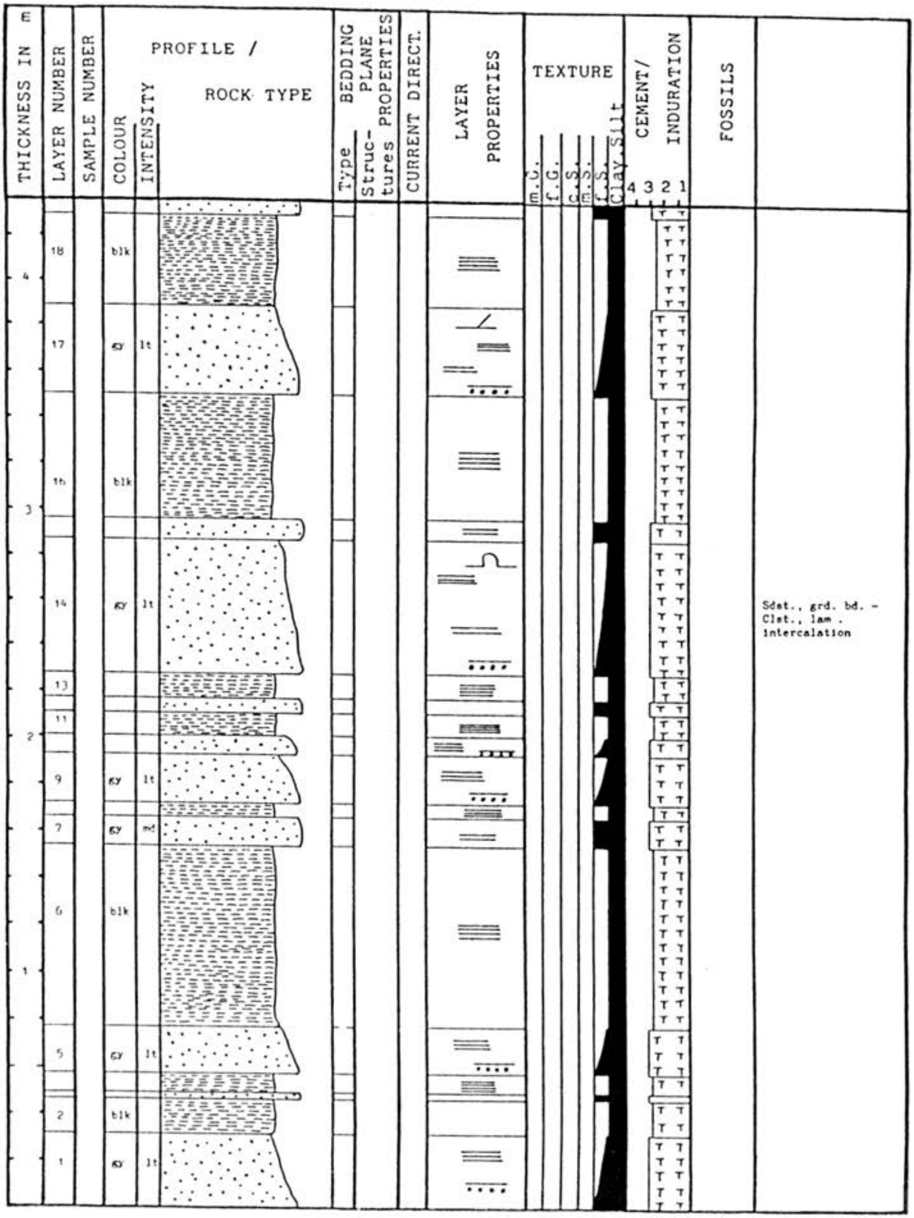
LOG PROFILE V (a)
Pelagic facies, Lom Sak-Chum Phae road, km 16.6.
(WINKEL, 1983)



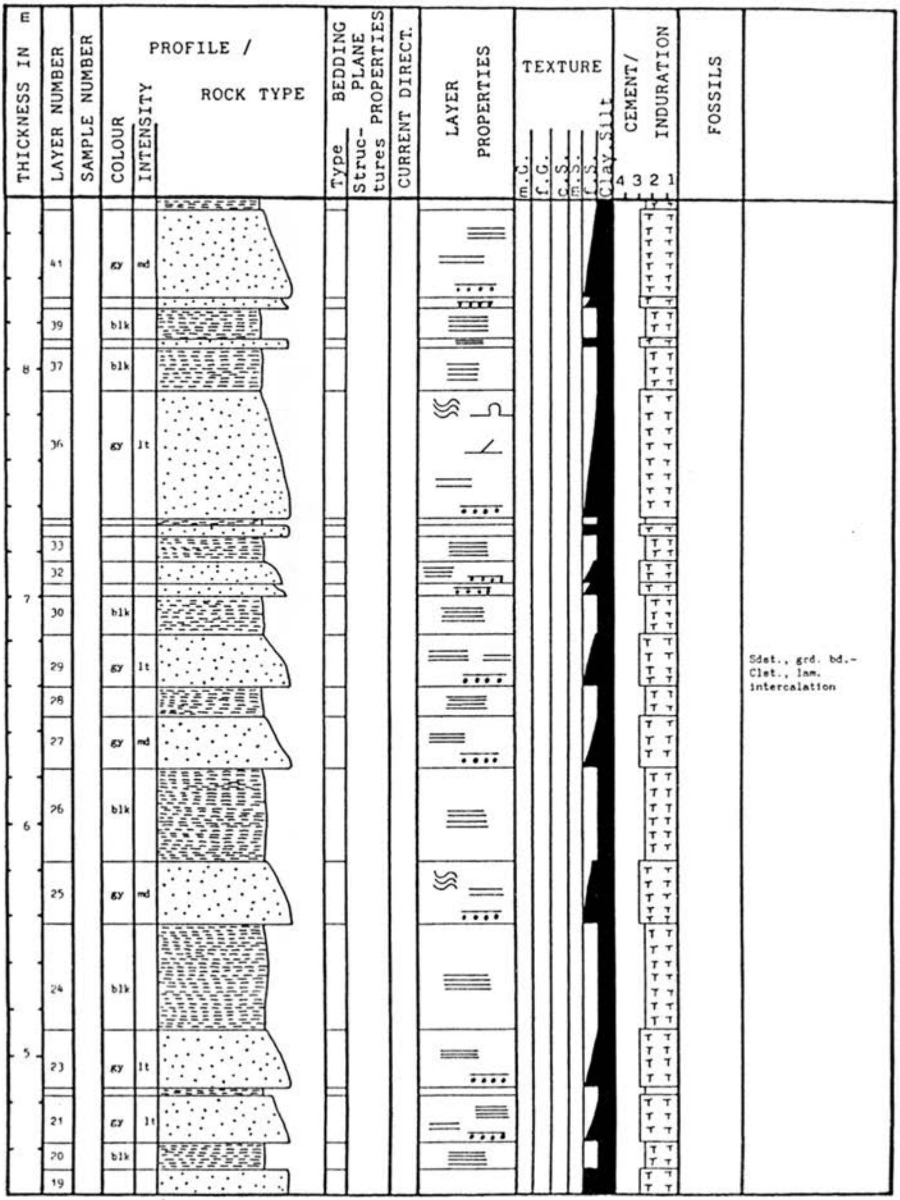
LOG PROFILE V (b)
Pelagic facies, Lom Sak-Chum Phae road, km 16.6.
(WINKEL, 1983)



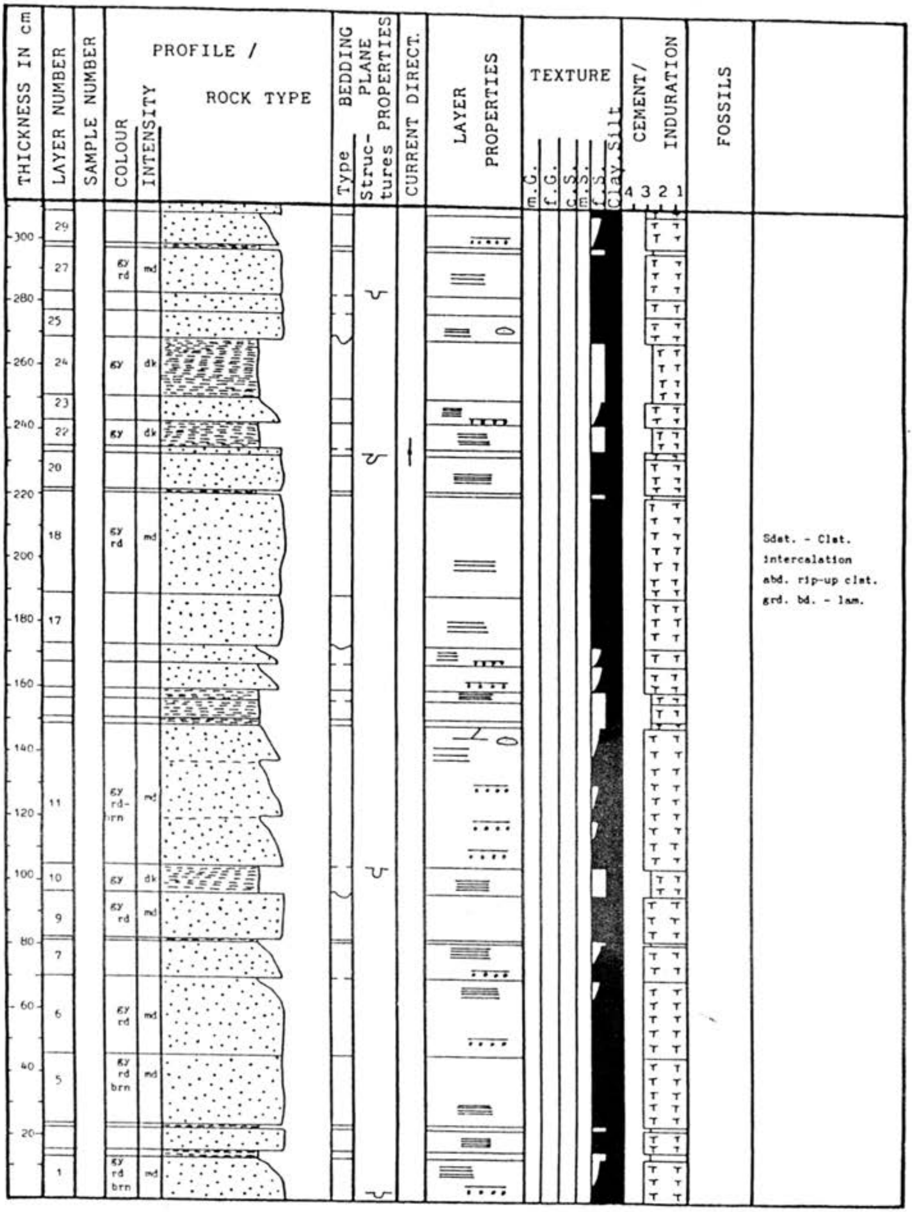
LOG PROFILE VI (a)
Flysch facies, Lom Sak-Chum Phae road, km 20.85.



LOG PROFILE VI (b)
Flysch facies, Lom Sak-Chum Phae road, km 20.85.

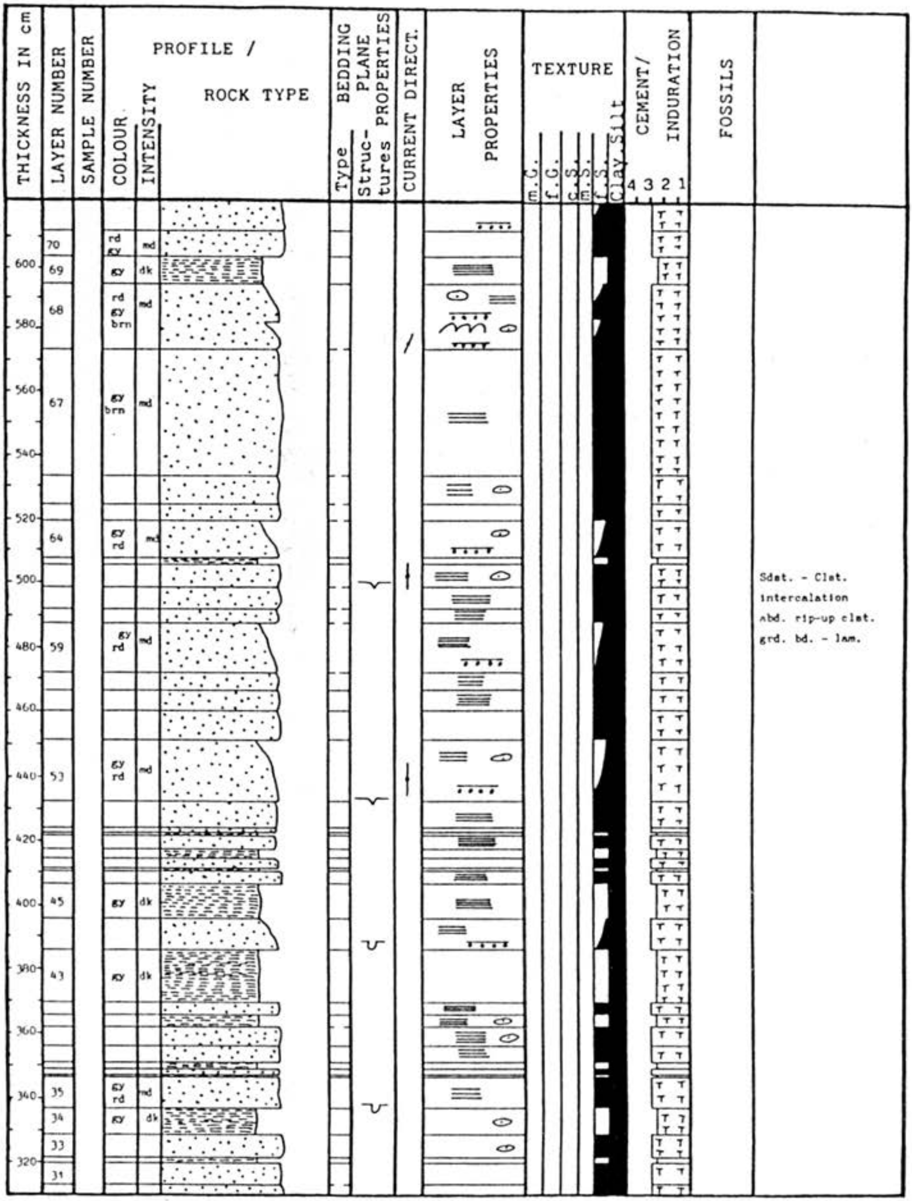


LOG PROFILE VII (a)
Molasse facies, Lom Sak Chum Phae road, km 34.85.
(Nam Nao Fm., Huai Rahong Unit, ALTERMANN, 1983)



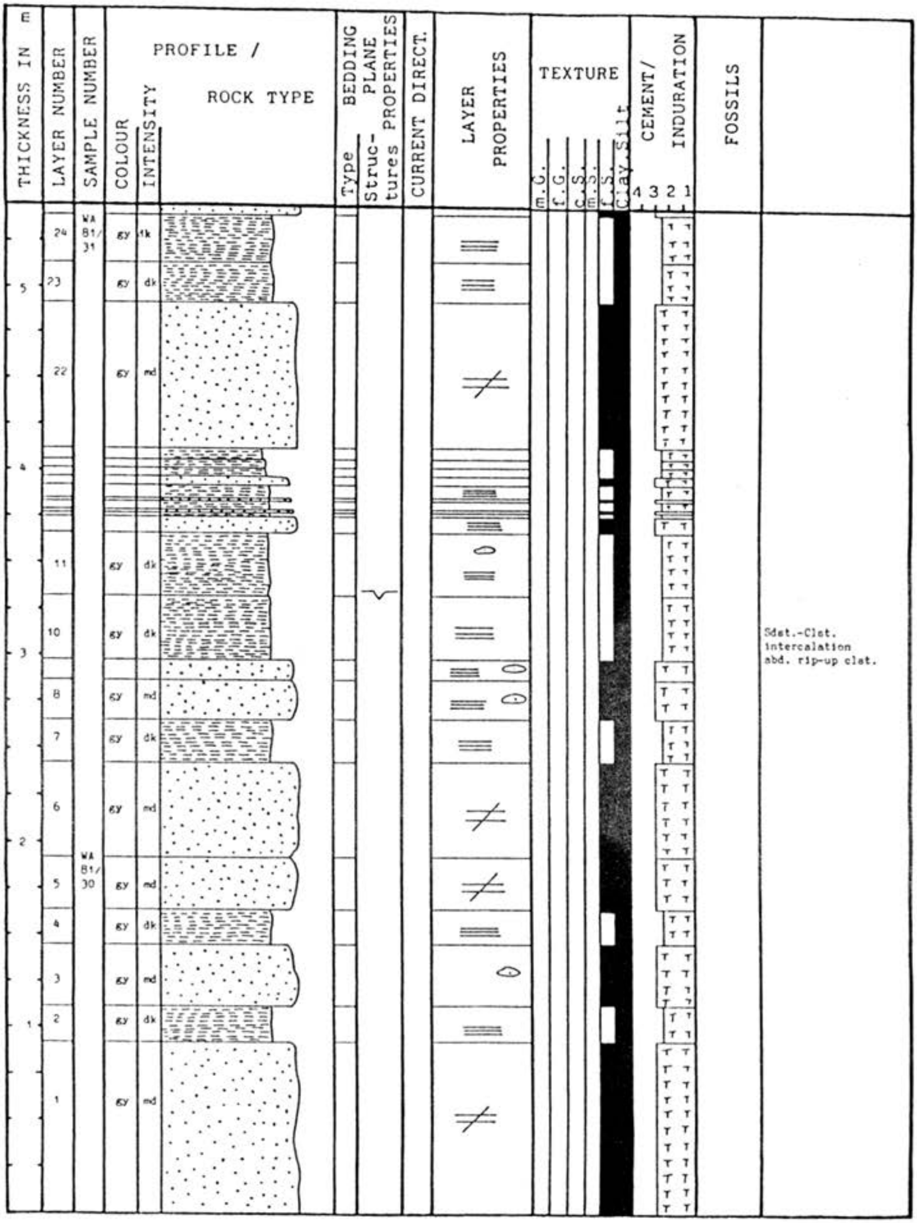
LOG PROFILE VII (b)

Molasse facies, Lom Sak-Chum Phae road, km 34.85.
(Nam Nao Fm., Huai Rahong Unit, ALTERMANN, 1983)

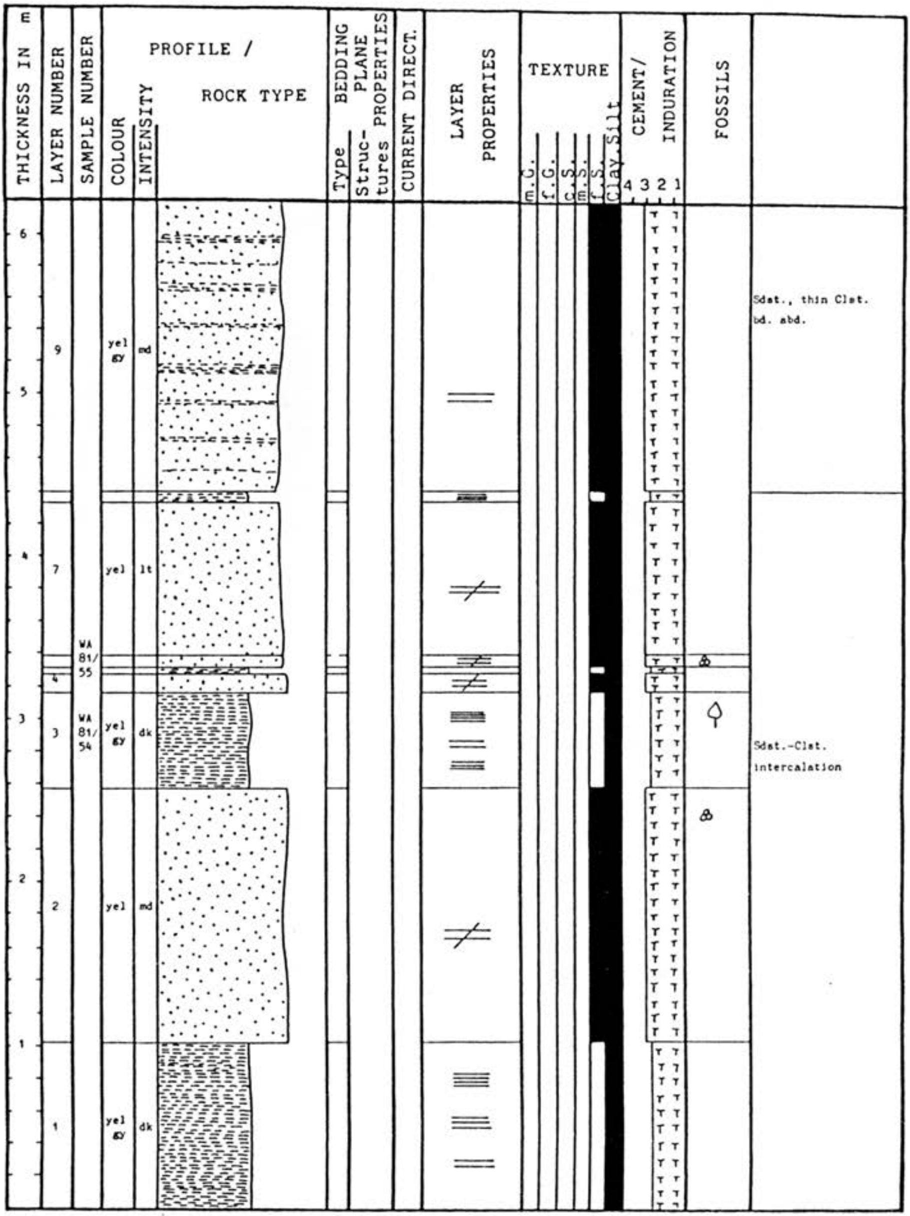


Sdst. - Clst.
intercalation
abd. rip-up clst.
grd. bd. - lam.

