ลักษณะปรากฏของชั้นตะกอนส่วนบนในมหายุคซีโนโซอิกบริเวณตอนใต้ของแอ่งแพร่
ภาคเหนือของประเทศไทย

นางสาว ราตรี เครือเถาว์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาธรณีวิทยา ภาควิชาธรณีวิทยา
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา. 2544

ISBN 974-17-0159-4

UPPER SUCCESSION OF CENOZOIC SEDIMENTARY FACIES IN THE SOUTHERN PART OF THE PHRAE BASIN, NORTHERN THAILAND

Ms. Ratri Khruathao

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science in Geology

Department of Geology

Faculty of Science

Chulalongkorn University

Academic Year 2001

ISBN 974-17-0159-4

Thesis Title	Upper Succession of Cenozoic Sedimentary Facies in the Southern Part of the Phrae Basin, Northern Thailand
By	Ms. Ratri Khruathao
Field of Study	Geology
Thesis Advisor	Associate Professor Chaiyudh Khantaprab, Ph.D.
Thesis Co-advisors	Mr. Somchai Poom-im, M.S.
	Mr. Montri Choowong, M.Sc.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

…………………………………...Deputy for Administrative Affairs
(Associate Professor Pipat Karntiang, Ph.D)Acting Dean, Faculty of Science

THESIS COMMITTEE

…………………………………..Chairman
(Assistant Professor Somchai Nakapadungrat, Ph.D)

…………………………………..Thesis Advisor
(Associate Professor Chaiyudh Khantaprab, Ph.D)

…………………………………..Thesis Co-advisor
(Mr. Somchai Poom-im, M.S.)

…………………………………. Thesis Co-advisor
(Mr. Montri Choowong, M.Sc.)

…………………………………. Member
(Dr. Pol Chaodumrong, Ph.D)

ราตรี เครือเถาว์ : ลักษณะปรากฏของชั้นตะกอนส่วนบนในมหายุคซีโนโซอิกบริเวณตอนใต้ของแอ่งแพร่ ภาคเหนือของประเทศไทย (UPPER SUCCESSION OF CENOZOIC SEDIMENTARY FACIES IN THE SOUTHERN PART OF THE PHRAE BASIN, NORTHERN THAILAND) อ. ที่ปรึกษา : ร.ศ ดร. ชัยยุทธ ขันทปราบ, อ. ที่ปรึกษาร่วม สมชาย พุ่มอิ่ม และมนตรี ชูวงษ์ จำนวนหน้า 130 หน้า. ISBN 974-17-0159-4

แอ่งแพร่ เป็นแอ่งระหว่างภูเขาอายุมหายุคซีโนโซอิก อยู่ในเขตจังหวัดแพร่ในภาคเหนือของประเทศไทย ตั้งอยู่ระหว่าง เส้นแวง $18^\circ\ 0'$ ถึง $18^\circ\ 35'$ เหนือและ เส้นรุ้ง $100^\circ 0'$ ถึง $100^\circ\ 20'$ ตะวันออก แอ่งแพร่มีรูปร่างคล้ายวงรี โดยมีแกนของแอ่งตามแนวยาว วางตัวในทิศเหนือ / ตะวันออกเฉียงเหนือ – ใต้ / ตะวันตกเฉียงใต้ แอ่งทางตอนเหนือสุดได้แยกออกเป็น 2 ส่วน ความกว้างของแอ่งมีค่ามากที่สุด 15 กิโลเมตร และความยาวของแอ่งประมาณ 60 กิโลเมตร ตัวแอ่งครอบคลุมพื้นที่ประมาณ 1,100 ตารางกิโลเมตร พื้นที่ศึกษาอยู่ทางตอนใต้ของแอ่งแพร่ ครอบคลุมพื้นที่ประมาณ 300 ตารางกิโลเมตร โดยหลักการพื้นฐานแล้ว การศึกษาครั้งนี้กำหนดเป้าหมายในการวิเคราะห์ลักษณะปรากฏของตะกอน สภาวะแวด-ล้อมของการตกสะสมตัว และวิวัฒนาการของแอ่งตะกอนในส่วนบนของแอ่งแพร่ โดยใช้ข้อมูลจากหลุมเจาะ 12 หลุมและประกอบด้วยข้อมูลการหยั่งทางธรณีฟิสิกส์ประกอบซึ่งได้แก่ รังสีแกมมา, แคลิเปอร์ และความหนาแน่น นอกจากนี้ได้ทำการวิเคราะห์ข้อมูลการสำรวจคลื่นไหวสะเทือนแบบสะท้อนระยะทาง 156 กิโลเมตร

แอ่งแพร่เป็นแอ่งที่เกิดจากรอยเลื่อน โดยมีรอยเลื่อนแพร่ เถิน เป็นรอยเลื่อนหลักที่ทำให้เกิดแอ่งรอยเลื่อนมีการวางตัวทางด้านทิศตะวันออกเฉียงเหนือ–ทิศตะวันตกเฉียงใต้ และมีรูปร่างเป็นรูปตัวอักษร เอส ความหนาของตะกอนในแอ่งแพร่ ประมาณ 1500 เมตร

ลักษณะของตะกอนในแอ่งจัดอยู่ในลักษณะเนินตะกอนน้ำพารูปพัด, ตะกอนแม่น้ำ,ตะกอนทะเล-สาบที่มีการแทรกของทางน้ำและพื้นที่ลุ่มมีน้ำขังที่พืชสะสมตัว

คาดว่าการเกิดธรณีวิทยาแปรสัณฐานทั้งขนาดท้องถิ่นและขนาดใหญ่ เป็นปัจจัยสำคัญที่ทำให้เกิดการเปลี่ยนแปลงสภาวะแวดล้อมของการสะสมตัวของตะกอน และจากลำดับการสะสมตัวของชั้นตะกอน สามารถบ่งบอกถึงการเปลี่ยนแปลงทางด้านธรณีสัณฐานอย่างน้อย 5 ครั้ง

ภาค	วิชาธรณีวิทยา	ลายมือชื่อนิสิต……………………………………..
สาขา	วิชาธรณีวิทยา	ลายมือชื่ออาจารย์ที่ปรึกษา………………………..
ปีการศึกษา	2544	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม…………………..
		ลายมือชื่ออาจารย์ที่ปรึกษาร่วม…………………..

##4272378423 :MAJOR GEOLOGY

KEY WORD :SEDIMETARY FACIES/ PHRAE BASIN

RATRI KHRUATHAO: UPPER SUCCESSION OF CENOZOIC SEDIMENTARY FACIES IN THE SOUTHERN PART OF THE PHRAE BASIN, NORTHERN THAILAND. THESIS ADVISOR : ASSOC.PROF.CHAIYUDH KHANTAPRAB, Ph.D., THESIS CO-ADVISORS SOMCHAI POOM-IM, M.S. AND MONTRI CHOOWONG, M.Sc., 130 pp. ISBN 974-17-0159-4

The Cenozoic intermontane Phrae basin is located in Changwat Phrae, northern Thailand. The basin lies between latitudes 18° to 18° 35′ N and longitudes 100°to 100° 20′ E. The shape of basin is ellipse with NNE – SSW of approximately 60 kilometres long and 15 kilometres wide. The northern end of the basin is bifurcated. The basin covers about 1,100 square kilometres. The study area occupies the southern half portion of the basin covering an area of approximately 300 square kilometres. This research aims at analysing the Cenozoic an area of sedimentary facies in the upper succession of the Phrae basin in order to reconstruct the depositional environment and the evolution of the sedimentary basin. The data employed in this study is composed of 12 drill–holes with wire-line geophysical logs of gamma ray, caliper, and density. The 2-D seismic survey data of 156 line–kilometres is also employed in the study.

The Phrae basin is classified as a fault– bounded basin. The Phrae–Thoen fault is the main fault that strongly influenced the development of the basin. The Phrae–Thoen fault trends northeast–southwest and displays a sigmoidal shape. The thickness of the Cenozoic sedimentary sequence within the Phrae basin is about 1,500 metres.

The sedimentary facies of the upper part of the Phrae basin are generally characterised as alluvial fan, fluviatile, lacustrine facies associated with fluviatile facies and peat swamp facies.

The regional and local tectonics are believed to be the major controlling factors of the variation in the depositional environment. At least five tectonic events can be recognised in the sedimentary sequence.

Department……..Geology……. Student's signature……………………...

Field of study……Geology……. Advisor's signature……………………..

Academic year……2001………. Co-advisor's signature………………….

Co-advisor's signature………………….

ACKNOWLEDGEMENTS

The author would like to thank Associate Professor Chaiyudh Khantaprab, thesis advisor, Mr. Somchai Poom-im, and Mr. Montri Choowong, co-advisors for their guidance, encouragement, valuable supervision and critical reading of the thesis.

Her appreciation goes to Graduate School, Department of Geology, Chulalongkorn University in continuously providing numerous facilities and financial support during the course of study.

Grateful acknowledgements are extended to Energy Resource Information and Data Unit, Mineral Fuels Division, the Department of Mineral Resources of Thailand (DMR), for the permission to use some confidential data. Deep appreciation is given to Mr. Wuttipong khongphetesak, Mr. Apichat Jeenagool, Mr. Bundit Chisilboon, and Mr. Kringkri Pomin for providing some data. The author is also grateful to the Ban Pu Plc. for the permission to assess some information of the Phrae Basin; in particular, special recognition and thanks to the staff of Geology Section.

Special acknowledgement goes to Mr. Nares Sattayarak, Assistant Professor Punya Charusiri, Assistant Professor Nopadon Muangnoicharoen, Assistant Professor Pongsak Phongprayoon, Assistant Professor Sompop Vedchakanchana, Dr. Songpop Polachan and Wickanet Songtham for their valuable advises. Special thank is given to Dr. Pol Chaudumrong for wonderful comments and reading the manuscript.

Moreover, great appreciation is directed towards Prapaporn Khursida, Krittaya Pattamlai, Panjai Saraphanchatwitthya, Ruschat Natee, Mongkol Audchachon, Thiraphat Srisumruat and Bhuwadol Wanthanachaisaeng for helping in the preparation of the manuscript during all phases of the work, especially Mr. Yongyut Mungkeaw who patiently typed the final thesis.

Finally, this thesis could not be possible without the help and encouragement of her family and friends who patiently provide both moral and physical supports. Mr. Mitzuo Yamada, the president of Siam Tone Co., Ltd., is highly appreciated for the permission to study during working period.

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CHAPTER I

INTRODUCTION

Areas underlain by the Cenozoic deposits in Thailand have been long known as prosperous human settlements and fertile agricultural land. Groundwater and construction materials, especially clay, sand and gravel has been exploited to serve the demand of human societies of different civilization periods. More recently, additional earth resources, namely, petroleum, coal, industrial clays, diatomaceous earth have been discovered and developed. Therefore, intermontane basins and other onshore and off shore Cenozoic deposits are considered to be economically important.

Geologically, the Cenozoic deposits are commonly confined within isolated intermontane basins in the northern and the southern Thailand, occupying the vast central plain of Thailand with varying in thicknesses, covering as the veneer in the Khorat plateau, and underlying the entire area of the Gulf of Thailand and the Andaman sea with great thicknesses (Figure 1.1).

It is interesting to note that almost all sedimentary successions of the Cenozoic deposits in Thailand have not reportedly been exposed. However, the subsurface geological conditions have been revealed from numerous projects regarding the exploration and development of earth resources.

The Phrae basin has been chosen for this research because of the availability of drilling and subsurface geophysical data so that subsurface geological information are properly available (Figure 1.2).

1.1 The Study Area

The Phrae basin is one of intermontane basins located in Changwat Phrae, northern Thailand. The basin lies between latitudes 18° 01′ N to 18° 35′ N and longitudes 100°0′ E to 100° 20′ E. The shape of the basin is elliptical with the NNE–SSW. The dimension

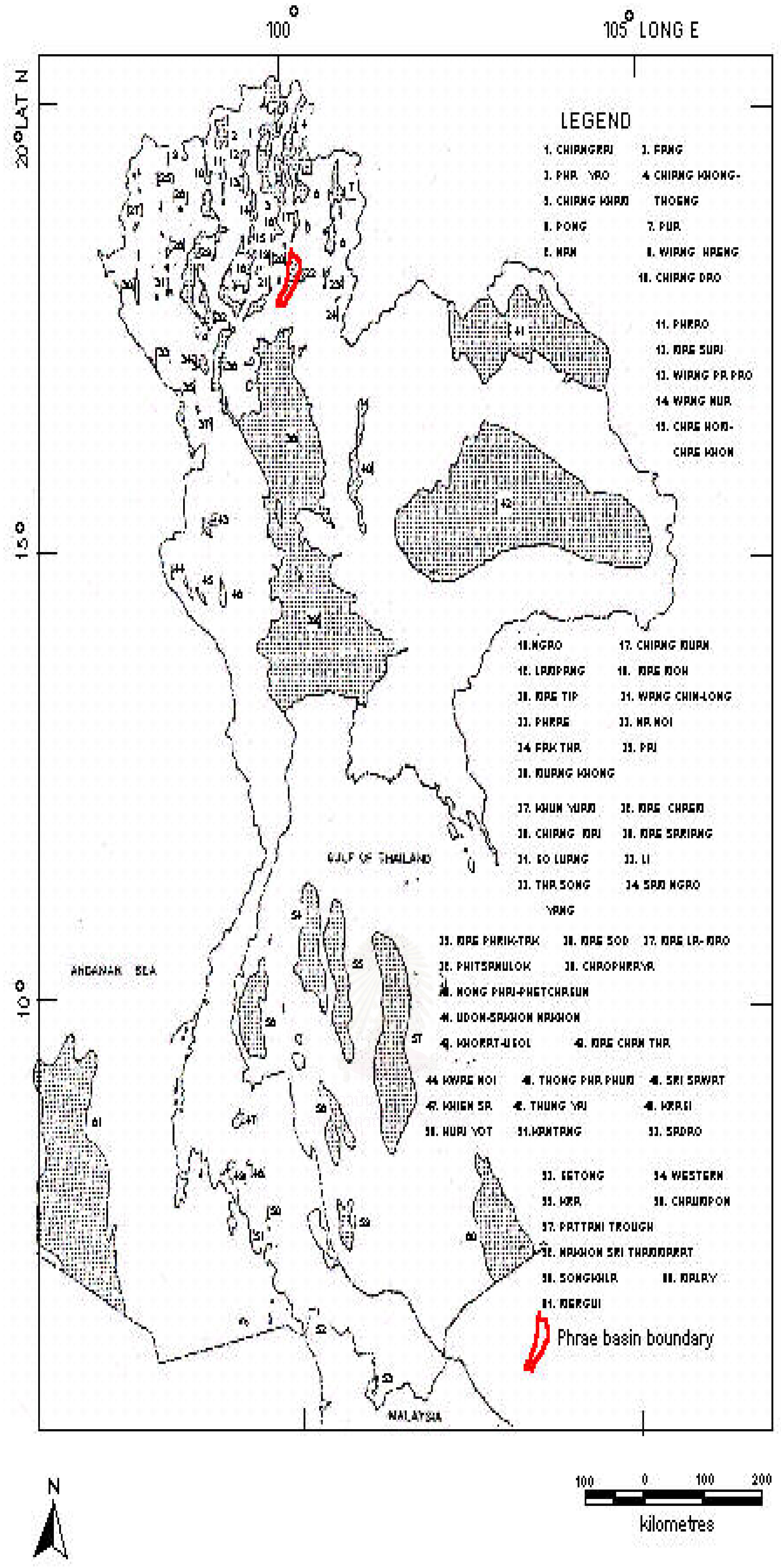

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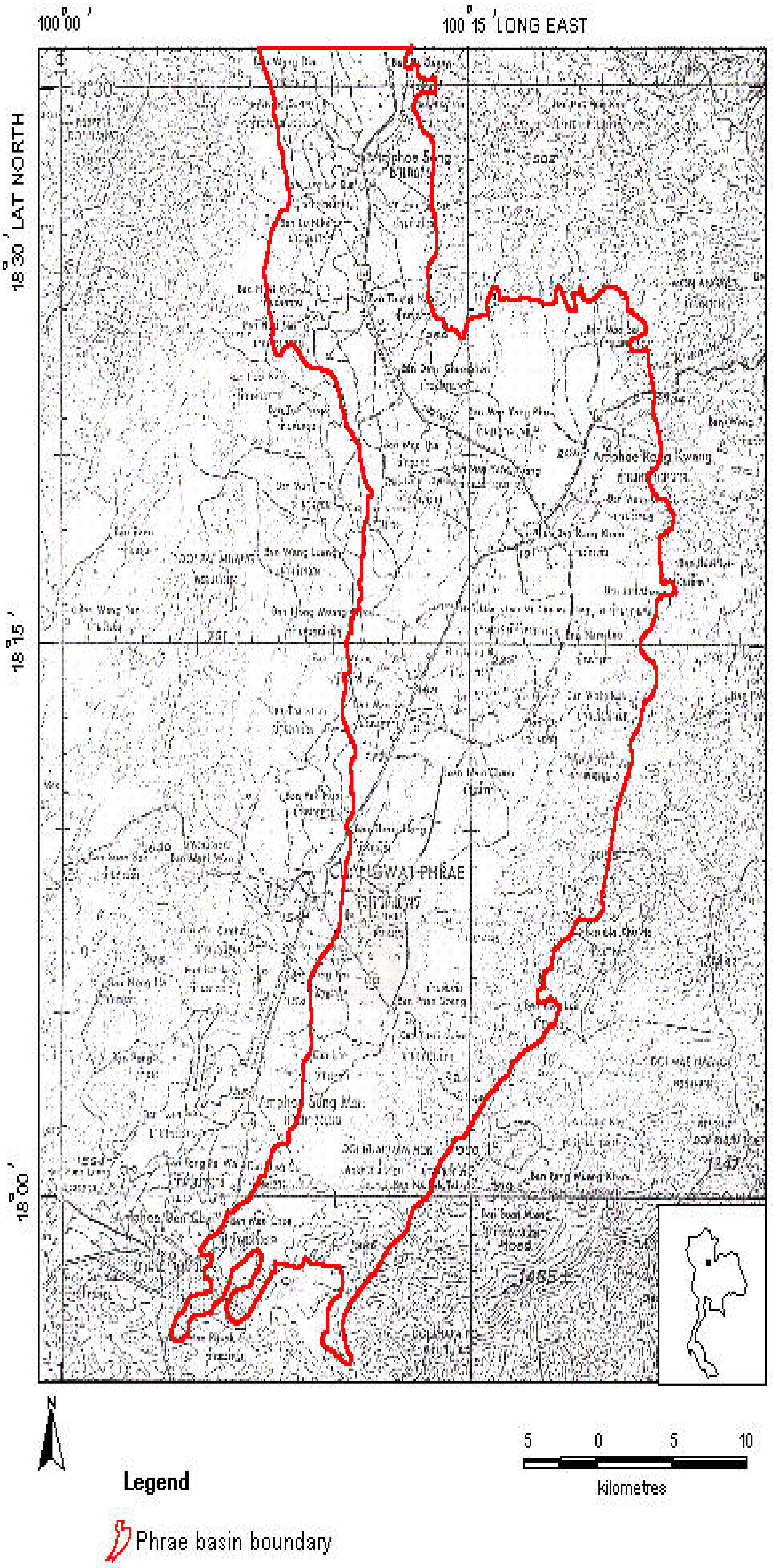
Figure 1.1 The Cenozoic basin of Thailand (modified after Chaodumrong et al.,1983)



PHRAE CENOZOIC BASIN	Figure 1.2 Topographic map of the Phrae basin and its vicinity NE 47-7 1 : 250,000
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of the basin is approximately 60 kilometres long and 15 kilometres wide, with the northern end of the basin bifurcated. The basin covers approximately 1,000 square kilometres. (Figure 1.1.1). The study area occupies the southern half portion of the basin covering approximately 300 square kilometres. (Figure 1.1.2)

1.2 Objective of the Study.

The study aims at analysing the upper succession of Cenozoic sedimentary facies of the Phrae basin in order to reconstruct the depositional environment and the geological evolution of the basin.

1.3 Scope of Work and Study Methodology

The study area covers estimately 300 square kilometres and the sub-surface geology extends from the ground surface down to the maximal depth of 850 metres.

The data and information employed in the study are obtained mainly from the Mineral Fuel Division, Department of Mineral Resources, PTT Exploration and Production Plc., and Banpu Plc.

The geological setting of the area is synthesised mainly from previous works and the reconnaissance field visits carried out in this research

The 2D seismic survey data available for this study is obtained from the PTT Exploration & Production Plc. of totally 156 line-kilometres from 9 survey-lines. This survey covers approximately 632 square kilometres. (Figure 1.3.1)

Totally, 12 drill-hole data and gravity survey data are available from the Department of Mineral Resources. The drill-hole with total depth of penetration of 7,686 metres have been chosen for the present study. The maximum drilling depths is 850 metres. The drill-hole data is supplemented with wireline geophysical logs of the following parameters, gamma ray, caliper, and density.

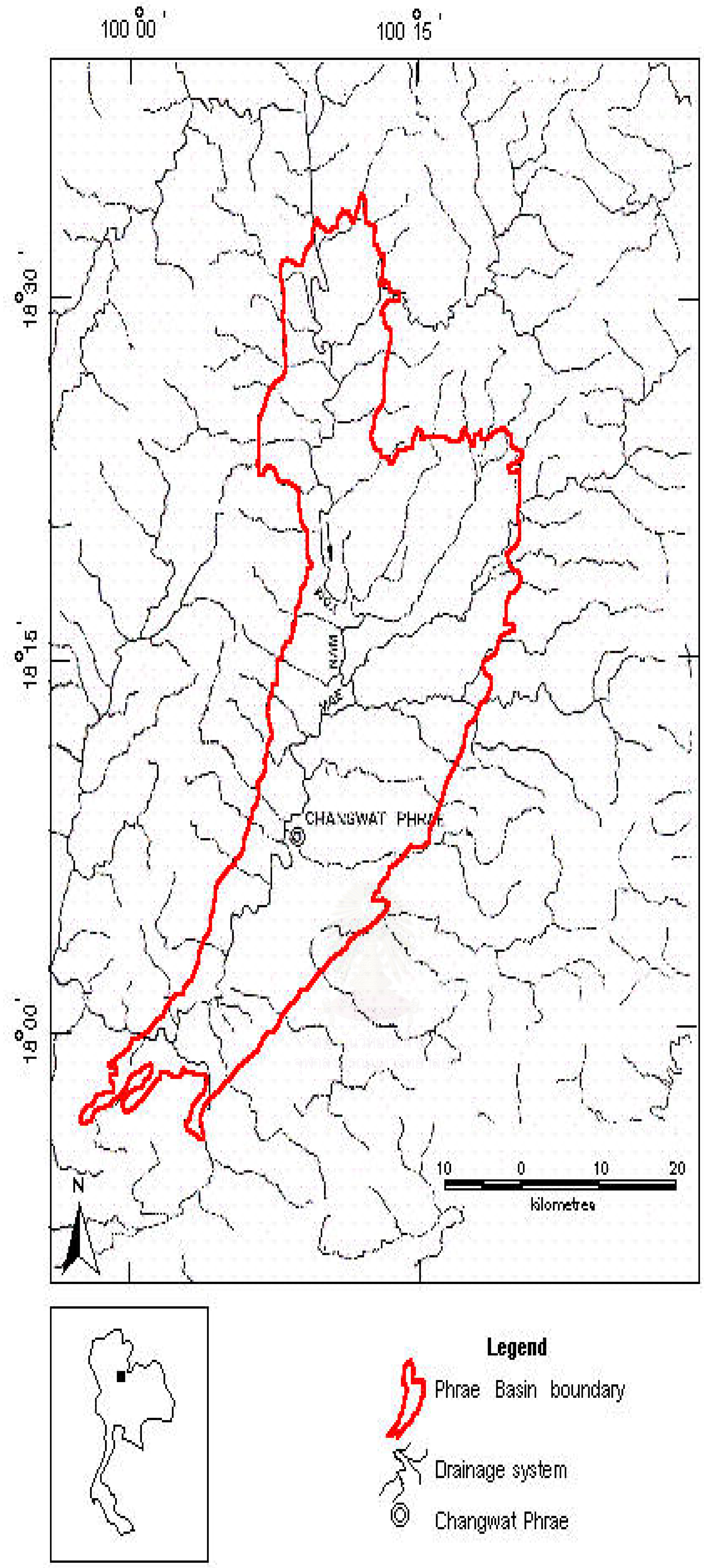

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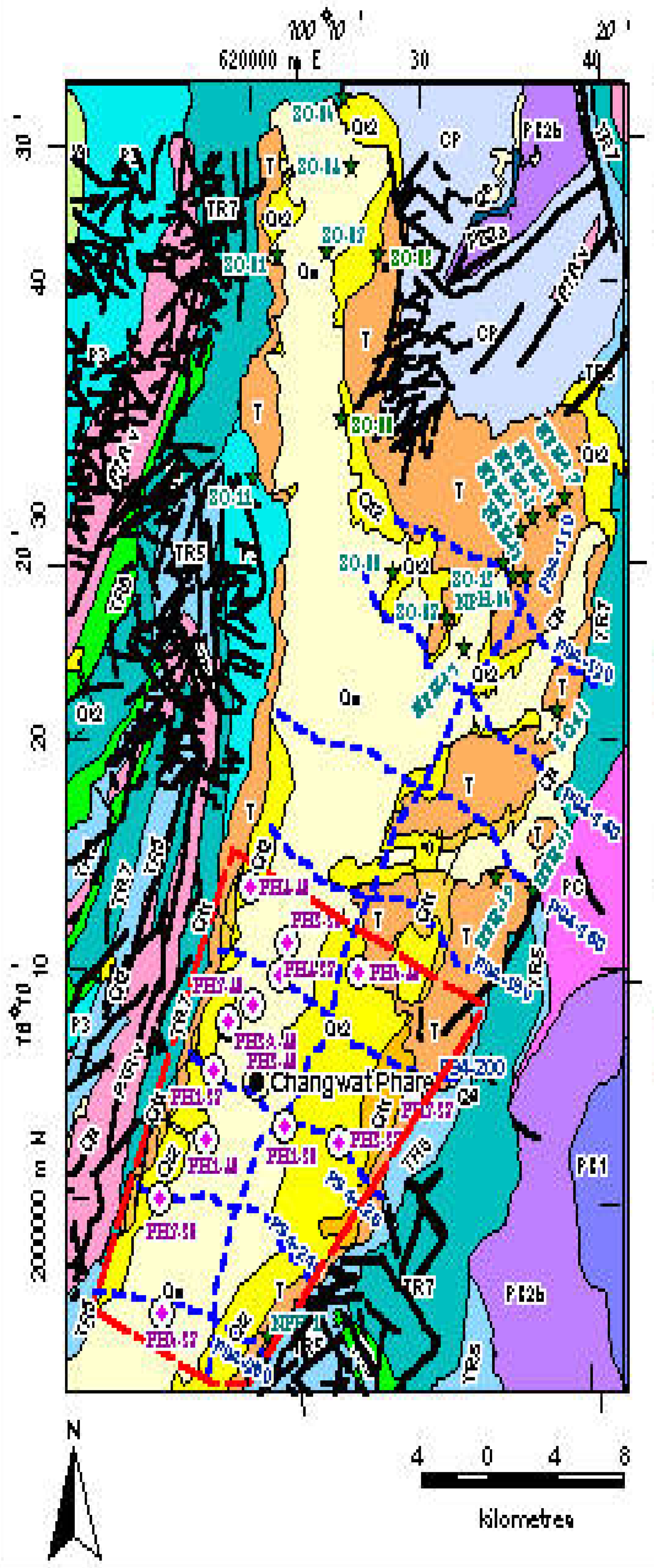
Figure 1.1.1 Surface drainage system and boundary of the Phrae basin



Explanation

- Qa — Alluvial deposits;sand,silt,clay,gravel
- Qt2 — Low terrace; sand, silt, clay, gravel and laterite
- Qt1 — High terrace, valley fills, alluvial fan; sand,silt, clay, laterite and gravel
- T — Sandstone, claystone with fossils of leaves, fish remains and gastropods(*Viviparus sp.*)
- J3 — Red beds of medium to coarse grained sandstone, quartz-arenite, siltstone, shale and conglomerate
- TR7 — Sandstone, shale, mudstone and grey to very dark grey limestone with fossils *Halobia sp.* sp., *Daonella sp.* ,and *Posidonia sp.*
- TR6 — Light to dark grey limestone, thin to thick beds, interbedded with shale and intercalated by siltstone, conglomerate and agglomerate with fossils of *Costatoria sp.*, Corals and Crinoid
- TR5 — Sandstone, siltstone, shale and red conglomerate with pebble of volcanic rocks, limestone and sandstone
- P3 — Black shale, grey sandstone, dark grey mudstone and grey limestone with chert nodules, fossils of Crinoids and Pelecypods and *Fenestella sp.*, in the interbedded between limestone and mudstone
- PB2b — Grey shale interbedded with dark grey limestone, Fossils of Fusulinids, Corals and Crinoids, sandstone, conglomerate and andesitic basalt
- PB2a — Reddish brown conglomerate, well rounded, clast of quartz, phyllite and greywacke
- PB1 — Grey shale, siltstone and thick beds clastic limestone
- PC — Green chert, shale, sandstone, limestone and andesite
- CP — Purple to greyish purple phyllite, brown sandstone and siltstone with mica
- PTRv — Basic igneous rocks: green to dark green quartz-gabbro, medium to coarse grained, consists of plagioclase, pyroxene, biotite and quartz
- Mzb — Volcanic rocks: rhyolite, andesite, tuff and agglomerate
- Changwat Phare
- fracture/fault
- seismic line
- drilling hole location of DMR
- drilling hole location of Banpu
- study area (300 square kilometres)

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Figure 1.1.2 The study area

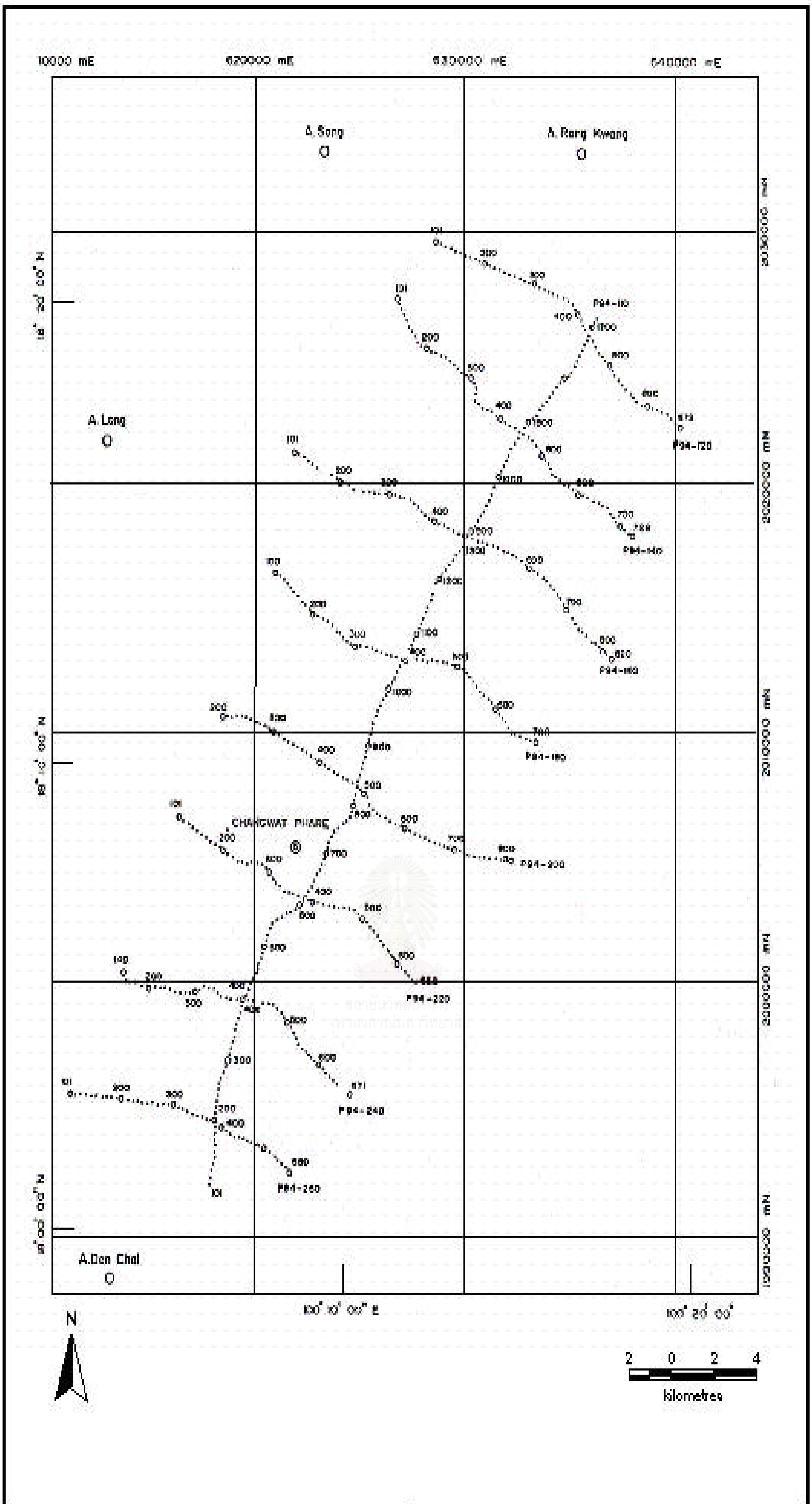

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Figure 1.3.1 Shot point map of seismic lines

Besides, the palynoflora study by the PTT Exploration & Production Plc. with emphasis on the geological age determination is available for the present study.