LOG PROFILE VIII
Molasse facies, Lom Sak-Chum Phae road, km 36.03.
(Nam Nao Fm., Huai Rahong Unit, ALTERMANN, 1983)

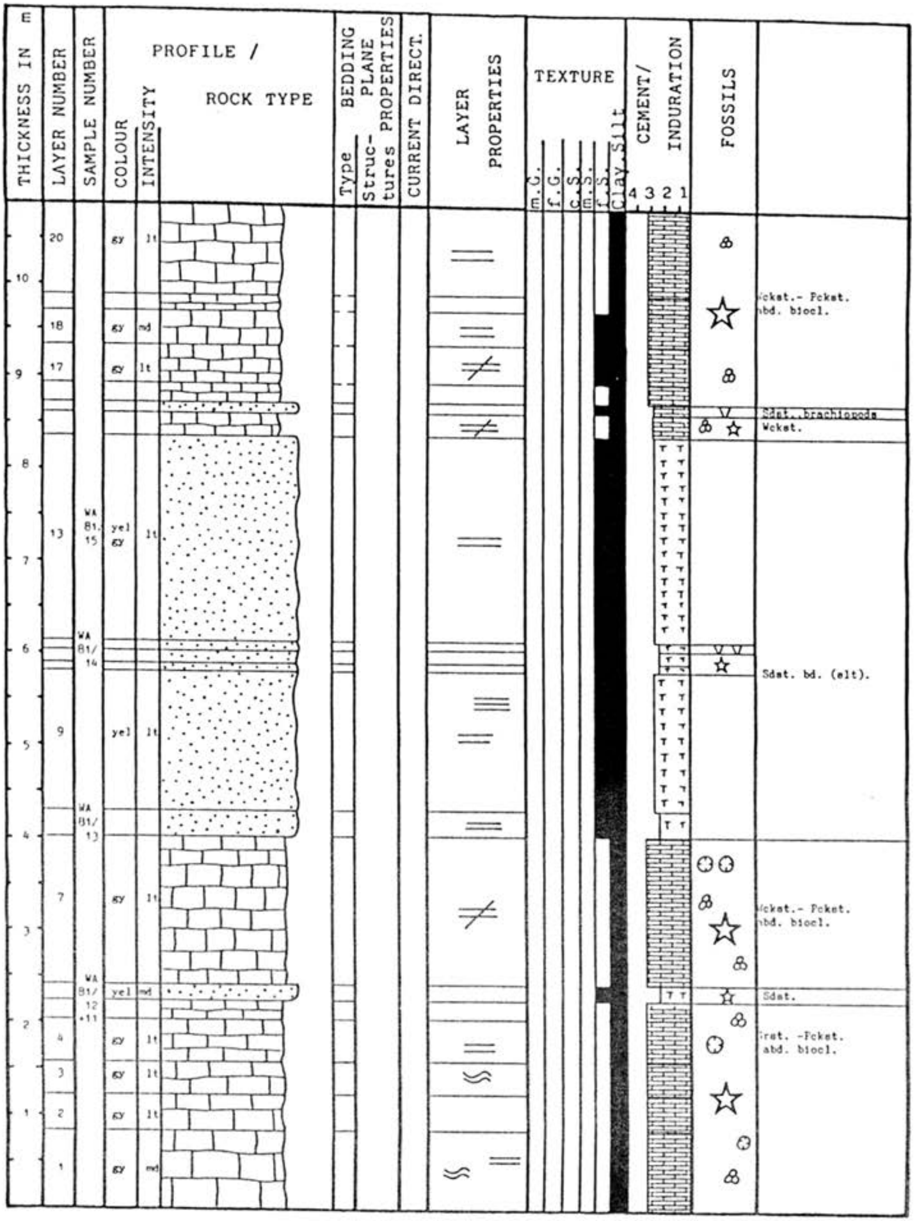


LOG PROFILE IX
Molasse facies, Lom Sak-Chum Phae road, km 38.19.
(Nam Nao Fm., Huai Wa Unit, ALTERMANN, 1983)



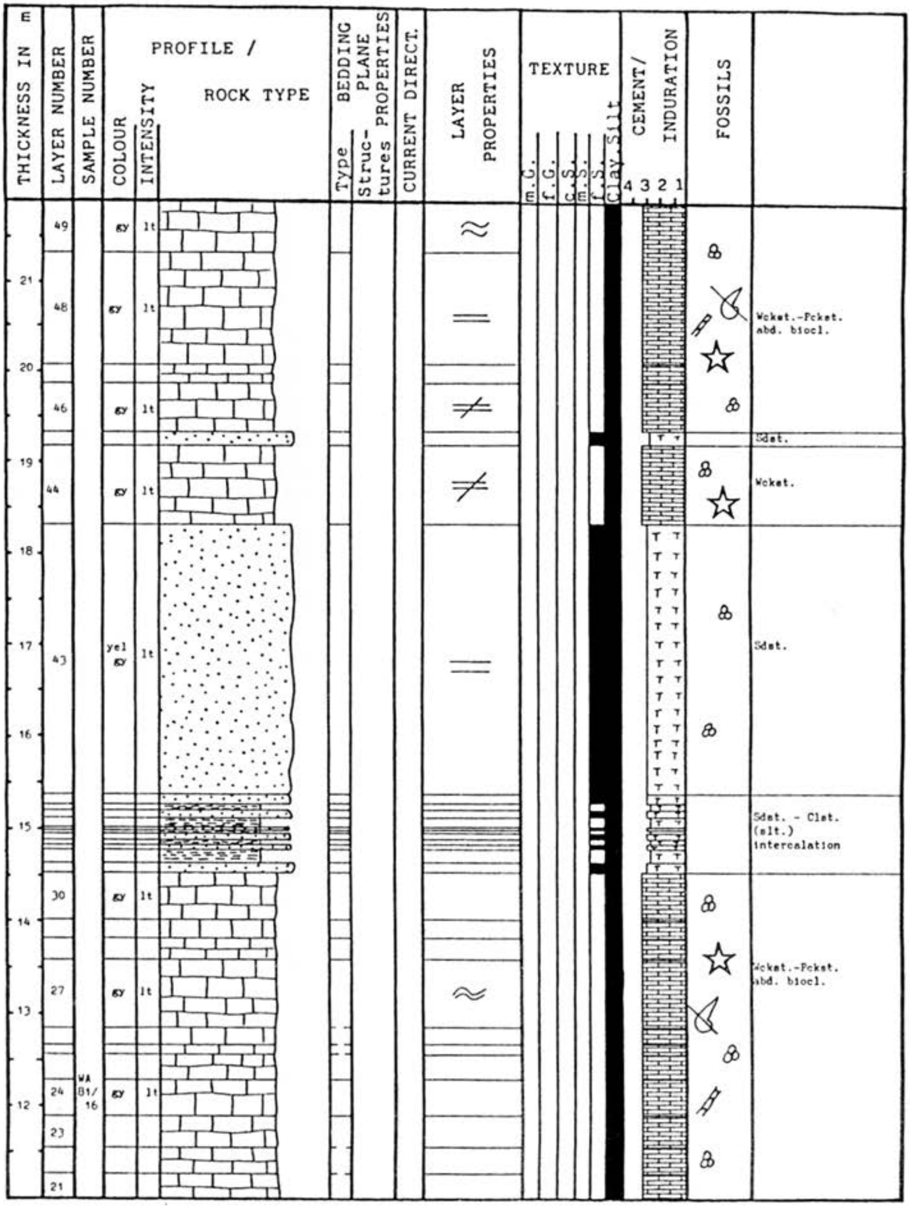
LOG PROFILE X (a)

Molasse facies, Lom Sak-Chum Phae road, km 40.09.
(Nam Nao Fm., Huai Wa Unit, ALTERMANN, 1983)



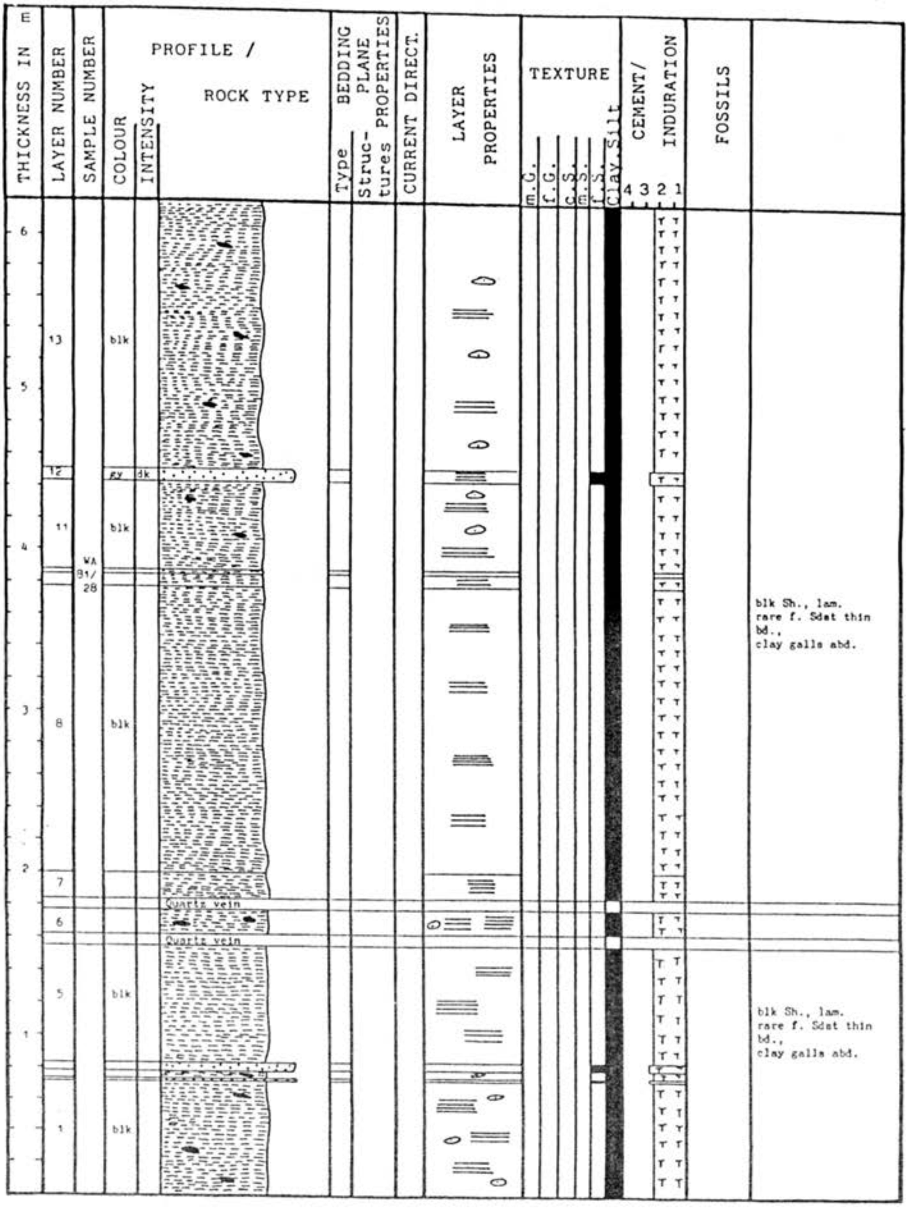
LOG PROFILE X (b)

Molasse facies, Lom Sak-Chum Phae road, km 40.09.
(Nam Nao Fm., Huai Wa Unit, ALTERMANN, 1983)

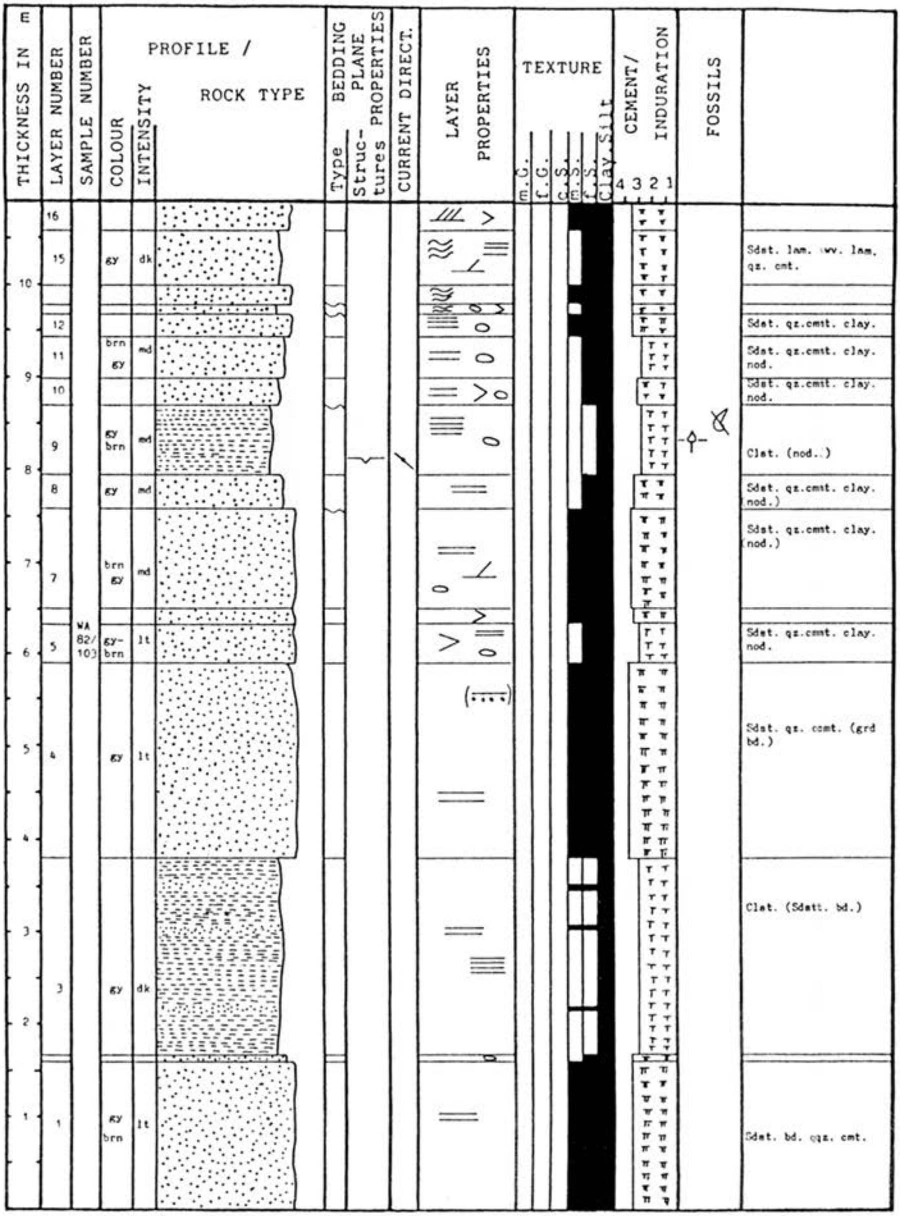


LOG PROFILE XI

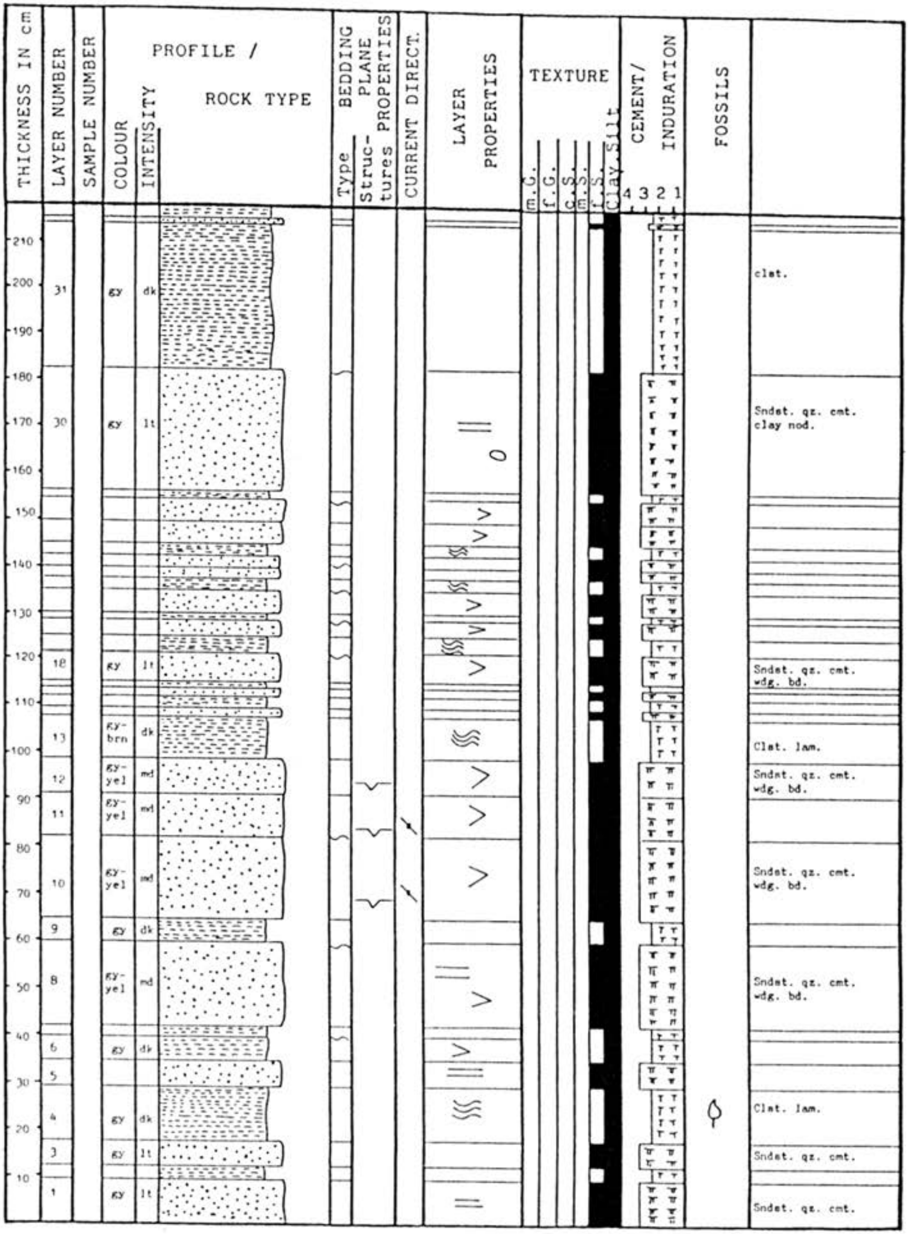
Molasse facies, Lom Sak-Chum Phae road, km 41.3.
(Nam Nao Fm., Khao Pha Daeng Unit, ALTERMANN, 1983)



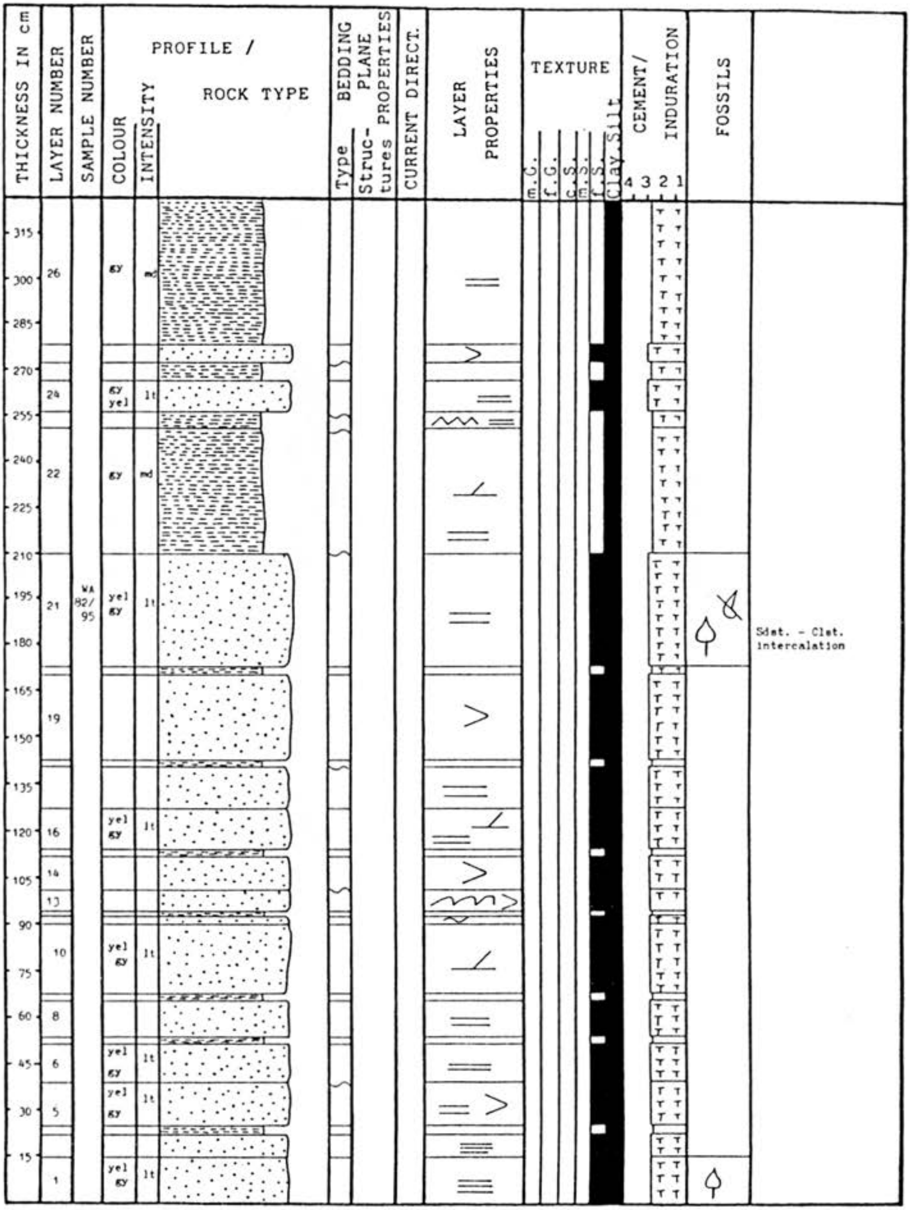
LOG PROFILE XII
Lom Sak-Chum Phae road, km 84.5 (eastern platform).



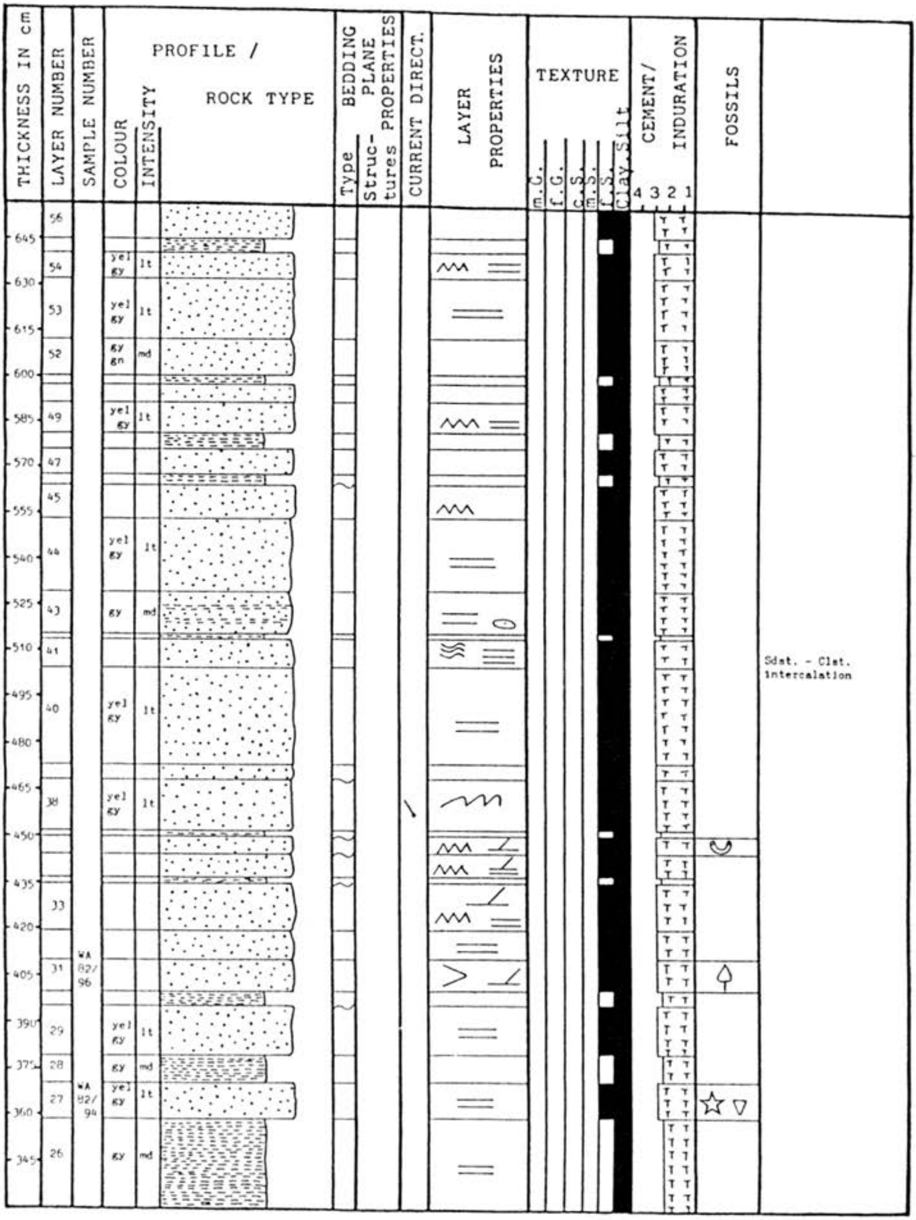
LOG PROFILE XIII
Lom Sak-Chum Phae road, km 85.3 (eastern platform).



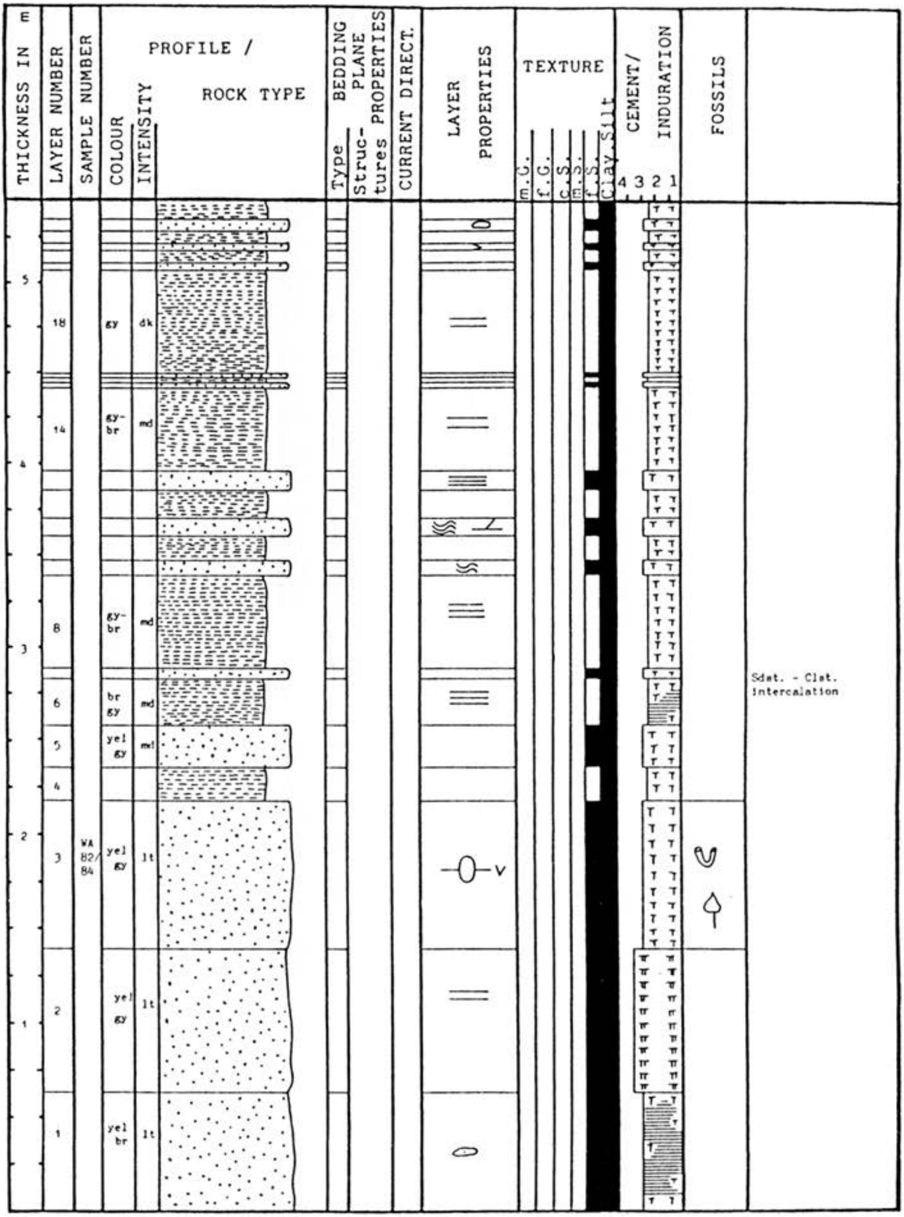
LOG PROFILE XIV (a)
Lom Sak-Chum Phae road, km 86.0 (eastern platform).



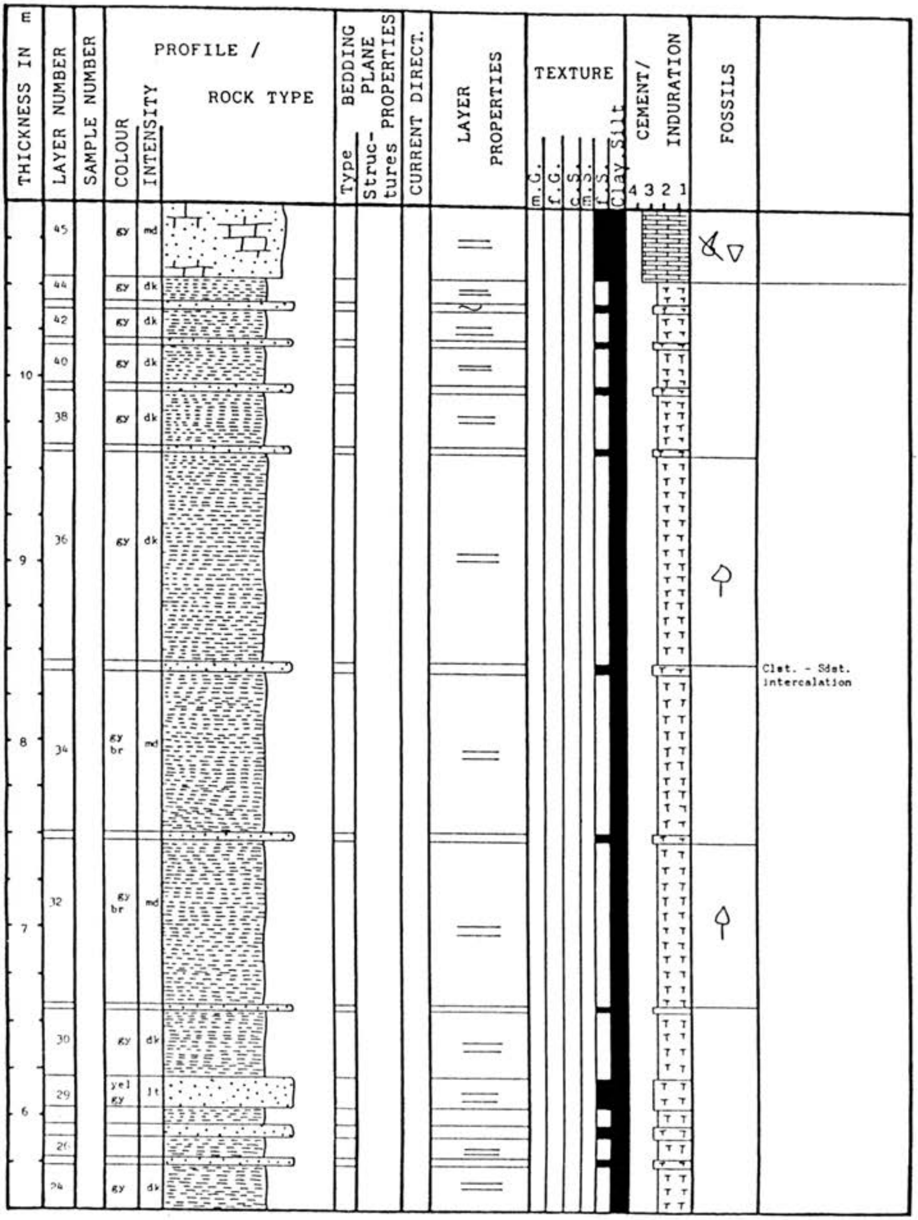
LOG PROFILE XIV (b)
Lom Sak-Chum Phae road, km 86.0 (eastern platform).



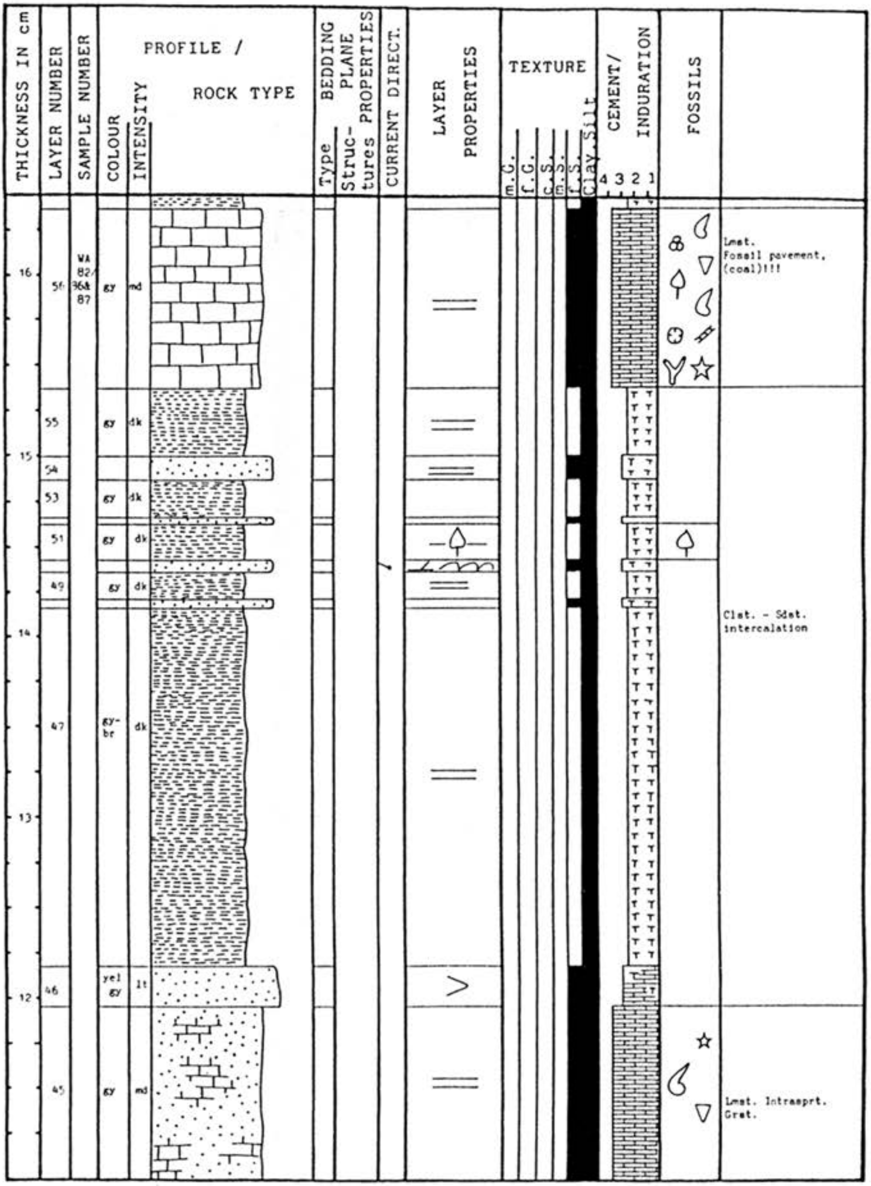
LOG PROFILE XV (a)
Nam Prom Dam road, km 22.8.



LOG PROFILE XV (b)
Nam Prom Dam road, km 22.8.

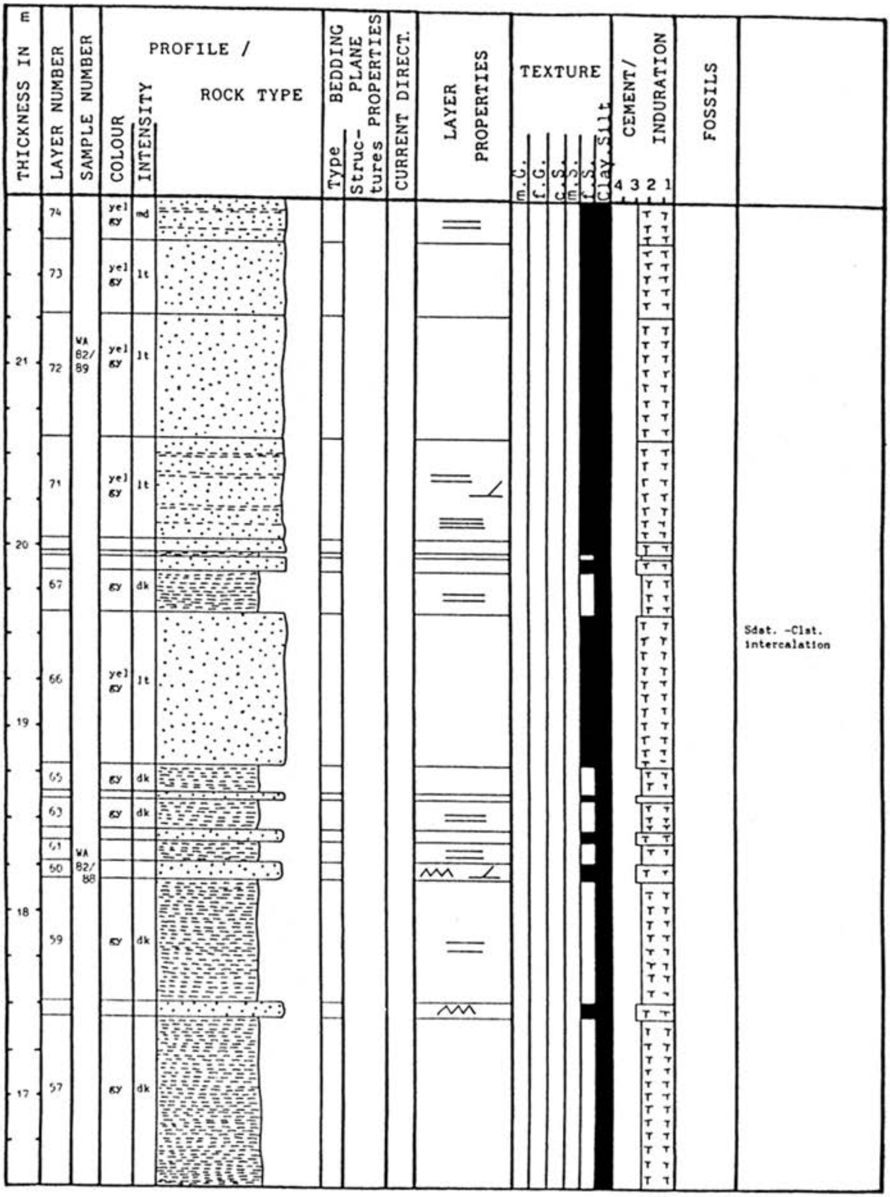


LOG PROFILE XV (c)
Nam Prom Dam road, km 22.8.

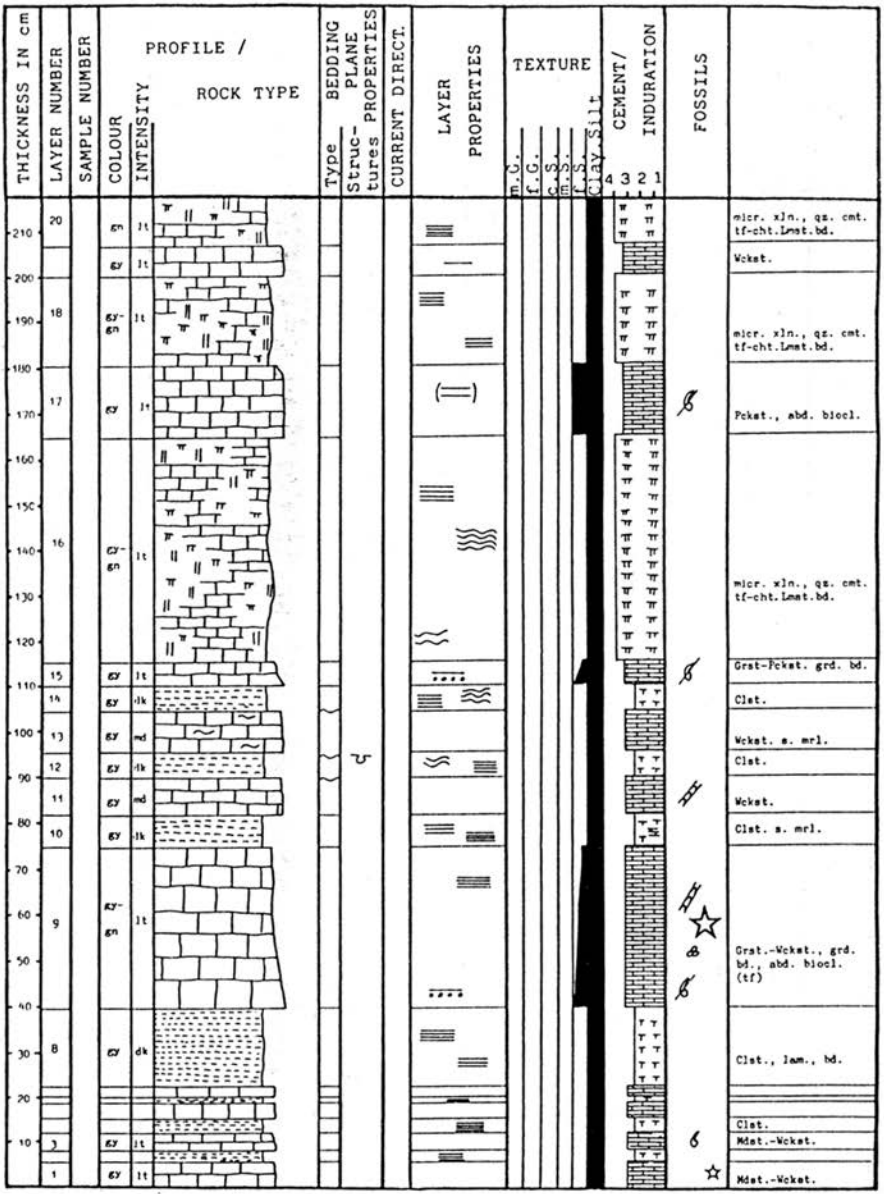


LOG PROFILE XV (d)

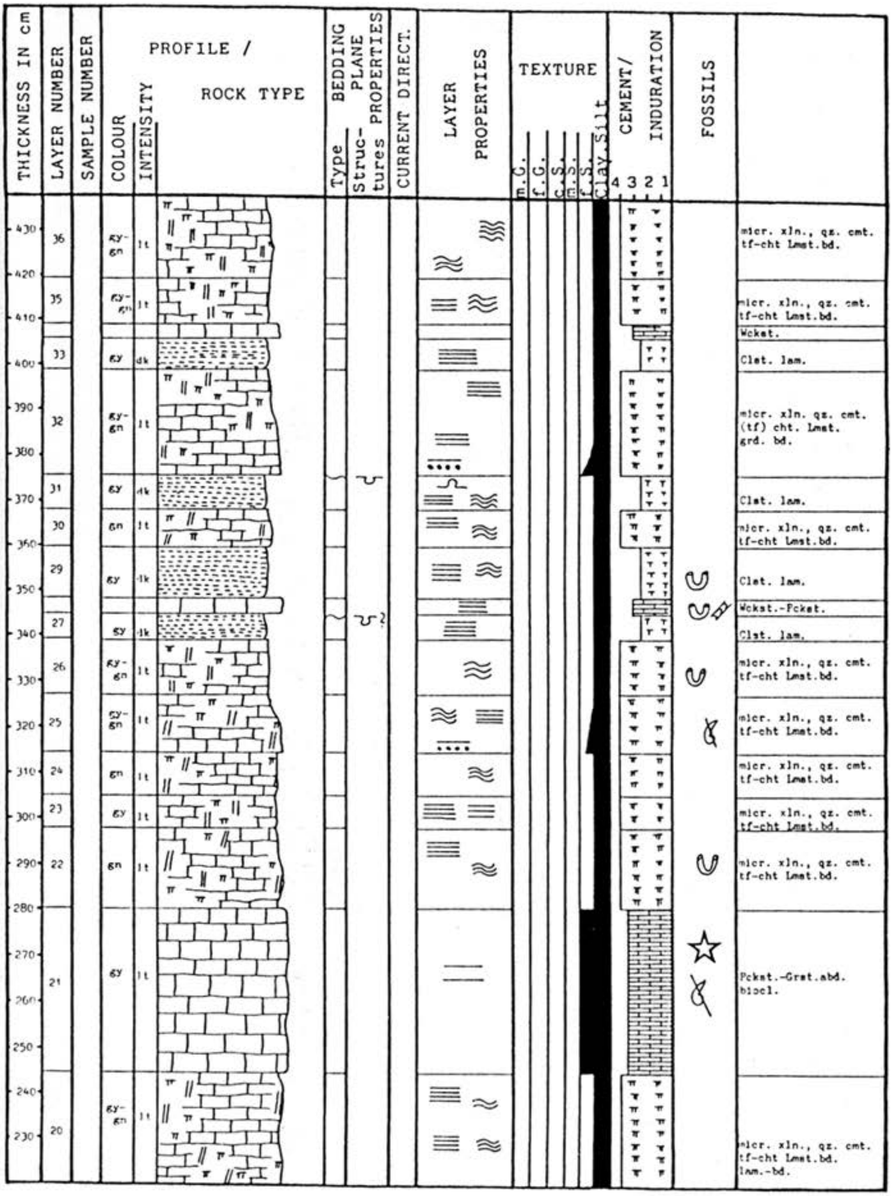
Nam Prom Dam road, km 22.8.



LOG PROFILE XVI (a)
Quarry N of Loei.



LOG PROFILE XVI (b)
Quarry N of Loei.