With respect to the coal quality determination, altogether 10 coal samples obtained from 3 drill-holes were analysed for the moisture contents, ash, volatile matter, specific heating value, sulphur, specific gravity, etc.

The landsat imageries are also employed to determine the framework of the geological structure of the area, (Figures 1.3.2 and 1.3.3)

Concerning the approach of the present study, various aspects of work have been undertaken as follows:

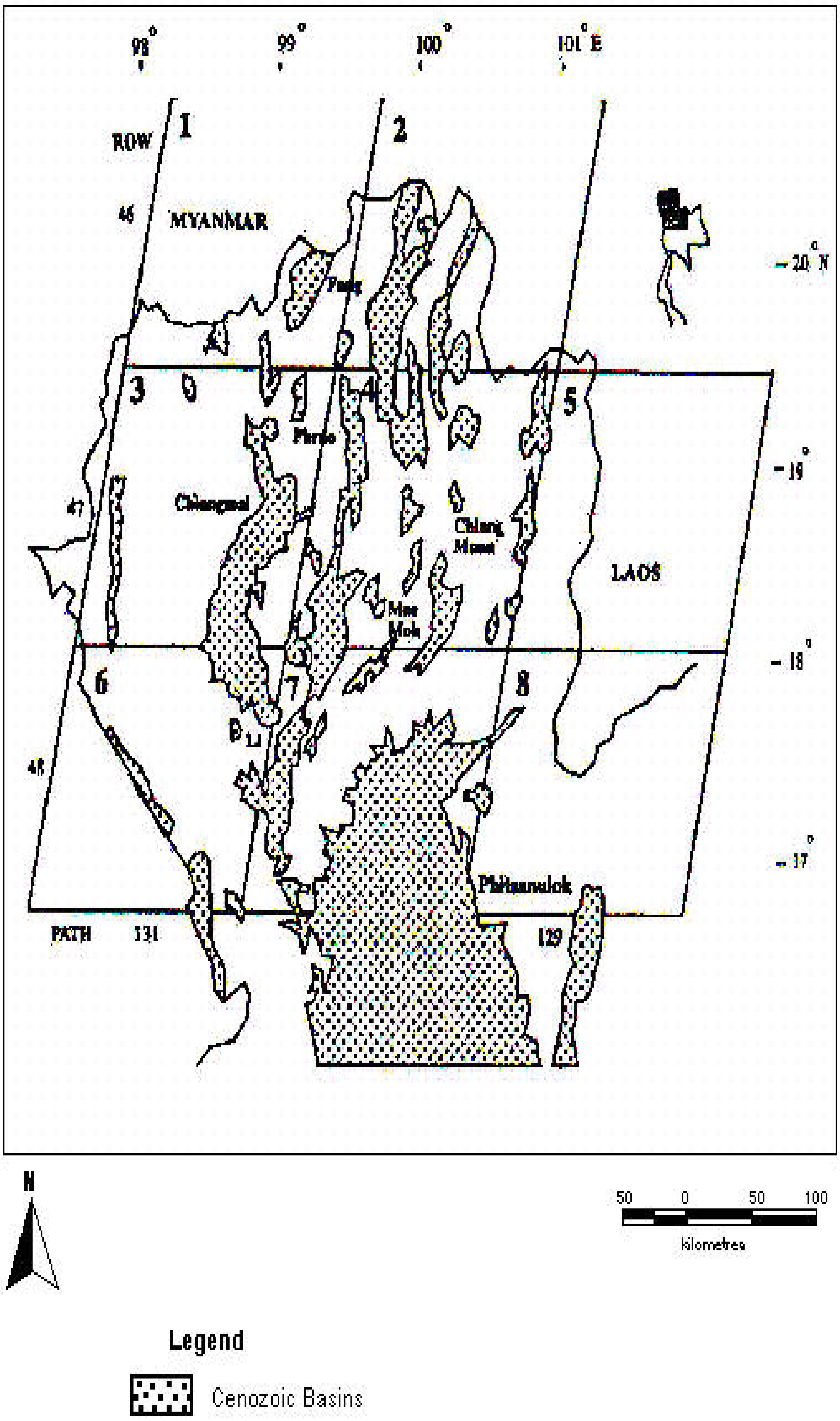
The literature survey is focused on two main aspects. The review of theoretical concepts and the review of previous investigation of the study area.

The second step involves data acquisition of both surface and subsurface geology including geophysics from various sources.

The third step concerns with the interpretation of geological and geophysical data including seismic interpretation, gravity interpretation (Figure 1.3.4) and the integration of bore - hole geological and geophysical data.

Surface geology from numerous pervious studies was examined during the reconnaissance field visits undertaken in this present investigation. As a result, the regional geology of the basin has been compiled under this step, the fourth step.

The fifth step emphasised on the determination of the subsurface lithofacies the Cenozoic deposits from the study area.



PHRAE CENOZOIC BASIN	Figure 1.3.2 Index map of Lansat TM images, coverage of northern Thailand (image 1 to image 8)
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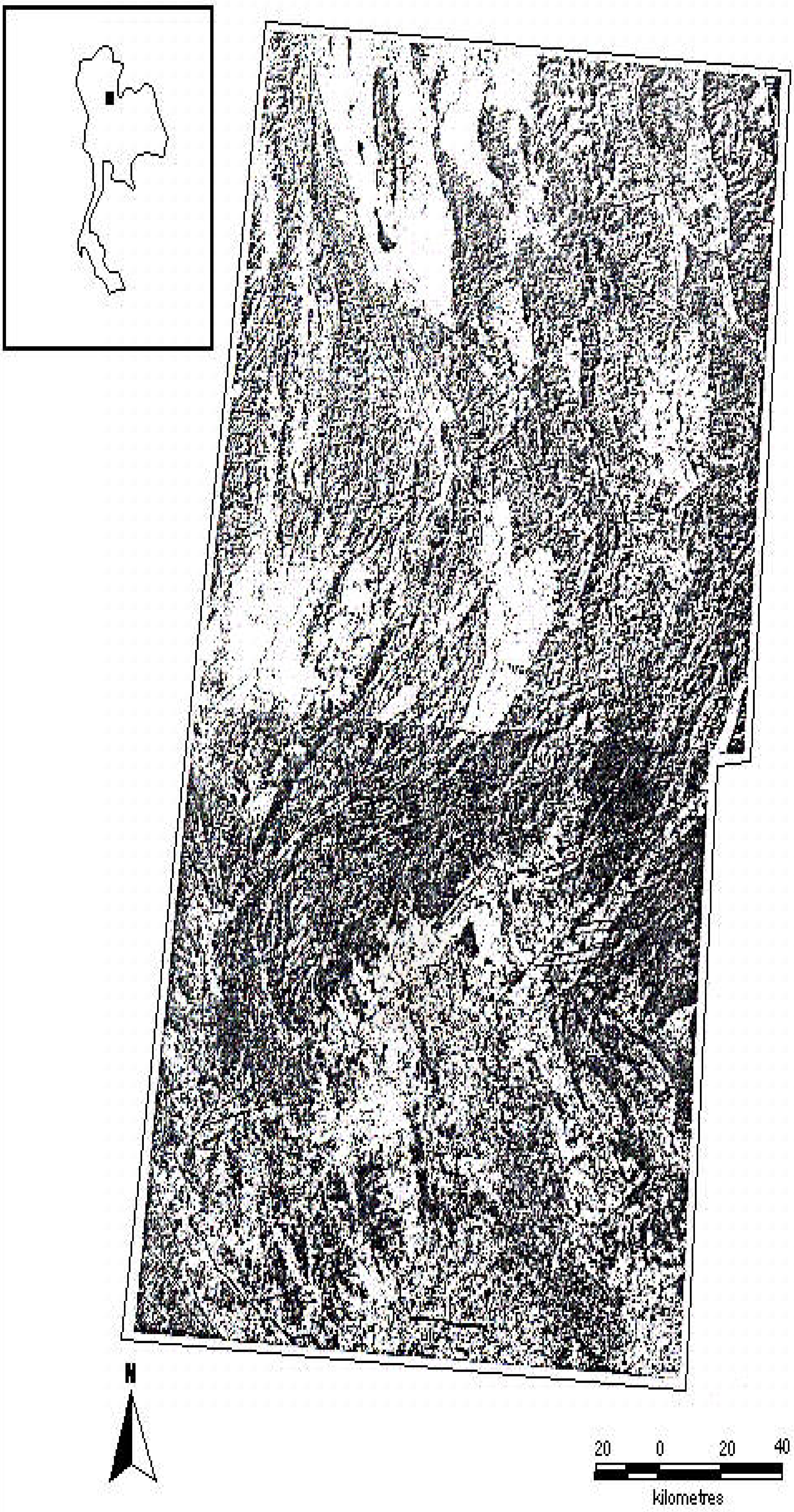

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Figure 1.3.3 Lansat image showing the interpretation of lineaments around the Phrae basin (after Srisuwan et.al., 1999)

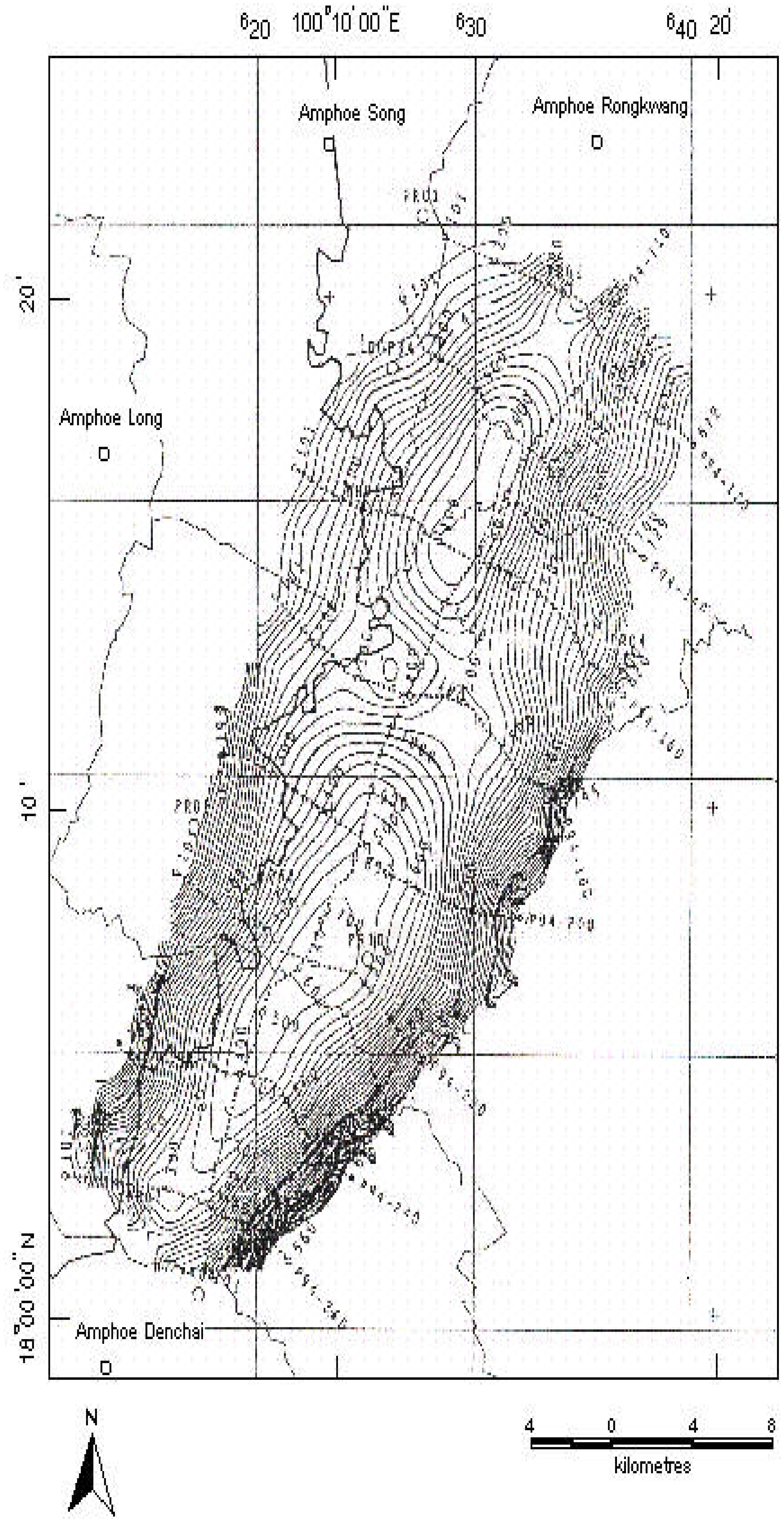

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Figure 1.3.4 Gravity map of the Phrae basin.

(DMR,1997)

The sixth step involved sedimentary facies analysis and the reconstruction of depositional environment using the appropriate facies models combined with the regional and basin geology.

The last step is the report preparation and presentation

The approach of the present study is summarised and presented in Figure 1.3.5

1.4 Previous Investigations.

The Phrae basin is among one of the Cenozoic sedimentary intermontane basins in northern Thailand with a high prospect of coal and petroleum reserves. Exploration works on the basin were carried out in the last three decades and are summarised as follows;

In 1967 – 1970, the Geological Survey Division, Department of Mineral Resources (DMR) and German Geological Mission (GGM) completed a 1:250,000 geological map of northern Thailand, including the area of the Phrae basin.

In 1972, Piyasin complied the 1:250,000 geological map of Lampang province, Sheet No. NE 47-7.

In 1976, Austhai Mineral Ltd. carried out the Bouger gravity survey on some parts of the Phrae basin.

Later, in 1987, Maneenai and other, conducted the surface geological study of Amphoe Mae Tha (Sheet No. 4945 III) and Ban Bo Keaw (Sheet No. 5054 III). They reported the approximate-three-metres outcrop of Tertiary shale, which exposed on river beds in Lai river, Ban Wang Nam Yen.

In 1992, the PTT Exploration and Production Plc. carried out the geophysical exploration, using a seismic reflection surveys, in the basin. The data revealed the thickness of the Tertiary deposits is up to 1.5 kilometres.

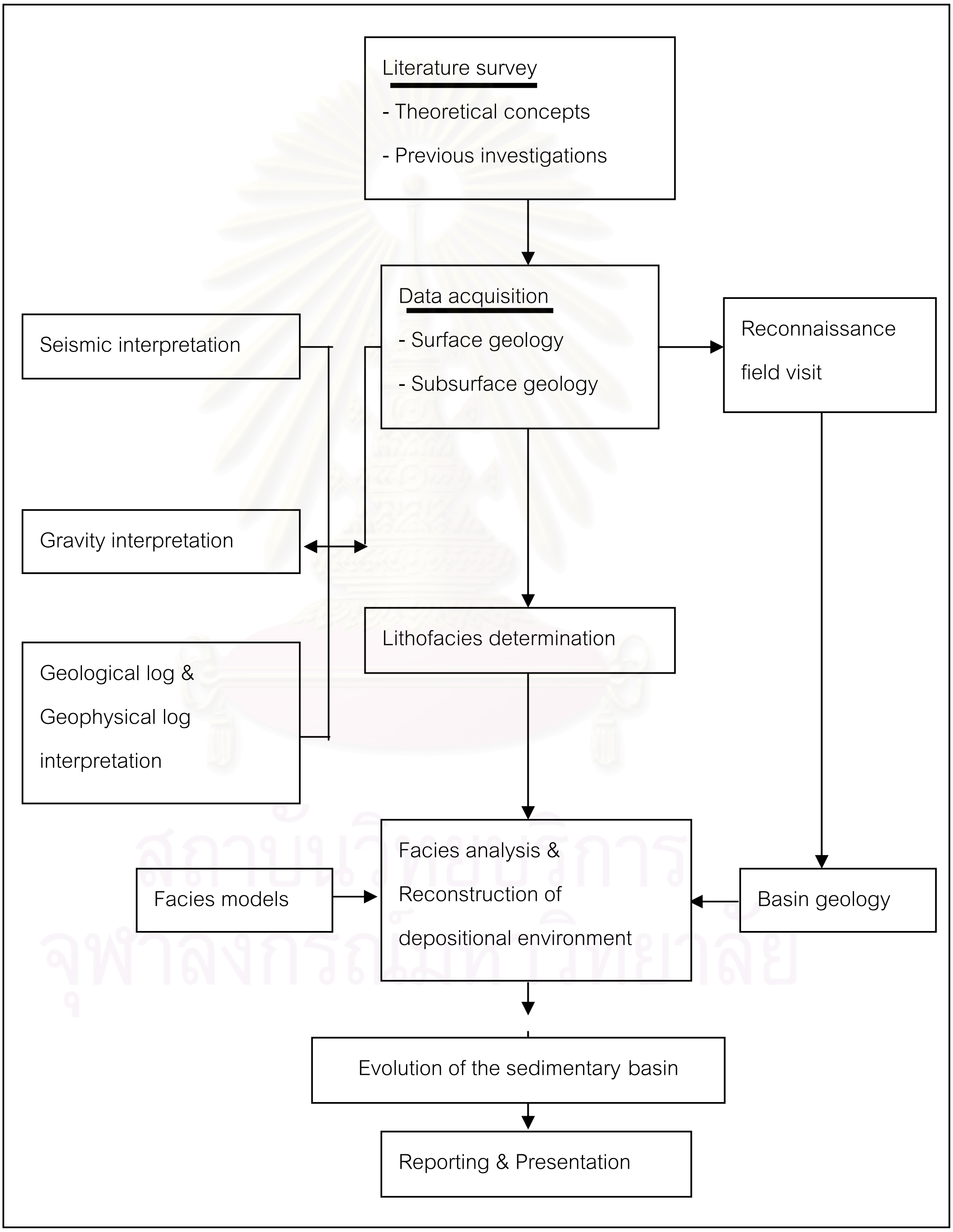

Figure 1.3.5. The approach of the study

A year later, in 1993, Ban Pu Plc. carried out both gravity survey and drilling exploration aiming for coal in Amphoe Song and the northern part of Amphoe Rong Kwang, Changwat Phrae. Data from the 13 drill-holes in the areas showed no potential coal reservation.

In 1994, Ban Pu Plc. has undertaken out the geological and drilling exploration in the southern parts of Amphoe Rong Kwang, Amphoe Muang, Amphoe Soung Men and Amphoe Den Chai, Changwat Phrae. The results from 10 drill-holes revealed that the Tertiary sediments comprise fluviatile and lacustrine sequences without any potential of the commercial coal deposition.

In 1995, the Mineral Fuels Division, Department of Mineral Resources (DMR), in collaboration with the Japan International Cooperation Agency (JICA), has carried out the seismic survey and drilling exploration in the Phrae basin in order to assess coal deposit. The results of 15 seismic lines, with total distance of 18 line-kilometres, the 13 drill-holes, with total depth of penetration of 8,284 metres and geophysical logging from 10 drill-holes, with total depth of 5,840.50 metres, indicated that the coal reserve of the Phrae basin is approximately 20,909,000 tonnes.

In 1996, the PTT Exploration and Production Plc. studied the biostratigraphy and paleoenvironment of the Phrae basin. The palynofloras. (i.e. *Comptostemon* type, *Eugeissona minor* type, *Floschuetzia trilobata*) suggested that sediments in the basin should not older than Miocene, either Neogene or Pliocene ages.

CHAPTER II

GEOLOGY

2.1 Physiography of Northern Thailand

Cenozoic basins in the northern Thailand extend within north-south trending mountain ranges between the Salween river in the west and Mekong river in the east. The area lies approximately within latitudes 17°30′ to 20°30′N and between longitudes 97°30′ to 101°10′E with approximately 180,000 square kilometres (Figures 2.1.1 and 2.1.2) oriented more or less in N-S to NNE-SSW and trending; in broad S shaped.

The average elevation of the mountains is about 1,600 m. above the present mean sea level. The important mountain ranges in the north are Daen Laos, Thanon Thongchai, Phi Pan Nam and Luang Phrabang ranges. The highest mountain peak is located in Doi Inthanon, which is 2565.3 metres above the mean sea level, and displays as the highest peak of the country in the northern segment of the metamorphic complex belt in the western part of northern Thailand. The topography of the hills and mountains in these ranges is strongly dissected and shows a high relief. There are many Cenozoic intermontane basins varying in sizes with the elevation of the basin ground surface ranging from 250 to 800 metres above the mean sea level. The drainage pattern are sluggish and commonly meandering. There are often broad belts of low rolling hills between the alluvial plains and mountains (Lee, 1923).

The streams also occur as the narrow and cut-steep ravines. It seems likely that the course of the stream is modified by the irregularities of the geological structure. Almost all streams and rivers drain southwardly such as the Ping, the Wang, the Yom, and the Nan, etc. as the tributaries of Chao Phraya river.

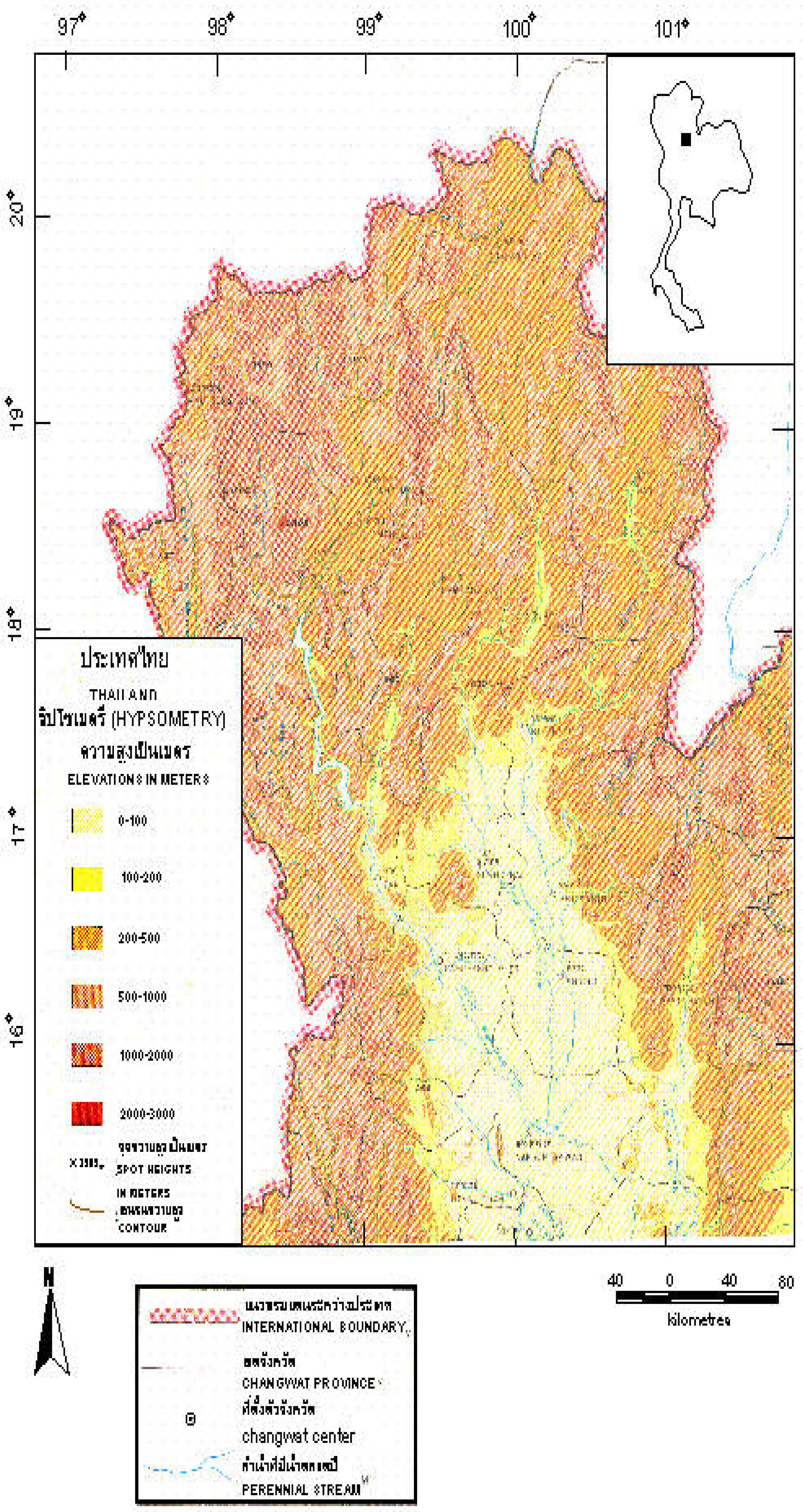

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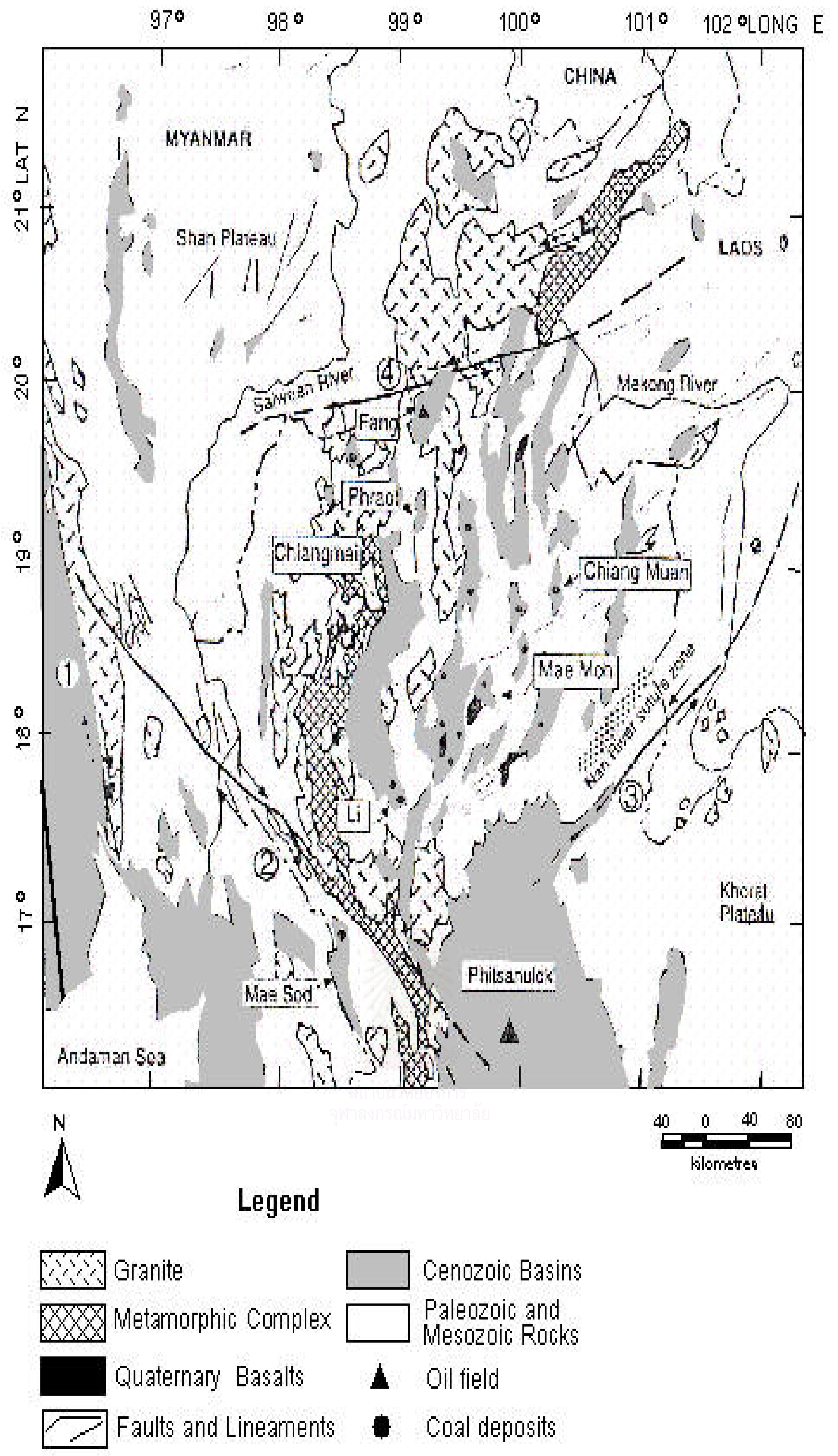
Figure 2.1.1 Hypsometry map of the Phrae basin and its vicinity



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Department of Geology, Faculty of Science

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Figure 2.1.2 Lineament map of northern Thailand and part of Myanmar and Laos showing major fault zone, Cenozoic basins, location of oil fields and coal deposits (complied from Chuaviroj et al., 1984; Workman, 1977; Goossens, 1987; Polachan, 1991; and Lacussin et al., 1997).

The Precambrian metamorphic complexes are exposed in the western mountain of Changwat Chiang Mai to the west and extending further south to Changwat Tak. There are composed of paragneisses, mica schist, calc-silicate hornfels and marble. (Campbell, 1975; GGM, 1972). They are intruded by granodiorite and pegmatite (Chuaviroj et al., 1984). In Doi Inthanon area (Figure 2.2.1), the U-Pb dating from megacrystic orthogneiss in the core of the metamorphic complex indicates metamorphic age of 203 Ma. from zircon and of 72 Ma from monazite. These are interpreted to represent, respectively, the age of crystallization of the granitic protolith and the age of the high-grade metamorphism which created the gneiss dome Precambrian gneiss series are fault contact overlain by less metamorphosed or unmetamorphosed Cambrian rocks.

Lower Palaeozoic strata have been affected by low-grade dynamic metamorphism. This metamorphism was considered to have taken place during a lower Carboniferous orogeny.

In the east of Changwat Mae Hong Son and the west of Changwat Kamphangpheat, rocks are well bedded to massive quartzite up to 500 metres in thickness, often show cross-bedded with some-conglomerate beds. . These rocks are Cambrian in age (Bunopas, 1976) and they are conformably overlain by Ordovician limestone. The lower Paleozoic rocks of Cambro-Ordovician consist of quartzitic rocks with locally increasing amounts of shaly and calcareous intercalations in the upper part. The average thickness of the Ordovician limestone in the north ranges from 80 to 100 metres.

The Silurian – Devonian sedimentary rocks occur in Changwat Mae Hong Son and extend throughout the northern Thailand particularly to the southeast, west of Chagwat Chiang Mai, Changwat Lumpang and the northeastern of Changwat Uttaradit. These rocks are graywackes, carbonaceous shales, cherts, and thin-bedded limestones. The thickness of the series does not exceed 500 metres (GGM, 1972) and the distribution generally corresponds with that of the Ordovician limestone.

The Carboniferous rocks are characterised by clastic sediments with some limestones or chert intercalations. They are mainly exposed in the west of Changwat Mae Hong Son, the north of Changwat Chiang Mai, the southwestern part of Changwat Lampang and the northern Changwat Uttaradit. The end of the Lower Carboniferous is marked by orogenic movements with magmatic activities (GGM, 1972), consisting of thick sandstone with local conglomeratic arkose, shale with occasional limestone and chert intercalation with average thickness ranging from 300 to 400 metres. The Upper Carboniferous sequence shows both marine and terrestrial facies. Marine sediments are chert, limestone, shale, and conglomerate. Deposition of continental or non-marine clastic facies is documented by a thick red conglomerate, shale, sandstone and chert. The thickness of Upper Carboniferous sequence is up to 200 metres. They laterally interfiger with marine Permo-Carboniferous limestone. In many places, the Uppermost Carboniferous formation contains mafic volcanic (GGM, 1972). Barr et.al,.(1978) found that the continental rift setting within Shan-Thai terrane.

The Permian rocks are crystalline limestone with subordinate clastic volcaniclastic sediments (Bunopas, 1981). In the central part of the northern Thailand, particularly between Changwat Lampang and Changwat Nan, the most complete succession of Permian rocks is exposed. The rocks, however, are predominantly clastic and rhyolite, with some interbedded limestones. In the north of Changwat Chiang Mai and northeastern part of Changwat Mae Hong Son, the Permian rocks consist mostly of thick limestone of the Ratburi Group. The thickness of the Permian limestone is about 100-150 metres.

The Permo-Triassic rocks are predominantly rhyolitic and andesitic in nature. They distribute in almost a north-south direction from the east of Changwat Chiang Rai to the southern part of Changwat Lampang.

The Mesozoic rocks are characterised by two principal facies, (1) marine sequence occurring in the west and (2) central parts and, paralic-continental strata in the northeastern part. The marine Triassic sedimentary rocks rest unconformably on the Permian rocks to the south of Changwat Mae Hong Son and southeast of Amphoe Mae Sariang and overly the Permo-Triassic volcanic rocks in the central and eastern regions (Figure 2.2.1). In general, the marine Triassic sedimentary rocks consist of shale and limestone with the facies change into a sandstone-shale sequence, described as resembling Alpine flysch (Bunopas, 1976).

The continental clastic sedimentation is thought to have commenced in the Late Triassic and continued into Jurassic and Cretaceous, particularly in the eastern region.In the north of Thailand, rocks of the continental environment appeared to have formed in Jurassic. These terrestrial sedimentary sequence consists of red sandstone, mudstone, shale and volcanic member of mafic to intermediate composition particularly in Changwat Nan and the east of Changwat Uttaradit, Changwat Sukhothai and Changwat Phichit areas.

The Cretaceous rocks expose in the eastern part of Changwat Uttaradit and Thai-Laos border. They consist mainly of quartz-sandstone and conglomeratic sandstone, with maximum thickness of the continental Mesozoic sediments may reach 2,000 metres. (GGM, 1972)

Tertiary sedimentary rocks are lacustrine and fluviatile carbonaceous shale, sandstone, marl beds, fresh-water limestone, and mostly interbedded with organic sediments. In northern Thailand, the Tertiary sediments predominantly occur in lowland and basins with a distinct north-south trend, following the regional strike of the older formations (Bunopas, 1976).

Pleistocene terraces and Holocene flood plains developed within the lowland areas of the basins all over northern Thailand region.