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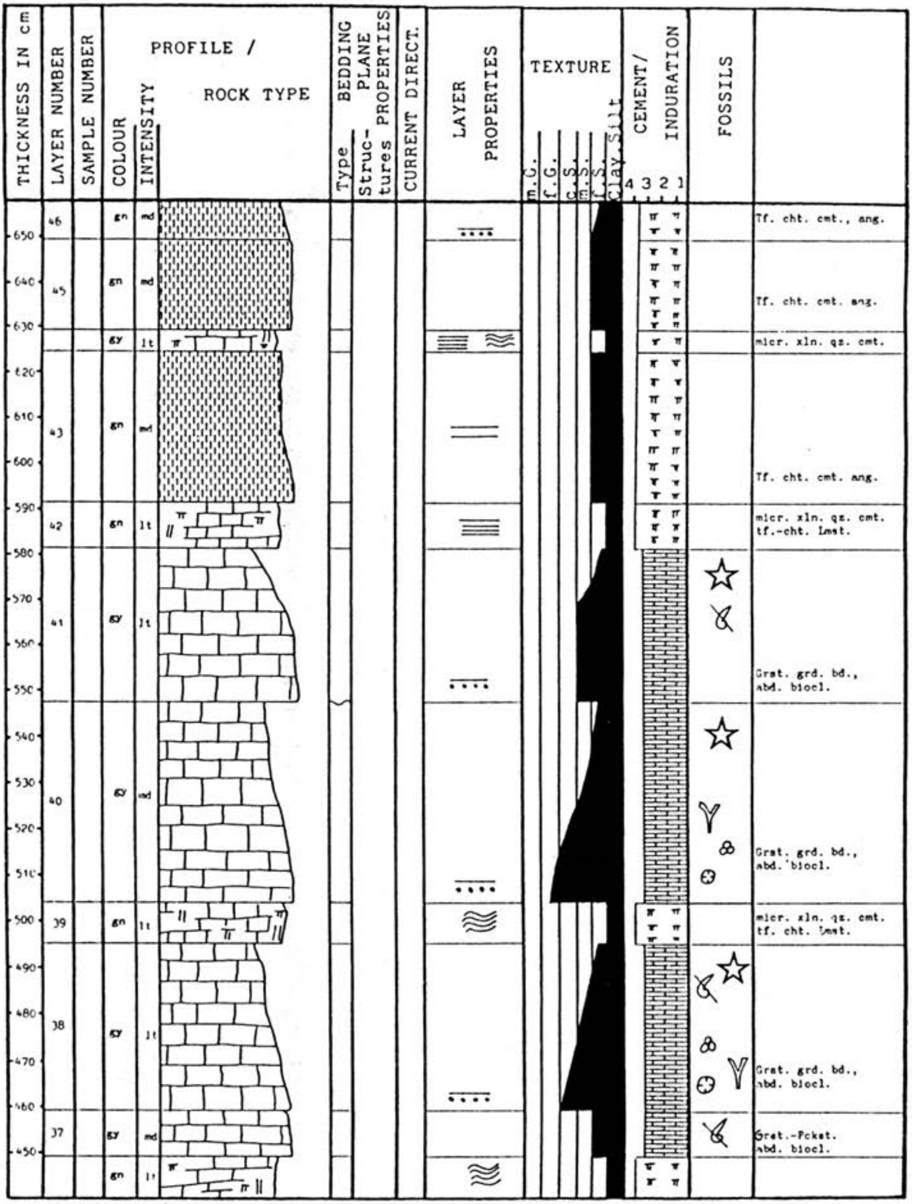
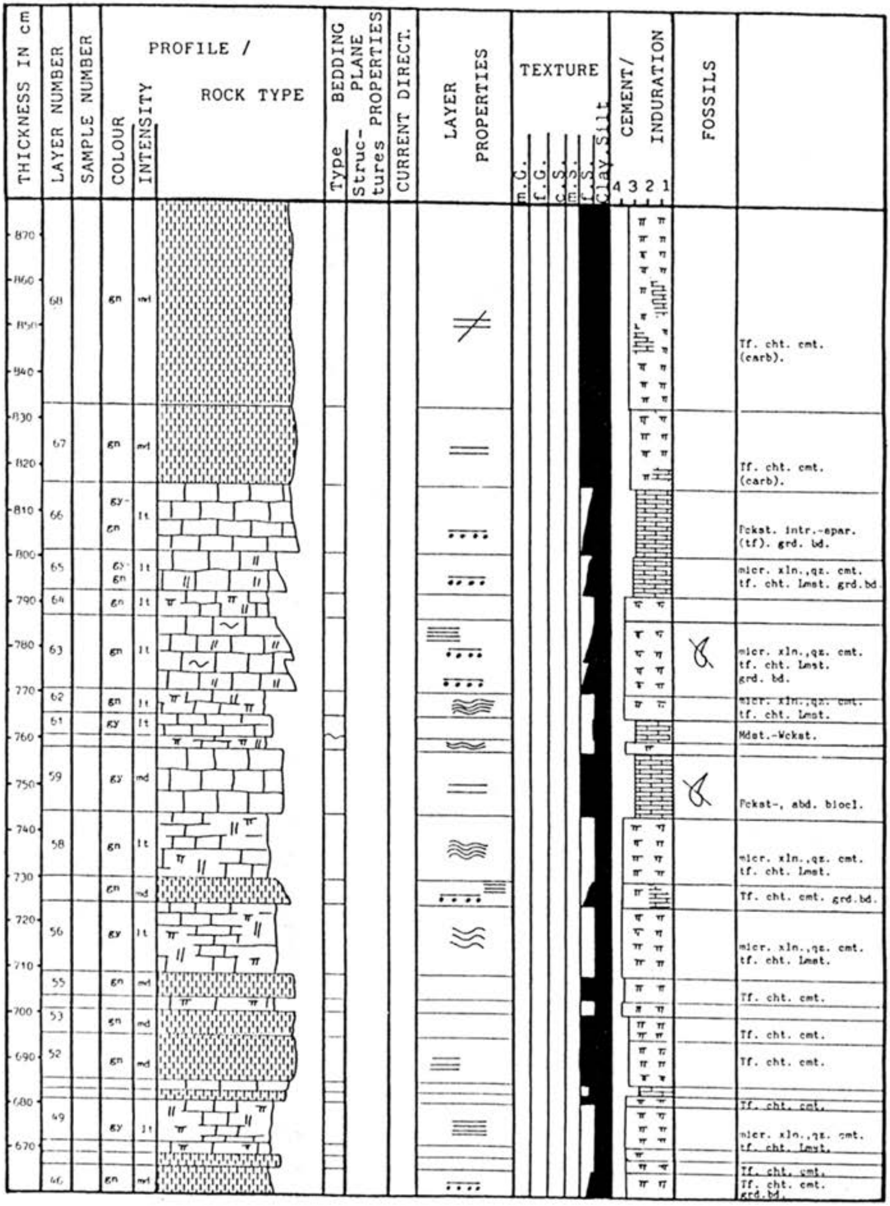
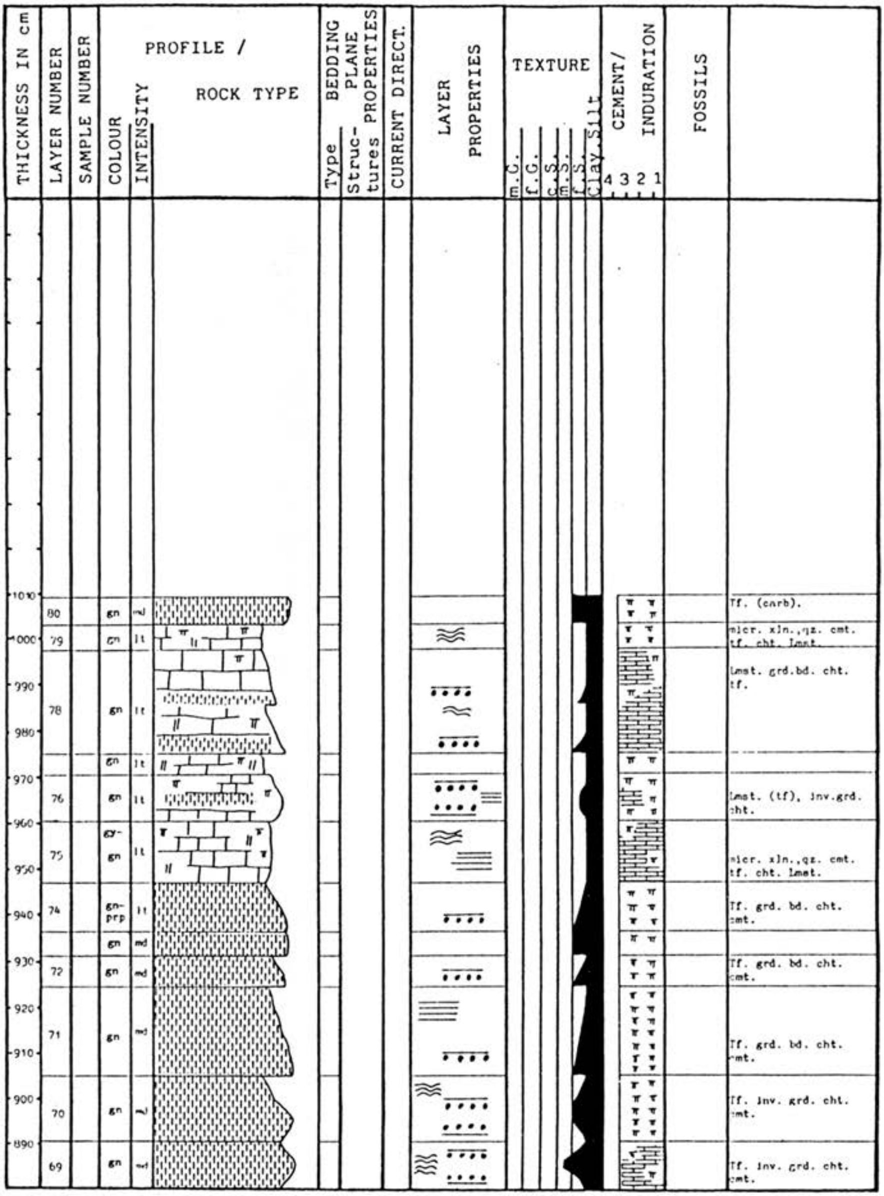
Quarry N of Loei.



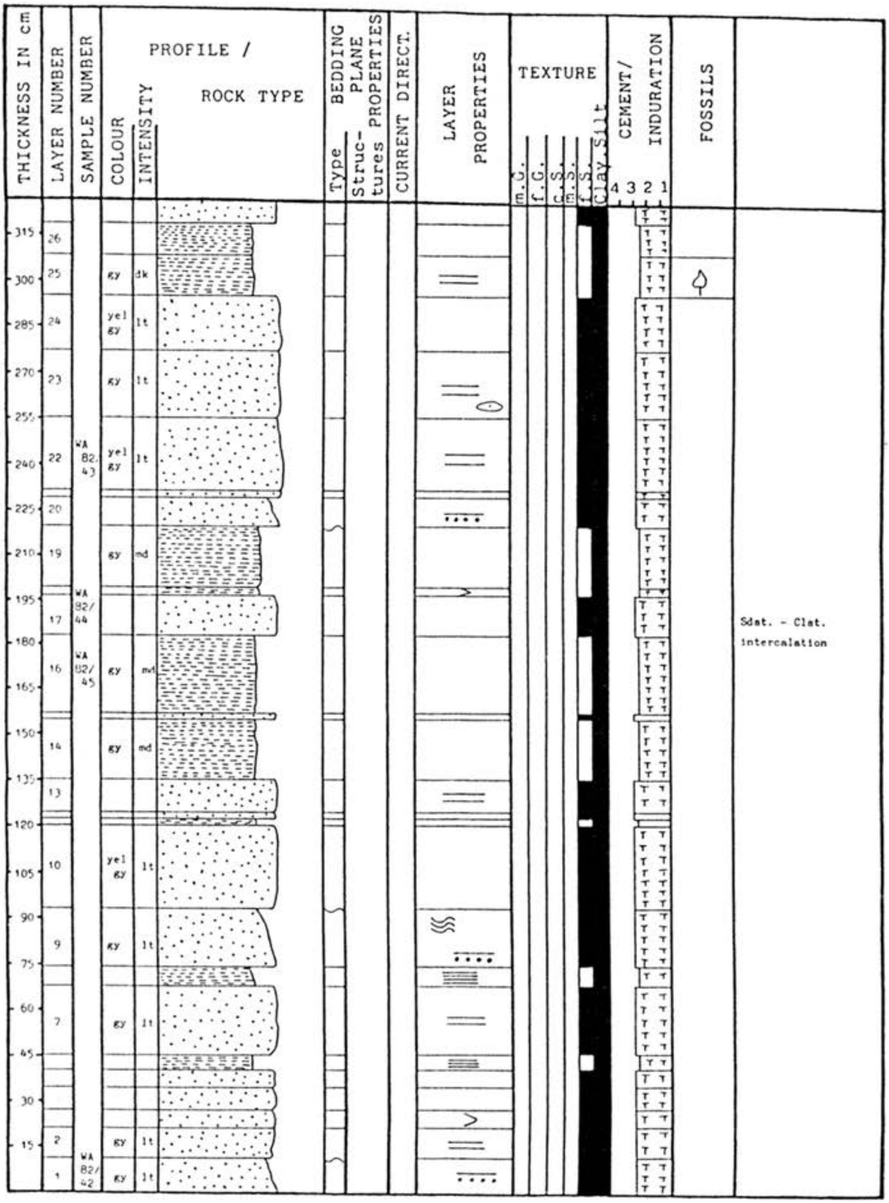
LOG PROFILE XVI (d)
Quarry N of Loei.



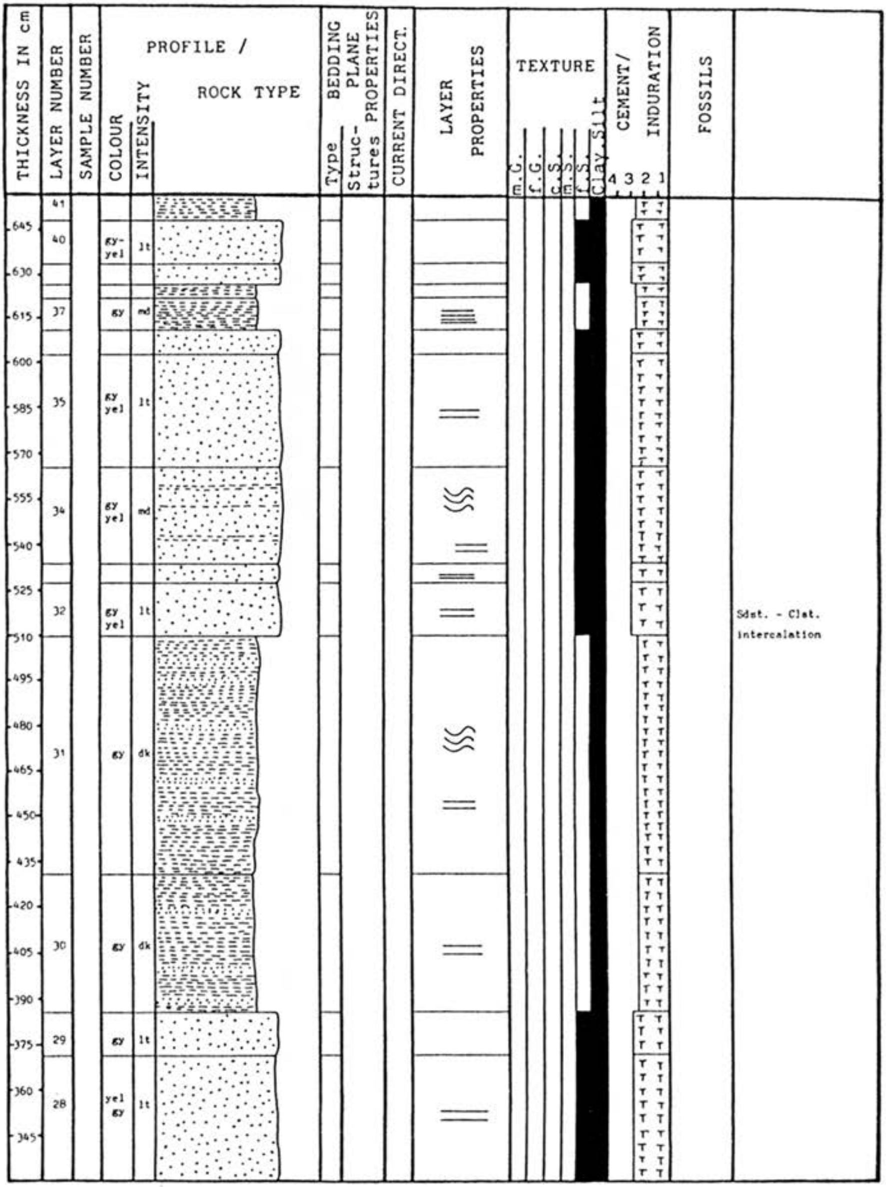
LOG PROFILE XVI (e)
Quarry N of Loei.



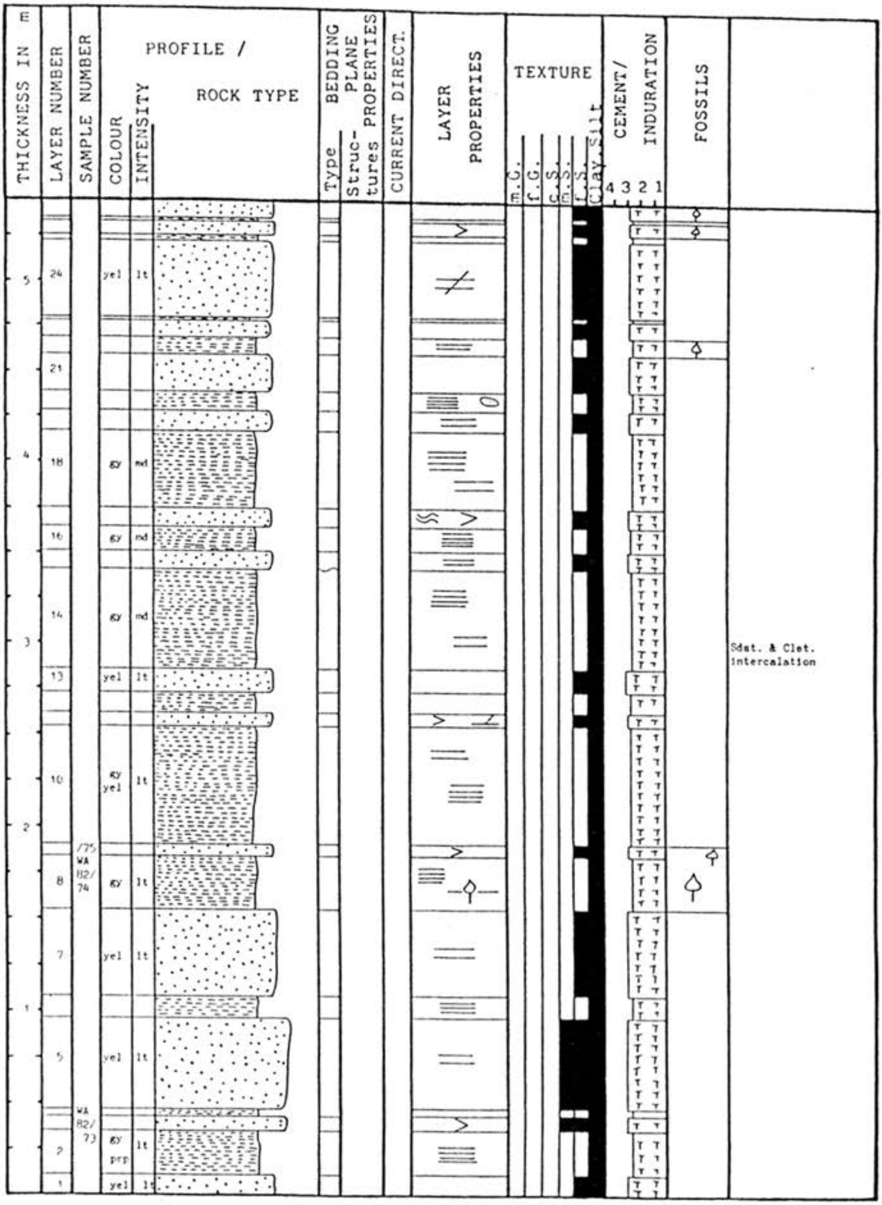
LOG PROFILE XVII (a)
Loei-Dan Sai road, km 3.0.



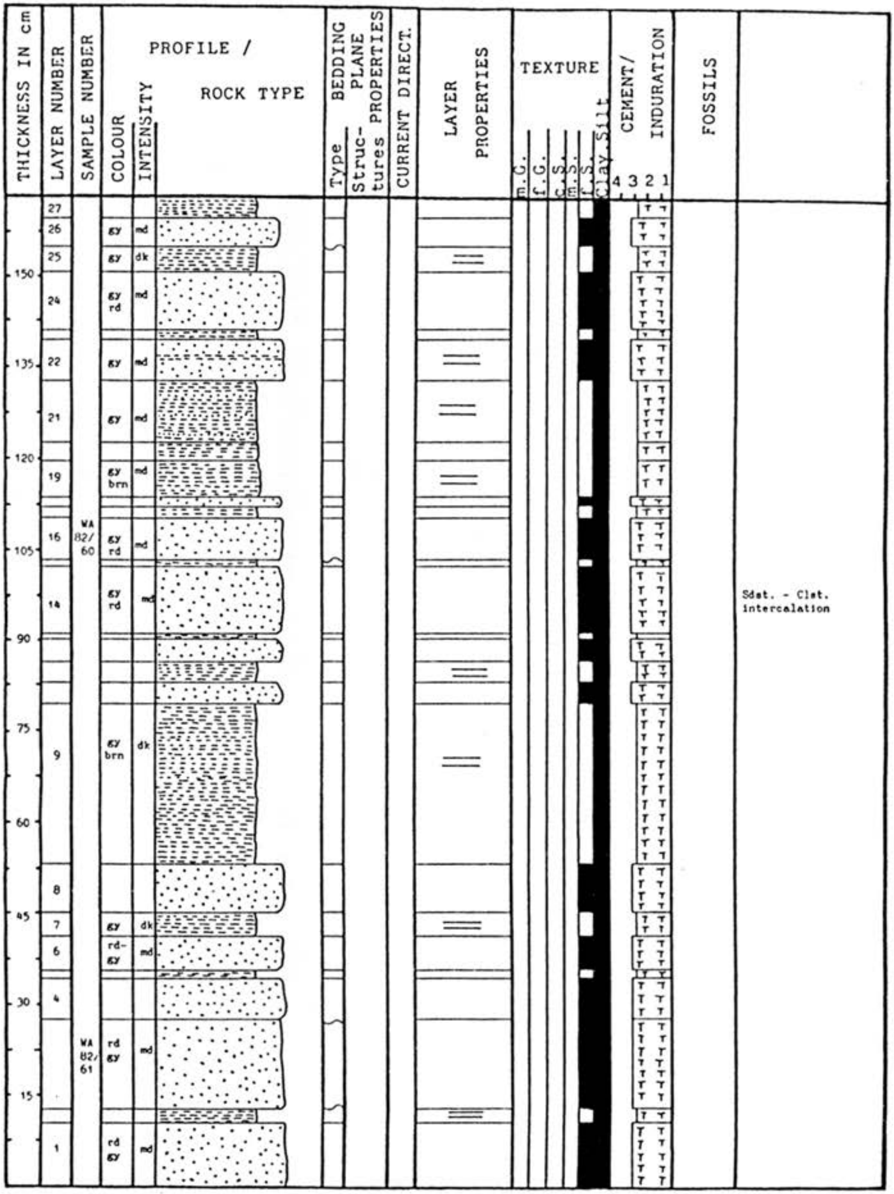
LOG PROFILE XVII (b)
Loei-Dan Sai road, km 3.0.



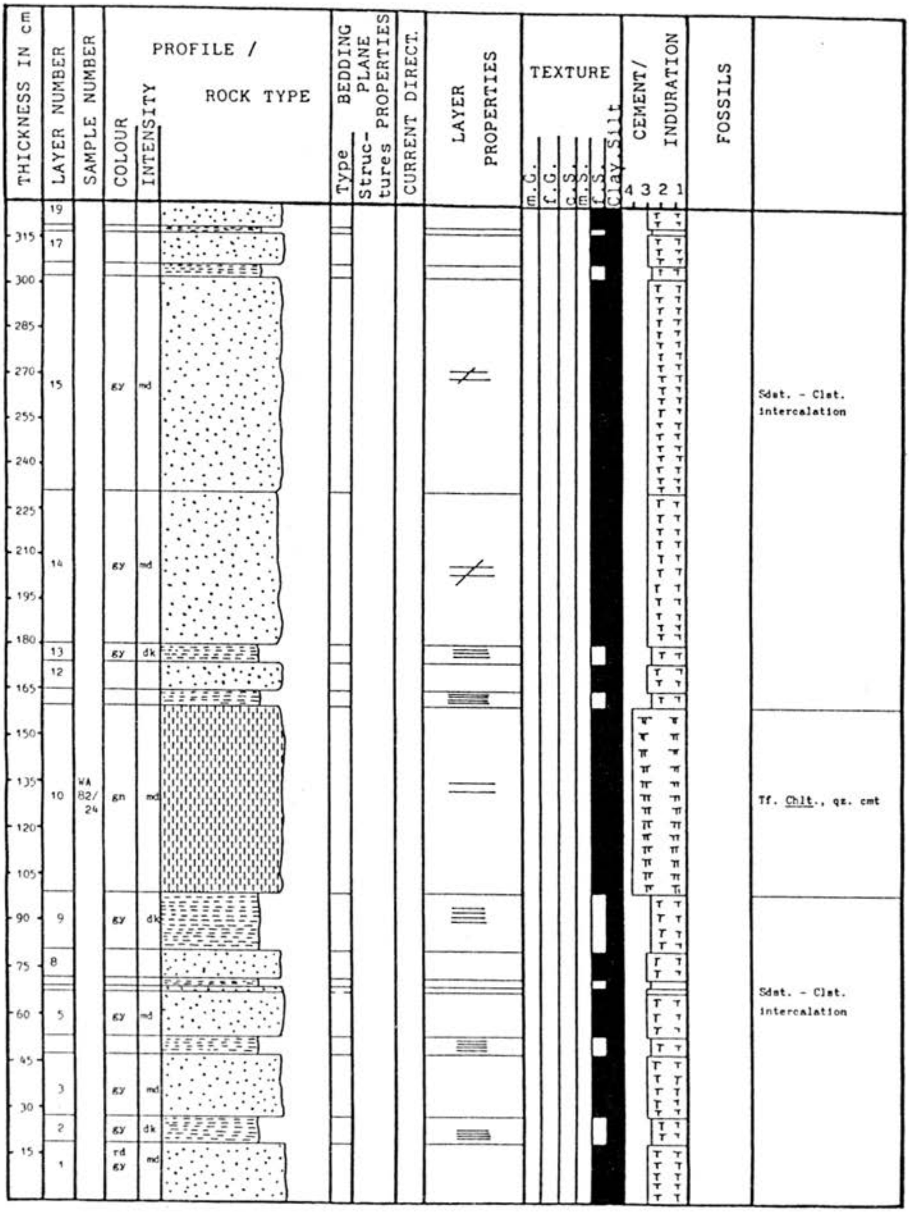
LOG PROFILE XVIII
Loei-Dan Sai road, km 9.2.