Precambrian rocks and Paleozoic formation have been affected by high-grade regional metamorphism and granitization. In several areas, plutonic activity made up of several intrusive rocks and they have been dated as middle Carboniferous age (GGM, 1972). After widespread deposition of felsic to intermediate volcanics, the tectonic activity started again in the early Upper Carboniferous age.

There are several granite complexes in northern Thailand. They were considered to be Early Triassic, Late Triassic to Early Jurassic, Cretaceous and Tertiary ages. Main batholiths intruded only during the Triassic, perhaps extending into the very earliest Jurassic. This period of intrusion coincides with the age of andesitic and rhyolitic volcanic activities. Bunopas and Vella (1972) suggested that the age of volcanics in the central part of northern Thailand extend from Late Permain to Early Triassic according to their category of volcanic belts. It is also believed that the collision of the Shan -Thai with the Indochina cratons took place in Early Jurassic marked by scattered occurrences of ultramafic rocks to the east of Changwat Nan and northeastern part of Changwat Uttaradit.

The Pleistocene basalts at Changwat Lampang have been investigated using paleomagnetic and dating techniques by Barr et al., (1976). The basalts to the north of Changwat Payao, Phrae and the eastern part of Changwat Nakorn Sawan areas are probably of the same age as the Lampang basalt.

2.3 Structural Framework of Northern Thailand

The regional structural framework of northern Thailand is strongly influenced by the Indosinian orogeny during Late Triassic so-called Sukhothai / Loei fold belts. These regional structures were subsequently modified by major sinistral faults, of Himalaya orogeny, namely, the Red River fault and the Mae Ping fault during Eocene to Early Miocene. As a result, the regional structural framework of northern Thailand appears roughly as the S-shaped. The last episode of tectonic movement was the time when tensional faulting commenced in Late Tertiary and Early Quaternary with wide spread occurrences of alkaline basalts (Figures 2.2.1 and 2.3.1**).**

Northern Thailand region is surrounded by four large strike-slip faults (Figure 2.3.2), in the far west, the Sagaing fault zone (in Myanmar) developed as a N-S trending dextral strike-slip fault (Maung, 1987). This fault separates the Shan plateau from central lowlands of Myanmar. The drag produced by the northward movement of Indian plate caused the Burma plate to decouple from the Sagaing fault. Northward movement of the Burma plate has results in an opening of the Andaman sea rift system since the Mid-Miocene (Maung, 1987).

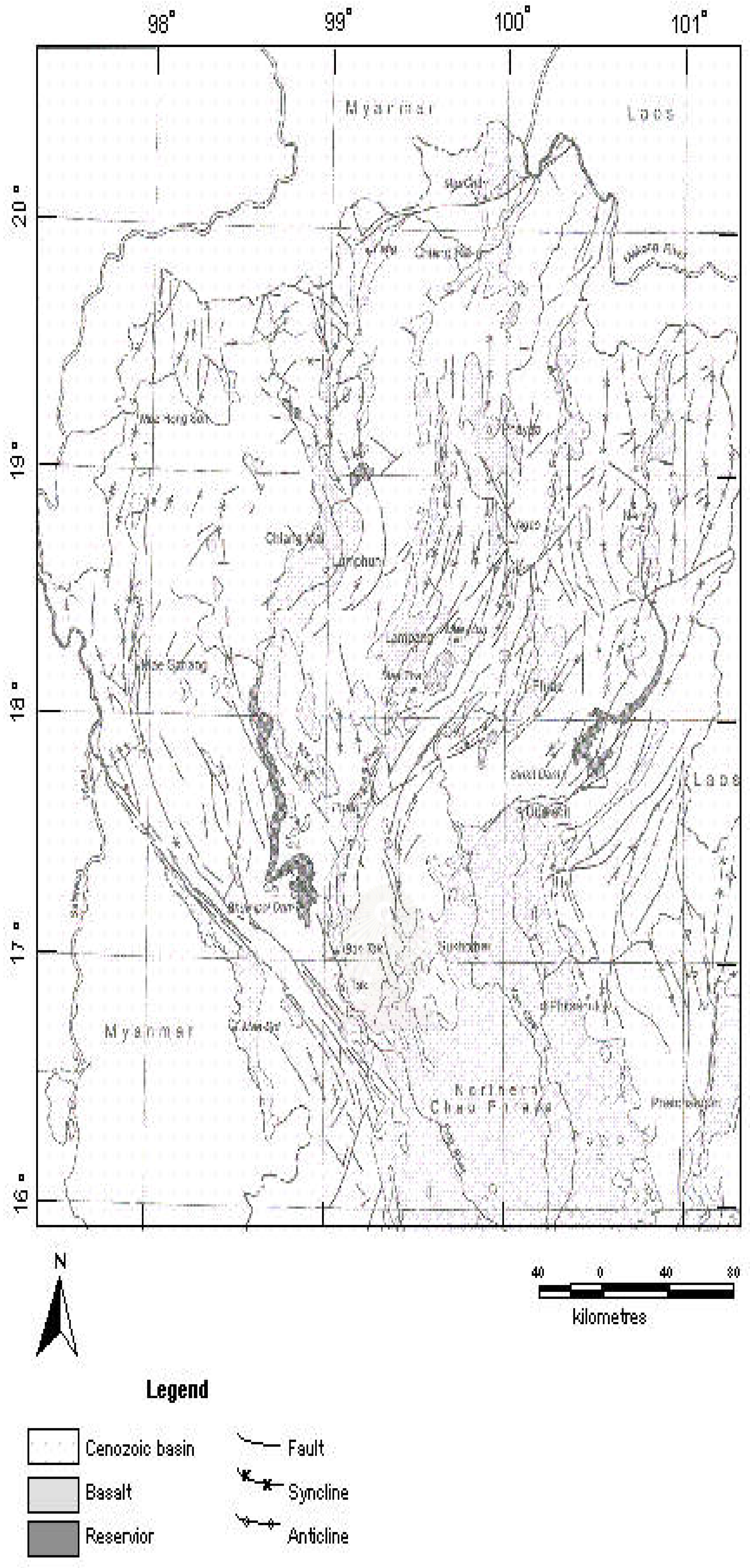

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Figure 2.3.1 Map showing the northern Thailand Cenozoic basins and geological structures (modified After Wittekindt, 1985; 1986).

In the southwest part of northern Thailand, the Mae Ping fault zone (the Wang Chao fault zone) occurred in NW-SE direction (Figure 2.3.2). The movement of this strike-slip fault is rather complex. During Oligocene-Miocene, this fault moved in right-lateral direction whilst during the Plio-Quaternary, it moved in left-lateral direction. The total left-lateral direction offset (about 300 km) on this fault zone was result of the Tertiary indentation of Indian within Asian (Lacassion et al., 1997).

In the southeast part of northern Thailand, the Uttaradit fault zone develops in NE-SW direction with sinistral strike-slip movement (Bal et al., 1992). This fault extends towards the southwest under the Chao Phraya plain and formed the north flank of the Phitsanulok basin. The Uttaradit fault zone occurs parallel to the Nan river suture zone (Figure 2.3.2). This suture zone consists of a belt of ophiolitic, mafic-ultramafic rocks (Figure 2.3.3). The Nan river belt forms part of the suture between the Indosinian and Shan-Thai cratonic blocks (Barr and Macdonald, 1987).

The Mae Chan fault zone occurs in the northern part of northern Thailand (Figure 2.3.2). This fault has a trend in ENE-WSW direction and shows sinistral strike-slip movement. There is strong geomorphic evidence for late Quaternary left-lateral displacement along this fault and recent trenching investigations have confirmed late Quaternary faulting (Fenton et al., 1997). The movement of these four strike-slip faults from the Tertiary to Holocene may have caused or influenced the deformation of the Cenozoic basins in Thailand.

2.4. Physiography of the Phrae Basin

The topography of the Phrae basin is generally flat to slightly rolling with the emerge ground elevation of 180 metres above the mean sea level. The basin is illustrated by the topographic maps of Ban Na Luang, sheet 5046 II, Ban Pa Dang, sheet 5046 III, Amphoe Rong Knang sheet 5045 I, Ban Wiang Nua sheet 5045 II, Changwat Phrea sheet 5045 III and Amphoe Song Sheet 5045 IV. The basin is surrounded by relatively

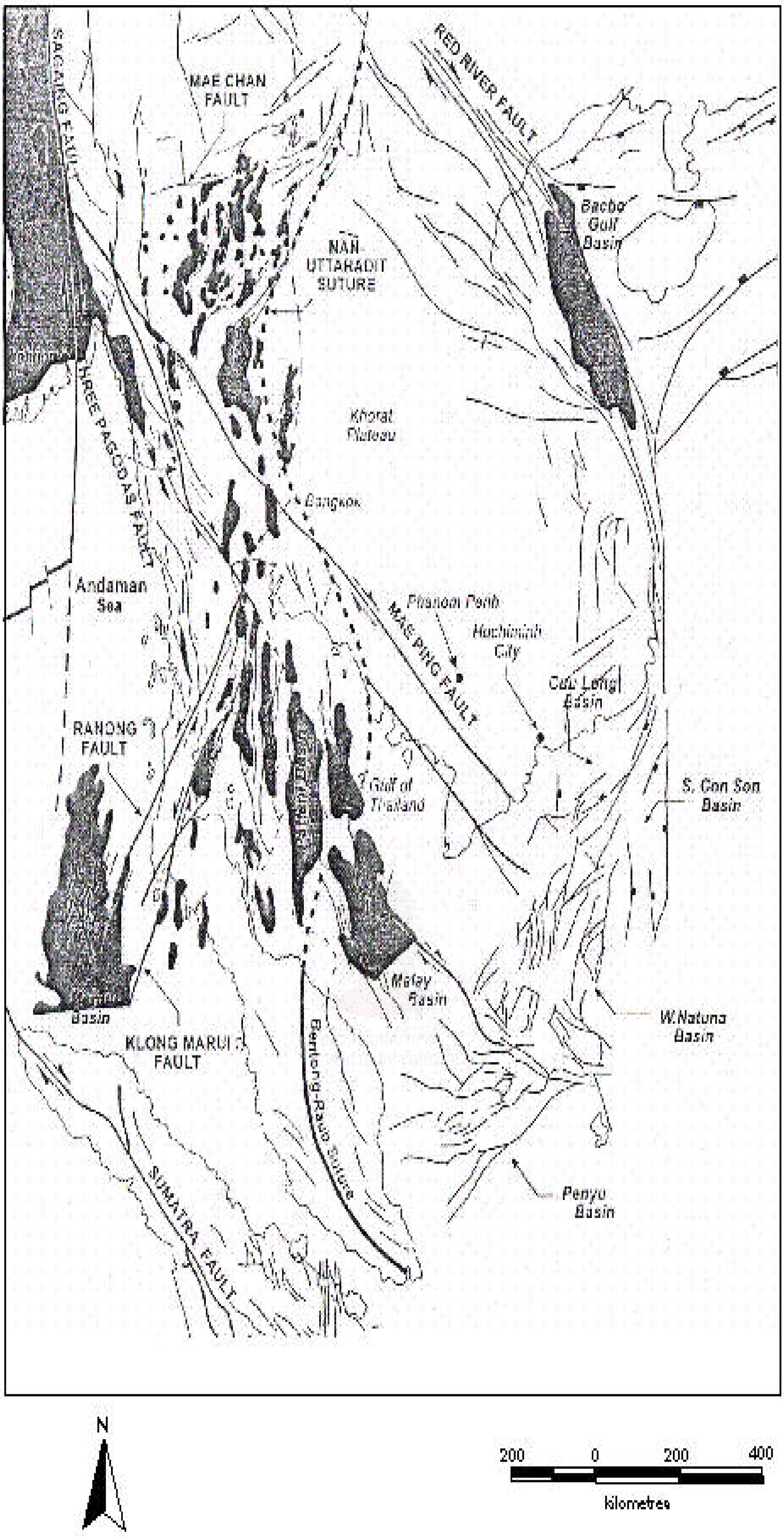

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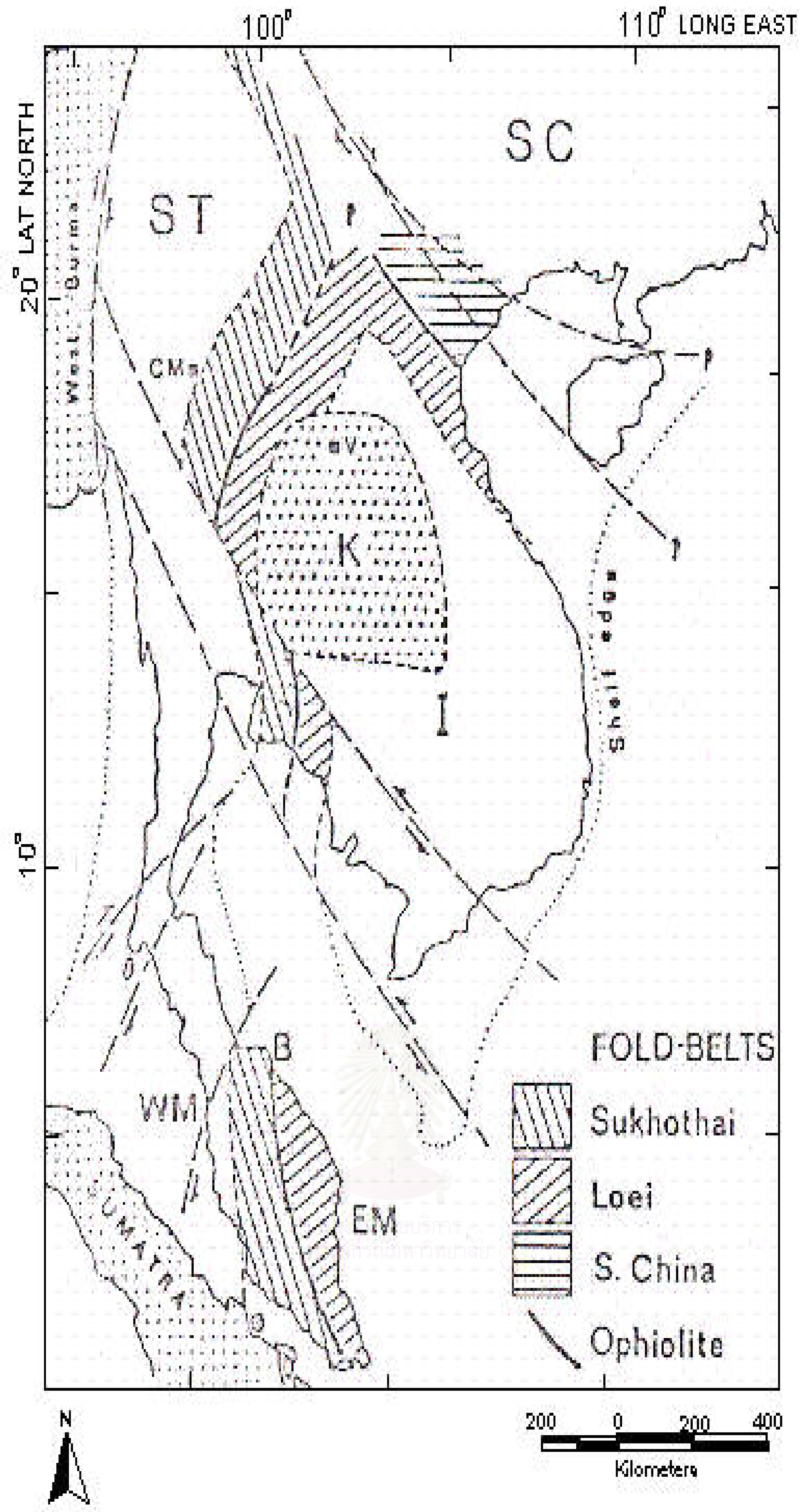
Figure 2.3.2 Cenozoic extensional basins and major strike-slip faults in Thailand and surrounding regions. (after Srisuwan et. al., 2000).



Note I = Indochina (including eastern Thailand) ; CM = Chiang Mai;

SC = South China V = Vientiane;

ST = Shan -Thai (eastern Burma, western Thailand and Northwestern Malay Peninsula) WM = West Malay Peninsula;

EM = East Malay Peninsula;

K = Khorat Basin; B = Bentong ophiolite line

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Figure 2.3.3 Ancient cratonic areas (I, CS, and ST). Adjacent fold-belts are formed of thick mainly marine Paleozoic to Triassic sediments and tholeitic volcanic rocks that accumulated along the margins of the cratons. Ophiolites lie between contiguous fold belts. Sinistral faulting and oroclinal bending occurred mainly during the Jurassic and Cretaceous.
(after Bunopas, 1981)

gentle mountain ranges from 500 to 1,000 metres in altitude. Terraces occur in the western periphery of the sub-basin.

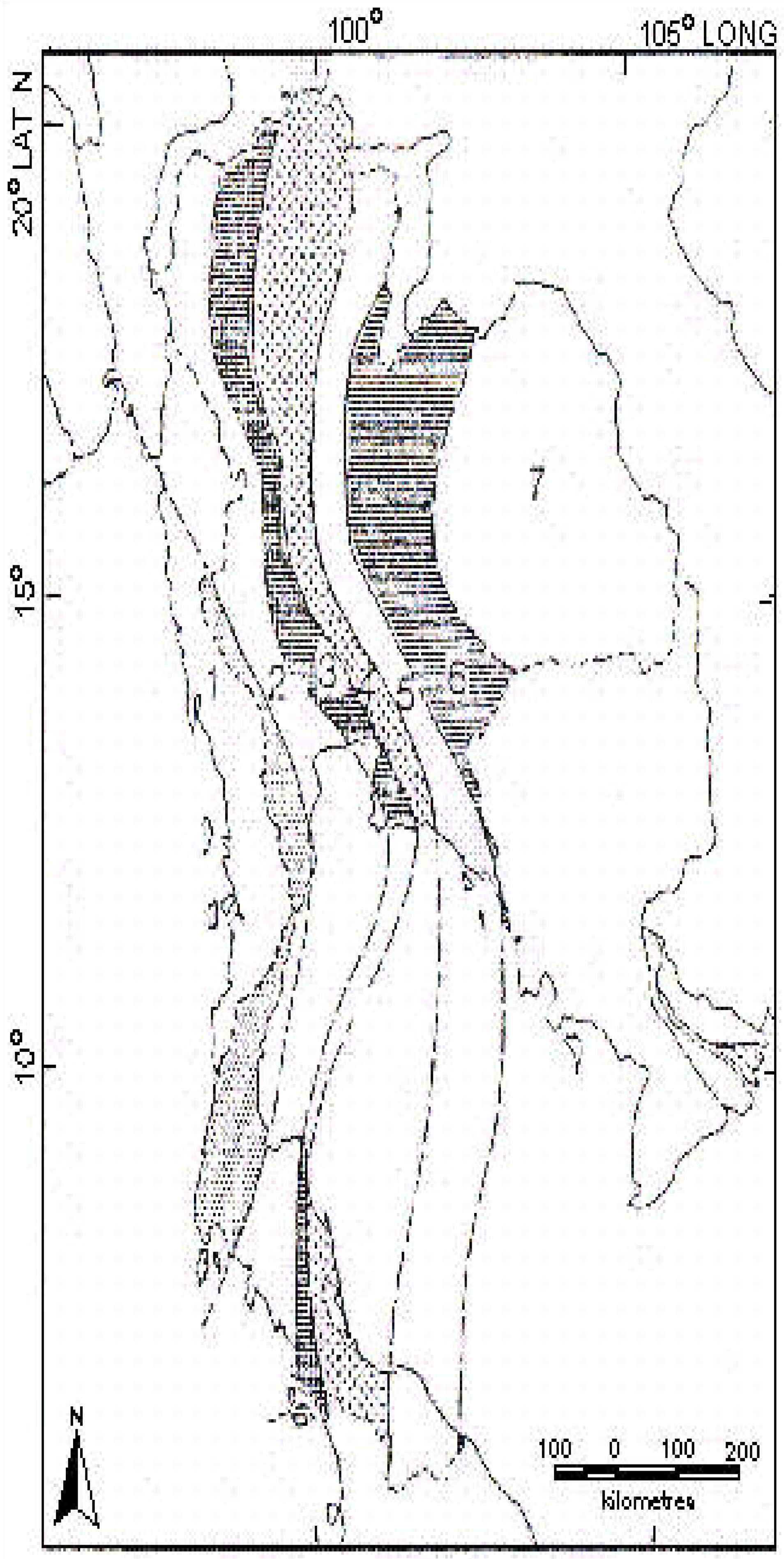
The Yom river, the main river, flows in the western side of the basin meandering and gathering tributaries, which flow into the basin from the east and the west. The northeastern hilly area is mainly utilised for extensive farming of maize, sugar cane, tobacco and stock farming. The rest is intensively cultivated for rice farming except housing sites.

The climate of the area is commonly definited by wet and dry seasons. The west or southwest monsoon starts from May to October. The mean maximum temperature of this area is 33.5 °C and the mean minimum temperature is 21.6°C. (1991-2000) The maximum wind speed of 83.34 kilometres per hour has been recorded at Phrae station. The mean annual rainfall is 1,088.5 millimetres (TMD, 2002).

2.5 Geological Setting of the Phrae Basin

According to Bunopas (1992), the study area is part of the Stratigraphic Belt No. 5, which is the margin of Eastern Shan-Thai Craton (Figure 2.5.1). The area was once an active mid-Paleozoic volcanic arc-trench before the collision between Shan-Thai and Indochina Cratons and the subsequent distribution of redbeds in Jurassic (Bunopas, 1992).

From the geological map with a scale 1:250,000 Sheet No. NE 47-7 Changwat Lampang (DMR, 2519) and the geological map scale 1:50,000, Sheet No. 5045 III Changwat Phrae (Maneenai et al., 1987), the stratigraphy of the area is described as follows (Figure 2.5.2).



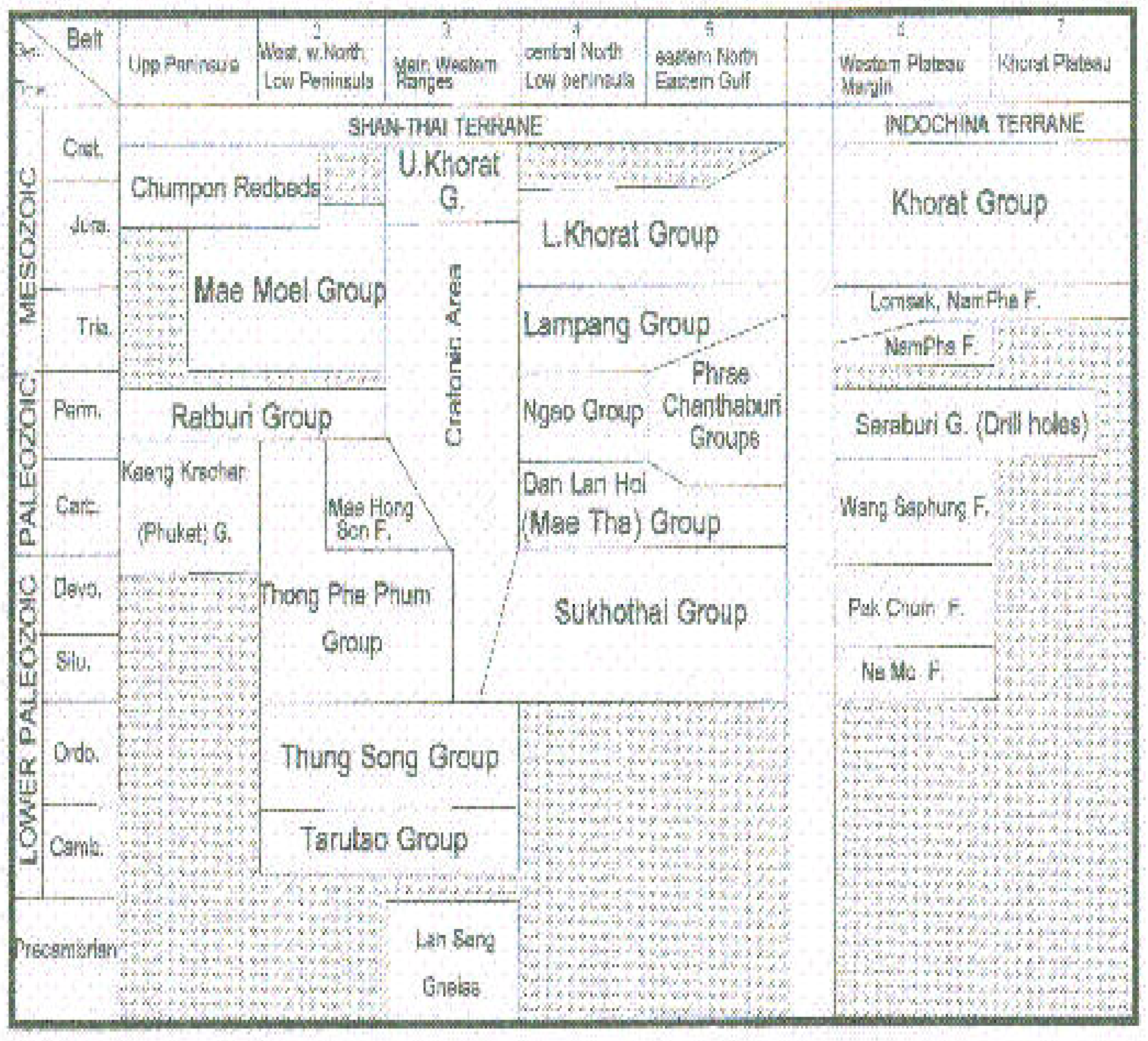


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Figure 2.5.1 Seven major stratigraphic belts (after Bunopas, 1992)

Paleozoic rocks

Carboniferous – Permian (CP) rocks

The rocks consist of grey to purplish grey phyllite and brown micaceous sandstone and siltstone, covering the northeastern part of the area.

Permo-Carboniferous (PC) rocks

The rocks consist of green chert, shale, sandstone, limestone and andesite, covering the eastern part of the area.

Permian (P) rocks

The rocks consist of four units, PB_1, PB_{2a}, $PB_{2b,}$ and PB_3, each of which has its distinguishable lithology as described as follows.

PB_1 unit consists of massive beds of black to grey calcareous shale, grey siltstone and grey sandy limestone. The unit covers the northeastern part of the area.

PB_{2a}unit consists of reddish brown conglomerate, covering the southeastern part of the area. The conglomerate is consisted of rounded to well-rounded pebbles of phyllite, greywackes and quartz.

PB_{2b} unit consists of shale and limestone interbedded with sandstone, conglomerate, andesite and basalt. The shale and limestone interbeds are grey to dark grey and contain abundant fossils of fusulinid, corals and crinoids.

P3 unit, covering the western part of the area, consists of black shale, gray sandstone and dark gray mudstone interbedded with gray chert nodule-containing limestone. Fossils found in the interbedding limestone and mudstone is *Paleofusulina* and

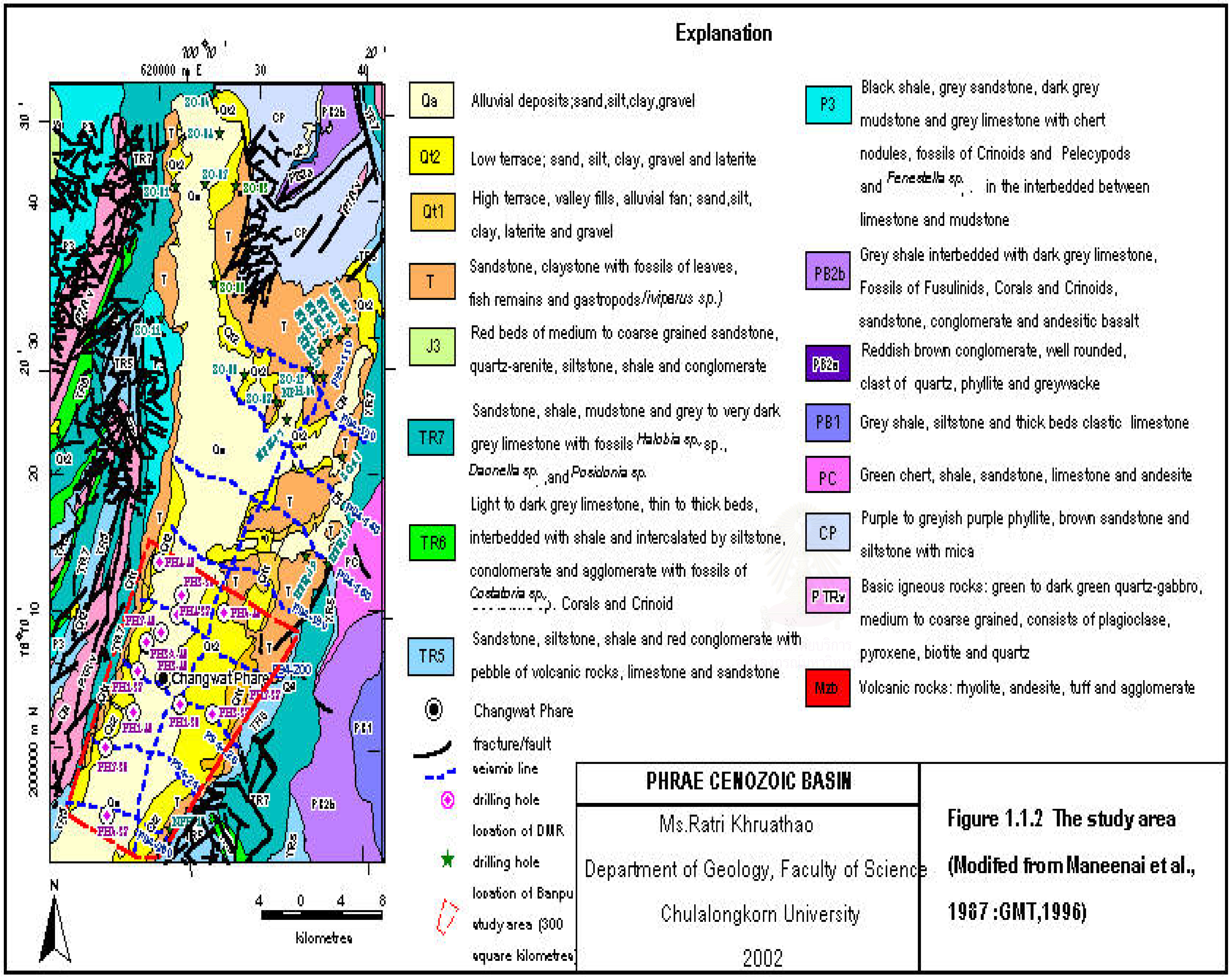


Figure 1.1.2 The study area (Modifed from Maneenai et al., 1987 :GMT,1996)

Calanclia ef. Lepida (wang), crinoid, bivalves and algae oncoliths, covering the western part of the area.

Mesozoic rocks

Triassic (Tr) rocks

The rocks are divided into three units, Tr5, Tr6 and Tr7, each of which is described as follows:

Tr5 unit consists mainly of sandstone, siltstone, shale and red conglomerate. The conglomerate is made up of volcanic fragments, limestone and sandstone pebbles. The rock unit displays graded bedding, and distributes all over the area, except for the Northwest region.

Tr6 unit consists of light to dark grey limestone interbedded shale and limestone, agglomerate and conglomerate. The limestone is fine to very fine-grained, thin to very thick bedding, and partly recrystallised. Fossils found in the unit are *Costatona* sp., *Corais* and crinoid. The rock distributes as relatively thin beds along the west and south of the area.

Tr7 unit consists of sandstone, shale, mudstone, dark grey to black limestone and calcareous clastic rocks. Fossils are *Halobia* sp., *Daonella* sp. and *Posidomia* sp. The unit distributes on both flanks of the basin.

Jurassic rocks (J3)

The rocks consist of medium to coarse-grained sandstone, orthoquartzite, siltstone, shale and conglomerate. The rock distributes around the southeast corner of the area.

Cenozoic rocks

Tertiary rock (T) consist of shale mudstone gray to dark grey sandstone and carbonaceous shale. Fossils are abundant, among which *Viviparus* sp., wood fragments, leaves, fish bones and insect wings are common. The rock distributes along both sides of the Phrae basin, but more vastly around the northeastern corner in Amphoe Rong Kwang.

Quaternary-Sediments (Q)

Qt1, covering along the margin of the basin in the south, consists of high terrace sediments, alluvium, conglomerate, siltstone, clays, lateritic soils and laterite. The conglomerate is made up of pebbles of sandstone, volcanic fragments, chert, quartz, shale and limestone.

Qt2, forms mostly as dunes along the basin margin and consists of low terrace sediments such as sands, silts, clays, gravels and lateritic soils.

Qt3, covering along the Yom floodplain, consists of fluvial sediments such as gravels, sands, silts, clays, and muds. These sediments are unconsolidated.

Igneous rocks

Permo-Triassic volcanic rocks (PTrV)

The rocks consist of rhyolite, andesite, tuff and agglomerate. The rock distributes along the North-South ridge in the west part of the basin, and around the northeast corner of the basin.

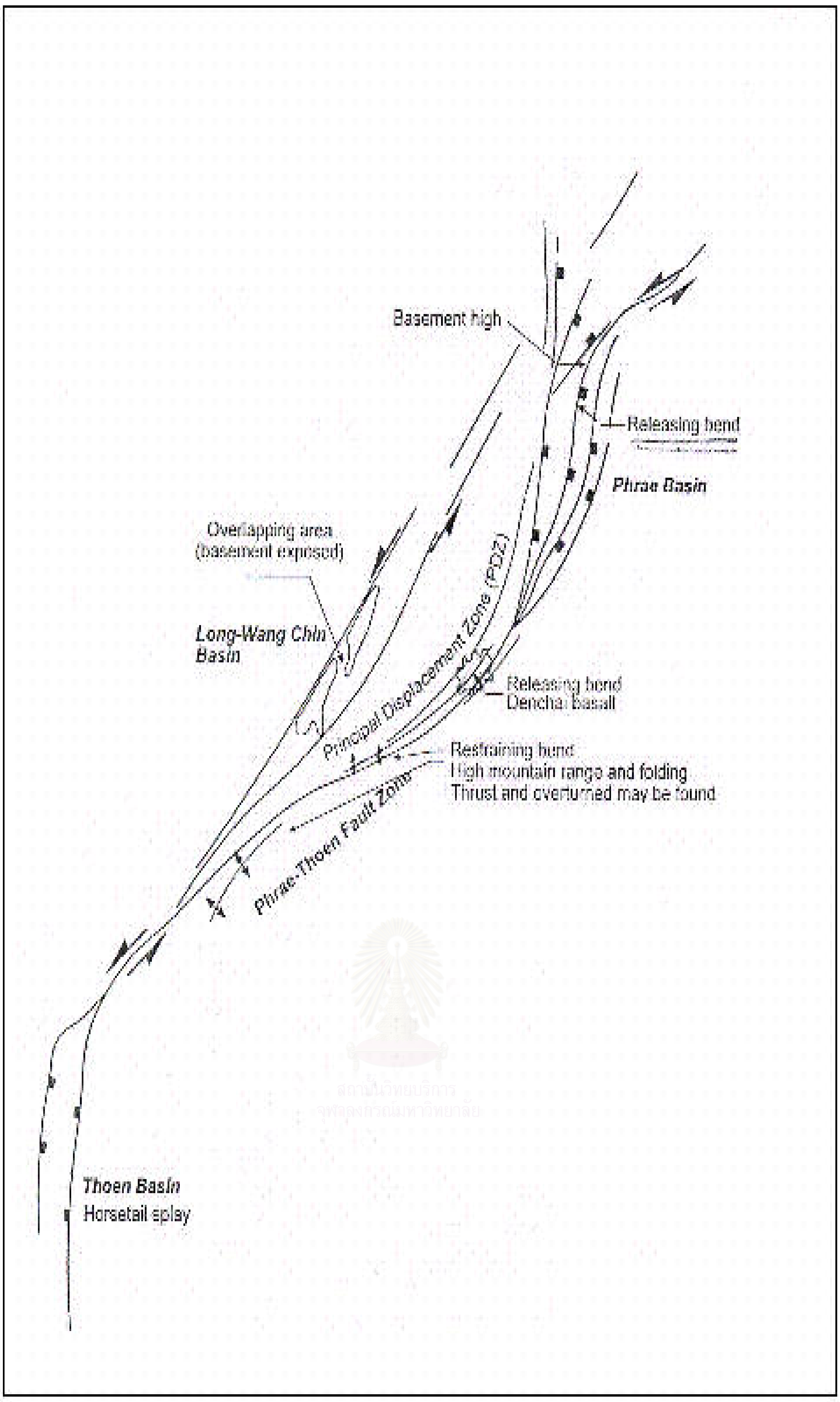
Basic igneous rocks (Mzb)

The rocks consist mainly of quartzite and dark green gabbro. The gabbro is composed of medium to coarse-grained plagioclase, pyroxene, biotite, quartz and some metamorphosed minerals. The rock displays foliation where it is in contact with dikes. The rock covers in the southwest corner of the basin and it is expected to be of Mesozoic era.

2.6 Geological Structure of the Phrae Basin

The Phrae basin is classified as a fault-bend basin, it has Phrae-thoen fault (Figures 2.3.1, 2.5.2 and 2.6.1), the main fault that strongly influenced the development of the basin. The Phrae Thoen-fault trends northeast southwest and has a sigmoidal shape. The Thoen basin is located at the southwest end of this fault and the Phrae basin is located at the fault's northeast end. The Phrae-Thoen fault is required to have a sinistral sense of movement of the master fault to explain the opening of these basins. The main Phrae-Thoen fault passed through the Phrae basin along the Yom river at the southern part of the basin, continued straight up the northeast, and bent to the east northeast, south of the Nan basin (Srisuwan, 2000).

The Long and Wang Chin basins are two small basins that are also associated with the Phrae-Thoen fault. These basins are located approximately 50 to 70 kilometers southwest of the Phrae basin. Both basins are very narrow, being 1 to 4 kilometers wide, and are 20 to 30 kilometers long. The basement is exposed in the basins and in the overlapping area between the basins. These basins are probably characterised of a pull-apart basin that has a small separation along the master fault. The structural high basement, which pop-ups into the basin, is a general feature of basins associated with the main strike-slip segment. The restraining bend tends to create crowding whereas the releasing bend is the site of open space.



PHRAE CENOZOIC BASIN	Figure 2.6 .1 The model of basins associated with the strike-slip zone applied to the Phrae-Thoen areas, including the Long and Wang Chin basins (after Srisuwon et.al., 2000)
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CHAPTER III

SUBSURFACE GEOLOGY OF THE PHRAE BASIN

3.1 General

The subsurface geology involves interpretation of the stratigraphic, structural, and economic values below the earth's surface. These interpretations are based on information obtained from bore-holes, geophysical data, and projected surface information. The subsurface geology demands a creative imagination, an analytical and systematic approach, and a multiple-hypothesis manner of thinking.

The subsurface geology of the Phrae basin is basically obtained from the drill-hole data, bore-hole geophysical data, bouguer gravity survey data and seismic survey data. The drill-hole data are essentially composed of the lithological description of both cuttings and core samples of totally 12 coal exploration drill-holes with the total lengths approximately of 7,685 metres. In addition, the geophysical logs of 9 drill-holes with the total lengths of approximately 5,270 metres of 3 main parameters, namely, gamma ray, caliper and density logs.

Initially, the continuous lithological sequence of each drill-hole is prepared from the integration of cutting/core data with geophysical logging data. After that, additional attempt has been made to correlate the lithological sequence of nearby drill-hole on the seismic profile, with the evidence of seismic interpretation

As a result, the three-dimensional subsurface geology within the upper succession of the southern part of the Phrae basin has been defined.

3.2 Sedimentary Sequence

Considering the availability of subsurface geological and geophysical data of the Phrae basin previously outlined, the Cenozoic sedimentary sequence of the upper succession of the southern part of the Phrae basin can be subdivided into 9 main units, namely, F1, L1, F2, L2, F3, L3, F4, L4 and Q in ascending order, respectively.(Figure 3.4.9.1) Detailed description of each unit will be discussed as follows;

3.2.1 F1-unit

The lowermost sedimentary sequence of the upper succession of the southern part of the Phrae basin within the study area is referred to "F1-unit". It underlies conformably the L1-unit, and in the south-eastern margin of the basin is clearly shown this unit is underlain unconformable by the pre-Tertiary basement rocks. The typical sedimentary sequence of F1-unit is the combination of the subsurface data derived from the drill-hole number PH2/39, PH 1/38 and PH 2/38 shown in Figures 3.2.1.1, 3.2.1.2 and 3.2.1.3. Upon integration of existing data previously stated, the continuous lithological sequences of all primary drill holes are analysed and interpreted from the ground surface down to depth range from 554-691 metres. The drill-hole number PH 2/38 is the only one drill-hole that reached the basinal basement rocks.

Generally, the F1-unit comprises of coarse-grained clastic sediments, associated with conglomerate and conglomeratic mudstone shown in Figure 3.2.1.4. The unit begins with conglomerate and sandstone at the base and grading upward to conglomeratic mudstone. The characteristics of conglomerate are consisting of granule to pebble of basement rocks, notably, phyllite and quartzite, subangular to subrounded, poorly sorted. The sandstone is grey, medium-to coarse-grained. The maximum thickness of this part is shown on the drill-hole number 1/38 at about 60 metres. The conglomeratic mudstone is characterised by yellowish green to light brown in colour. Phenoclasts are fragments of basement rocks of quartzite, greenish grey, phyllite fragments with mud matrix. The thickness of this upper part of F1-unit varies from 34 metres in drill-hole number PH 2/39 to 40 metres in drill-hole number PH2/38.

The overall thickness of this unit varies from 34 metres in PH 2/39 to 80 metres in PH 2/38, and only one drill-hole situated on the eastern edge of the southern basin that reached the basement, as shown in Figures 3.2.1.5 and 3.2.1.6.

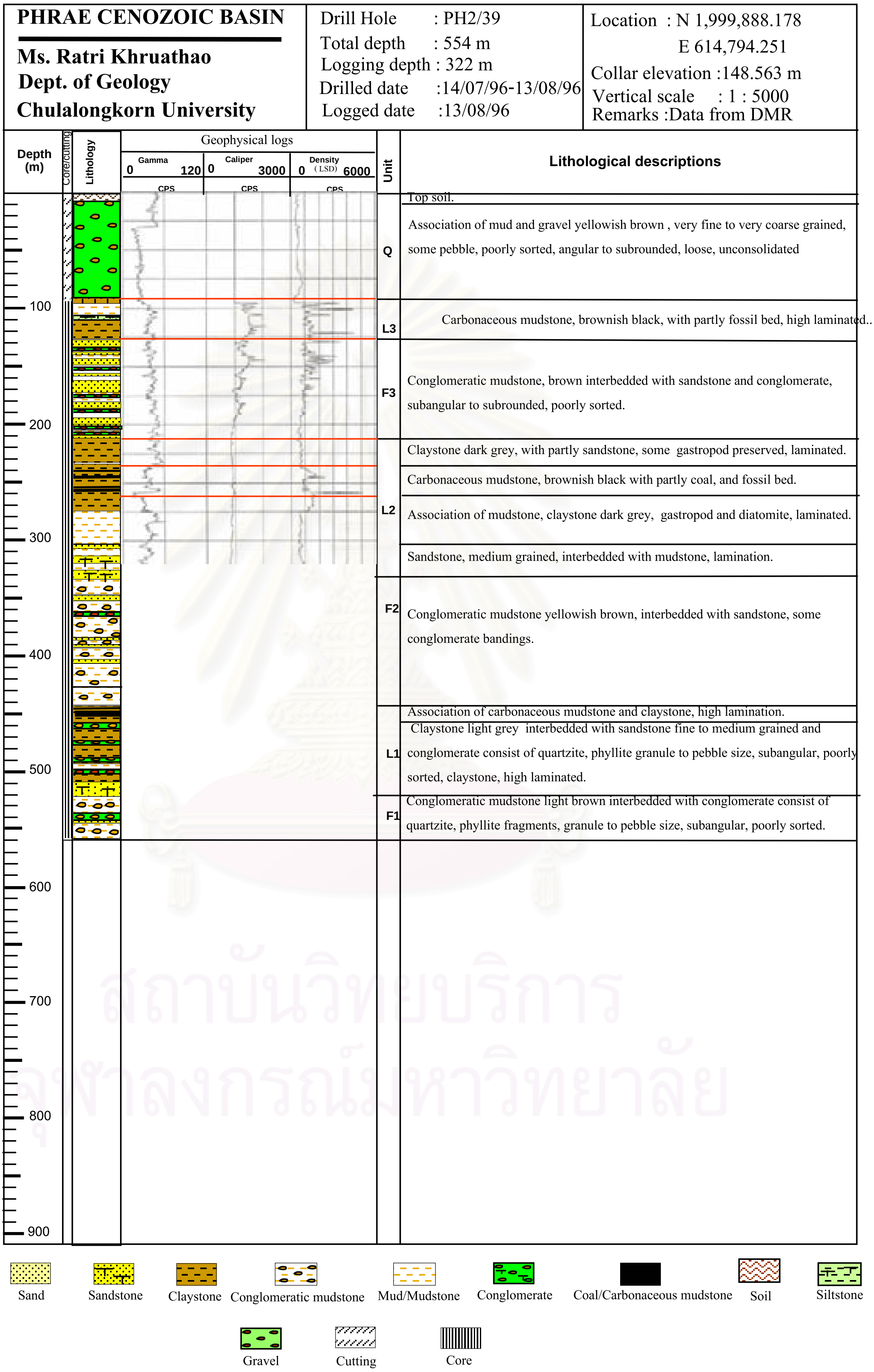

Figure 3.2.1.1 The geological drill-chart of drill-hole number PH2/39

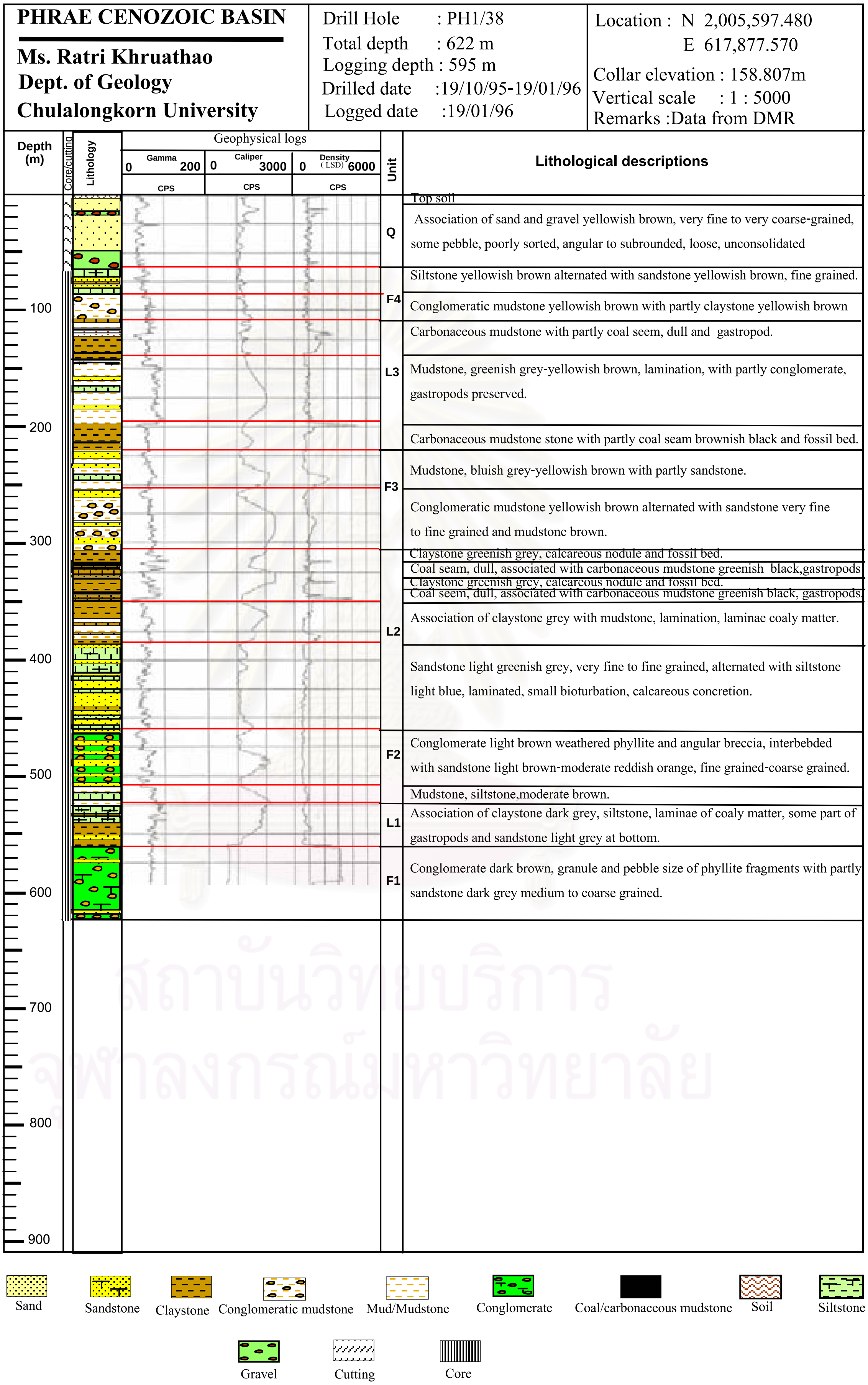

Figure 3.2.1.2 The geological drill chart of drill-hole number PH1/38

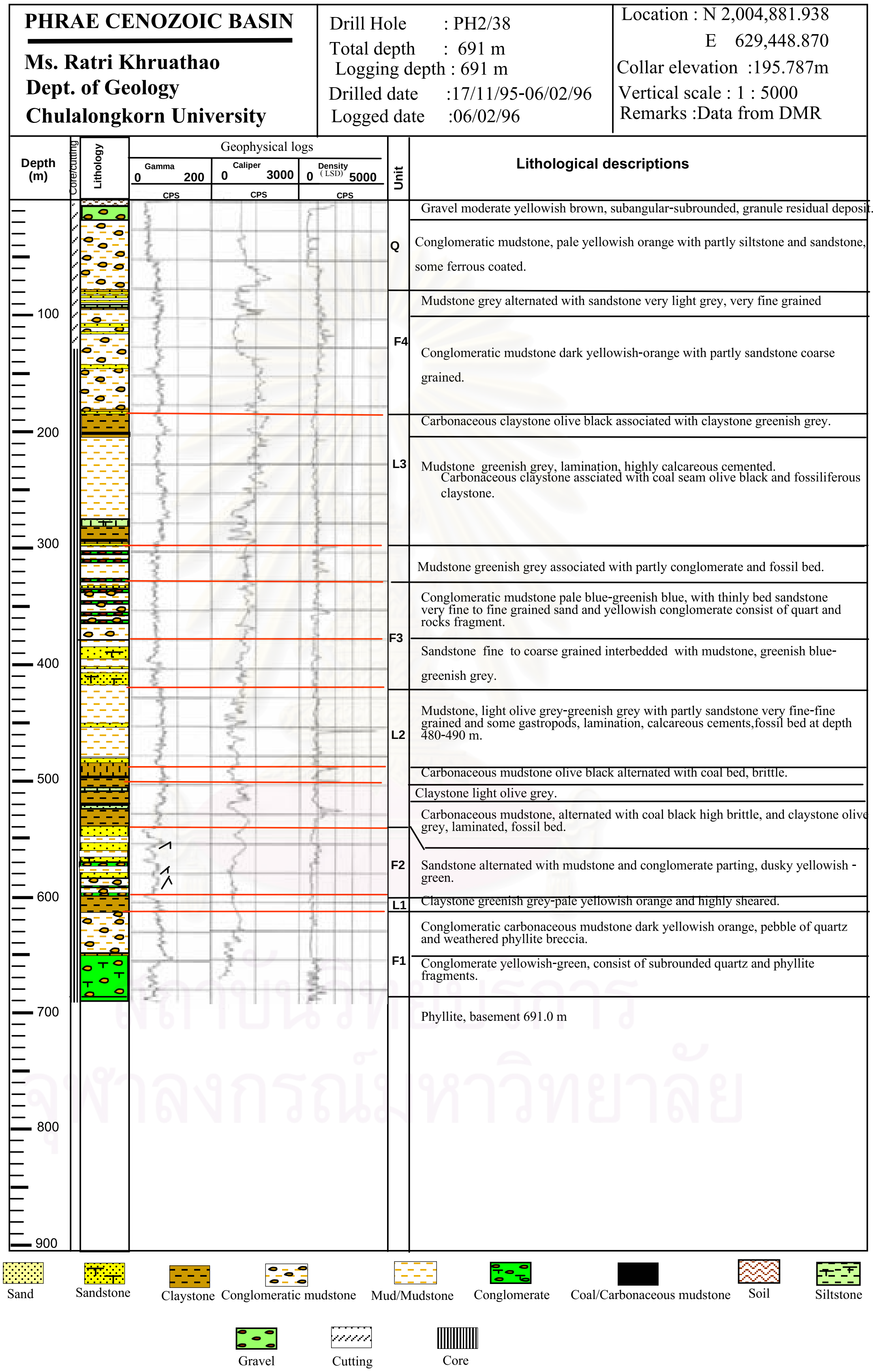

Figure 3.2.1.3 The geological drill chart of drill-hole number PH2/38

Figure 3.2.1.4 The photograph of conglomerate in alluvial fan facies.
PH 2/39, 537-538 m

Figure 3.2.1.5 The photograph of phyllite, basement of the Phrae basin
PH 2/38, 685.3 m

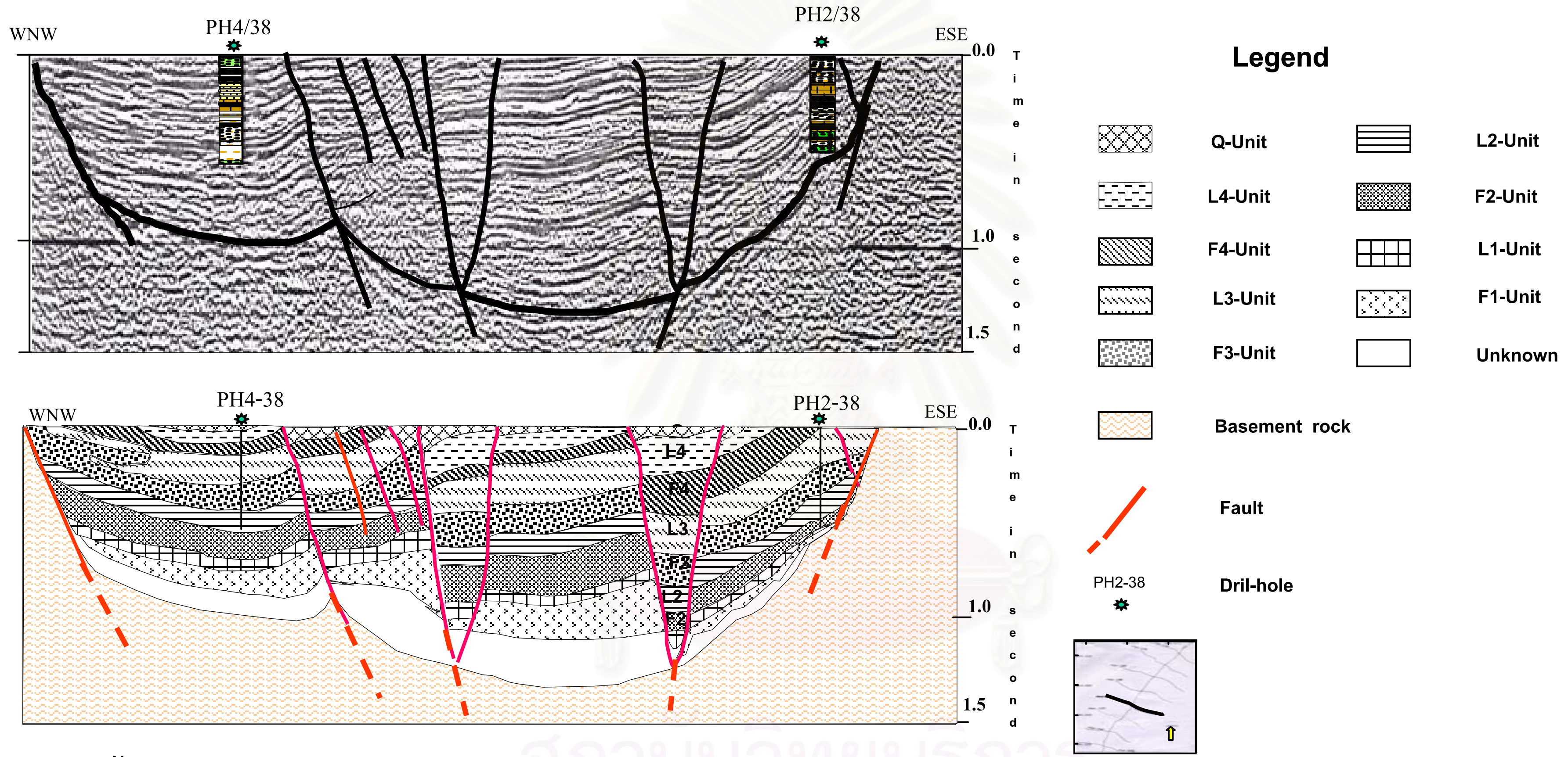

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Figure 3.2.1.6 The geological cross-section of seismic line PH-200 across the drill-holes numbers PH4/38 and PH2/38

3.2.2 L1-unit

This unit is predominantly characterised by fine-grained terrigenous sediments associated with coal and carbonaceous mudstone, as well as some medium-grained clastic, such as siltstone and sandstone with some influenced of conglomerate in some parts. The nature of the rock is relatively compacted comparison with the overlying and underlying units.

Upon integration of existing data previously stated, the continuous lithological sequences of primary drill-hole are analysed and interpreted. Typical lithological sequence of L1-unit is presented by the combination of the subsurface data from drill hole numbers PH5/38, PH 2/39, PH 1/38 and PH 2/38 as shown in Figures 3.2.1.1, 3.2.1.2, 3.2.1.3, and 3.2.2.1.

Generally, the lithological characteristics of the rocks can be separated into three parts, namely, the lower, the middle and the upper parts. The lithological sequence of the L1–unit is widely distributed thoughout the study area as shown in Figure 3.4.9.1.

L1-unit is characterised by mudstone, light grey, highly laminated, with some conglomerate contents in the lower part of this unit. The clast of conglomerate consists of quartzite, phyllite, granule to pebble size, subangular, poorly sorted. This appears in the western part of the area as evidence from drill-hole number PH 2/39, with thickness of about 65 metres, as shown in Figure 3.2.1.1.

In the middle part of the unit, mudstone alternates with sandstone, and siltstone of light grey - greenish grey, with common gastropod fossils, lamina of coally matter, sandy composition appeared in some parts, sandstone, light grey, very fine grained, as shown in Figures 3.2.2.1 and 3.2.2.2, with thickness varies from 35 metres in drill-hole number PH1/38 to 100 metres in drill-hole number PH 5/38.

The upper part of the unit is composed of brownish black carbonaceous mudstone associated with coal seam, with thickness varies from 0.1-0.3 metres. The coal

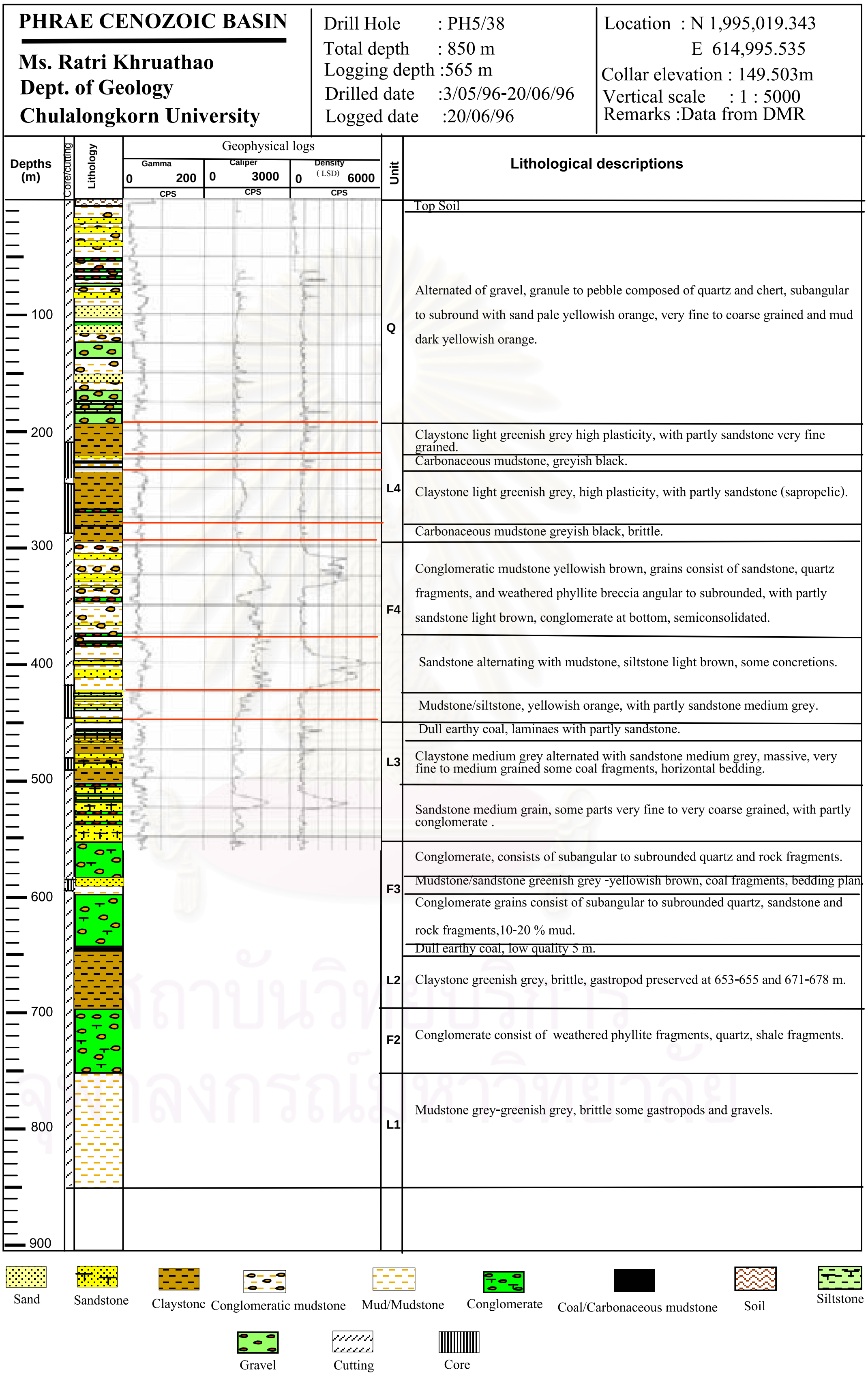

Figure 3.2.2.1 The geological drill chart of drill-hole number PH5/38

Figure 3.2.2.2 The photograph of mudstone in facustrine facies of the Phrae basin PH1/38,544-551 m.

Figure 3.2.3.1 The photograph of conglomerate in fluviatile facies of the Phrae basin PH1/38, 467-474 m.

in this unit is characterised by dull earthy coal, of low quality, the coal rank has been determined as lignite. The thickness of about 10 metres.

The total thickness of this unit varies from 20 metres in the eastern margin as evident from drill-hole number PH 2/38 to about 100 metres in the western margin as evident from drill-hole number PH 5/38 and is thickening from southwardly in the study area.

3.2.3 F2-unit

The typical lithological sequence of F2-unit is excerpted from the combination of subsurface data from nearly all drill- holes in the study area except drill-hole number PH 1/39. The unit overlies conformably the L1 unit and underlies conformably the L2 unit.

In general, the lithological sequence of F2-unit can be separated into three parts, namely, the lower, the middle, and the upper part. The lithological sequence of F2–unit is widely distributed thoughout the study area.

The lower part is characterised by the thick sequence of conglomerate with clasts consisting of phyllite, quartzite associated with some sandstone and mudstone in some parts, poorly sorted, subangular. This part is appeared in drill-hole number PH5/38 as shown in Figure 32.2.1 with thickness of about 50 metres and then the sequence changed upward to be the alternation of conglomerate, conglomeratic mudstone and sandstone of yellowish brown-yellowish orange, as evident from the drill-hole number PH3/38 as shown in Figure 3.2.3.1.

In the middle part of the F2-unit, is characterised by mudstone, siltstone and very fine-grained yellowish brown sandstone. This part of the unit is appeared only in drill-hole number PH 1/38, with thickness of about 15 metres as shown in Figures 3.2.1.2 and 3.2.2.2.

The uppermost part of the F2-unit is characterised by the sequence of sandstone dominant, associated with conglomerate, sandstone light brown to moderately reddish orange, very fine-to coarse-grained. The fining upward sequence are generally beginning with conglomerate or coarse-grained sandstone and passing upward through the top with mudstone and siltstone of yellowish green, as shown in Figures 3.2.3.2 and 3.2.3.3.The thickness of this part is about 50-60 metres as evident from drill hole number PH 1/38 and PH 2/38.

The overall thickness of the unit varies within the range of 50 metres from the south as appeared in drill-hole number PH 5/38 to the north with thickness of about 100 metres. It is noted that this unit is thickening to the northern of the study area and gradually thinning towards the southern margins. The deepest part of the unit is quite similar to the underlying units, which thick accumulations is confined within 5 major fault zones which shown in Figure 3.2.3.4

3.2.4 L2-unit

The L2–unit is characterised by thick sequence of fine-grained clastic rocks. It overlies conformably the F2-unit and underlies conformably the F3-unit.

Generally, the lithological characteristics of the L2-unit can be separated into two parts, namely, the lower and the upper parts. The lithological sequence of L2-unit is extended throughout almost all parts of the study area as shown in Figure 3.2.1.6

The lower part of the unit, is characterised as a sequence of fine-grained clastic sediments with some beds of medium-grained clastics, represented by association of sandstone, siltstone and mudstone of light blue to greenish grey, bioturbation with calcareous concretion. The sandstone is greenish grey, medium- grained, but some place are very fine-to very coarse-grained with some conglomerate in part. The conglomerate consists of weathered phyllite, quartzite, sandstone and mudstone clasts, poorly sorted, subangular, associated of fine-grained clastic sediments, the thickness varies from 30 metres as evident form drill-hole number PH2/39 to 70 metres in drill-hole number PH 1/38 as shown in Figures 3.2.1.1 and 3.2.1.2.

Figure 3.2.3.2 The photograph of sandstone in fluviatile facies of the Phrae basin PH3/38,538-544 m.

Figure 3.2.3.3 The photograph of sandstone with siltstone in fluviatile facies of the Phrae basin PH1/38, 58-463 m.