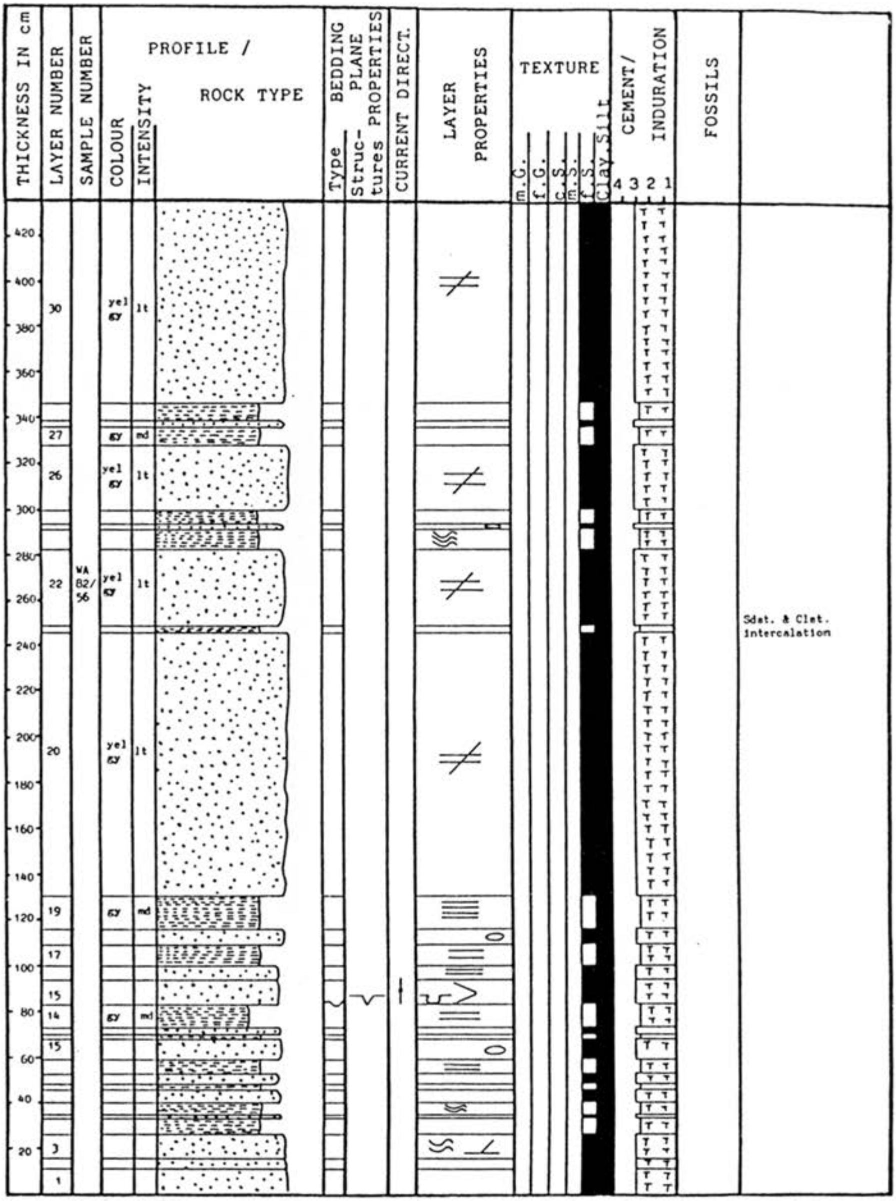
LOG PROFILE XIX
Loei-Dan Sai road, km 13.7.



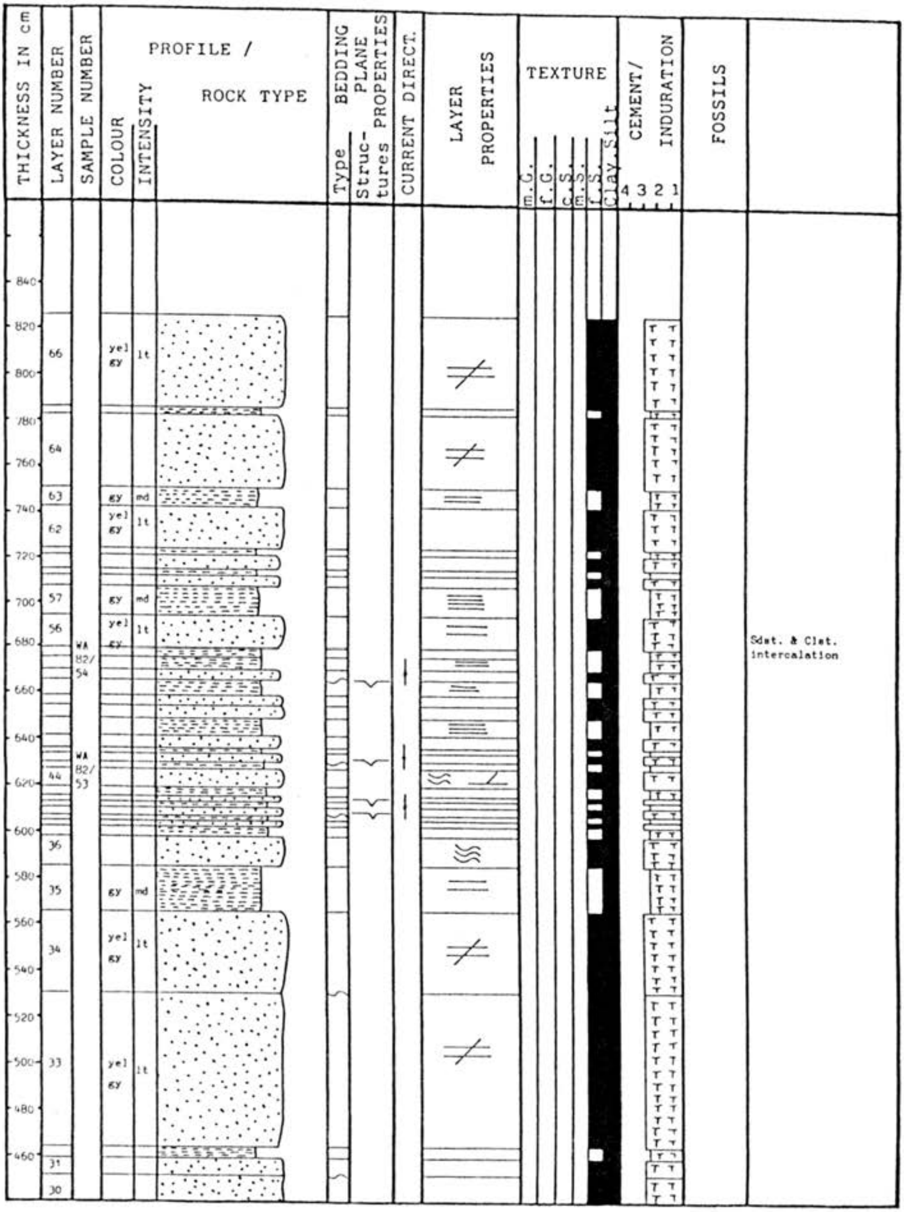
LOG PROFILE XX
Loei-Dan Sai road, km 17.9.



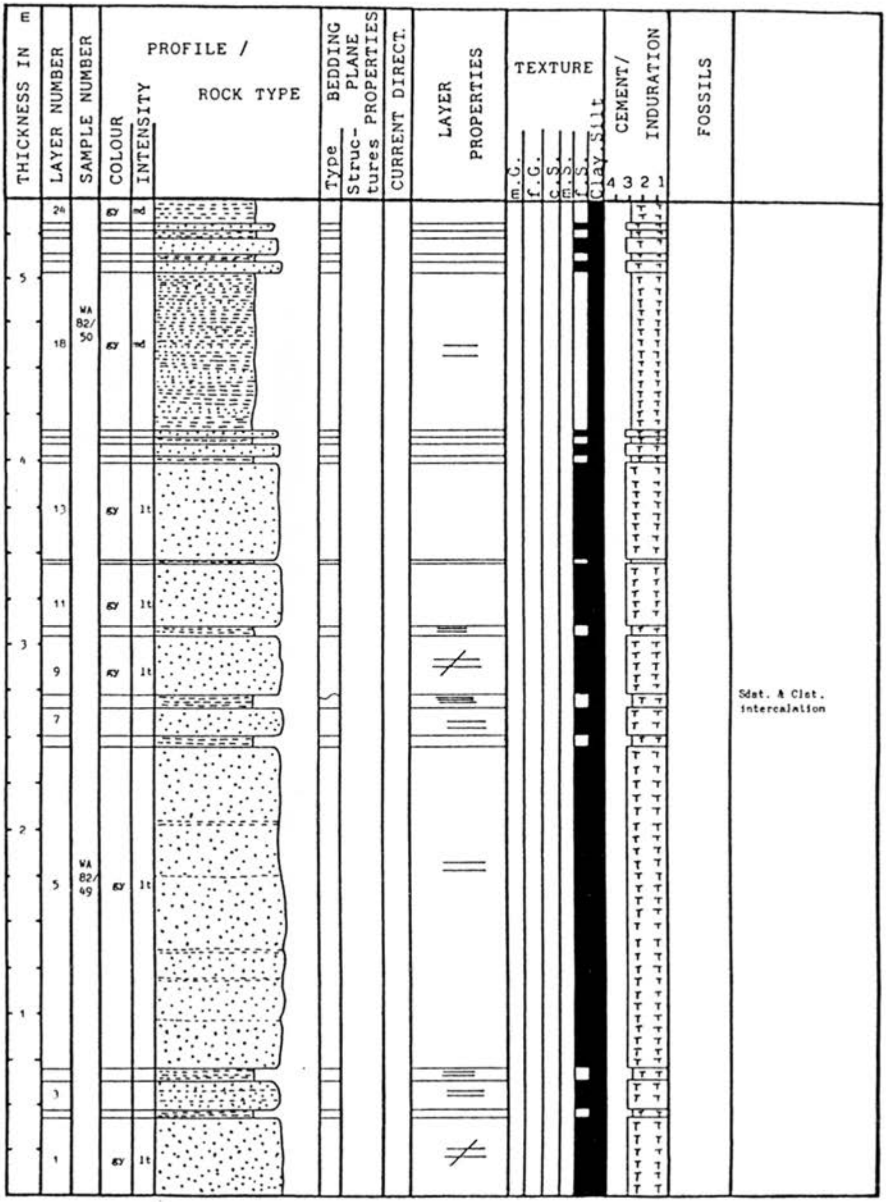
LOG PROFILE XXI (a)
Loei-Dan Sai road, km 18.5.



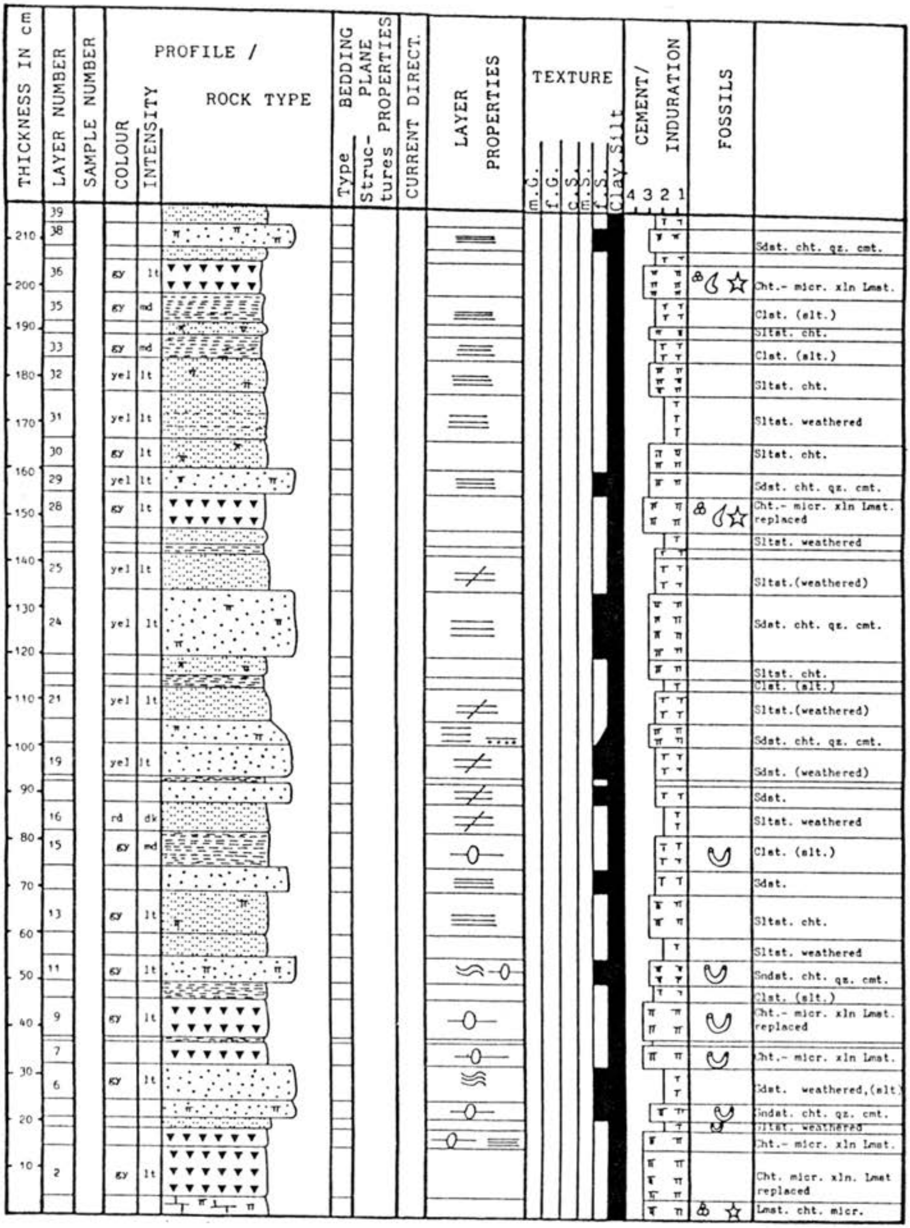
LOG PROFILE XXI (b)
Loei-Dan Sai road, km 18.5.



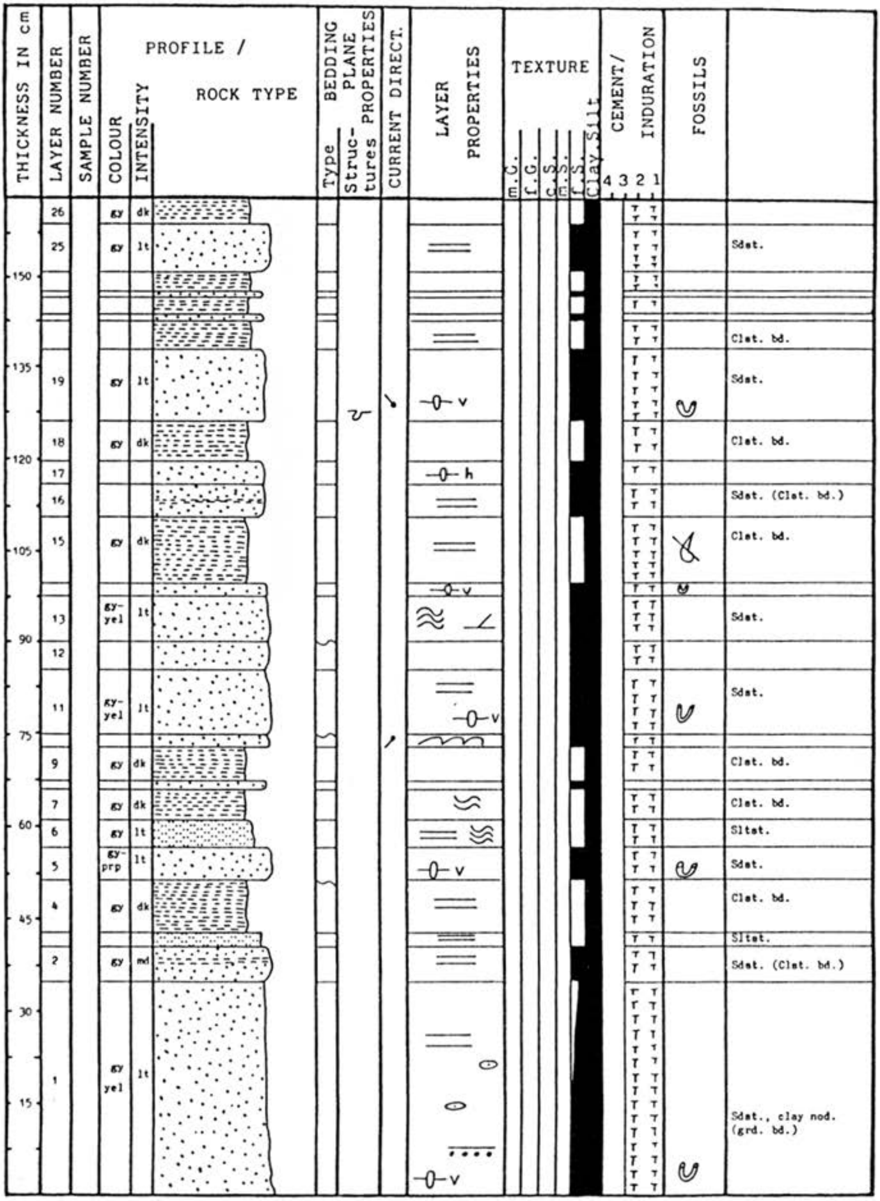
LOG PROFILE XXII
Loei-Dan Sai road, km 20.7.



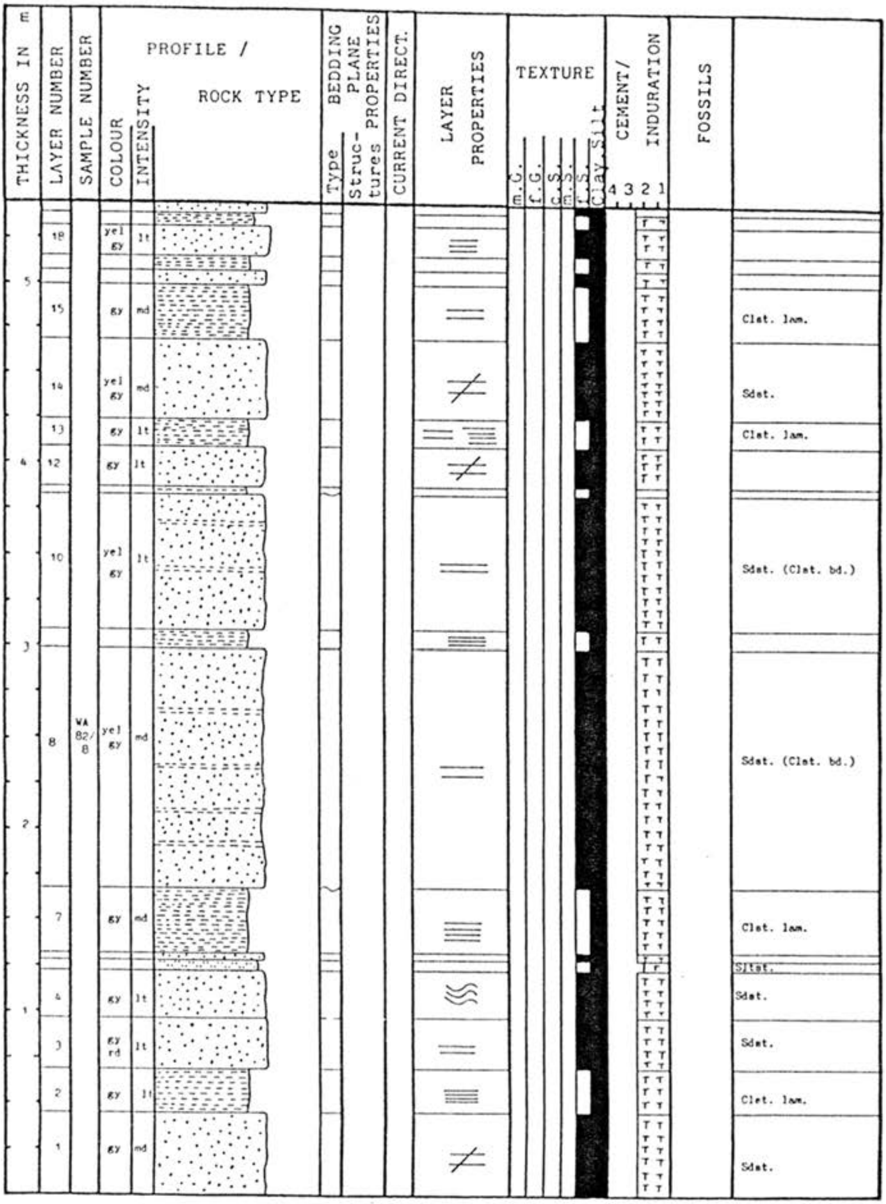
LOG PROFILE XXIII
Loei-Tha Li road, km 2.8.



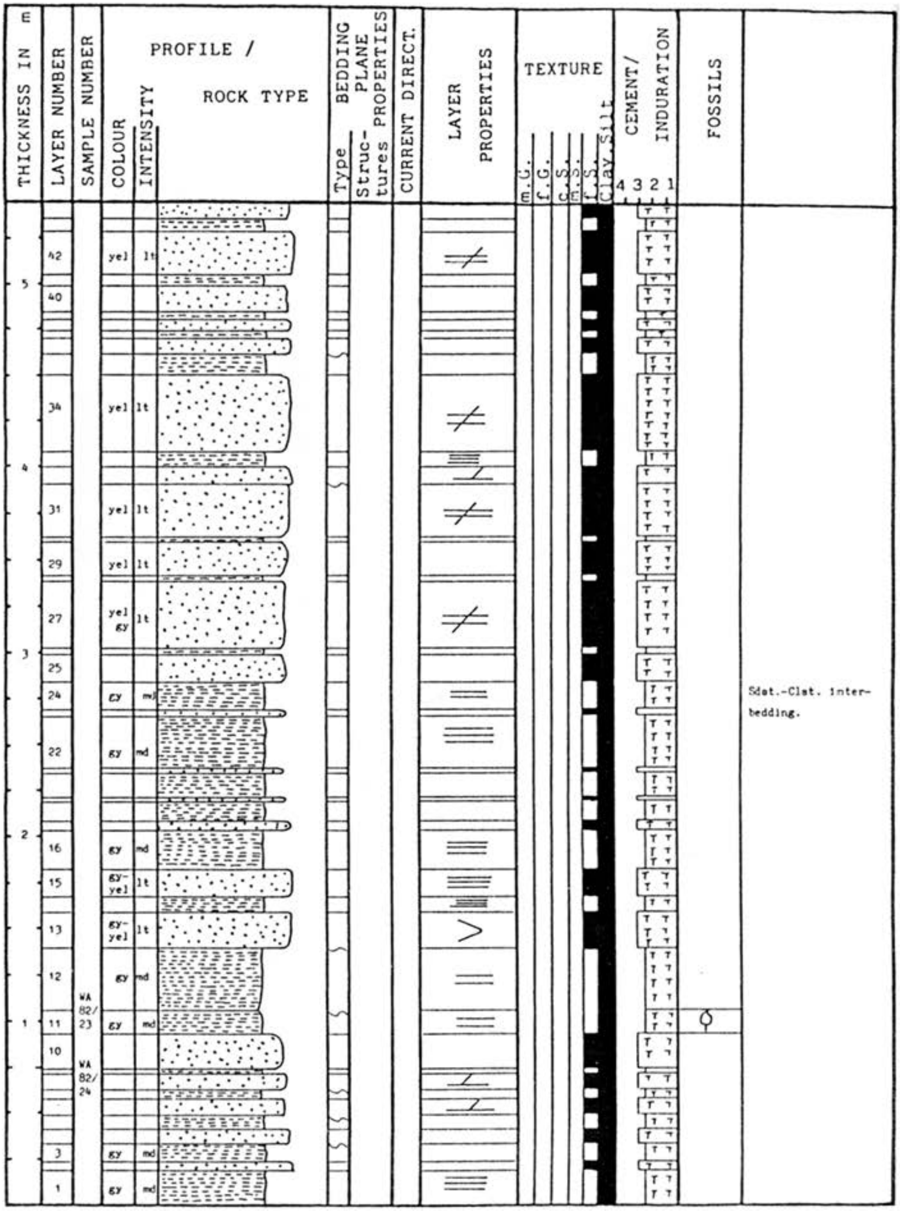
LOG PROFILE XXIV
Loei–Tha Li road, km 3.3.