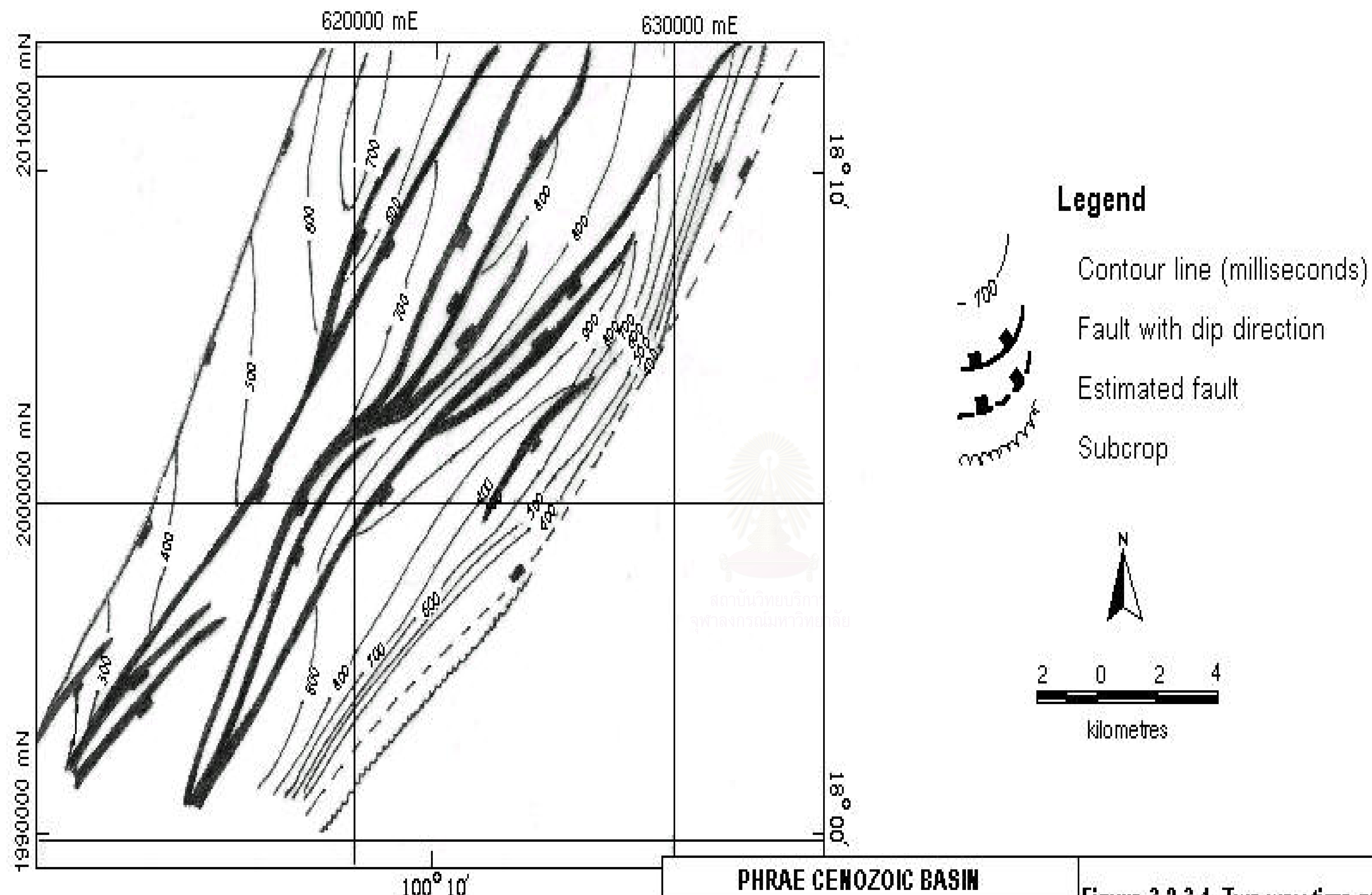

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Figure 3.2.3.4 Two way time structural map of the base of F2 unit, the Phrae basin (contour interval 100 milliseconds).

In the upper part, the lithology is graded from the lower part of coarser grained into a more finer-grained which characterised by a repeating of two cycles of relatively thick sequence of mudstone, claystone, greenish grey, highly calcareous, thin bed to lamination. Gastropods, diatomite and bioturbation are occasionally present. The upper part consists of fine- grained clastic sedimentary rock including siltstone, carbonaceous mudstone and coal bed. The carbonaceous mudstone is moderately brownish black. The coal is characterised by dull, brittle, thin bed, varies from 0.1-0.35 metre as shown in Figure 3.2.4.1. In the drill-hole number PH 1/38 and Ph2/38 claystone bed is appeared to be associated with fossil bed overlies on the Upper carbonaceous bed. Claystone is characterised by greenish grey with calcareous nudules and partly with sandstone very fine to fine grained, some gastropod, lamination as shown in Figures 3.2.1.2 and 3.2.1.3. The thickness in this part is varies from 15-70 metres.

The overall, thickness of the L2-unit varies within the range of 50 to 160 metres thickening towards the northern and central parts of the study area, and gradually thinning towards southern margins of the basin as shown in Figure 3.2.4.2. The deepest part of the unit is similar to the underlying units which is confined within 5 major fault zones as shown in Figure 3.2.4.3

3.2.5 F3-unit

The typical lithological sequence of the F3-unit is represented by the combination of subsurface data from nearly all drill-holes in the study area except the drill-hole number PH1/39. The unit overlies conformably the L2-unit and underlies conformably the L3 -unit.

Generally, the lithology of the F3-unit can be separated into 4 parts. The lithological sequence of F3-unit occurs widely throughout the study area.

The first part, is the lowest part of the unit, is characterised by a sequence of conglomerate which clasts consisting of phyllite, quartzite with sandstone and mudstone in some parts, subangular to subrounded, poorly sorted. The lowest part appears as a representative in the drill-hole number PH 5/38 with thickness of 100 metres.

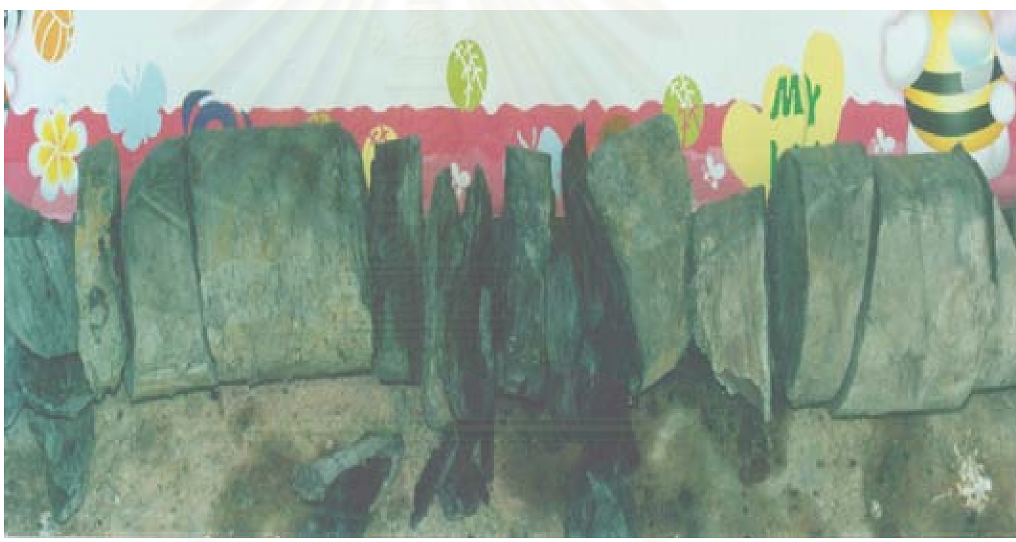

Figure 3.2.4.1 The photograph of carbonaceous and fossil bed of the Phrae basin PH2/38,520-521 m.

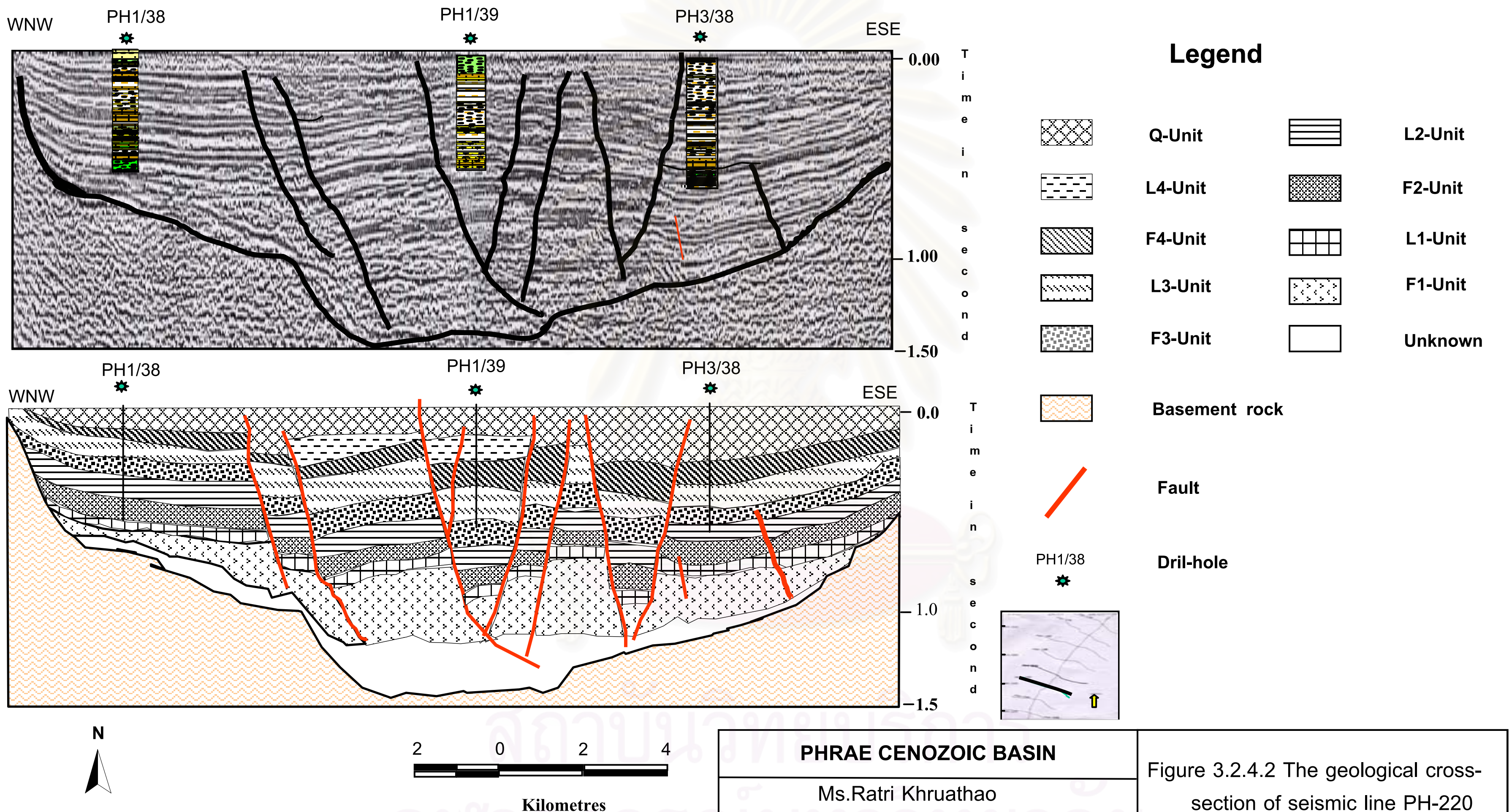

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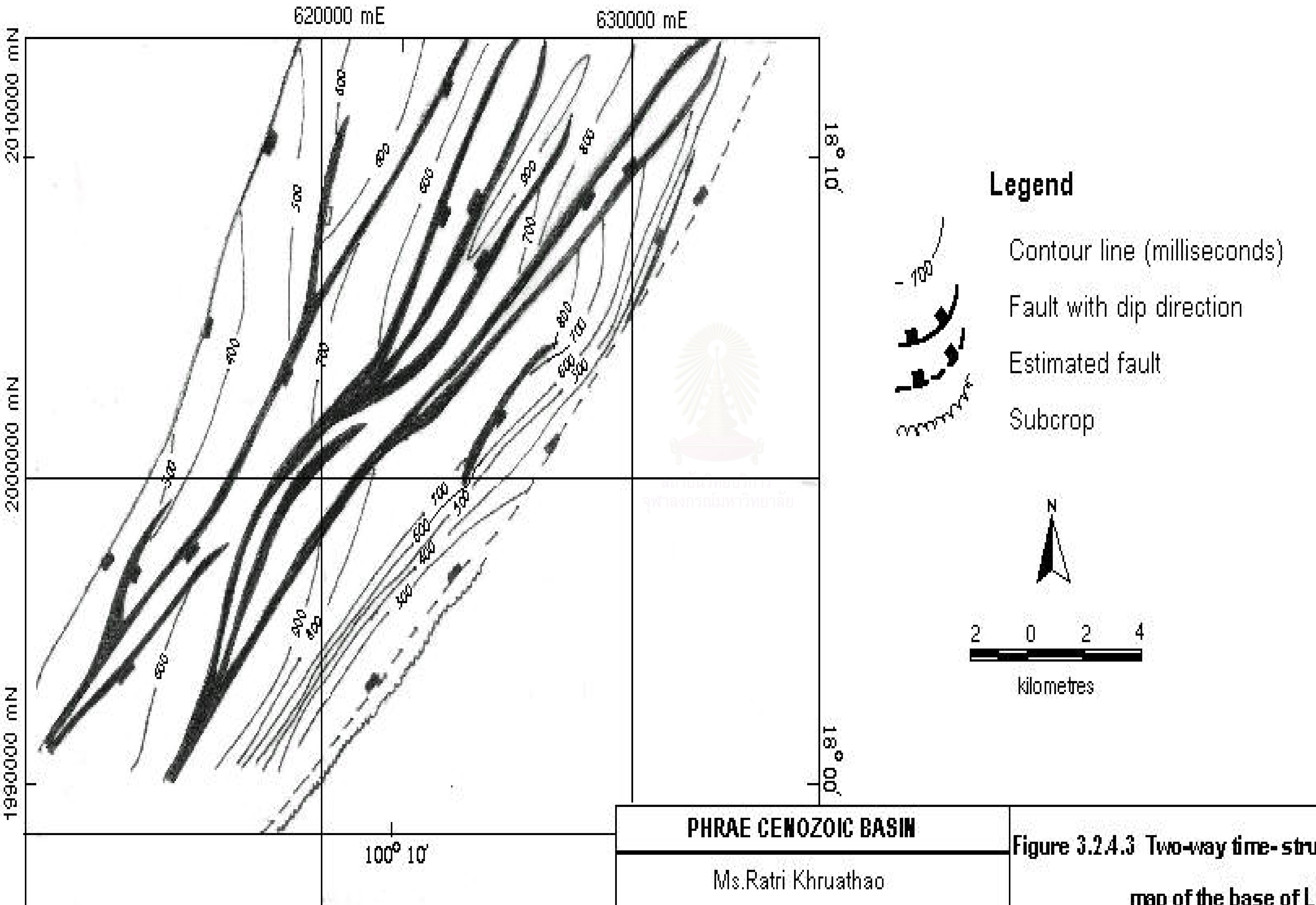
Figure 3.2.4.2 The geological cross-section of seismic line PH-220 across the drill-holes numbers PH1/38,PH1/39 and PH3/38



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Ms.Ratri Khruathao
Department of Geology, Faculty of Science
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Figure 3.2.4.3 Two-way time- structural map of the base of L2 unit, the Phrae basin (contour interval 100 milliseconds).

The second part of the unit is characterised by lithology of the alternation of conglomerate, conglomeratic mudstone, sandstone and mudstone, yellowish-brown to yellowish -orange, subangular to subrounded, poorly sorted, with repeated fining upward sequences as shown in Figures 3.2.1.1 and 3.2.1.3. The fining upward sequences are generally begun with conglomerate or coarse-grained sandstone with the top most of fine-grained mudstone and siltstone of yellowish green colour. The thickness varies from 40 meters in drill-hole number PH2/38 to 80 metres in drill-hole number PH2/39.

The third part is characterised by conglomeratic mudstone associated with conglomerate and some sandstones. The conglomeratic mudstone is yellowish brown to pale blue-greenish blue, the clasts of conglomerate consist of quartz and rock fragment, the sandstone is very fine-to fine-grained. This portion of the unit appeares in the northwestern and northeastern edges as represented in the drill-hole numbers PH4/38 and PH 2/38 of the study area, the thickness of this part ranges from 40 metres in drill-hole number PH2/38 to 90 metres in drill-hole number PH4/38

The fourth part, the uppermost part of the unit is represented by the association of sandstone, mudstone and siltstone, bluish grey to yellowish brown, sandstone is very fine to medium-grained. It is noted that, this part is represented in the drill-hole numbers PH3/38 and PH1/38 (Figures 3.2.1.2 and 3.2.5.1) with thickness of about 40 metres.

The overall thickness of this unit varies within the range of 40-100 metres with maximum thickness in the north and eastern parts of the study area and gradually thinning towards the western margin. The deepest part of the unit is similar to others underlying units which is confined within 5 major fault zones as shown in Figure 3.2.5.2

3.2.6 L3-unit

The L3–unit is characterised by the thick sequence of fine-grained clastic sedimentary rocks. It overlies conformably the F2-unit and underlies conformably the F3-unit.

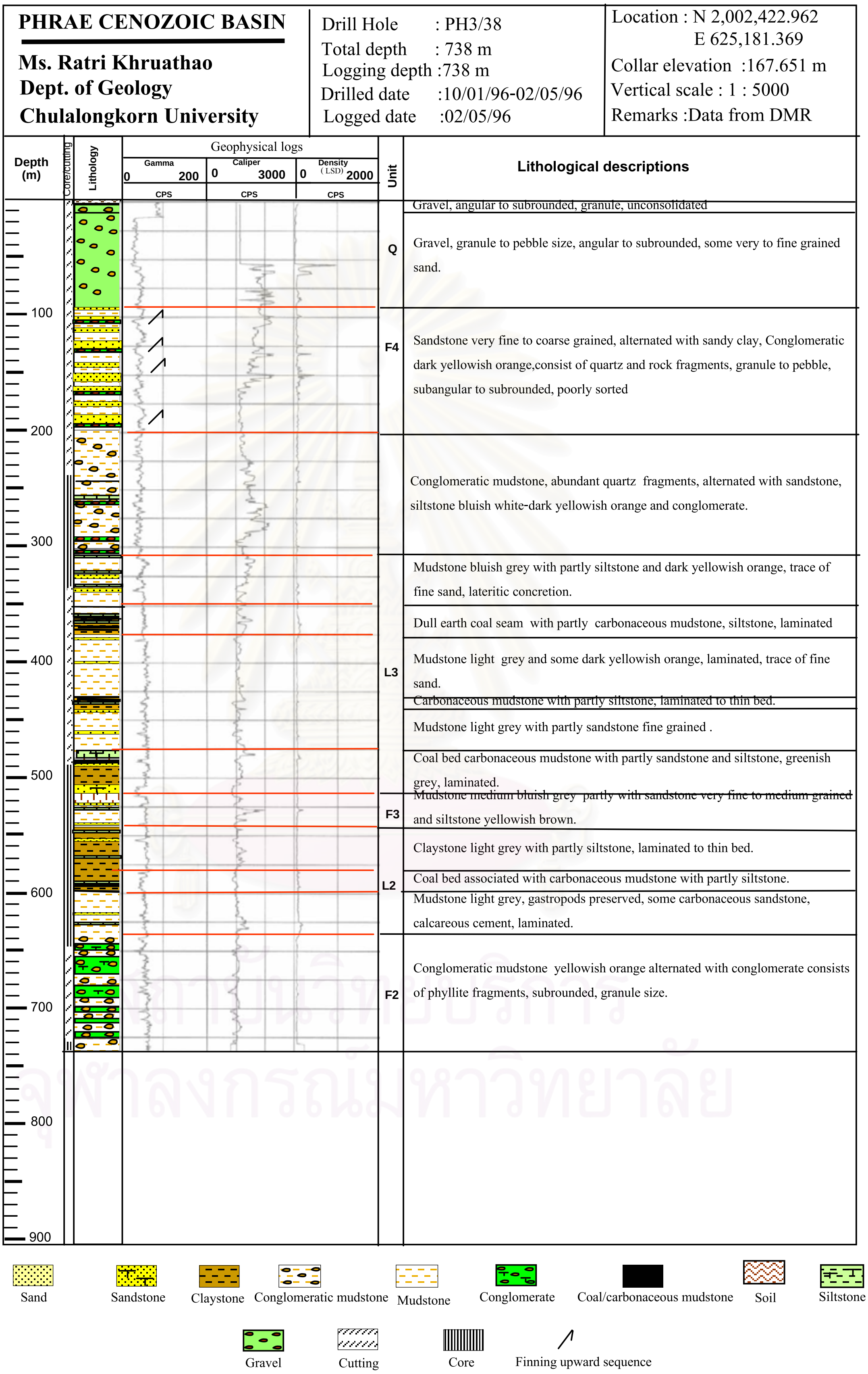
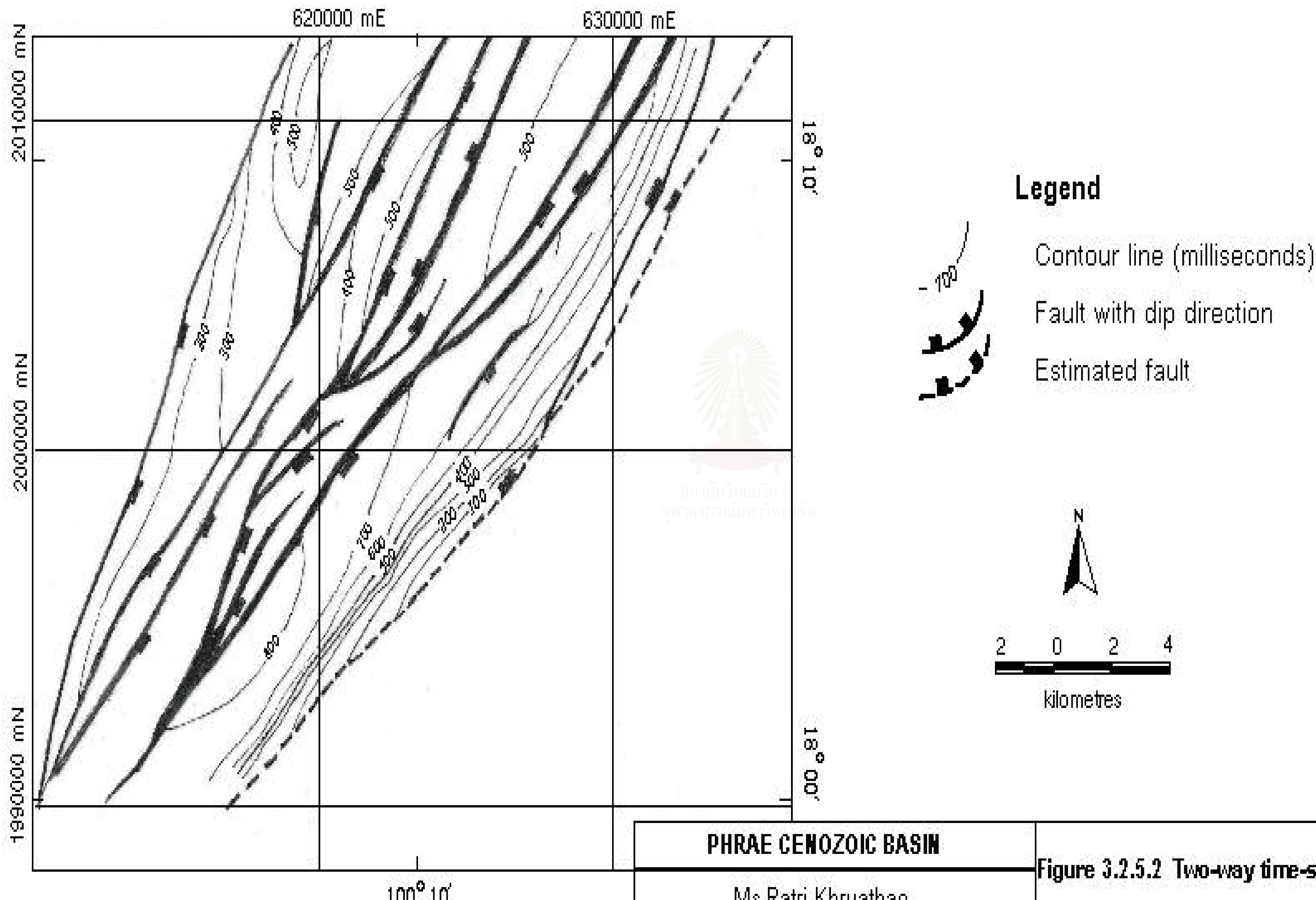


Figure 3.2.5.1 The geological drill chart of drill-hole number PH3/38



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Department of Geology, Faculty of Science
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Figure 3.2.5.2 Two-way time-structural map of the base of F3 unit, the Phrae basin (contour interval 100 milliseconds).

Generally, the lithology can be separated into 2 parts, namely, the lower part and the upper parts. The lithological sequence of the L3-unit is extended over almost all parts of the study area.

The lower part of the L3 unit is displays as a sequence of fine-grained clastic sediments; the fossiliferous claystone, alternating with mudstone and sandstone. Mudstone is light grey to greenish grey in colour. Sandstone is medium-grained, some part is very fine-to very coarse-grained, laminated, highly calcareous with some influences of conglomerate with clasts consisting of phyllite, quartzite with sandstone and mudstone, subangular to subround, poorly sorted, as shown in Figures 3.2.6.1 and 3.2.1.3 the thickness of this part varies from 50 meters in drill-hole number PH5/38 to 150 metres in drill-hole number PH1/39.

In the upper part, the lithology is characterised by three cycles of thick sequence of associated mudstone and claystone, including siltstone, carbonaceous mudstone and coal bed on the top of the cycle. The mudstone in the lower part of the cycle is characterised by light grey to greenish grey, highly calcareous, thin-bed to laminated, with gastropods and bioturbation of 10-100 metres thick. On top of the cycle is the association of siltstone, carbonaceous mudstone and coal bed. The carbonaceous mudstone is greyish black in colour. The coal is characterised by dull, brittle, with thickness varies from 0.1-0.7 metre as shown in Figures 3.2.1.3 and 3.2.6.2

The thickness of the L3-unit is relatively thicker than other fine-grained clastic units within the study area. The thickness varies within the range from 38 metres in drill-hole number PH2/39 to 220 metres in the north and central parts of the study area, and gradually thinning towards the western margin of the basin as shown in Figure 3.2.6.3. The deepest part of the unit appears to be similar to the other underlying units, and is confined within 5 major fault zones as shown in Figure 3.2.6.4.

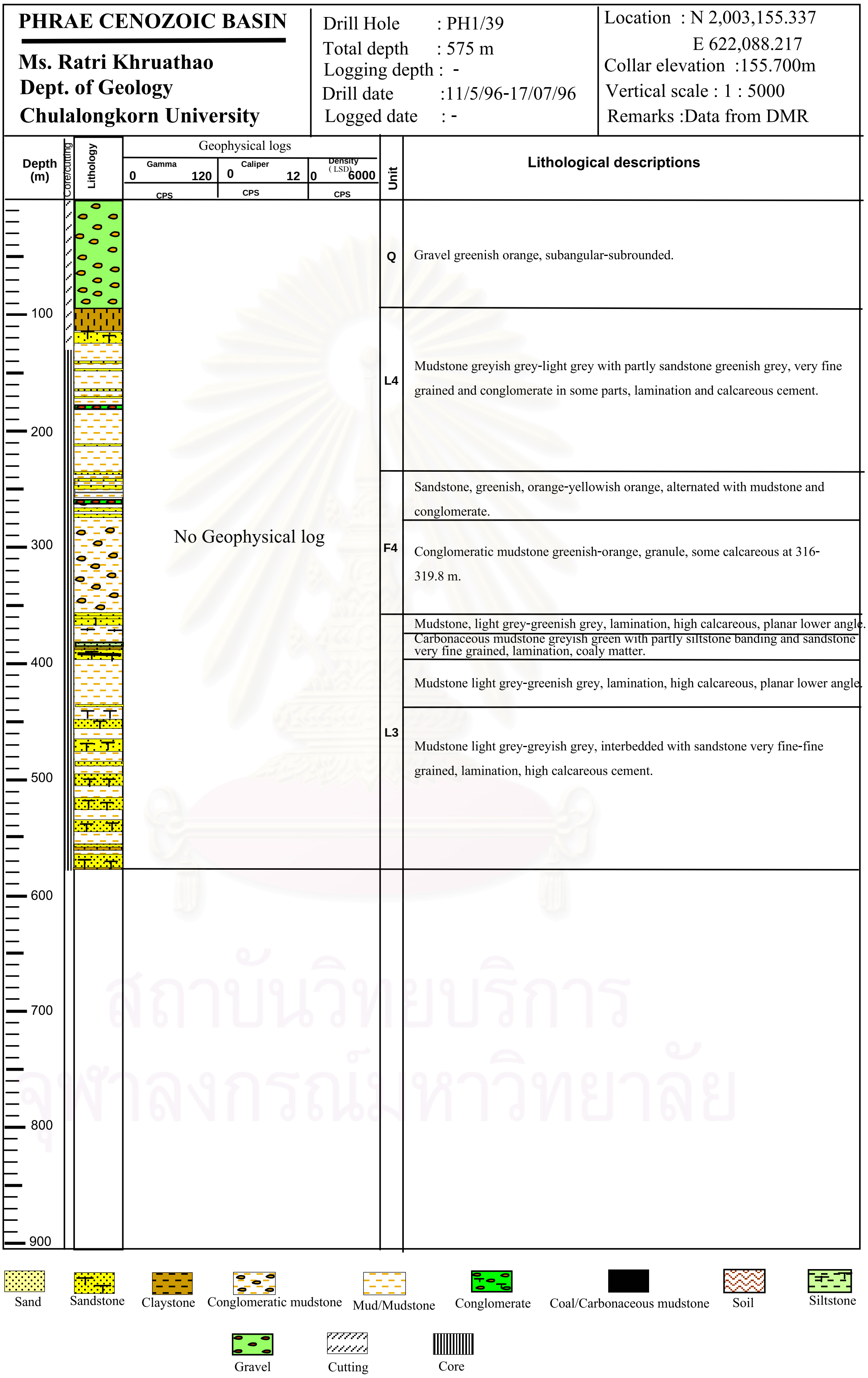
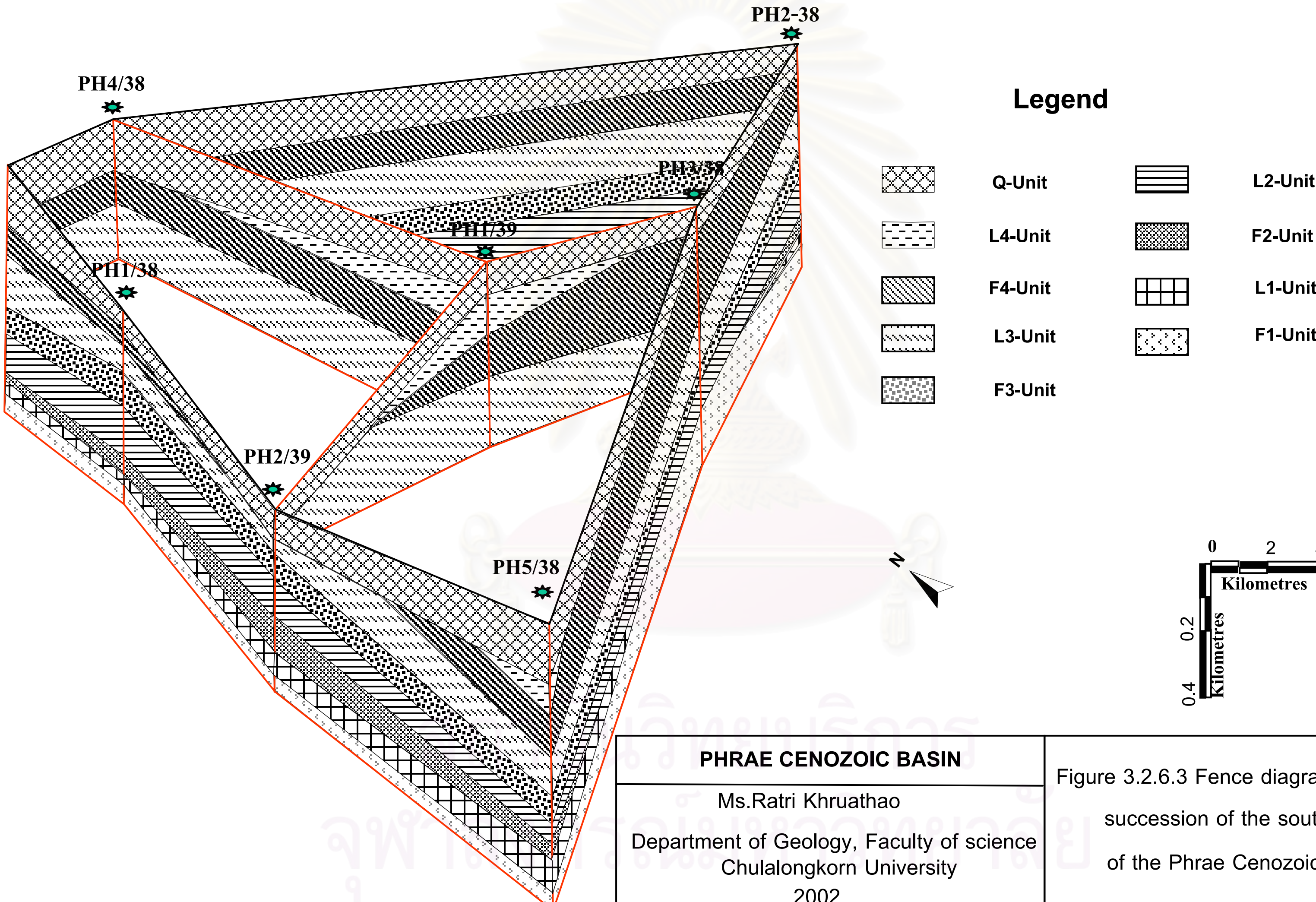


Figure 3.2.6.1 The geological drill chart of drill-hole number PH1/39

Figure 3.2.6.2 The photograph of coal and carbonaceous bed of the Phrae basin PH 4/38,304-310m.



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Ms.Ratri Khruathao

Department of Geology, Faculty of science
Chulalongkorn University
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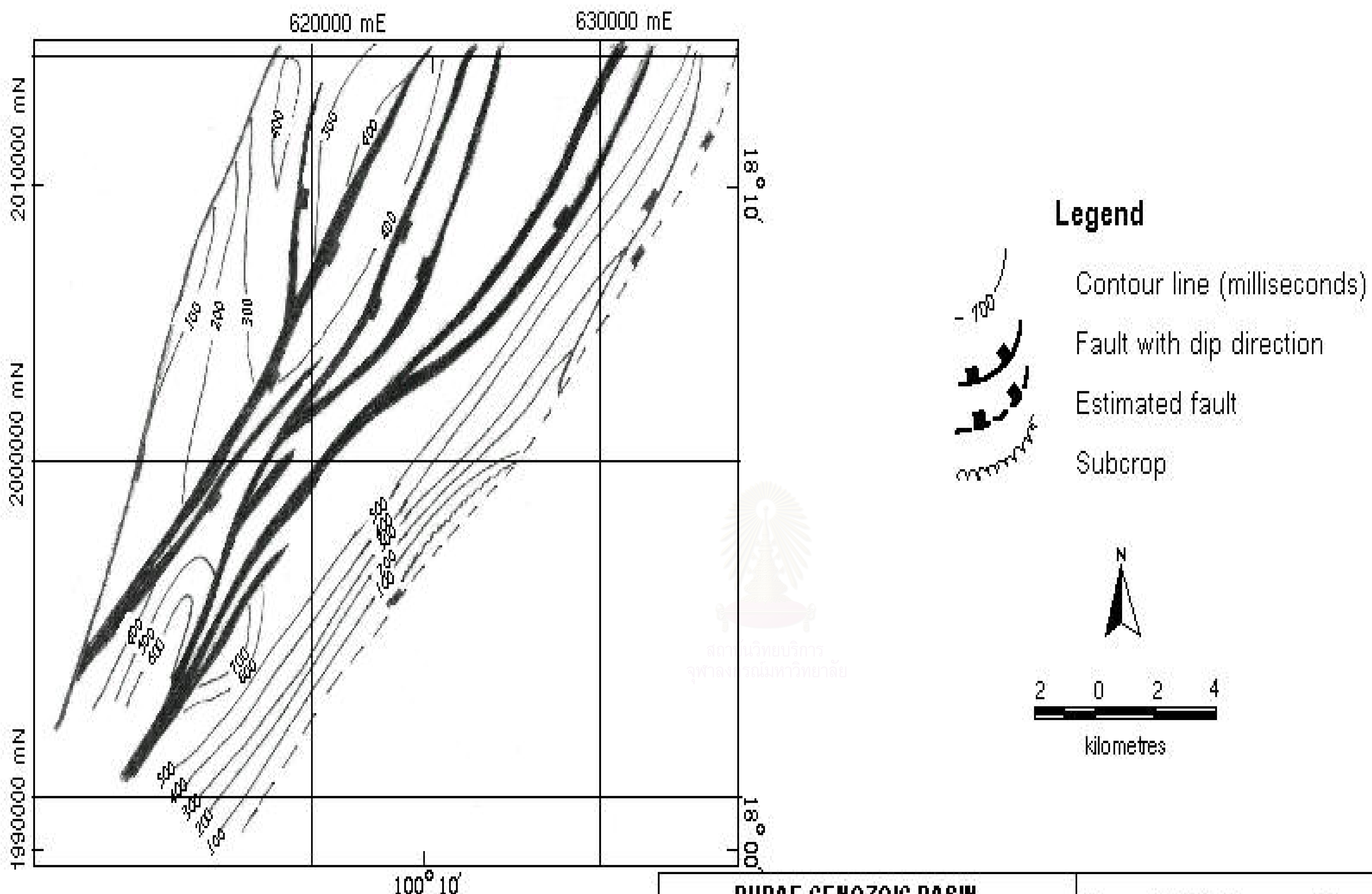
Figure 3.2.6.3 Fence diagram of upper succession of the southern part of the Phrae Cenozoic basin



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Ms.Ratri Khruathao

Department of Geology, Faculty of Science

Chulalongkorn University

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Figure 3.2.6.4 Two-way time-structural map of the base of L3 unit, the Phrae basin (contour interval 100 milliseconds).

3.2.7 F4 –unit

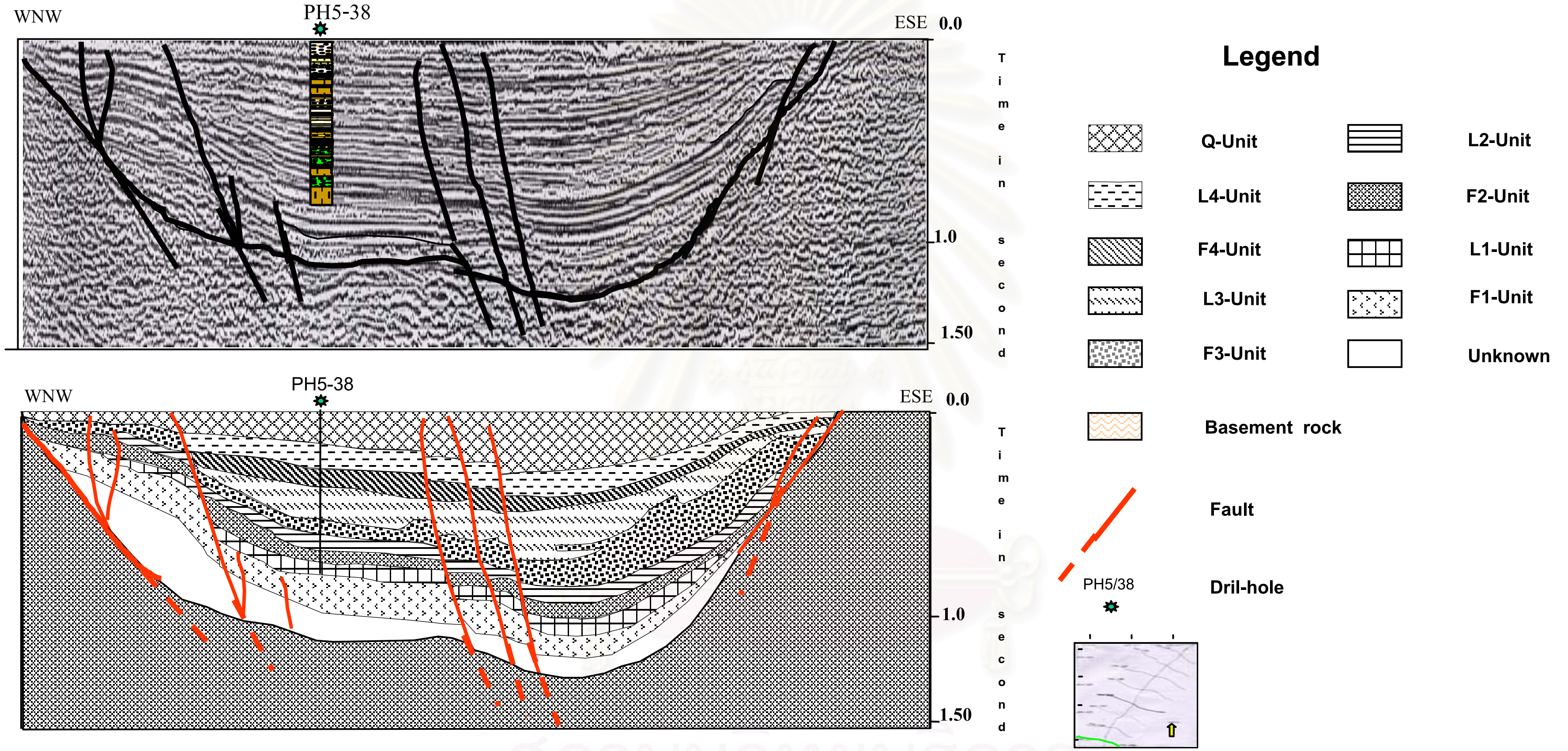
The typical lithological sequence of F4-unit is represented by the combination of subsurface data from nearly all drill-holes for sedimentary facies analysis in the study area except drill-hole number PH2/39 .The unit overlies conformably the L3-unit and underlies conformably the L4-unit.

Generally, the lithological of the F4-unit can be separated into four parts. The lithological sequence of F4-unit spreads throughout the study area except on the western margin in southern end of the basin as shown in the Figures 3.2.7.1 and 3.2.7.2.

The lower part of the F4-Unit, is characterised by the sequence of fine-to medium-grained clastic sedimentary rock, consisting mainly of mudstone, siltstone with some minor sandstone of various colours, yellowish brown to yellowish orange. The sequence is graded into more sandstone associated with mudstone and siltstone with some concretions in some areas. This part of the sequence appears in drill-hole number PH5/38 with thickness of 70 metres as shown in Figures 3.2.2.1, 3.4.4.1, and 3.4.4.2, located in the southern part of the study area and drill-hole number PH3/38 (Figure 3.2.4.1) with thickness of 50 metres in the eastern part of the study area.

Above the lowest part of the F4-unit is the second part of the unit. The lithological sequence is characterised by the association of conglomerate, conglomeratic mudstone and sandstone, with colour varies from yellowish brown to yellowish orange. The conglomeratic mudstone consists of sandstone, quartz, and weathered phyllite fragments, angular to subrounded, poorly sorted, semiconsolidated with clay matrix, as shown in Figures 3.2.5.1 and 3.2.7.3. The thickness of this part varies from 35 metres in drill-hole number PH1/38 as shown in Figure 3.2.1.2, in the western part to 100 metres in drill-hole number PH3/38

The third part of the F4-unit is sand dominant characterised by the association of sandstone with mudstone and conglomerate in some parts. Sandstone is yellowish brown, very fine-to-coarse grained. Conglomerate clasts consists of quartz and rock fragments, dark yellowish orange, subangular to subrounded, poorly sorted, with



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Ms.Ratri Khruathao

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Chulalongkorn University
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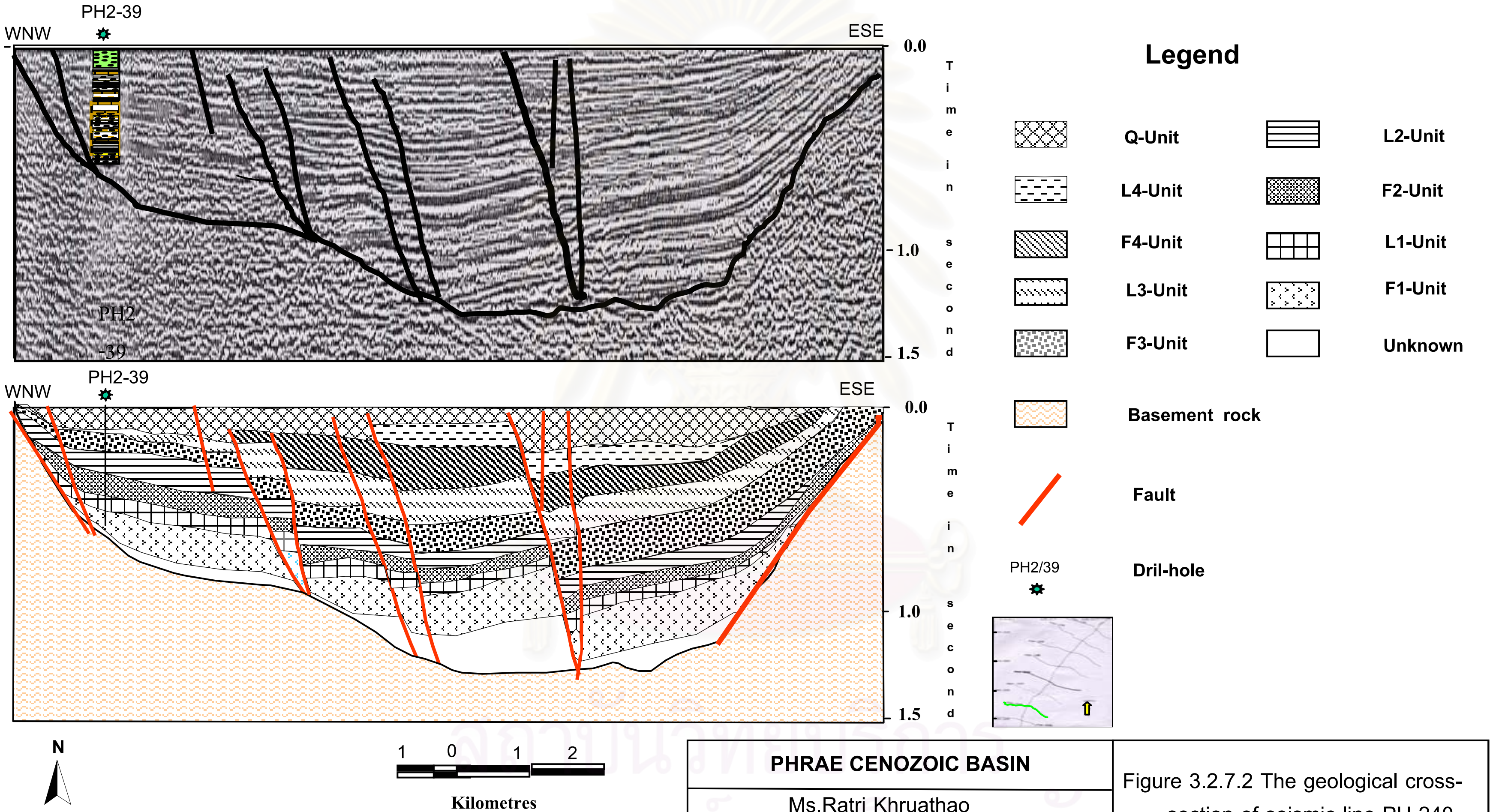
Figure 3.2.7.1 The geological cross-section of seismic line PH-260 across the drill-holes numbers PH5/38



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Ms.Ratri Khruathao
Department of Geology, Faculty of Science
Chulalongkorn University
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Figure 3.2.7.2 The geological cross-section of seismic line PH-240 across the drill-holes numbers PH2/39

Figure 3.2.7.3 The photograph of conglomeratic mudstone in fluviatile facies PH3/38, 288 M

repeated cycles of fining upward sequence. The fining upward sequence generally begins with conglomerate or coarse-grained sandstone with mudstone and siltstone at the top as shown in Figure 3.2.5.1. The thickness of this part is about 100 metres, which appeared in the drill-hole numbers PH 3/38, and PH 4/38, as shown in Figure 3.2.7.4.

The fourth part, the uppermost of the unit, is represented by silt dominant with alternation of mudstone and sandstone. Sandstone is very fine-grained, greenish orange to yellowish orange. This part appeares in the drill-hole numbers PH2/38 and PH1/38 with thicknesses of 20 and 15 metres, respectively.

The overall thickness of the F4-unit varies within the range of 50-335 metres with thickening towards the northern and eastern part of the study area and gradually thinning towards the western margin. The deepest part of the unit, similar to others underlying units, is confined within 5 major fault zone, which shown in Figure 3.2.7.2

3.2.8 L4-unit

The L4-unit is characterised by thick sequence of fine-grained clastic rocks. It overlies conformably the F4-unit and underlies conformably the Q-unit which is unconsolidated Q -unit.

Generally, the lithology of the unit can be separated into 2 parts which shows 2 cycles of repeated depositions, the lower cycle makes made up the lower part and the repeated upper cycle is represented in the upper part.

The lower part of the unit is characterised by a carbonaceous mudstone greyish black, brittle, laminated, as shown in Figure 3.2.2.1; the thickness of this part is about 10-20 metres.

The upper part shows gradational contact with the lower part and is characterised by thick sequence of mudstone, claystone, greenish grey to dark-grey, highly calcareous, laminated to thin bedded. Claystone of high plasticity there contains

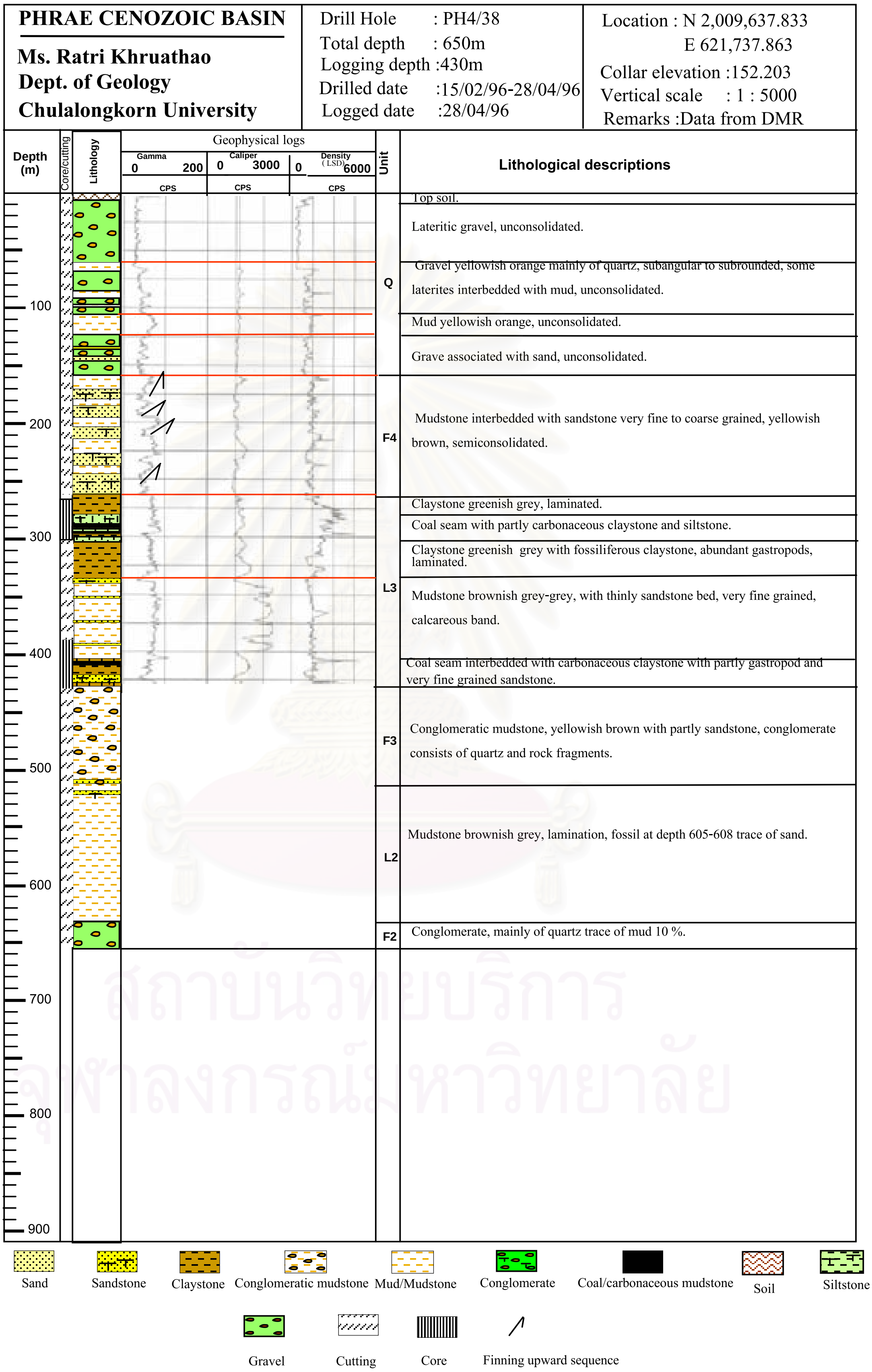

Figure 3.2.7.4 The geological drill-chart of drill-hole number PH4/38.

some preserved gastropods. The thickness in this part varies from 50 to 140 metres in drill-hole numbers PH5/38 and PH1/39. (Figures 3.2.2.1 and 3.2.6.1)

The thickness of the L4-unit varies within the range of 100 metres in the southwestern part in drill-hole number PH5/38 to 140 metres in the central part of the unit in drill-hole number PH 1/39, it is noted that, this unit is thickening towards the central part of the study area, and gradually thinning towards the eastern margin and does not preserved in the western edge of the basin as shown in Figure 3.2.7.1 The deepest part of the unit is similar to other underlying units, and is confined within 5 major fault zones as shown in Figure 3.2.7.2.

3.2.9 Q-unit

The unconsolidated uppermost portion of sedimentary sequence of the Phrae basin is generally exposed all over the study area. It comprises unconsolidated sediments of gravel, lateritic gravel, sand, silt and clay, varies in colours from yellowish brown, moderately brown to very pale orange. The gravel is characterised by the size of granule to pebble composing of quartz and chert, subangular to subrounded. The sand is fine-to-coarse-grained exposed in the southwestern part of the study area, as evident from the lithology and geophysical logs, and is characterised by the fining-upward nature. It is interesting to note that top soils and recent channel sediments are also included in this unit. The thickness of this unit varies from 65 metres as evident from drill-hole PH1/38 to 200 metres in drill-hole number 5/38

3.3 The Palynology of the Upper Succession of the Phrae Basin

As the results of palynological analysis of eleven core samples from the two drill-holes, namely, drill-hole numbers PH 1/38 and PH2/38, the palynofloras in the samples suggested the age of deposition is not older than Miocene possibly in Neogene or Pliocene ages (PTT, 1996), as shown in the Tables 3.3.1 and 3.3.2.

Table 3.3.1 Biostratigraphic summary from the drill-hole number Ph1-38

(modified after PTT, 1996)

BIOSTRATIGRAPIC SUMMARY FROM THE DRILL-HOLE NUMBER PH1-38						
Sample Number	**Depths** (M)	**Lithology**	**Flora**	**Facies**	**Depositional environment**	**Age**
Ph1-2	199	Claystone	*Liquidambarpollenites stigmosus*, *Pediastrum* spp. *Botryococcus* spp	**L3**	Lacustrine (deep water)	
Ph1-3	328	Claystone.	*Acacia type* , *Liquidambarpollenites stigmosus*, *Pediastrum* spp. *Botryococcus* spp	**L2**	Lacustrine (deep water)	Not older than Middle Miocene
Ph1-6	366	Claystone.	*Camptostemon* type, *Polygonum* type, *Pediastrum* spp. *Botryococcus* spp	**L2**	Lacustrine (deep water)	
Ph1-7	368	Claystone.	*Eugeissona miner* type, *Florschuetzia semilobata*	**L2**	Lacustrine (shallow water)	
Ph1-8	534	Claystone.	*Cephalomappa* type, *Echitriporites spinosus* , *Perfotricolpites digitatus* *Florschuetzia semilobata* , *Acacia type* , *Polygonum type*, *Pediastrum* spp. *Botryococcus* spp	**L1**	Lacustrine (shallow water)	Not older than Miocene
Ph1-9	537	Claystone.	*Polygonum* type, *Acrostichum aureum* type, *Terminalia type* and *Leiospheridia* spp	**L1**	Lacustrine (deep water)	

Table3.3.2 Biostratigraphic summary from the drill-hole number Ph2-38 (modified after PTT,1996)

BIOSTRATIGRAPIC SUMMARY FROM THE DRILL-HOLE NO. PH2-38						
Sample Number	**Depths** (M)	**Lithology**	**Flora**	**Facies**	**Depositional environment**	**Age**
Ph2-1	209	Claystone	*Canthium dicocum* type, *Botryococcus* spp, *Leiospheridia* spp, *Pediastrum* spp. *Liquidambarpollenites stigmosus,* *Polygonum* type.	**L3**	Lacustrine (shallow water)	
Ph2-3	297	Claystone.	*Liquidambarpollenites stigmosus,* *Pediastrum* spp.	**L3**	Lacustrine (deep water)	Not older than Middle Miocene
Ph2-4	483	Claystone.	*Pediastrum* spp. *Botryococcus* spp.	**L2**	Lacustrine (shallow water)	
Ph2-5	485	Claystone.	*Pediastrum* spp. *Botryococcus* spp. Lophopelalum multinervium type	**L2**	Lacustrine (deep water)	
Ph2-8	524	Claystone.	*Malvaceae pollen* *Pediastrum* spp *Botryococcus* spp, Polygonum type	**L2**	Lacustrine (shallow water)	Not older than Miocene

3.4 Sedimentary Facies and Reconstructed Depositional Environment

One of the objectives of the present investigation is to define the sedimentary facies of the upper succession of Cenozoic deposits in the southern part of the Phrae basin

The term "facies" has been variously interpreted by stratigraphers. According to Moore (1949), " Sedimentary facies are segregated parts of differing nature belonging to any genetically related body of sedimentary deposits" He also states that the term "lithofacies" "denotes the collective characters of any sedimentary rock which record of its depositional environment."

This analysis is dependent on the ability of the subsurface geological, geophysical data in terms of distribution pattern of data points, quantity and quality of data.

By this approach, the facies analysis relies heavily on the reconstruction of the basin morphology and bedding architecture, determination of gross lithology, delineation of the geometry, and recognition of vertical and lateral succession of the facies association. In addition, the aspect of tectonic sedimentation has to be fully appreciated.

The lithological sequence of the area identified earlier will be employed in the determination of the depositional sequence concerned or sedimentary facies using facies models. Fundamentally, the concept of facies model is a summary of a depositional environment and its products. The facies models used in this study are described in Rust (1983) and Miall (1978) for alluvial fan facies; Miall (1978) for braided fluviatile facies; Allen (1964) for meandering fluviatile facies; Visher (1965) Kukal (1971) and Picard and High (1972) for lacustrine facies. Therefore, the foregoing discussion will be made upon the sedimentary facies analysis in upper succession of the southern part of the Phrae basin.

3.4.1 Facies F1

The lowermost sedimentary deposits are consisting of thick sequence of coarse-grained clastics sedimentary rock of conglomerate and conglomeratic mudstone. The unit begins with conglomerate at the base and passing upward into conglomeratic mudstone. The geophysical logs signature responses with irregular shapes and patterns. The thickness varies from 30 to over 80 metres. According to lithological and geophysical log signatures, this sedimentary unit is believed to be deposited under the relatively high-energy condition. It is interpreted as a product of sedimentary deposits of proximal portion of alluvial fan system or also possible as a reworked braided fluviatile system when put in comparison with the alluvial fan facies of Rust (1983) and braided facies model of Miall (1978). The lithological sequence, sedimentary facies and reconstructed depositional system of the F1-unit, the lowest part of the sedimentary sequence within the study area, are presented as profile in Figures 3.4.1.1, 3.4.1.2, 3.4.1.3, 3.4.1.4, 3.4.1.5 and 3.4.1.6

3.4.2 Facies L1

The sedimentary unit overlies conformably the alluvial fan/braided fluviatile facies of the L1-unit. The lowermost sedimentary deposits of the L1-unit, is characterised by its composition consisting of mudstone, light grey, highly laminated, with some conglomerate contents the thickness of this part is about 65 metres and passing upward into the mudstone interbedded with siltstone and fine-grained sandstone. The thickness varies from 35 to over 100 metres. The gamma-ray log signature represents the irregular shale line to irregular sand line pattern. The gastropod and *Pediastrum* spp are dominantly present in place. According to the lithology, geophysical logs and palynology, it is suggested that this sedimentary unit was deposited in the relatively low energy condition of shallow fresh-water lake of terrigenous clastic environment when put in comparison with lacustrine facies models of Visher (1965), Kukal (1971), and Picard & High (1972) this sequence was influenced by conglomerate of alluvial fan facies in the lower part.

The upper part of facies L1 is consisting of carbonaceous mudstone, brownish grey colour, associated with coal beds. It is a shallow lacustrine facies. Some influence of alluvial fan facies is observed in this subunit. The signature of geophysical logs show

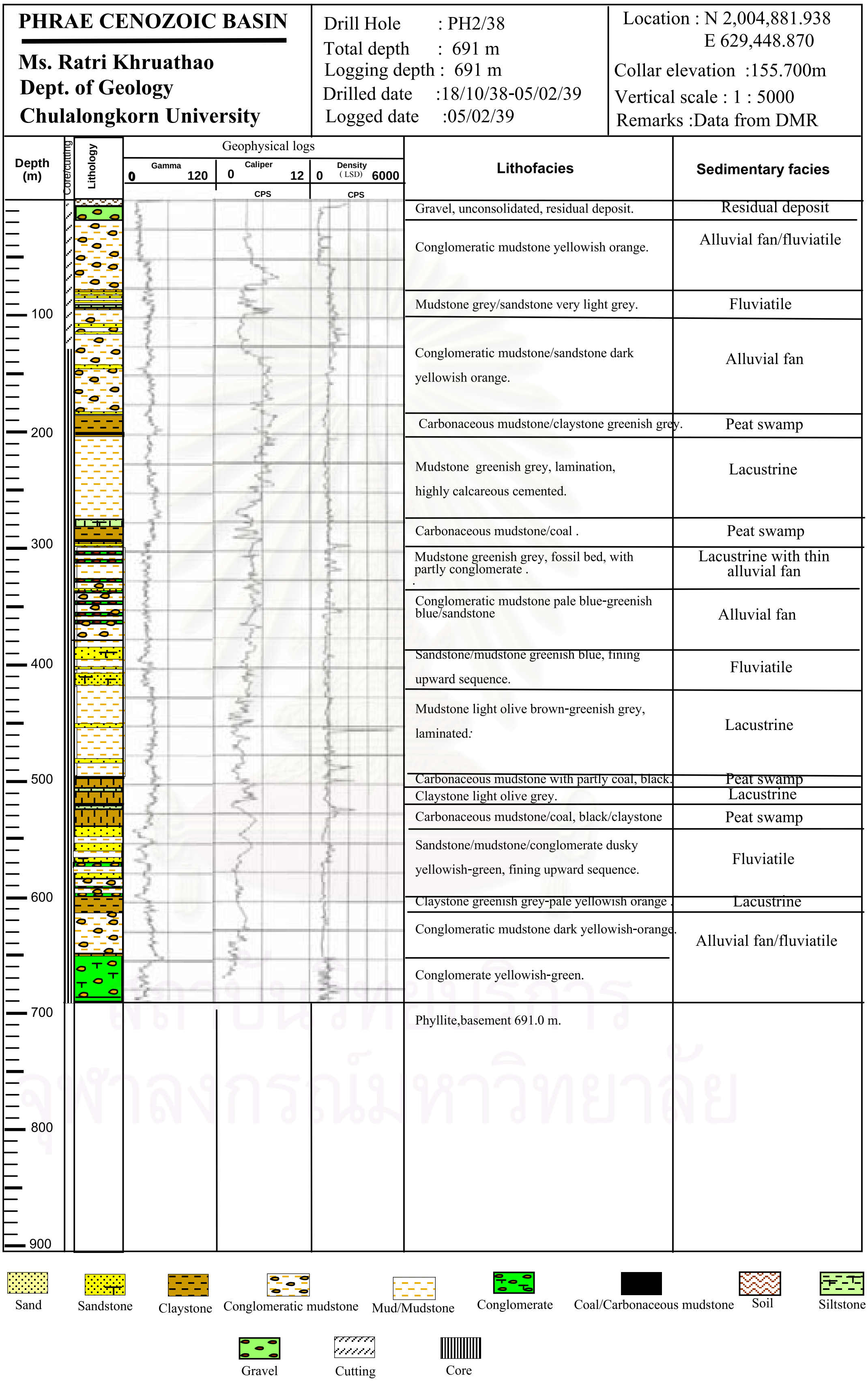

Figure 3.4.1.1 Summary sedimentary facies of drill-hole number PH2/38

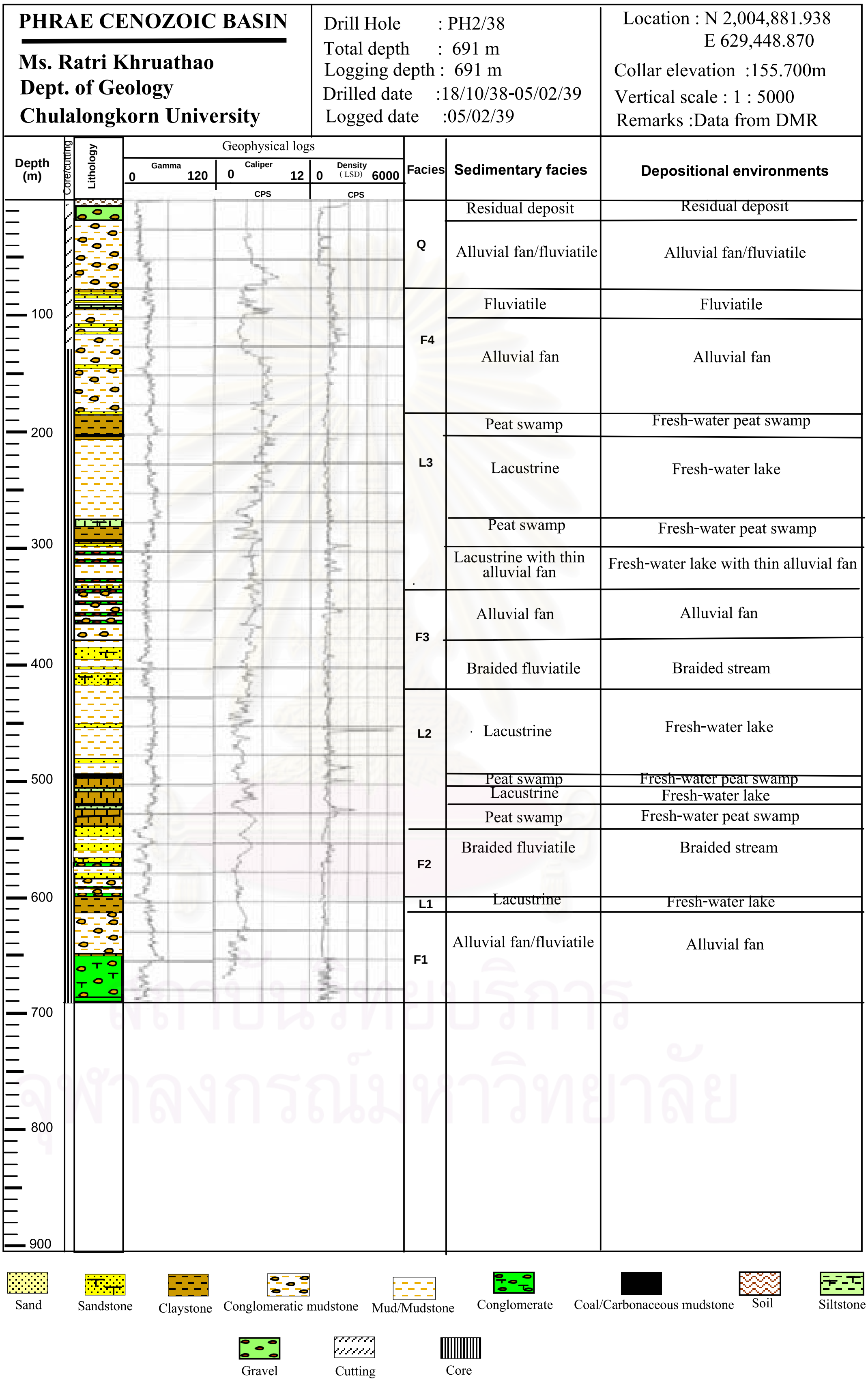

Figure 3.4.1.2 Summary of sedimentary facies and depositional environment of drill-hole number PH2/38.