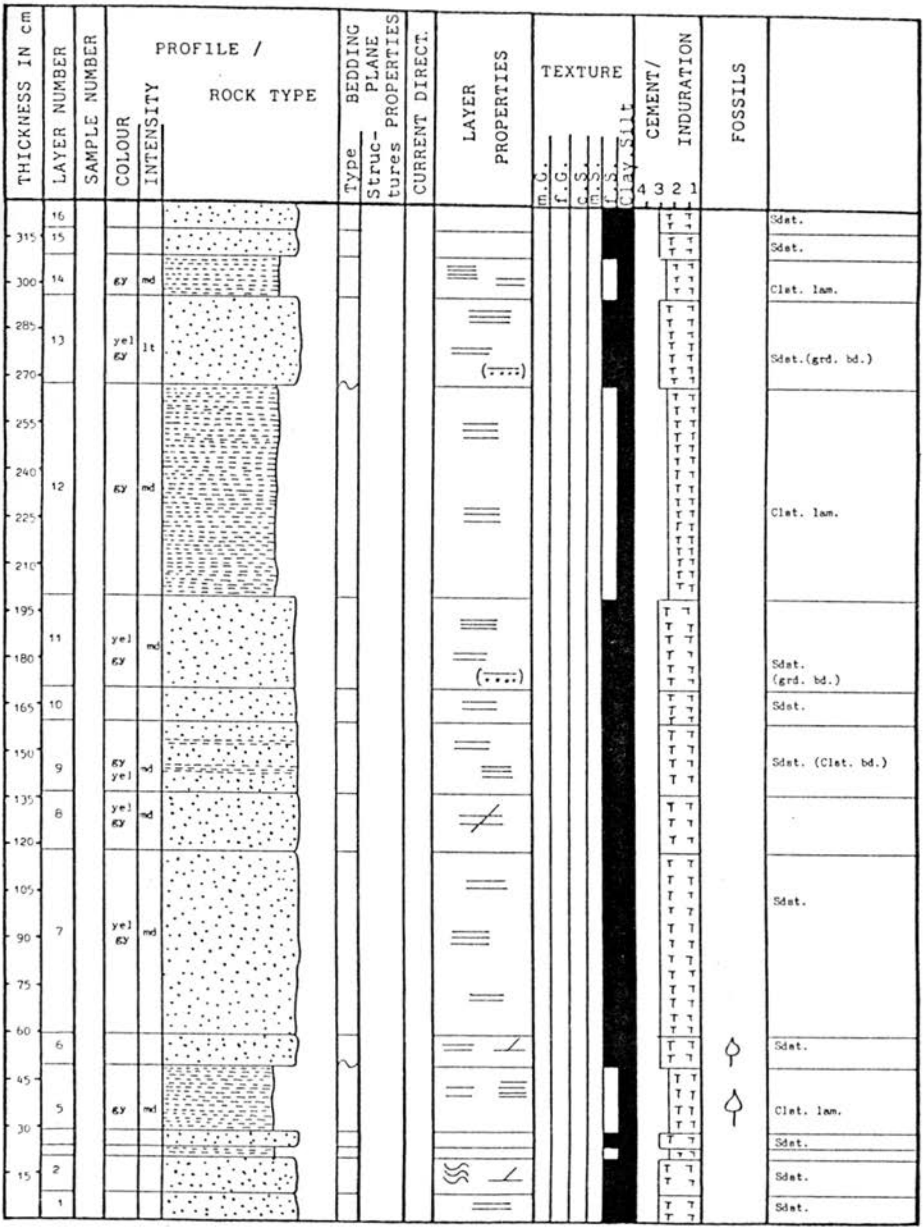
LOG PROFILE XXV
Loei-Tha Li road, km 7.5.



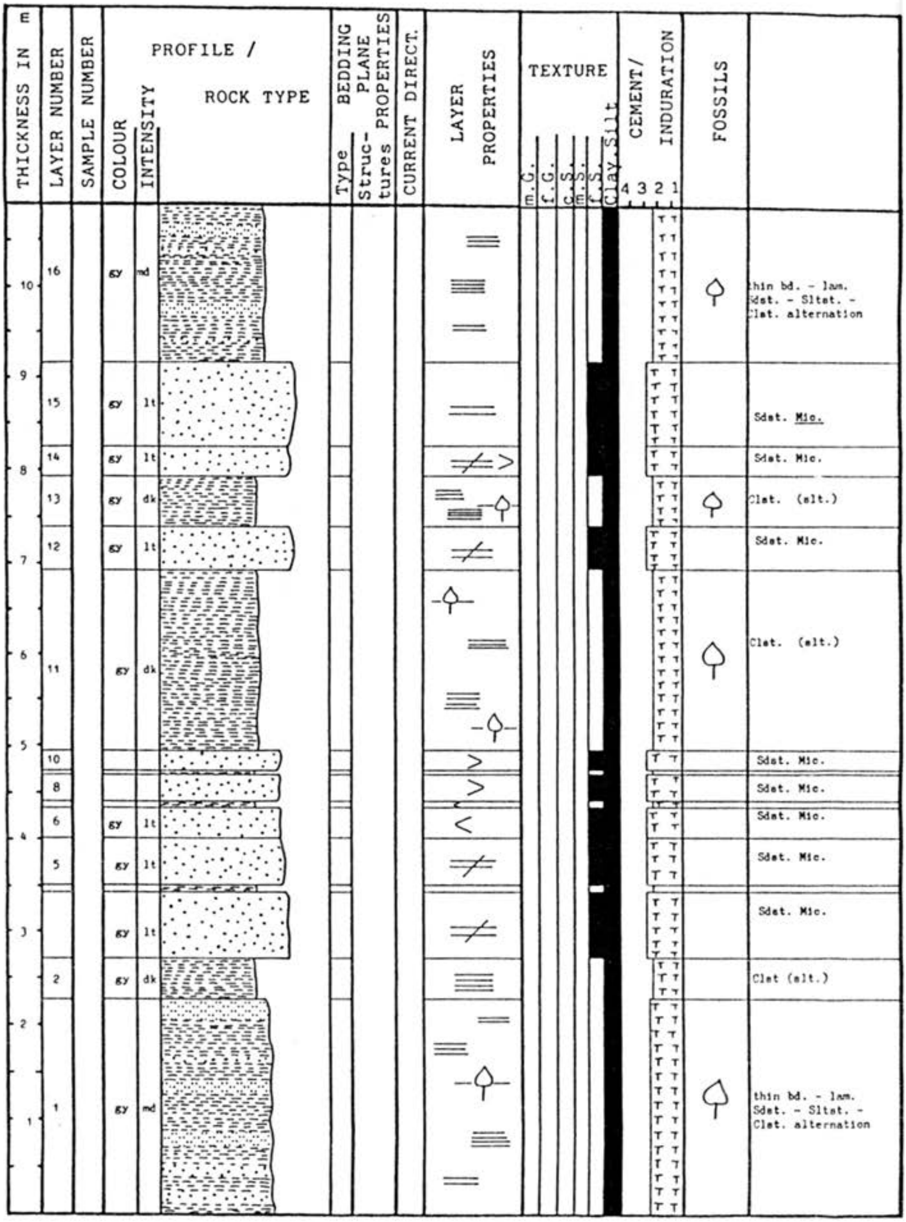
LOG PROFILE XXVI
Loei-Tha Li road, km 7.6.



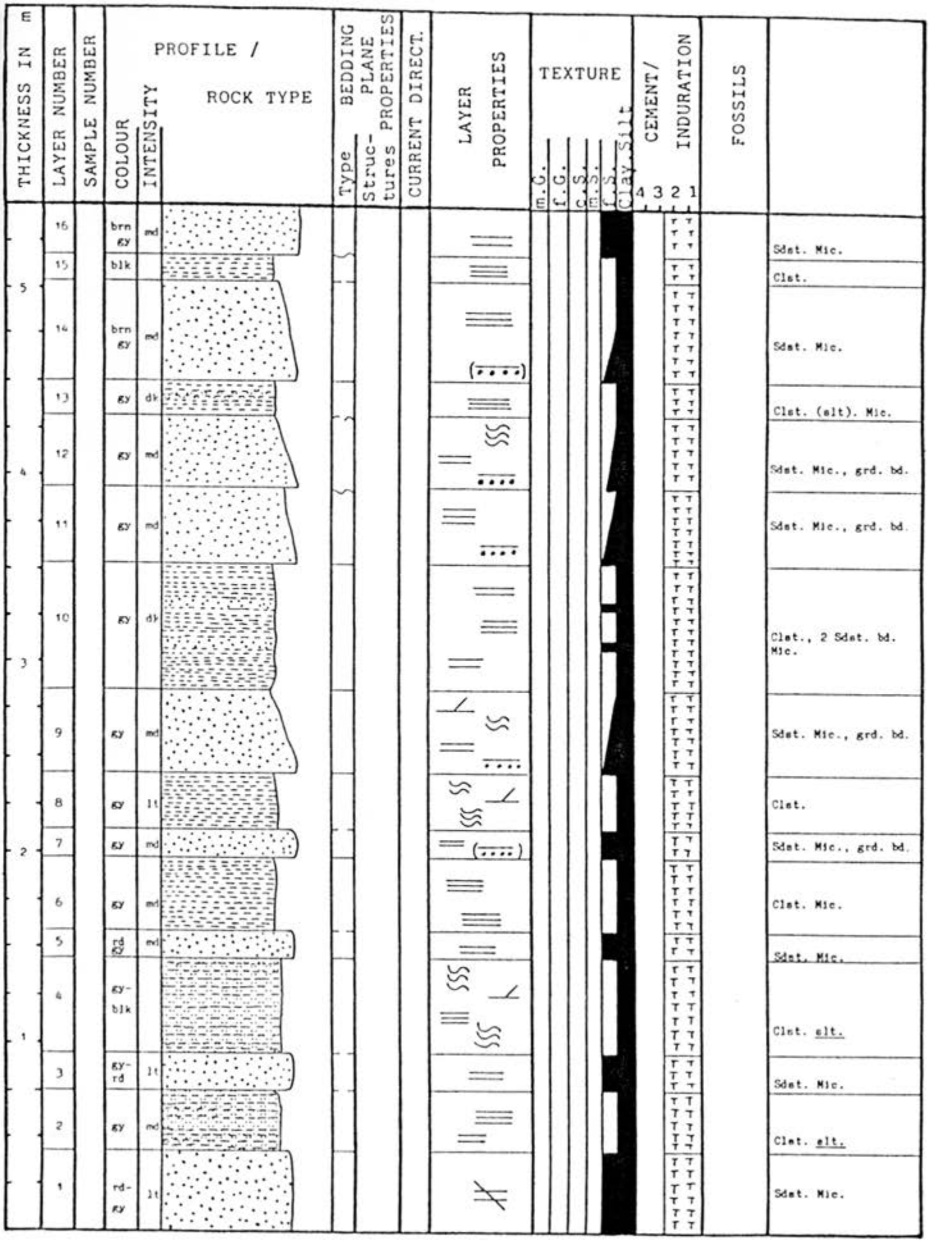
LOG PROFILE XXVII
Loei-Tha Li road, km 11.7.



LOG PROFILE XXVIII
W of Chiang Khan, km 31.0.

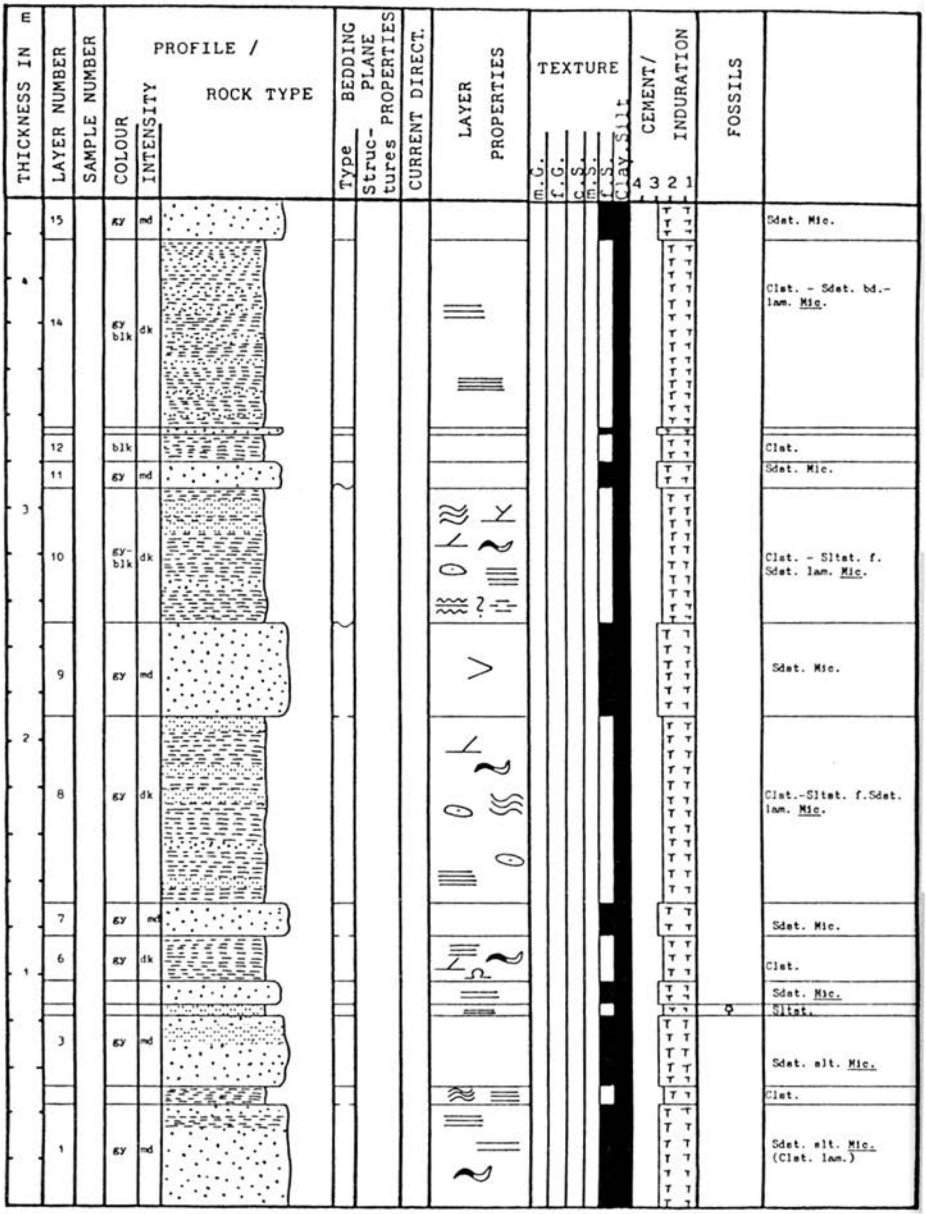


LOG PROFILE XXIX
W of Chiang Khan, between Ban Nong Phu and Ban Na Yan.

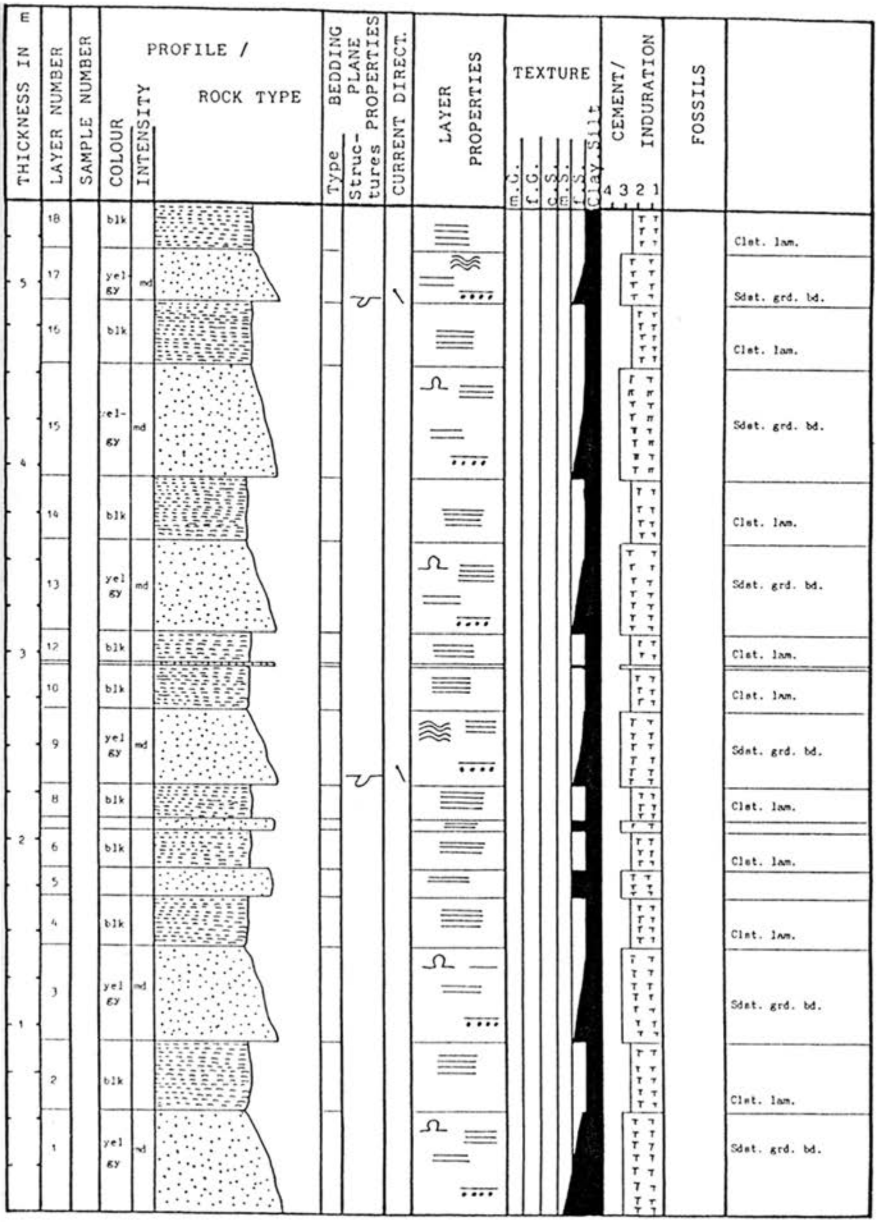


LAYER NUMBER	SAMPLE NUMBER	COLOUR	INTENSITY	FOSSILS	
16		brn gy	md		Sdst. Mic.
15		blk			Clst.
14		brn gy	md		Sdst. Mic.
13		gy	dk		Clst. (slt). Mic.
12		gy	md		Sdst. Mic., grd. bd.
11		gy	md		Sdst. Mic., grd. bd.
10		gy	dk		Clst., 2 Sdst. bd. Mic.
9		gy	md		Sdst. Mic., grd. bd.
8		gy	lt		Clst.
7		gy	md		Sdst. Mic., grd. bd.
6		gy	md		Clst. Mic.
5		rd gy	md		Sdst. Mic.
4		gy-blk			Clst. slt.
3		gy-rd	lt		Sdst. Mic.
2		gy	md		Clst. slt.
1		rd-gy	lt		Sdst. Mic.

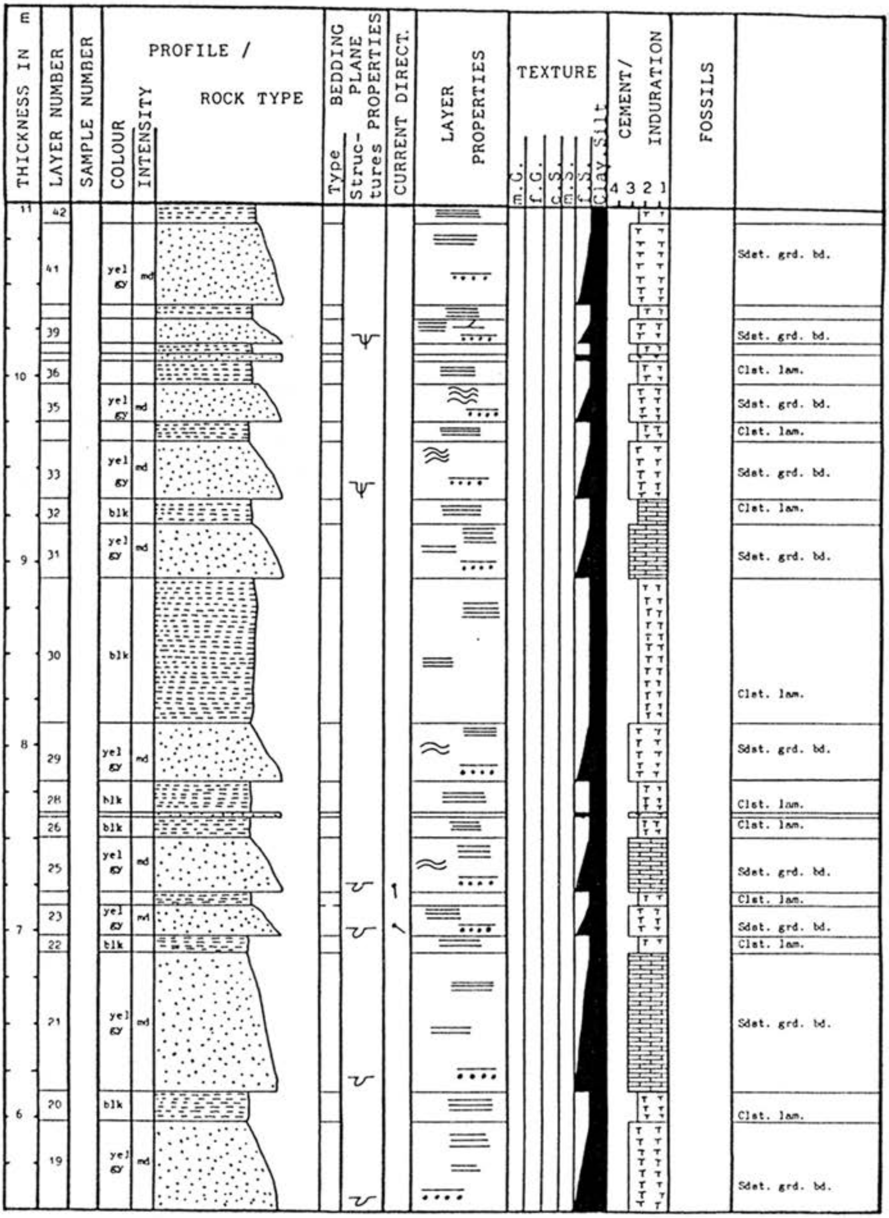
LOG PROFILE XXX
W of Chiang Khan, between Ban Nong Phu and Ban Na Yan.



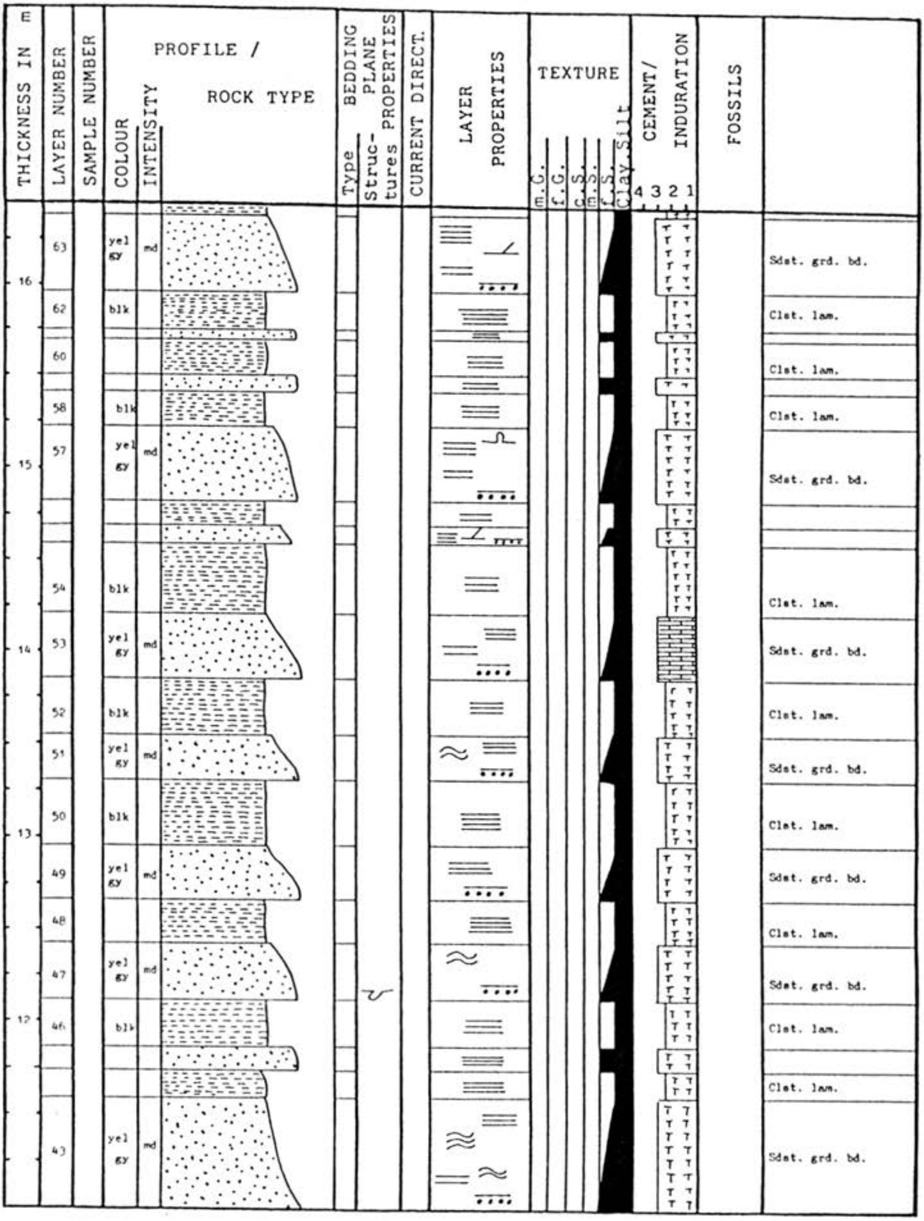
LOG PROFILE XXXI (a)
Flysch facies, W of Chiang Khan.