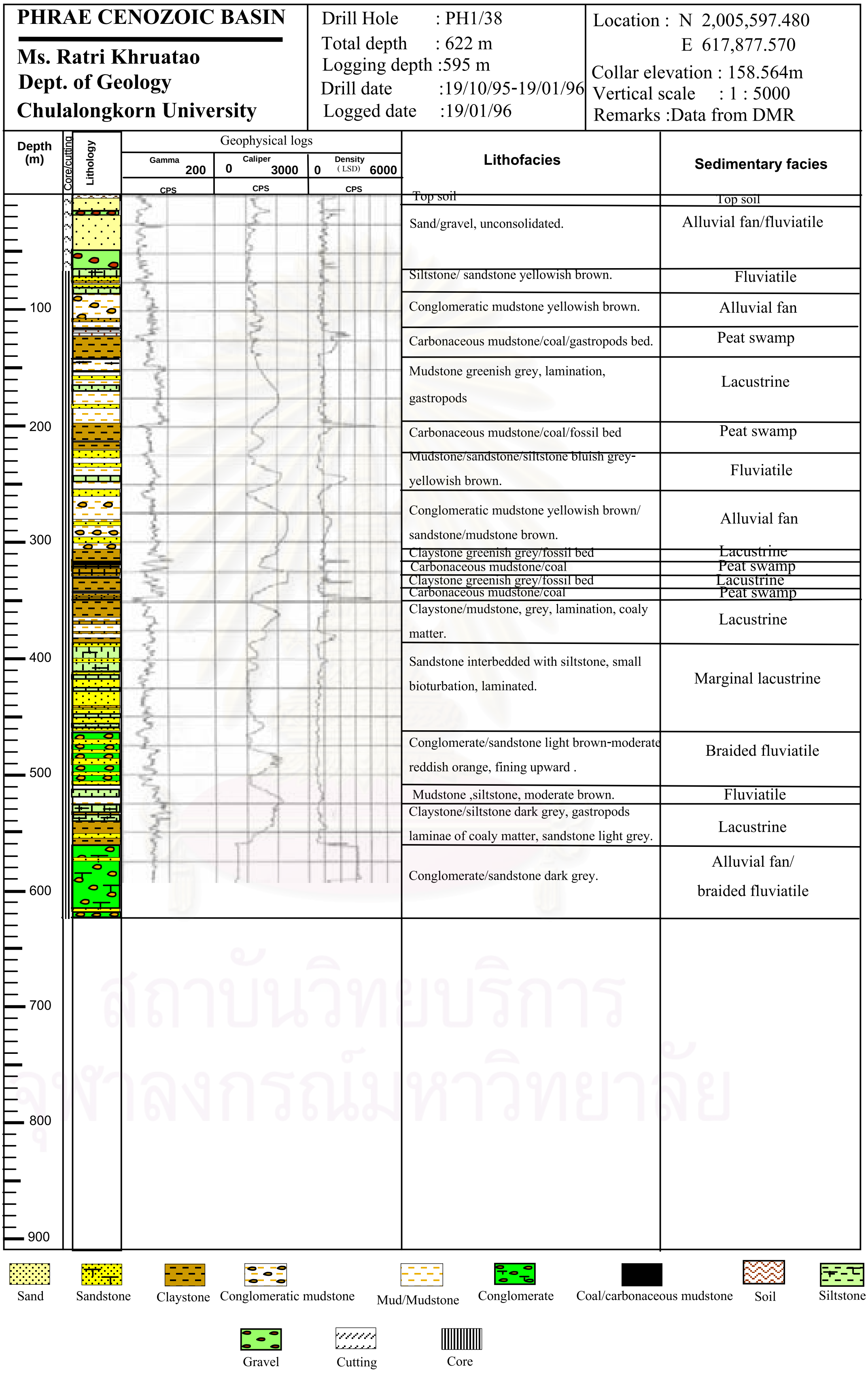

Figure 3.4.1.3 Summary sedimentary facies of drill-hole number PH1/38

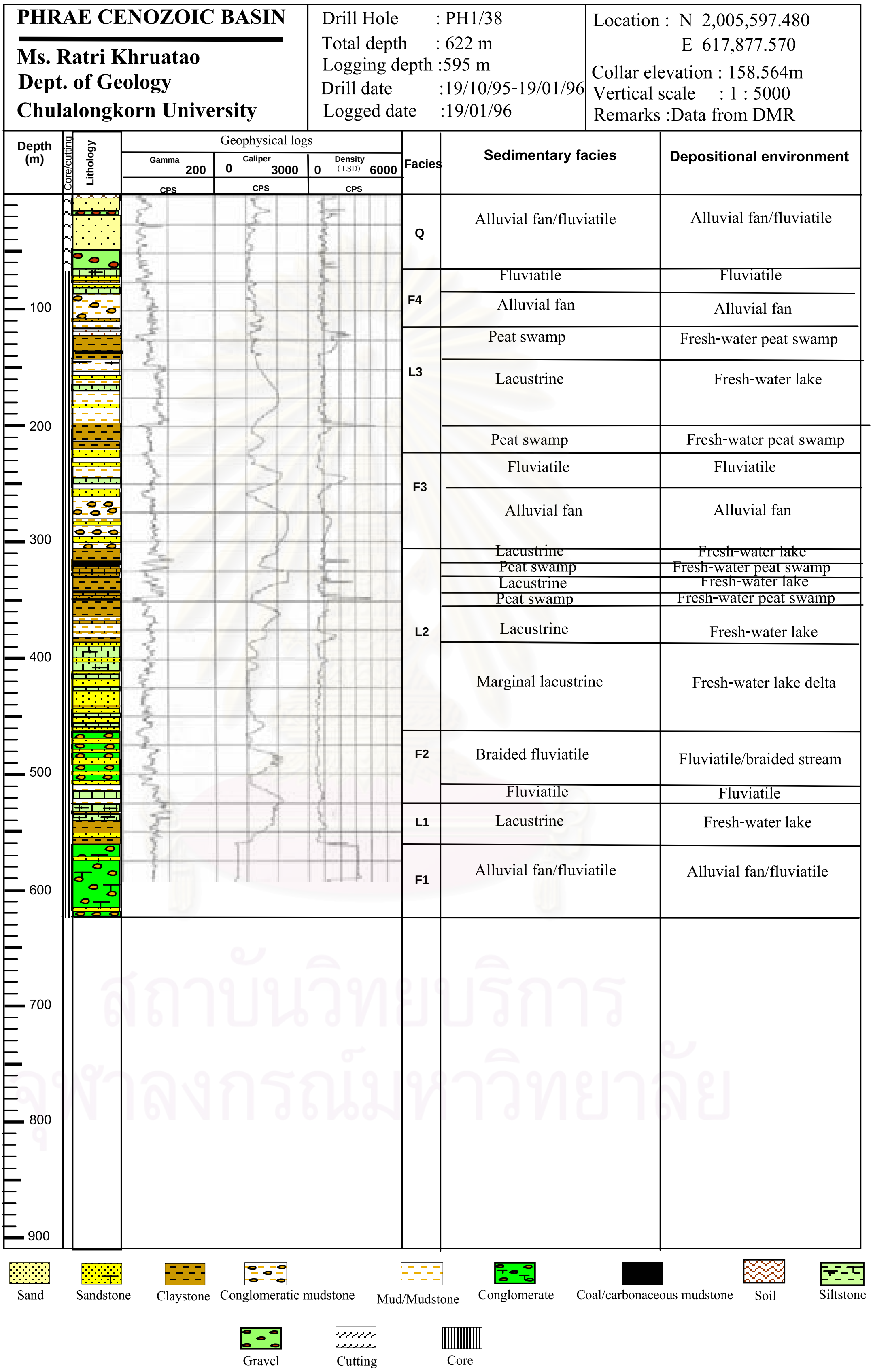

Figure 3.4.1.4 Summary of sedimentary facies and depositional environment of drill-hole number PH1/38

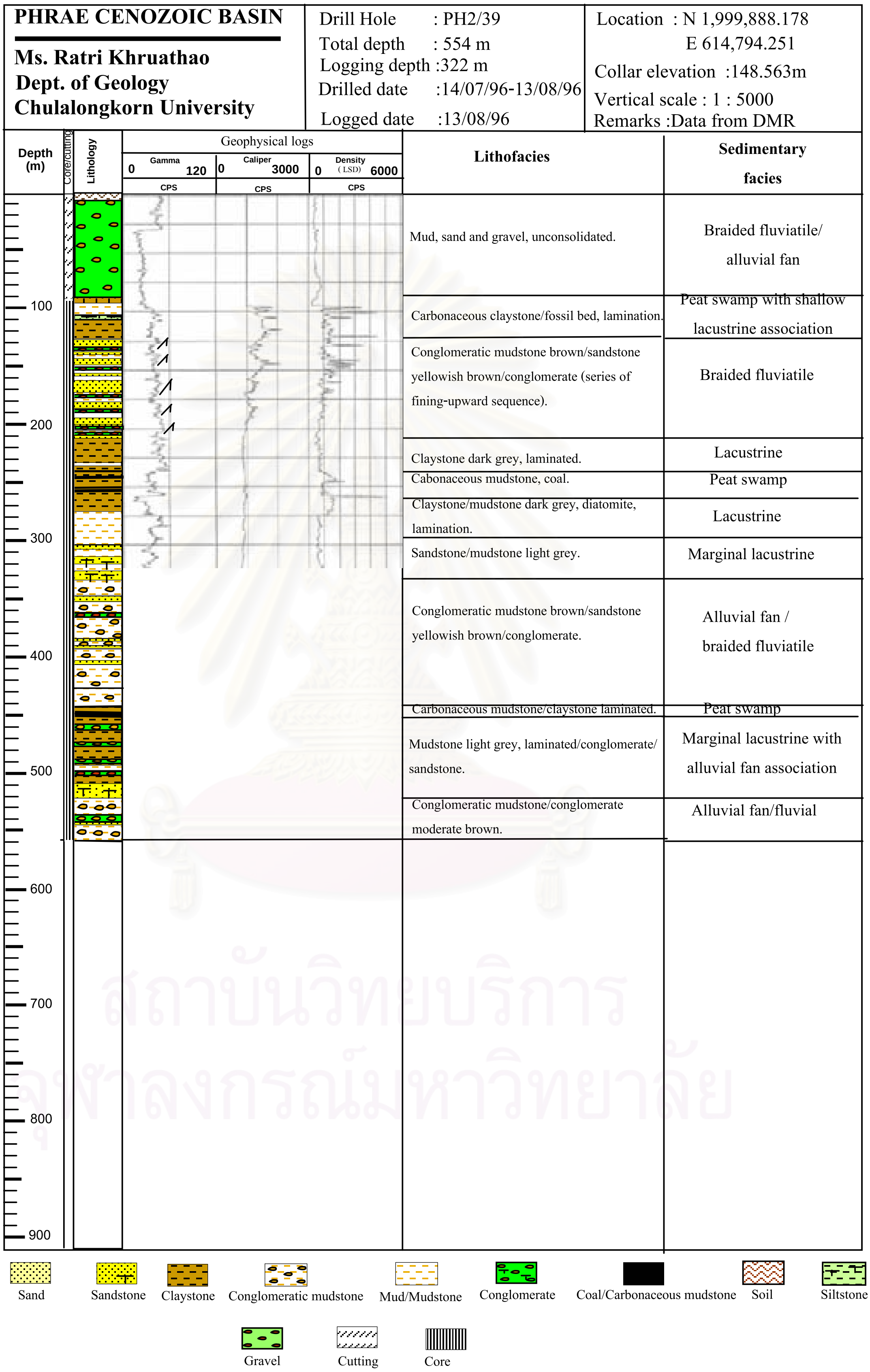

Figure 3.4.1.5 Summary sedimentary facies of drill-hole number PH2/39

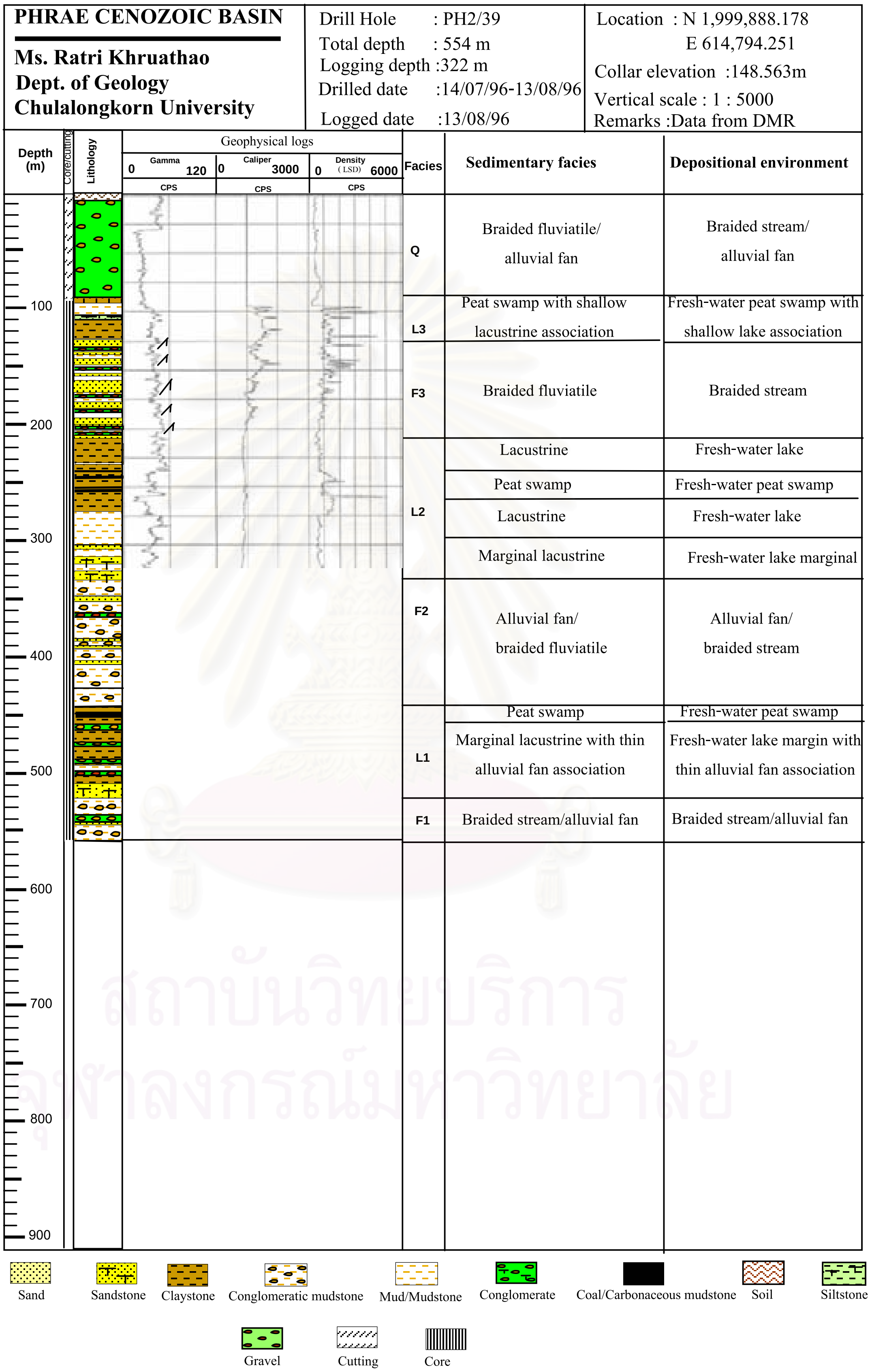

Figure 3.4.1.6 Summary of sedimentary facies and depositional environment of drill-hole number. PH2/39

irregular shale patterns. The thickness of this part is about 10 metres. This unit is considered to be deposited in the low energy condition of peat swamp environment, therefor, it is concluded to be deposited under condition of slowly subsiding peat swamp facies, the peat swamp facies are represented as profile in Figures 3.4.1.5 and 3.4.1.6. However, it is interesting to note that the lacustrine facies is partly interrupted near the southern western margin by alluvial fan facies. The overall thickness of the facies L1 varies from 20 metres in the eastern margin to about 100 metres in western margin and thickening from the northern to southern part of the study area.

3.4.3. Facies F2

Above the peat swamp facies of facies L1 is the thick succession of the sedimentary sequences of conglomerate passing upward to conglomeratic mudstone interbedded with sandstone and conglomerate. The thickness of this part varies from 50 to 100 metres. Generally, this lithological sequence is composed of sediments with texturally and mineralogically immature .The gamma-ray log signature displays irregular sand and shale line patterns. The lithological characteristics and geological log signature indicate that this sedimentary unit was deposited in high-energy condition of alluvial fan. Its conclusion is based on the comparison results with the alluvial fan model of Rust (1983), or also possible as a reworked braided fluviatile system (Miall, 1978).

The upper part of the alluvial fan facies is the sequence of mudstone interbedded with siltstone and of very fine-grained sandstone, brown in colour. The thickness of this part is about 15 metres. The geophysical logs signature is response with irregular shale line. The lithological and geophysical logs indicate that this unit was deposited under the fluviatile environment. This conclusion is drawn from the comparison with depositional model of Allen (1964).

The uppermost part of facies F2 is represented by the lithological unit of sandstone dominated with conglomerate and layers of clay interbedding. The electric log signature shows the cycles represented fining upward sequence as shown in Figures 3.4.1.1, 3.4.1.2, 3.4.1.3 and 3.4.1.4. The thickness of this part is about 50-60 metres. The lithological and geophysical log indicate that the sequence of this unit was deposited under the fluviatile environment of braided system as compared with the braided river depositional model of Donjek or South Saskatchewan types of Miall (1978). The lithological unit is the braided fluviatile facies, which was deposited under relatively, steep slope, broad, shallow rivers with more steady discharge.

The overall thickness of the facies F2 is varies from 50 metres in the southern part to 100 metres in the northern part. It is to noted that, this unit is thickening to the northern and eastern parts of the study area.

3.4.4 Facies L2

Above the fluviatile facies of facies F2 is the thick succession of claystone dominant unit. The unit begins with a sequence of fine-grained clastic sedimentary rock of mudstone with some beds of medium grained clastic interrupted by very fine-grained sandstone and some conglomerates interbedding. The thickness of this sedimentary sequence is about 70 metres. The geophysical log signatures response rather irregular shale and sand patterns. The gastropods and *Pediastrum* spp are dominantly present in place. According to the lithological, geophysical logs and palynology, it is suggested that this sedimentary unit was deposited under the relatively low flow regime of the marginal zone of lake on the lake–deltaic environment with influences of conglomerate from alluvial fan facies. This part is interpreted as lacustrine facies upon comparing with the lacustrine facies model of Visher (1965), Kukal (1971) and Picard & High (1972.).

Lying on top of the marginal lacustrine facies is the thick sequence mudstone facies with thickness varies from 10 to 40 metres. The gamma-ray log signatures represent shale line as irregular pattern. The lithological characteristics is considered to be deposited in a relatively low-energy condition of fresh water lacustrine environment. The top of mudstone is passing upward into the sequence of carbonaceous mudstone with coal bed with thickness is about 10 metres. The signature of density log clearly represents coal pattern. This lithological sequence is suggested to be deposited under the low energy condition of fresh-water peat-swamp environment. It is worth to note that, this sedimentary unit comprises of two cycles of fresh-water lake within the lower part and grading upward into peat-swamp environment in the upper part.

The uppermost part of the L2-unit is characterised by a thick sequence of mudstone with partly sandstone very fine- to fine-grained with thickness varies from 15 to 70 metres The gamma-ray log signature is represented as irregular shale-line pattern. According to the lithological and geophysical logs signature, it is suggested that this sedimentary unit was deposited under the relatively low-energy condition. It is interpreted as a product of sedimentary deposits of the fresh-water lake system, as shown in Figures 3.4.1.1, 3.4.1.2, 3.4.1.3 and 3.4.1.4. It is, interesting to note that, the presence of some thin sandstone intercalated in thick mudstone indicates the occasional influx of fluviatile sediments in to fine-grained fresh-water lake deposits.

The overall thickness of the unit varies from 50 to 160 metres thickening to the north and central parts within the study area.

3.4.5 Facies F3

The overlying unit of the fresh-water lake environment of facies L2 is represented by thick sequence of coarse -grained clastic sedimentary rocks of facies F3.

Generally, the lowermost part of facies F3, is displayed dominantly sequence of conglomerate with thickness of about 100 metres as shown in Figures 3.4.4.1 and 3.4.4.2. According to lithological and geophysical log signatures, it is suggested that this sedimentary unit was deposited under the relatively high energy condition. It is interpreted as the products of sedimentary deposits of proximal alluvial fan. The sedimentary facies of this lithological succession is equivalent to alluvial fan system when put in comparison with the alluvial fan model of Rust (1983) or also possible as a reworked braided fluviatile system (Miall, 1978).

Above the alluvial fan facies is the lithological unit of sandstone dominant with layers, previously mentioned, of mudstone and conglomerate interbedded. The electric log signature shows several cycles of fining upward sequence, beginning with conglomerate or coarse-grained sandstone with relatively abundant clay at the top of the cycle. The lithological and geophysical logs indicate that the whole succession of this unit was deposited in fluviatile environment of braided system as compared with the

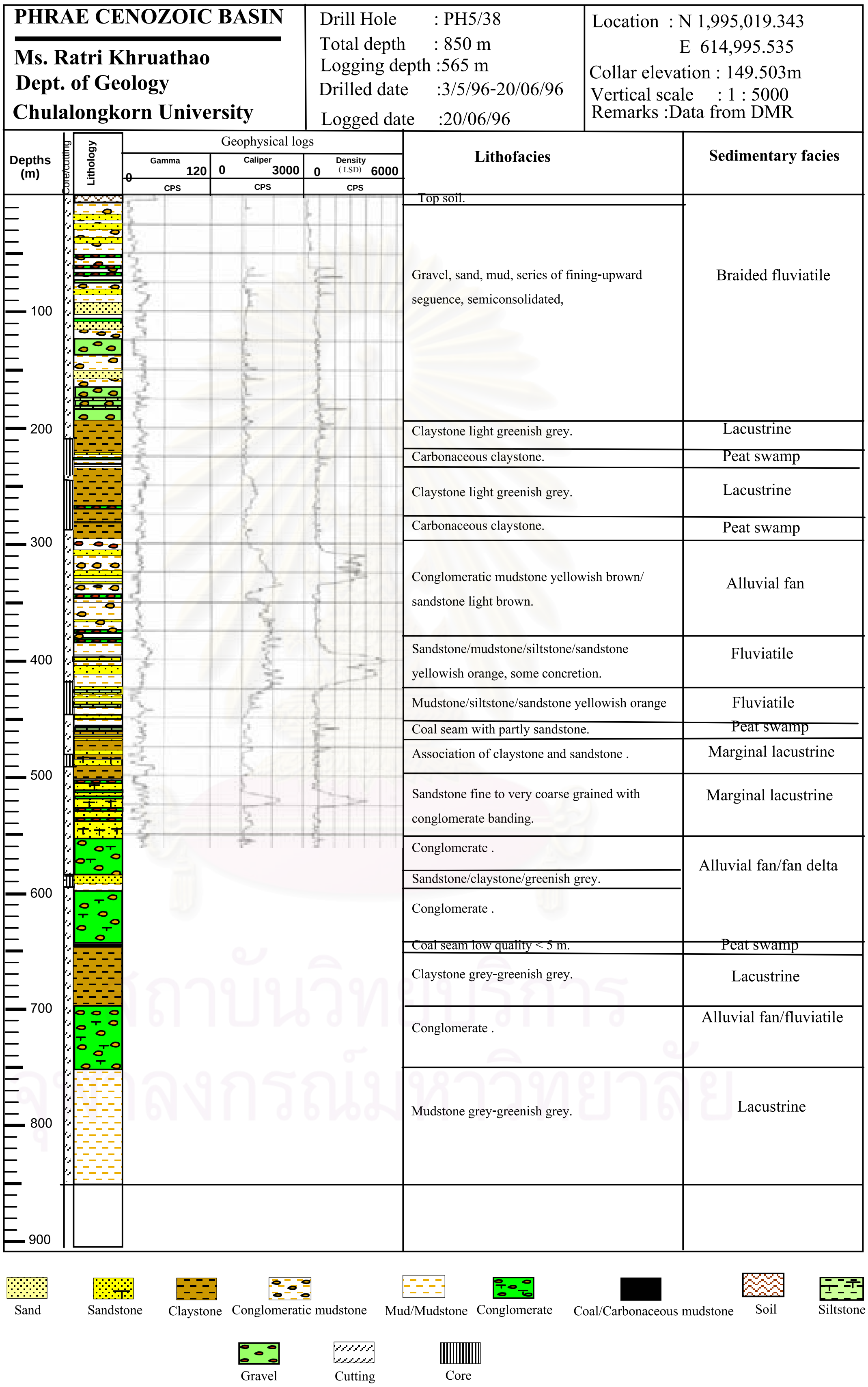

Figure 3.4.4.1 Summary sedimentary facies of drill-hole number PH5/38

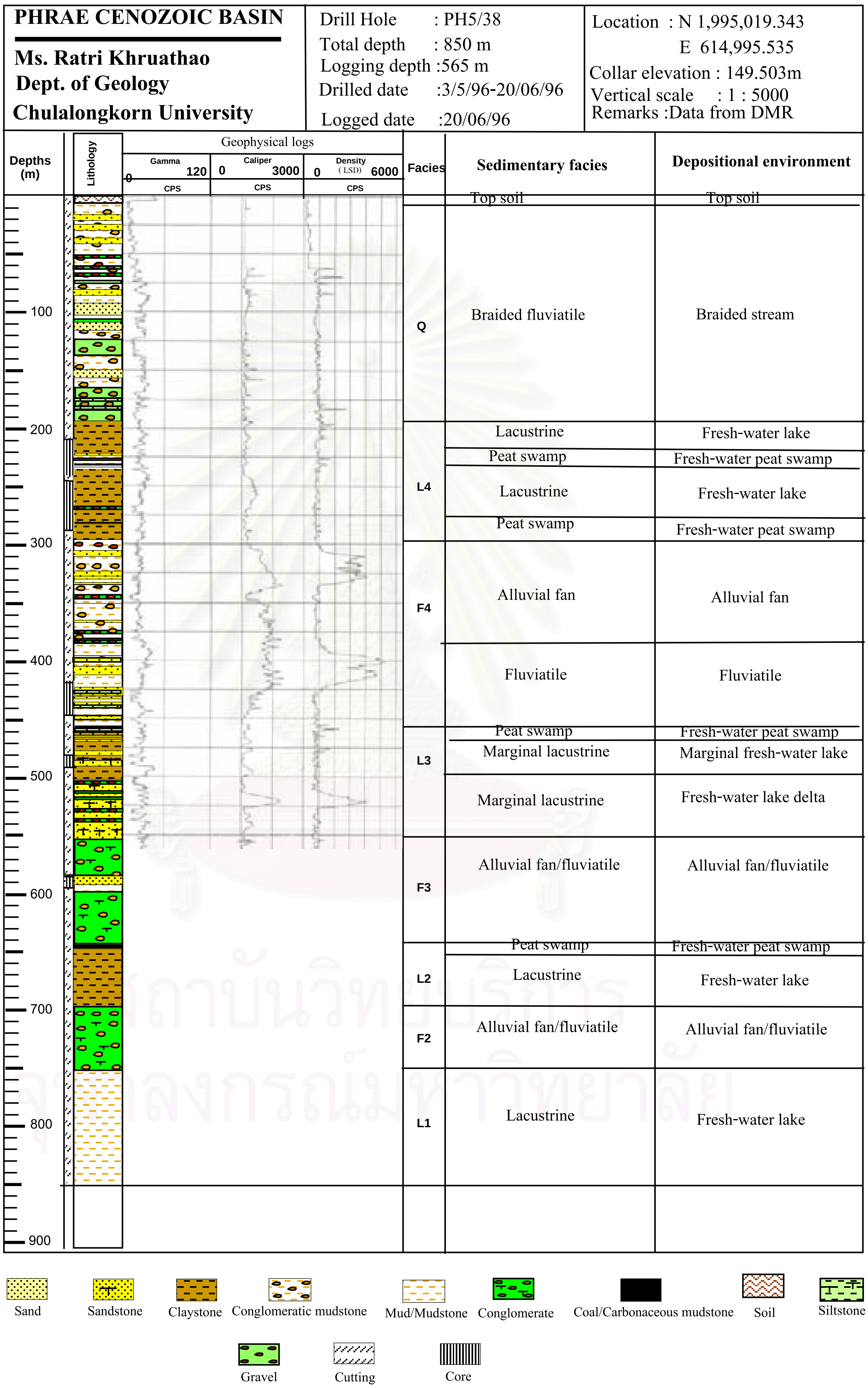

Figure 3.4.4.2 Summary of sedimentary facies and depositional environment of drill-hole number PH5/38

braided river depositional model of Donjek or South Saskatchewan types of Miall (1978). The lithological unit is the braided fluviatile facies, which was deposited under relatively steep slope, broad, shallow rivers with more steady discharge as shown in Figures 3.4.1.1, 3.4.1.2, 3.4.1.5 and 3.4.1.6

The sequence that laid down under the braided fluviatile system is consisting of thick sequence of coarse-grained clastic association of conglomerate and conglomeratic mudstone and sandstone, which thickness varies from 40 metres to 80 metres. The geophysical logs signature responses with irregular shapes and patterns. According to lithological and geophysical log signatures, it is suggested that this sedimentary unit was deposited under the relatively high energy condition. It is interpreted as a product of sedimentary deposits of alluvial fan system when put in comparison with the alluvial fan facies of Rust (1983).

The uppermost part of this unit is represented by interbedding of mudstone and siltstone bluish-grey to yellowish-orange in colour, with thickness of about 40 metres. The gamma-ray log signature exhibits the irregular shale line pattern. The lithological and geophysical log indicates that this unit was deposited under fluviatile environment. This conclusion is drawn from the comparison with depositional model of Allen (1964). The representative profile for this facies is shown in Figures 3.4.1.3, 3.4.1.4, 3.4.5.1 and 3.4.5.2.

The overall thickness of F3 unit varies in the range of 40 to 100 metres with the sequence thickening to the north.

3.4.6 Facies L3

The sedimentary sequence lying upper the fluviatile facies F2 is represented by thick unit of fine terrigenous sediments of Facies L3.