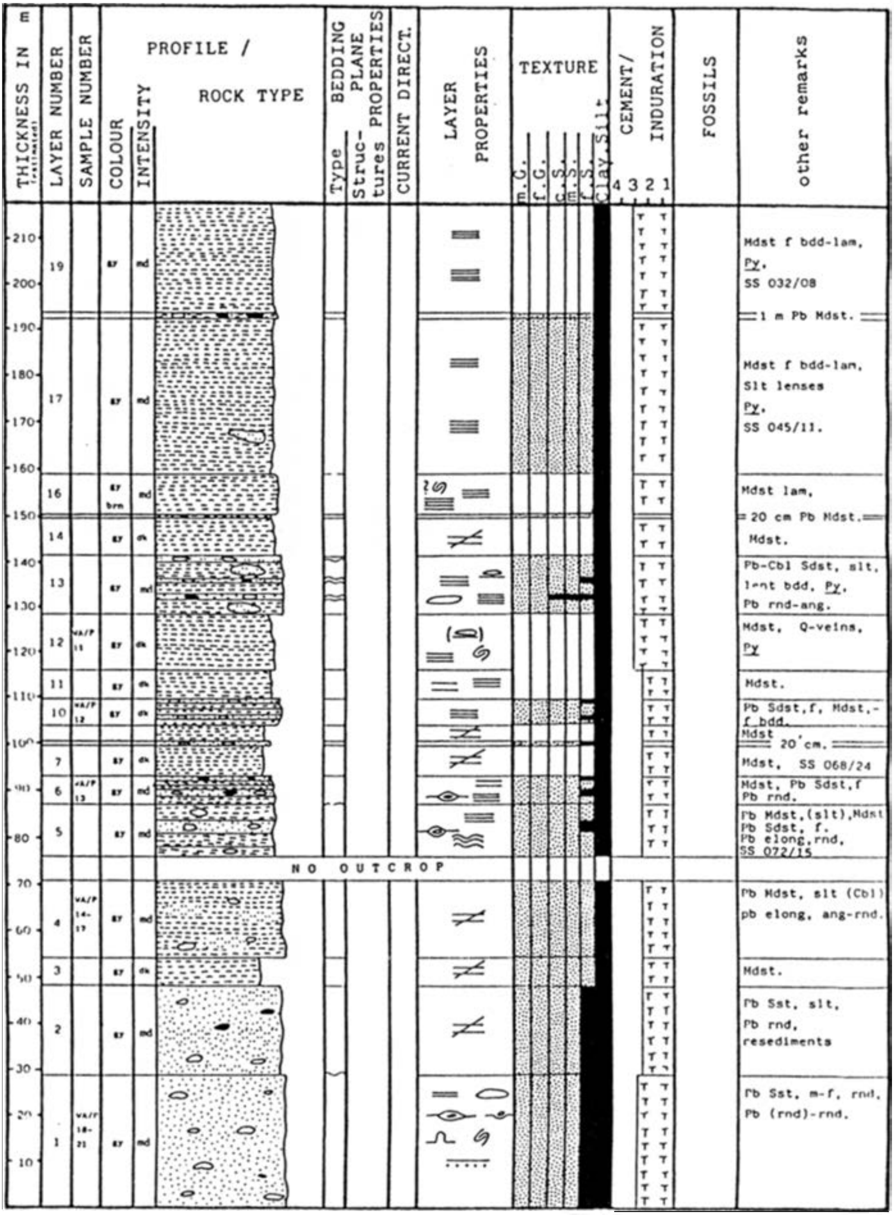
LOG PROFILE XXXI (b)
Flysch facies, W of Chiang Khan.



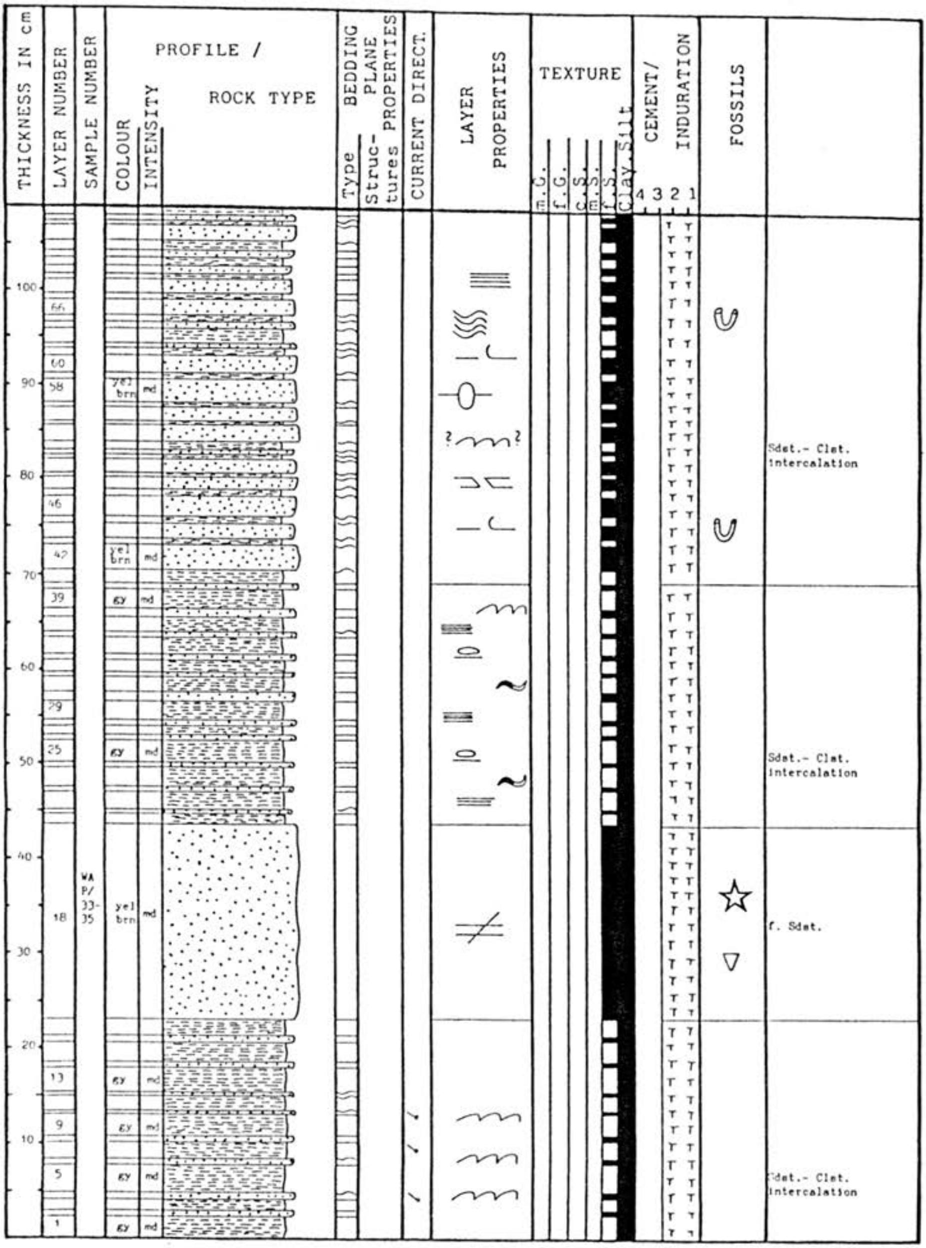
LOG PROFILE XXXI (c)
Flysch facies, W of Chiang Khan.



LOG PROFILE XXXII
Ko Sire - Phuket Island.



LOG PROFILE XXXIII
Ban Pak Thai Sakeo - Phuket Island.



PHOTOGRAPH-PLATES

Plate I

Petchabun Fold and Thrust Belt

A: *An intercalation of shale, chert, and green tuffite at Huai Nam Lao. Fold with steep dipping axis (hammer); ß=160°/55°. Pelagic, ?pre-Asselian strata of the Petchabun Fold and Thrust Belt.*

B: *Turbidite layer, flysch facies – W of Chiang Khan.*

C: *Sample HE82/80. Lithic graywacke with carbonatic intraclasts and foraminifera bioclast (Pseudodoliolina). Flysch facies (Ta-sequence of a turbidite), Petchabun Fold and Thrust Belt, Lom Sak - Chum Phae road.*

D: *Steeply dipping fold axis (ß=158°/46°, parallel to hammers handle) at Huai Nam Lao - Petchabun Fold and Thrust Belt.*

E: *Crinoidal-foraminiferal limestone, wackestone. Nam Nao Fm., Huai Wa member, molasse facies along the Lom Sak - Chum Phae road, at km 40.36.*

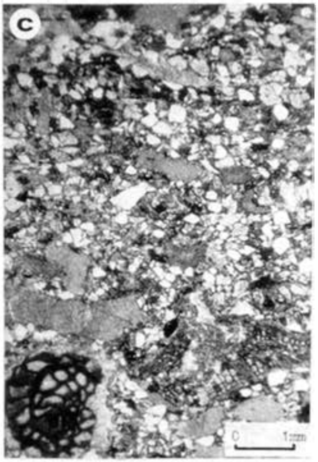
F + G: *Brachiopod pavement on shale and sandstone. Nam Nao Fm., Huai Wa member.*

H: *Plant remains in sandstone. Nam Nao Fm., Huai Wa member.*

I: *Sample WA81/83 – immaturte lithic graywacke with sericitic-clayish matrix, containing mainly angulare quartz grains and lithic fragments and few feldspar grains. Nam Nao Fm., Huai Rahong member, km 34.120 of the Lom Sak - Chum Phae road.*


A


B


C
0
1mm


D


E
WESERKRISTALL Stuckp


F
W.A.Th. 81/14
0
1cm


G
W.A.Th. 81/65
0
1cm


H
W.A.Th. 81/66
6
7
8

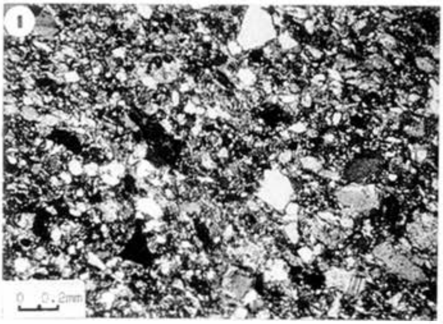

I
0
0.2mm

Plate II

Carbonate facies

A + B: Sample WA84/92 – ooid packstone. Mostly multiple coated ooids. The higher magnification (B, XN) shows the matrix and nuclei replaced by quartz. Rare, coated foraminifera and bivalve fragments probably indicate open marine circulation, SMF 15. Phu Khao Samo Rat.

C: Sample WA84/71 – onkoidal grainstone, SMF 22. Thuak. Khao Sompot.

D: Sample WA82/152 – iron oolites, wackestone - packstone. The matrix is replaced by quartz. Thuak Khao Sompot.

E: Sample WA84/150 – burrowed lime mudstone containing ostracods and calcispheres. Wang Saphung area, eastern platform.

F: Sample WA84/83 – limestone breccia, clast-supported. The clasts consist of burrowed mudstones and dolomitic biomicrites, ?SMF 24. Weak siliciclastic influx in the matrix. Phu Khao Samo Rat area.

G: Sample WA84/145 – tempestite. Graded bedded to laminated limestone containing bioclasts, clayish intraclasts and rip-up clasts. Loei - Wang Saphung road.

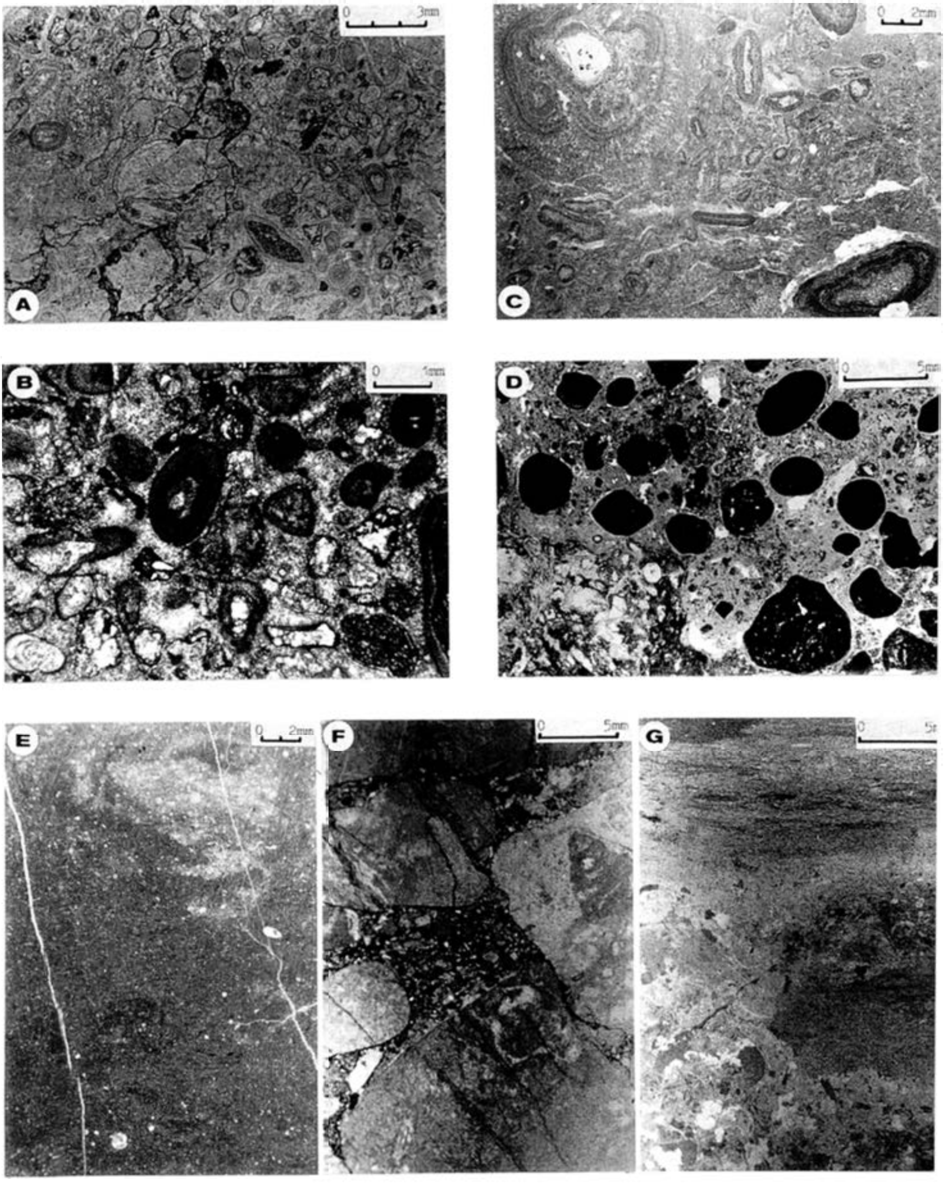

A
0
3mm
C
0
2mm
B
0
1mm
D
0
5mm
E
0
2mm
F
0
5mm
G
0

Plate III

Carbonate facies

- *A:* *Sample HE82/25 – foraminiferal packstone, SMF 10. Foraminifera and other bioclasts together with fine intersitial bioclastic debris in micritic to sparitic matrix. East of Wang Saphung.*
- *B:* *Sample WA84/156 – biomicrite, packstone platy algal (phylloid) facies. South of Wang Saphung.*
- *C:* *Sample WA82/207 – silicified, bioclastic wackestone containing foraminifera, dasycladacean algae and sponge bioclasts (see also plate IVc), SMF 18. Saraburi - Lam Na Rai road, km 6.0.*
- *D:* *Sample HE82/20 – algal/foraminiferal packstone - wackestone, SMF 18, containing bioclasts and fine intersitial bioclastic debris. Nam Nao Formation, Huai Wa member, molasse facies at km 40.05 of the Lom Sak - Chum Phae highway.*
- *E:* *Sample WA84/198 – silicified packstone - wackestone with dasycladacean and foraminiferal bioclasts, SMF 18. Wang Saphung - Na Klang road, km 17.8.*
- *F:* *Sample HE82/43 – crinoidal - foraminiferal packstone, SMF 12. Loei - Tha Li road, km 13.1.*

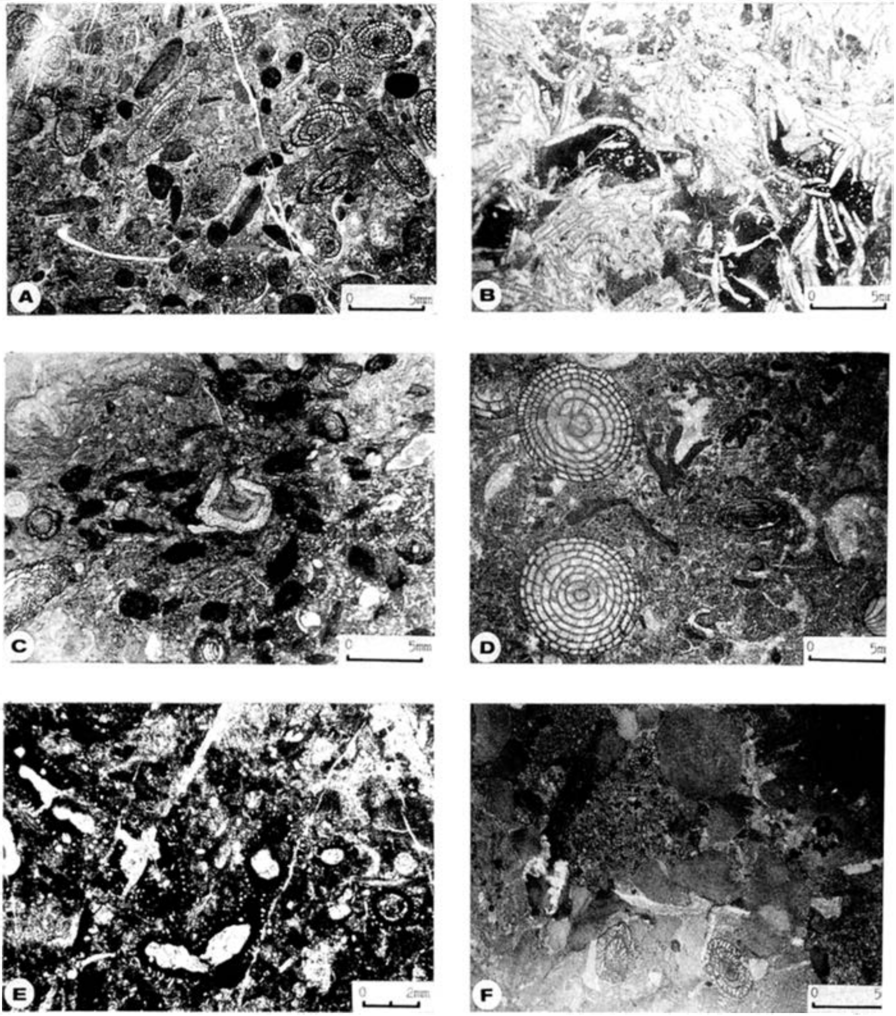

A
0
5mm
B
0
5m
C
0
5mm
D
0
5m
E
0
2mm
F
0
5

Plate IV

Carbonate facis

A: *Sample WA84/121 – replacement of calcite by chalcedony along a stylolite line. The lower part of the micrograph shows bioclastic wackestone, while in the upper part the original texture is obliterated by the late diagenetic replacement, (sparse biomicrite, SMF 9). Khao Yang Ta Po area.*
B: *Coral boundstone at Thuak Khao Sompot.*
C: *Sample WA82/207 – compactionally demolished foraminifer in a diagenetically silicified limestone (see also plate IIIc). Saraburi - Lam Na Rai road, km 6.0.*
D: *Sample WA84/136 – coral boundstone, covered by biomicrite. Nong Pai - Chon Daen road. (See also F).*
E: *Sample WA85/7 – onkoidal limestone (silicified). The micrograph shows an onkoid with a nucleus of foraminiferal packstone. The laminae of the onkoid are rich in iron oxide and red brown in color. Iron oxide is also abundant in the matrix where dolomite crystals are present, SMF 13. Phu Kaho Samo Rat area.*
F: *Sample WA84/136 – dog tooth cement in a coral sceleton (see also D). Nong Pai - Chon Daen road.*

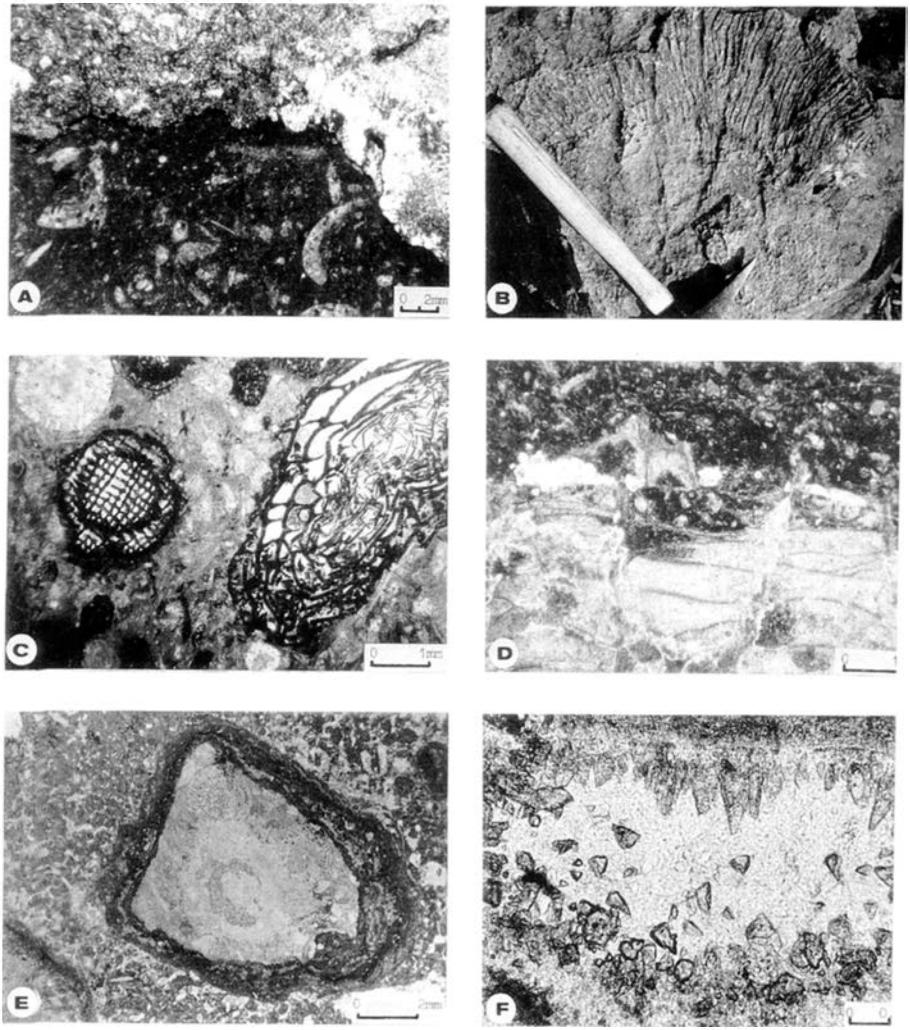

A
0 2mm
B
C
0 1mm
D
0 1
E
0 2mm
F
0 0

Plate V

Volcanic rocks

- *A: Brachiopod shell in a tuffite layer. Nong Pai, km 181.5.*
- *B: Tuffitic limestone arenite (lower layer) and pelitic tuffite (upper layer). The rock is gray to light green in color. N of Loei.*
- *C: Diverse brachiopod shells and bryozoa fragments in a tuffite layer. Nong Pai, km 181.5.*
- *D: Sample WA82/160 – (XN). Thin section micrograph of keratophyric tuffite with shreds of aphanitic and keratophyric texture, K-feldspar, chlorite and epidote. E of Nong Pai, at Huai Klong Nam Kong.*
- *E + F: Sample WA84/18, thin section photomicrographs (F-XN) of keratophyric - spilitic tuffite with crinoid bioclast (upper, left corner, abundant calcite grains and calcite cement. Other components are small phenocrysts of plagioclase (albite - oligoclase) and fragments of recrystallized glass with a fine fluidal texture of plagioclase crystals. Nong Pai, km 181.1.*
- *G + H: Sample WA82/159, thin section photomicrographs (H-XN) of keratophyric to quartzkeratophyric tuffite. The arenitic layer (right side) shows phenocrysts of albitic plagioclase, recrystallized glass shreds and chlorite. The pelitic layer contains a mixture of chlorite, micritic carbonate and aphanitic volcanic fragments.*

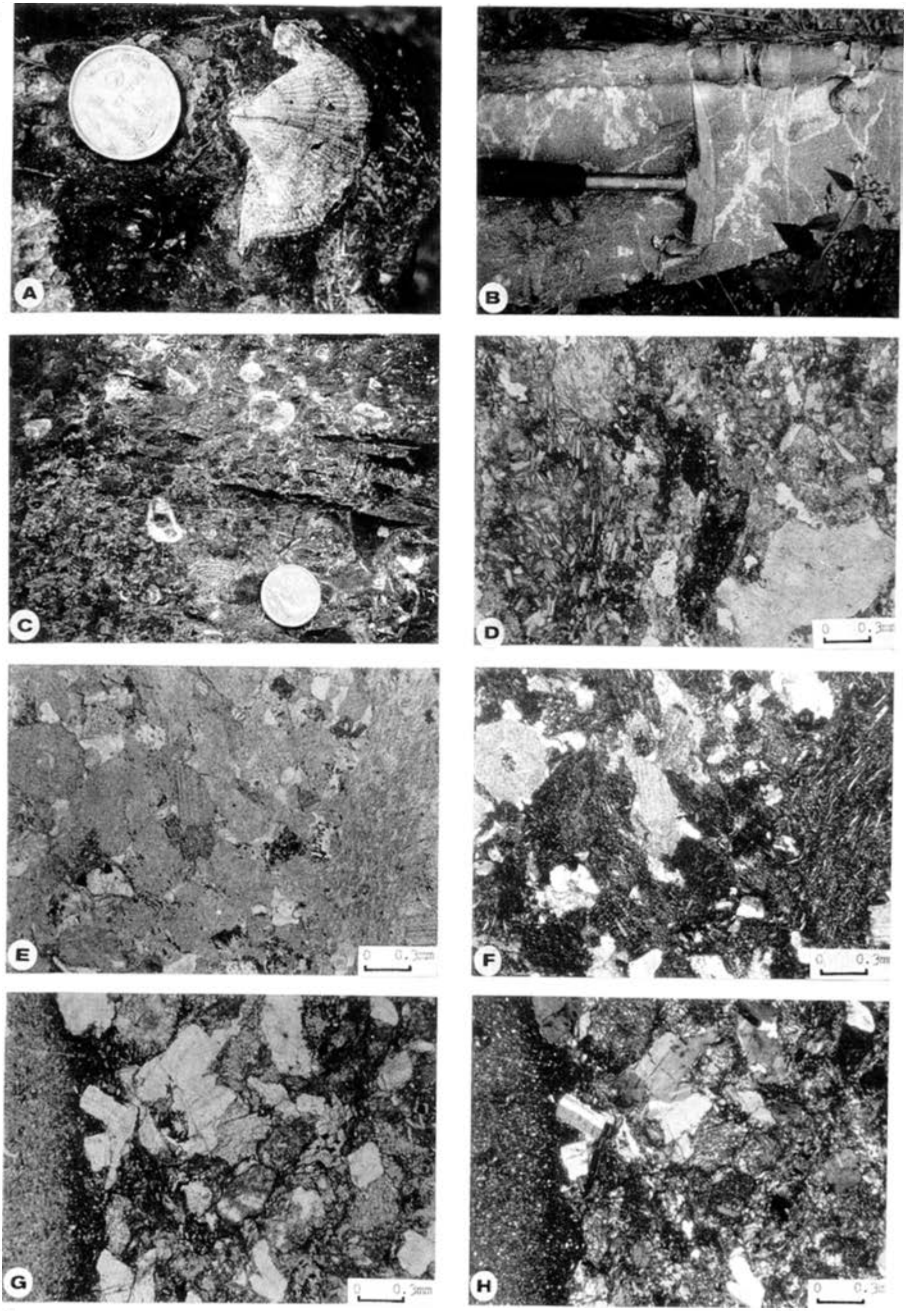

A
B
C
D
0 0.3mm
E
0 0.3mm
F
0 0.3mm
G
0 0.3mm
H
0 0.3

Plate VI

Pebbly mudstones

A + B: Compactional loadcasts surrounding the clast. Such loadcasts were misinterpreted as dropstone impacts. Phuket Island.
C: Limestone boulder in the pebbly mudstone. Langkawi Island.
D: Scattered polymictic megaclasts in a muddy to sandy matrix. Phuket Island.
E: Soft sediment deformation structure - slump structure. Phuket Island.
F: Clastic sills and sedimentary boudinage in the sandstone - mudstone intercalation. Langkawi Island, photograph by Y. NAKASHIMA.

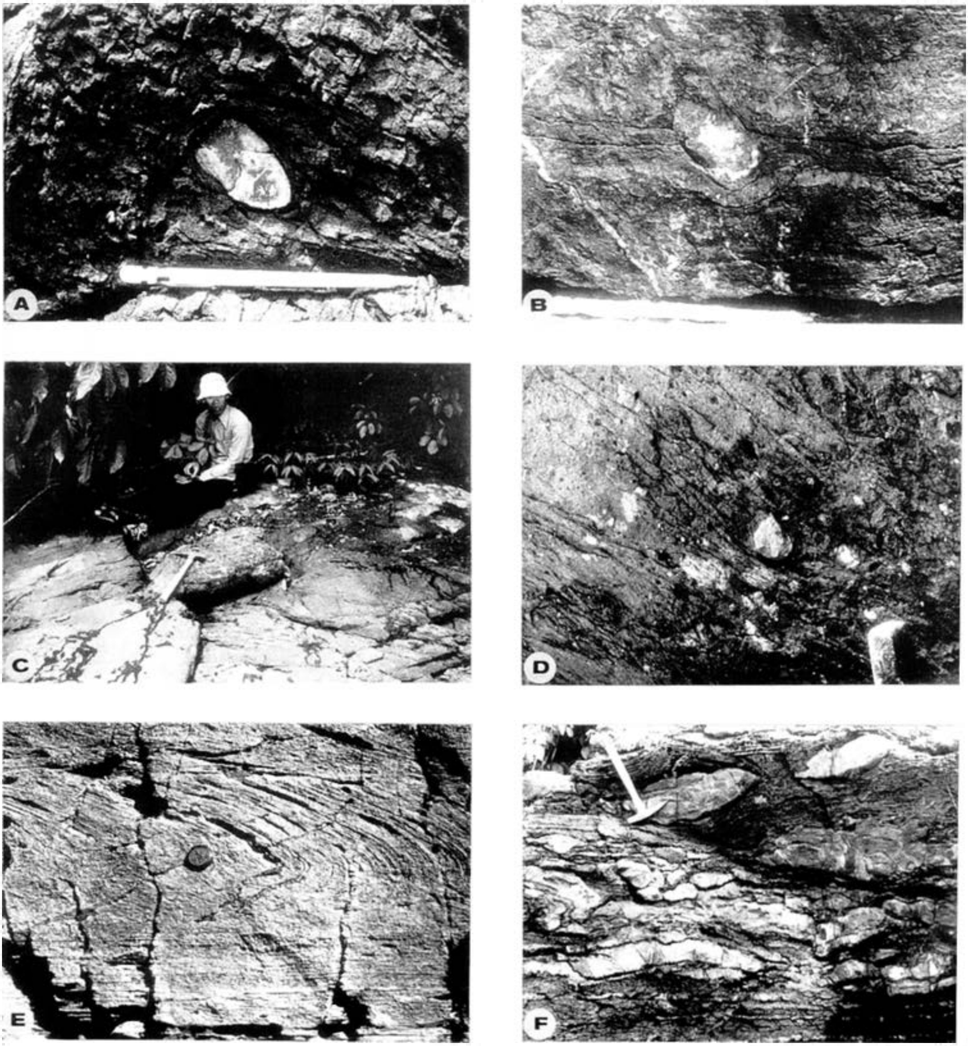

A
B
C
D
E
F

Plate VII

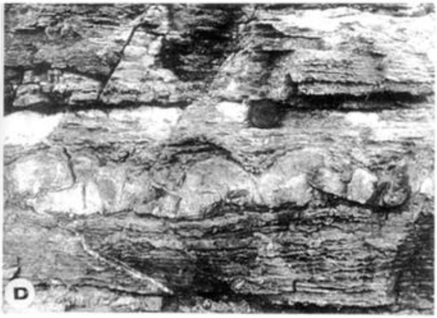
Pebbly mudstones

A + B: Bioturbated mudstone and siltstone. Langkawi Island.
C: Laminated and lenticular bedded siltstone from a tidal deposit (LEE pers. com.). Langkawi Island.
D + E: Pseudoripples in a sandstone layer (D), that originated in front of a slump structure (E). Phuket Island.
F + G: Sedimentary boudinage, sand sills and injection structures documenting water overpressure in the unconsolidated sediment. Langkawi Island, phot. by Y. NAKASHIMA.

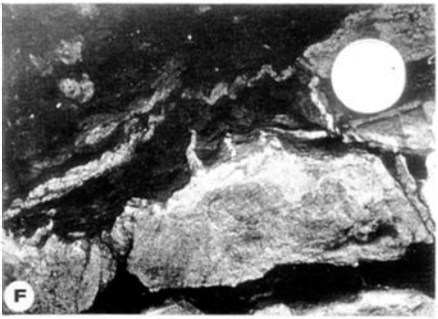

A


B


C


D


E


F

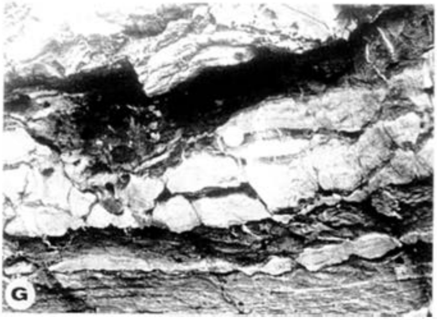

G

Plate VIII

Pebbly mudstone

A: Sample WAP/16, polished section - volcanic clasts in a siltstone matrix. Phuket Island.
B: Slump structure. Phuket Island.
C: Sample WAP/11, polished section - bioturbated mudstone from the pebbly mudstone of Ko Sire. Phuket Island.
D + E: Sample WAP/13 and WAP/14 – mudstone and siltstone with scattered polymictic megaclasts. Phuket Island.
F + G: Sample WAP/27: Mudstone with scattered clasts and clayish rip-up clast showing shrinkage structures. Phuket Island.

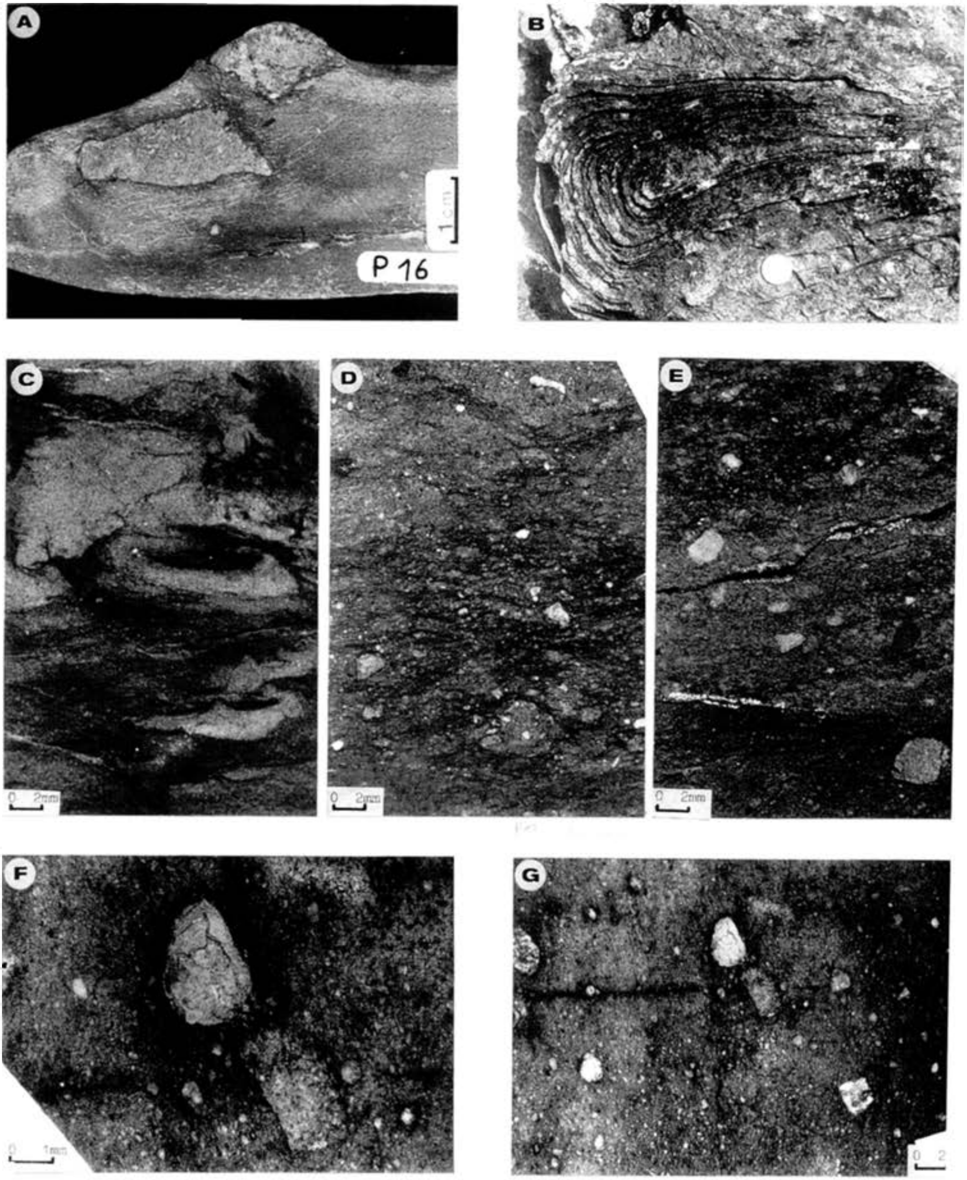

A
1cm
P 16
B
C
0 2mm
D
0 2mm
E
0 2mm
F
0 1mm
G
0 2

Plate IX

Pebbly mudstone

A: Sample WAP/28, thin section photomicrograph showing dolomite clast (in center) in the pebbly mudstone graywacke. Phuket Island.

B: Sample HEP/83 – thin section photomicrograph (XN) showing well rounded quartz clast and angulare granitic clast (upper right corner). Phuket Island.

C: Sample HEP/83a – thin section photomicrograph (XN) of clayish resediment particle with stratified phyllosilicates in a fine sandstone (pebbly sandstone) with unstratified matrix. Phuket Island.

D: Sample WAP/6 – photomicrograph showing lepidoblastic crystals of actinolite in the pebbly mudstone. Phuket Island.

E + F: Sample WAP/21 and WAP/20 – photomicrographs (XN) of lithic graywackes (pebbly sandstones), showing cleavage planes with serizite crystallization along the foliation planes (E) and pressure shadows (F). Phuket Island.

G + H: Sample WAP/44 – showing poikilotopic calcite cement in a pebbly sandstone (H - XN). Kho Phi Phi Island.

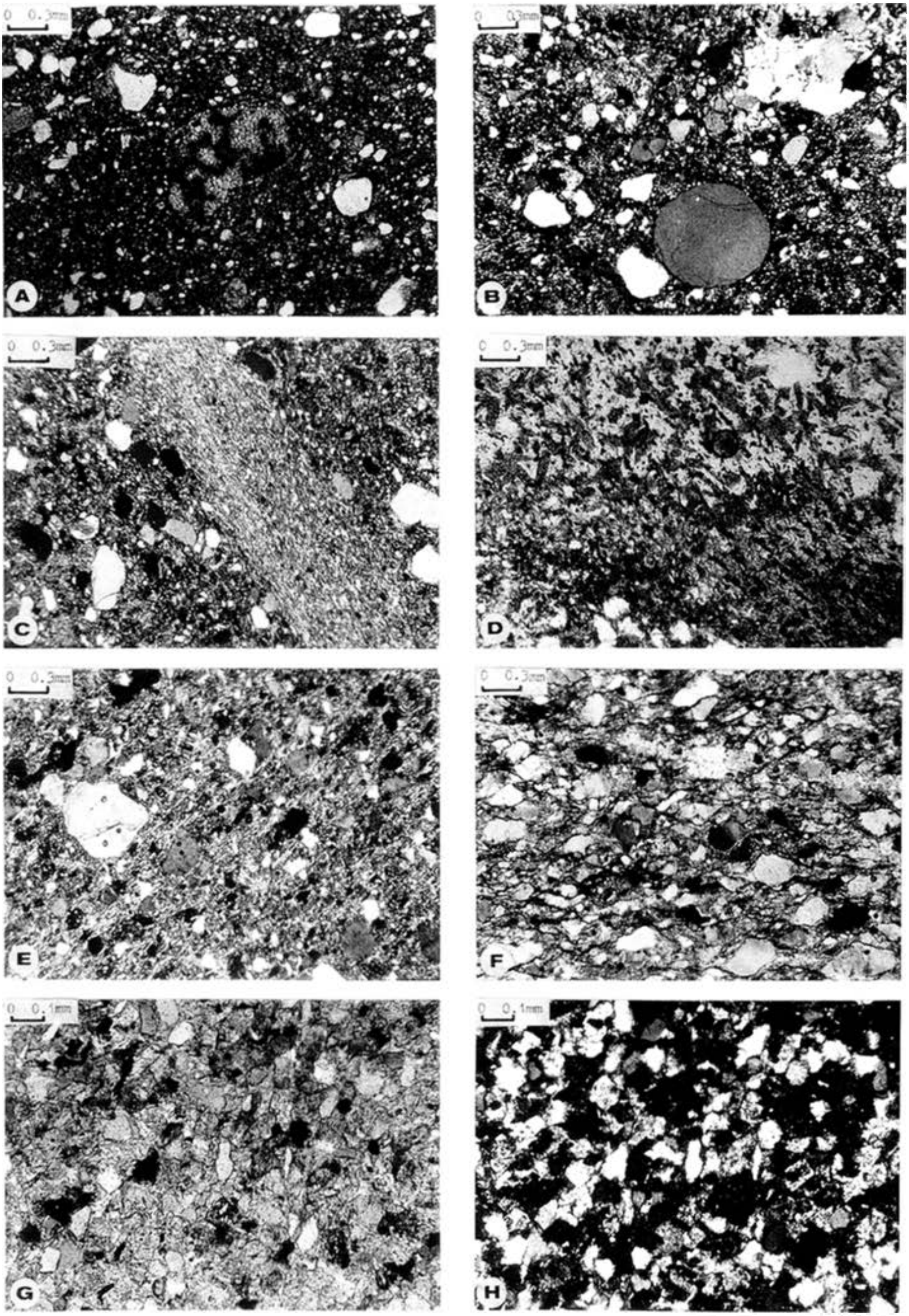

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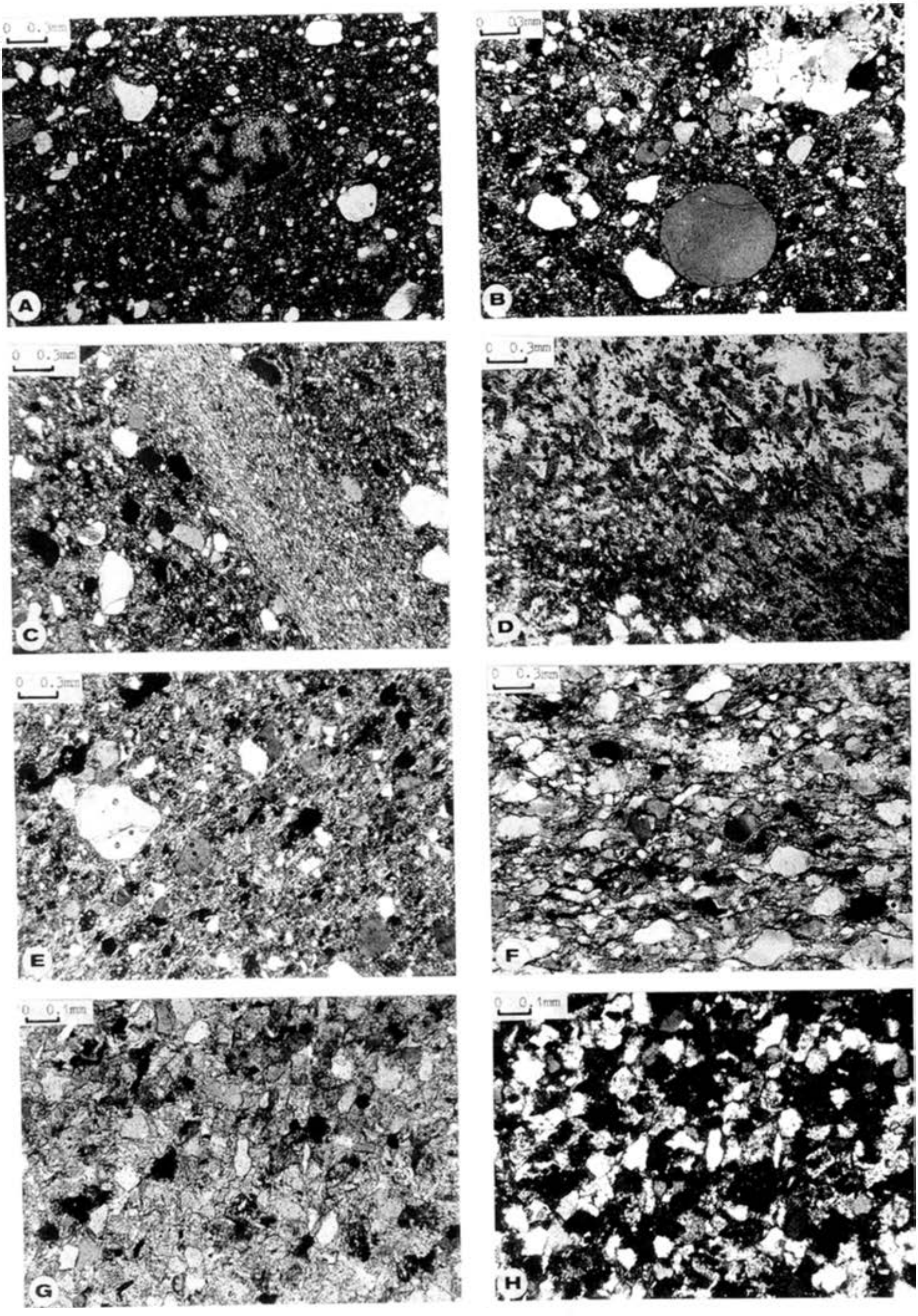
Plate X

Pebbly mudstone – SEM photomicrographs

A: Quartz grain with overgrowth obliterating the grains surface.
B - H: Quartz grain surfaces free of overgrowthy display V-shaped patterns and irregular pitting typical of aqueous abraded grains.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