Generally, the lower part of this unit is characterised by a sequence of fine-grained clastic sedimentary rocks consisting of thick succession of dominant claystone, mudstone interbedded with fossiliferous claystone, and sandstone of medium-grained

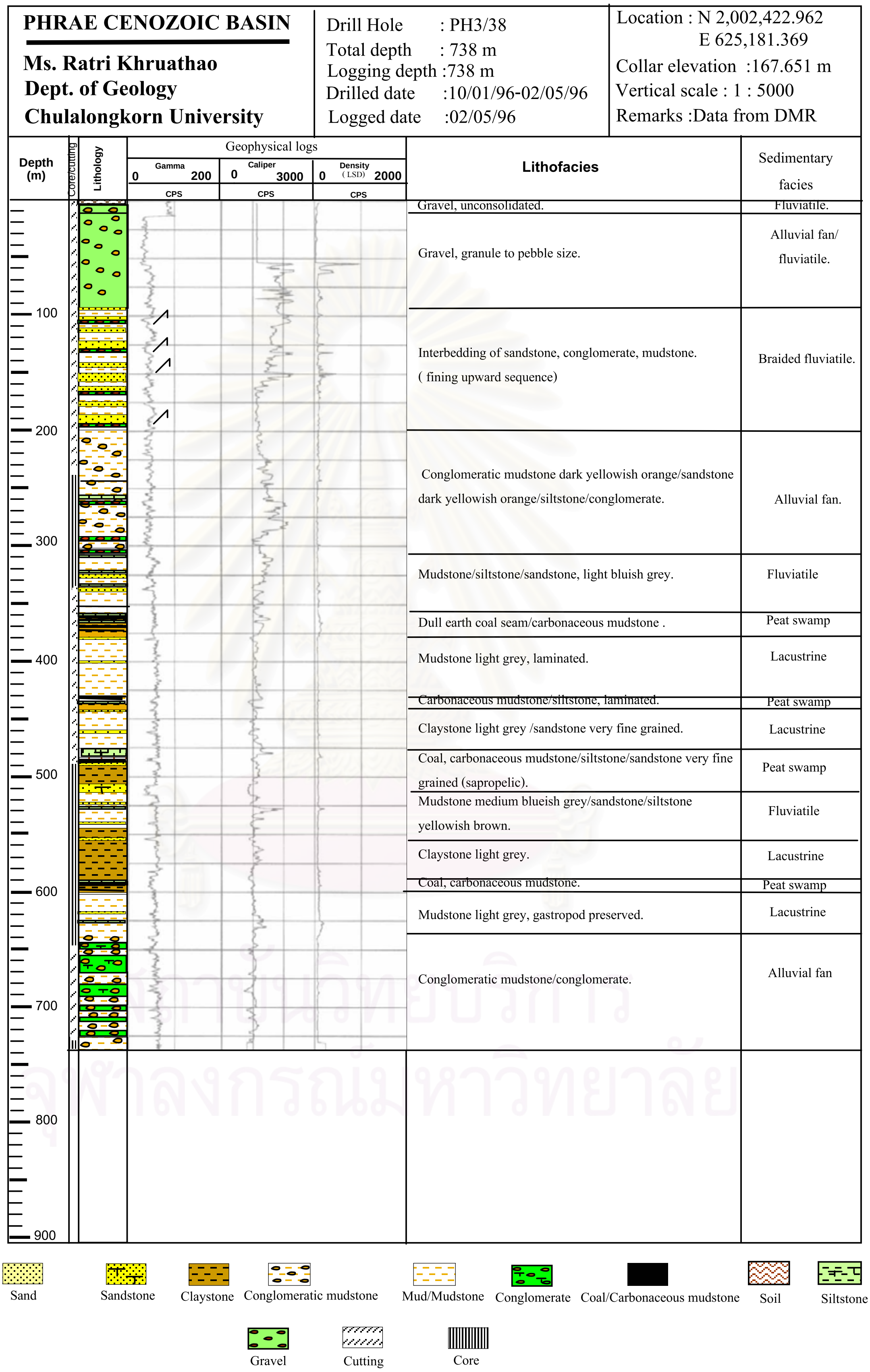

Figure 3.4.5.1 Summary sedimentary facies of drill-hole number PH3/38

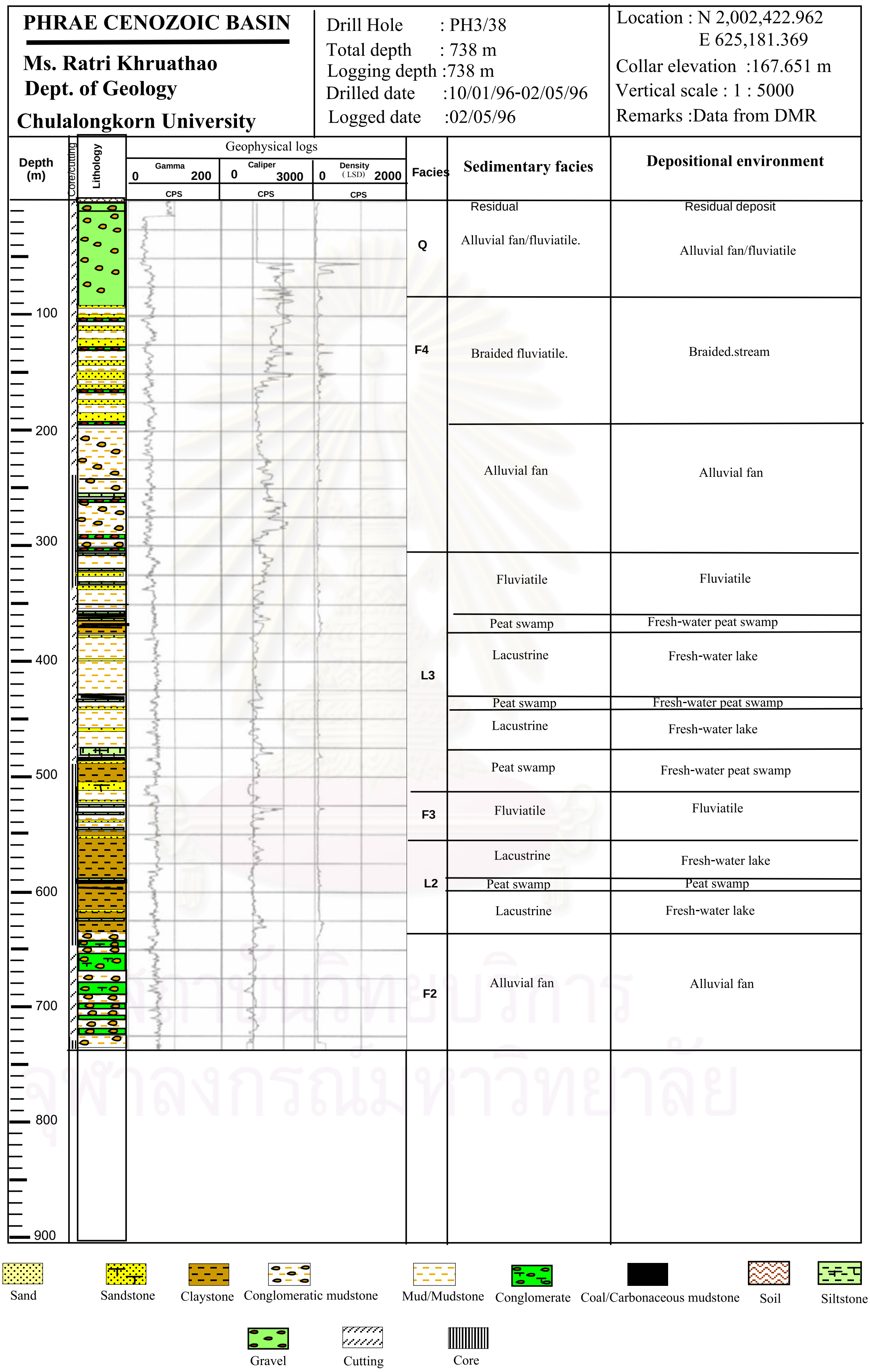

Figure 3.4.5.2 Summary of sedimentary facies and depositional environment of drill-hole No. PH3/38

with some laminated, is very fine to very coarse-grained sandstones lamination. The unit begins with the sequence of fine-grained clastic sedimentary rocks of mudstone with some beds of medium-grained clastics interrupted by very fine-grained sandstone. There are some conglomerates interbedding. This sedimentary unit varies in thickness from 40 to 150 metres. The geophysical log signature response rather irregular shale and sand patterns. The gastropods and *Pediastrum* spp are dominantly present in place. According to the lithological, geophysical logs and palynology, it is suggested that this sedimentary unit was deposited under a relatively high-flow regime of the marginal zone of lake on the lake–deltaic environment with some influences of conglomerate from alluvial fan facies. This part is interpreted as lacustrine facies based upon comparison with the lacustrine facies model of Visher (1965) Kukal (1971) and Picard & High (1972), as shown in Figures 3.4.4.1, 3.4.4.2, 3.4.6.1 and 3.4.6.2.

In the upper part of the L3-unit, the lithology is grading from coarse-to fine in the lower part and characterised by three repeating cycles of sedimentary deposits beginning with thick sequence mudstone, claystone of greenish grey, highly calcareous, thin bed to laminated, gastropods and bioturbated. The thickness varies from 10 to 100 metres, passing upward to the association of finer terrigeneous sediments including silt, carbonaceous mudstone and coal bed on the top. The thickness varies from 10 to 20 metres. The carbonaceous mudstone is greyish black. The coal is characterised by dull, brittle, thin bedded, varies from 0.1-0.7 metre. The geophysical log signatures are represent by irregular shale pattern as shown in Figures 3.4.6.3 and 3.4.6.4. The lithological characteristics and geographical log signatures indicated that this sedimentary unit was deposited under the relatively low-energy condition of fresh-water lake and grading upward into peat swamp environment, it is noted that there are three repeating cycles of fresh-water lake deposits grading to peat swamp deposits in this part.

The thickness of the L3-unit is relatively higher than the other fine-grained clastic units within the study area. The overall thickness varies within the range of 40 to 220 metres thickening toward the northern and central parts of the study area.

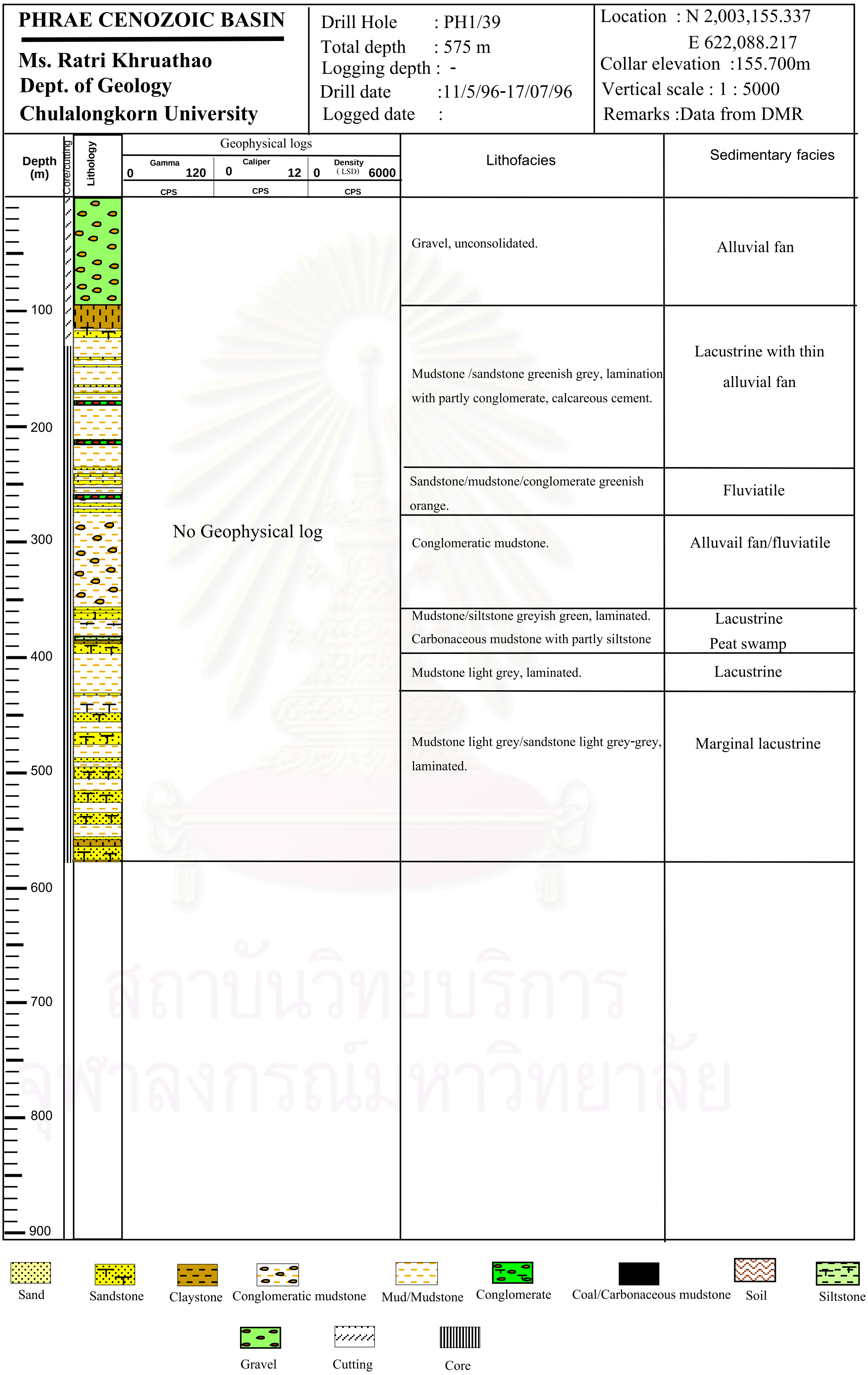

Figure 3.4.6.1 Summary sedimentary facies of drill-hole number PH1/39

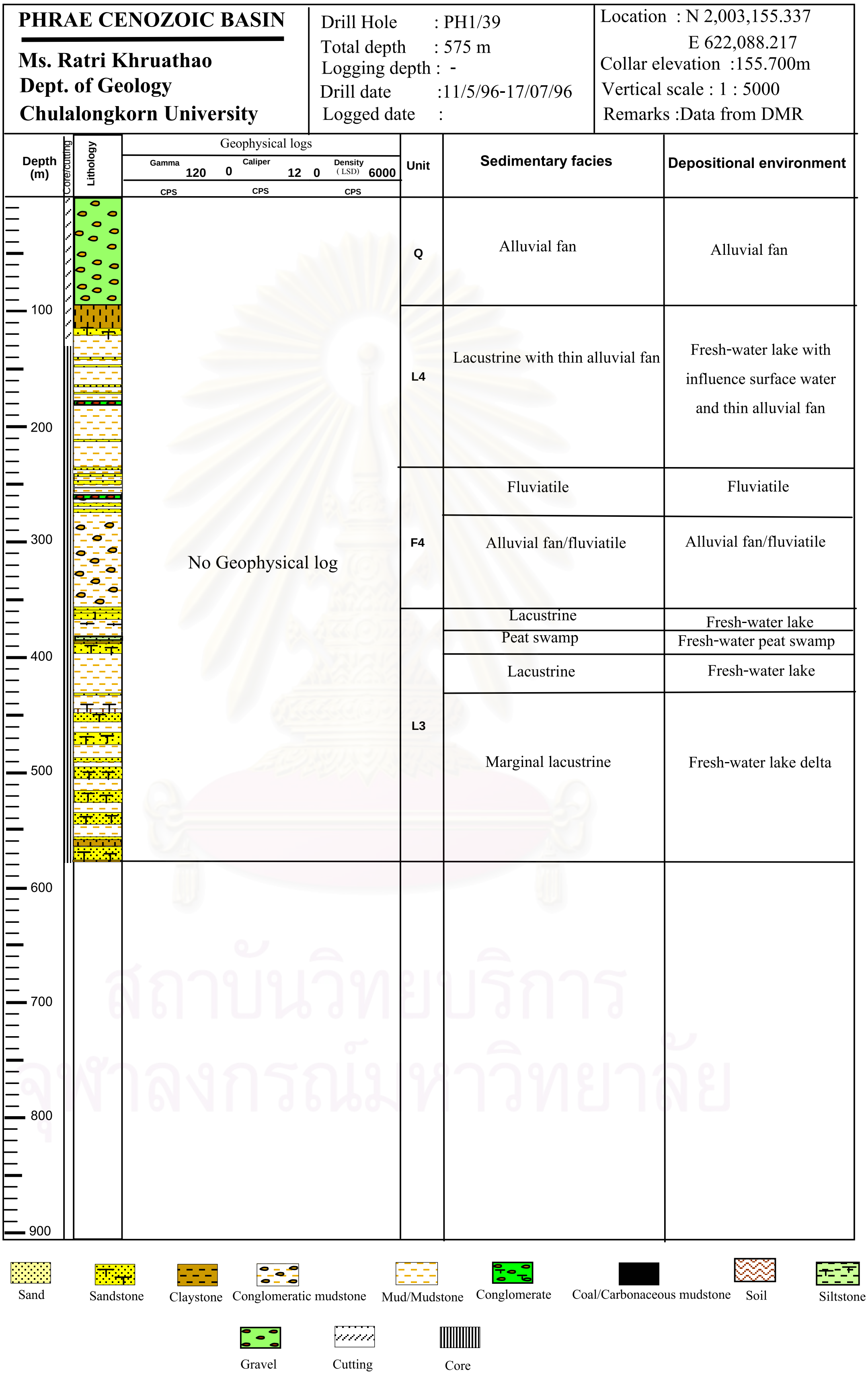

Figure 3.4.6.2 Summary of sedimentary facies and depositional environment of drill-hole number PH1/39

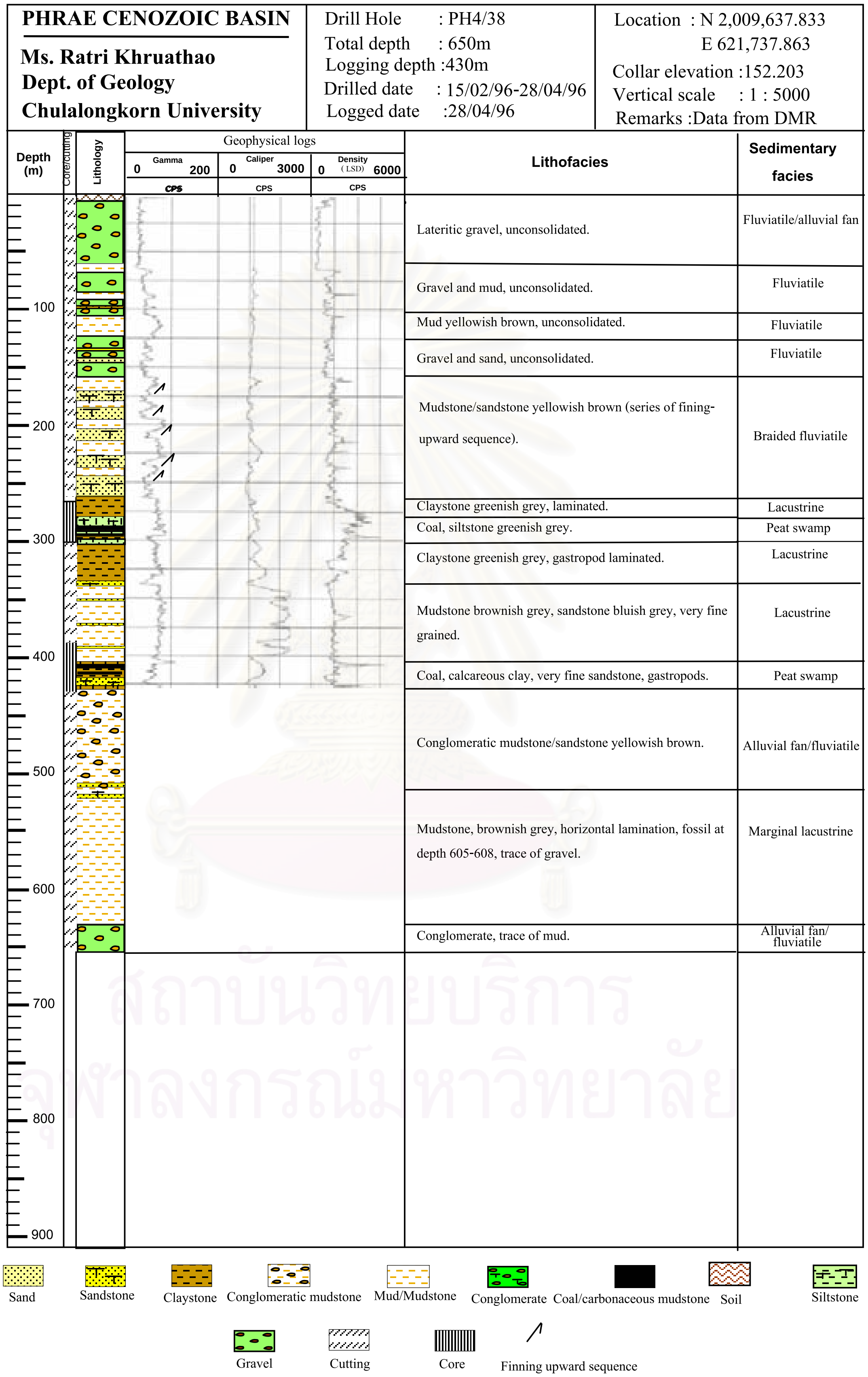

Figure 3.4.6.3 Summary sedimentary facies of drill-hole number PH4/38

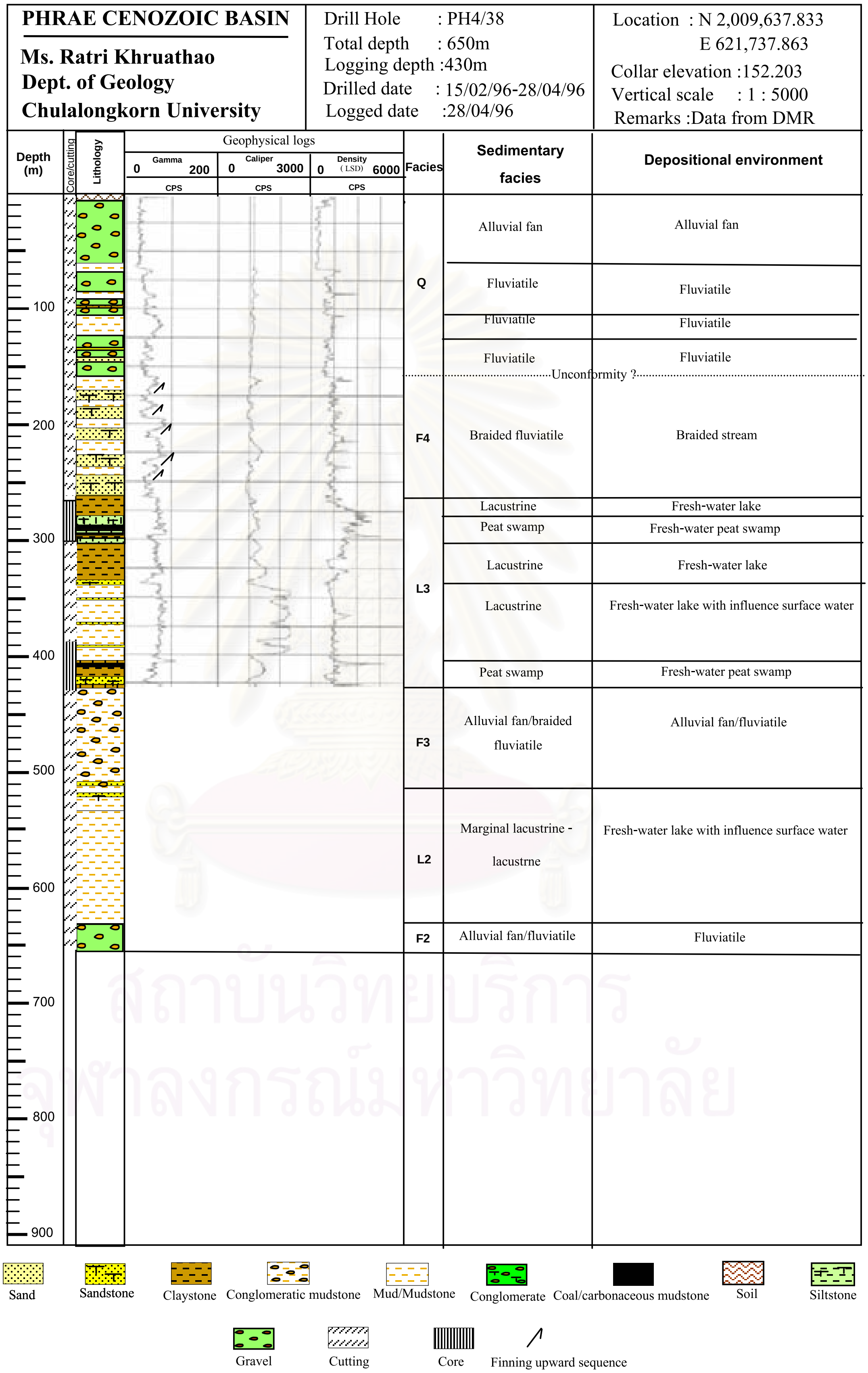

Figure 3.4.6.4 Summary of sedimentary facies and depositional environment of drill-hole number PH4/38.

3.4.7 Facies F4

Above the peat swamp facies is the sedimentary association of fine-to medium-grained clastic sediments, consisting of mudstone interbedded with siltstone, varying in colors, from yellowish brown to yellowish orange. The sequence is sandstone interbedded with mudstone and siltstone with the thickness of sandstone and siltstone varies from a few tens of centimetres to a few of metres with thickness varies from 50 to 70 metres and the gamma-ray log is represented by irregular shale pattern. This unit is considered to be deposited in fluviatile environment. This conclusion can be compared with depositional model of Allen (1964).

In the middle part of the unit, the lithology is consisting of thick sequence of coarse-grained clastic sedimentary rock of conglomeratic mudstone interbedded with conglomerate, and sandstone. The geophysical log signature exhibits with irregular shapes and patterns. The thickness varies from 35 to 100 metres. According to lithological and geophysical log signature, it is suggested that this sedimentary unit was deposited under the relatively high-energy condition. It is interpreted as the products of sedimentary deposits of proximal portion of alluvial fan system, when put in comparison with the alluvial fan facies of Rust (1983) or also possible as a reworked braided fluviatile system (Miall, 1978).

Above the alluvial fan facies is the sedimentary sequence of dominant sandstone interbedded with conglomerate and thin layers of mudstone. The thickness varies from 40 to 80 metres. The electric log signature shows several cycles of fining upward sequence beginning with conglomerate or coarse-grained sandstone at the base of cycles grading upward to relatively abundant clay at the top of the cycle. The lithological and geophysical log indicates that the whole succession of this unit was deposited under fluviatile environment of braided system as compared with the braided river depositional model of Donjek or South Saskatchewan types of Miall (1978). The lithological unit is therefore the braided fluviatile facies deposited under relatively steep slope, broad, shallow rivers with more steady discharge.

The uppermost part of the F4-unit represented is by interbedding of sandstone, mudstone, and siltstone, yellowsh orange with the gamma-ray log representing an irregular shale pattern This unit is considered to be deposited under fluviatile environment, This conclusion can be compared with depositional model of Allen (1964).

It is important to note that, the thickness of this unit varies from 50 to 335 metres thickening toward the northern and the eastern parts of the study area. The lithological sequence, sedimentary facies and reconstructed depositional system of the F4-unit, the lowest part of the sedimentary sequence within the study area presented as profiles in Figures 3.4.1.1, 3.4.1.2, 3.4.1.5, 3.4.1.6, 3.4.5.1 3.4.5.2, 3.4.6.3, and 3.4.6.4.

3.4.8 Facies L4

Conformably overlying the F4-unit is characterised by thick sequence of fine-grained clastic rocks of the L4 unit, showing repetition of two cycles of sedimentary deposits beginning with the association of fine terrigeneous sediments including silt, carbonaceous mudstone and coal bed with thickness varies from 10 to 20 metres, passing upward to thick sedimentary sequence of mudstone, claystone, greenish grey, highly calcareous, thin bedded to laminated, gastropods and bioturbated with thickness range from 20 to 140 metres. Generally, the carbonaceous mudstone is greyish black. The coal is characterised by dull, brittle, thin bedded, which thicknesses varies from 0.1-0.7 metre. The geophysical log signature is represented by irregular shale line pattern as shown in Figures 3.4.4.1, 3.4.4.2, 3.4.6.1 and 3.4.6.2. The lithological characteristics and geophysical log signature is indicated that this sedimentary unit was deposited in the relatively low-energy condition of fresh-water lake and grading into peat swamp environment. It is noted that the repetitions of two cycles of peat swamp environment passing into fresh-water lake are represented in this part.

The thickness of the L4-unit varies from 100 to 140 metres, from the marginal part to the central part of the basin within the study area.

3.4.9.Facies Q

The uppermost of the sedimentary succession of the southern part of the Phrae basin is represented by topsoil deposit with the association of very fine sand, silt and clay of lateritic in composition.

Under the topsoil deposit is the sedimentary association of clay and fine-to coarse-grained clastic sediments. The sediments are almost entirely represented by clay, very fine to very coarse sand with some pebbles, and are unconsolidated. The gamma-ray log signature represents irregular sand line pattern. This sedimentary unit is considered to be deposited under the high-energy condition. It is interpreted that they were deposited under the alluvial fan environment. This conclusion is drawn from the comparison with the alluvial fan facies of Rust (1983). Therefore, this lithological sequence is probably alluvial facies.

Below the alluvial fan facies is the lithological unit of dominant sand with layers of mud interbedding. The electric log signature shows several cycles of fining upward sequence with relatively abundant clay at the top of the cycle. The lithological and geophysical logs indicate that the whole succession of this unit was deposited in fluviatile environment of braided system as compared with the braided river depositional model of Donjek or South Saskatchewan types of Miall (1978). The lithological unit is the braided fluviatile facies which was deposited under relatively steep slope, broad, shallow rivers with more steady discharge. The thickness of this unit varies from 65 to 200 metres from the eastern to western parts of the study area.

Under the braided fluviatile facies is the sedimentary sequence consisted of sand silt, clay, soft and loose. The gamma-ray log represents an irregular shale line pattern. This unit is considered to be deposited in fluviatile environment, This conclusion is quite similar to deposition model of Allen (1964).

It is important to note that the overall thickness varies from 15 to 200 metres thickening to the northern part of the study area.

The lithological sequence, reconstructed depositional environment, and the Cenozoic sedimentary facies of the upper succession of the southern part of the Phrae basin are summarised and presented in Figure 3.4.9.1

3.5 Intrabasinal structures

The analysis of drill-hole data, seismic profiles as shown in Figures 3.2.4.2, 3.2.1.6, 3.2.7.1, and 3.2.7.2 and two way time-structural map as shown in Figures 3.2.2.3, 3.2.3.4, 3.2.5.2 and 3.2.6.4. In some areas of the Phrae basin have further revealed the detailed structures of the Cenozoic deposits. Under the present investigation, only the southern part of the Phrae basin has been selected to illustrate some intrabasinal structures.

For the southern part of the Phrae basin, the intrabasinal structure is mainly characterised by a series of north/northeast to south/southwest faults cross-cutting all the Cenozoic sequence but some of them cut through the basinal basement. These faults are mainly normal faults and block type.

The structural contour map of the upper surface of each sequence and seismic cross-section has been prepared to illustrate the intrabasinal structure. The density of the intrabasinal faults appears higher in the northern part of the study area whereas it consists of numerous of north/northeast-south/southwest trending faults that are eastern and western dipping faults with maximum displacement of these faults are about 200 metres, as compared with those in the southern end of the basin. A gentle syncline of north/northeast- south/southwest axis is present, extending towards north to northeast direction. The general structure dedicates relatively gentle deformation dipping angle of 5 to 10 degrees. There are some more details structural information on the Cenozoic deposits of the Phrae basin outside of the study area available .The present day study is aimed to investigating only the southern portion of the Phrae basin in older to produce some intrabasinal structural.

Age	Facies	Thickness(m) Hole no. ph- 5/38	2/39	1/38	1/39	3/38	4/38	2/38	Thick-ness(m)		Lithological description	Depositional-environment	Fossils
Neogene	Q	193	90	65	95	95	155	80	65 -200	60-193	Gravel/mud/lateritic gravel/sand : varied in colors yellowish brown, moderate brown-very pale orange, soft-loose.	Fluviatile environment	
										40-65	Gravel/sand/clay : fining upward sequence, loose.		
										20	Sand/silt/clay : varied in colors moderate, soft-loose.		
										35-90	Gravelsand : varied in colors yellowish brown, unconsolidated.		
	L4	100			140				100-140	20	Claystone: greenish grey, high plasticity.	Lake	
										10	Carbonaceous mudstone/sandstone: greenish grey- dark grey,	Peat swamp	
										50-140	Claystone: light greenish grey-dark grey, high plasticity.	Lake	
										20	Carbonaceous mudstone: greenish grey-dark grey,	Peat swamp	
	F4	150		50	120	335	100	100	50-335	15-20	Associate sandstone, siltstone, claystone yellowish orange,	Fluviatile environment	
										100	Conglomerate/sandstone/ mudstone : yellowish brown repeating of fining upward sequence.	Braided stream	
										35-100	Conglomeratic mudstone/sandstone/conglomerate : varied in colors yellowish brown-yellowish orange.	Alluvial fan	
										50-70	Associate sandstone, siltstone, claystone yellowish orange.	Fluviatile environment	
	L3	100	38	100	220+	150	170	140	40-220	20	Coal dull/carbonaceous mudstone greenish black	Peat swamp	*Liquidambarpollenites stigmosus*,
										10-50	Mudstone: greenish grey, laminae of coaly matter, gastropods preserved, bioturbation,calcareous nudules.	Lake	
										10-20	Coal dull/carbonaceous mudstone greenish black	Peat swamp	*Pediastrum* spp. *Botryococcus* spp
										40-100	Mudstone: greenish grey, laminae of coaly matter, gastropods preserved, bioturbation, calcareous nudule.	Lake	
										10-30	Coal dull/carbonaceous mudstone greenish black	Peat swamp	*Acacia type* , *Liquidambarpollenites stigmosus*,
										30-35	Mudstone: greenish grey, laminae of coaly matter, gastropods preserved, bioturbation, calcareous nudules.	Lake	
										40-150	Associated sandstone mudston :light greenish grey, very fine to fine sand, biotubation, calcareous concretion.	lake margin	*Pediastrum* spp. *Botryococcus* spp
	F3	100	80	80		40	90	40	40-100	40	Associate sandstone, siltstone, claystone yellowish orange	Fluviatile environment	
										40-90	Conglomeratic mudstone/sandstone/conglomerate : varied in colors yellowish brown-yellowish orange.	Alluvial fan	
										40-80	Conglomerate/sandstone/mudstone : yellowish brown repeating of fining upward sequence.	Braided stream	
										100	Conglomerate consist of quartz, phyllite fragment granule to pebble size, poor sorted, subangular.	Alluvial fan/ fluviatile environment	
	L2	60	125	160		80	110	110	50-160	15-70	Mudstone/claystone: greenish grey, laminae of coolly matter, gastropods preserved, bioturbation, calcareous nudules.	Lake	
										10	Coal dull/carbonaceous mudstone greenish black	Peat swamp	*Camptostemon* type, *Polygonum* type,
										15-20	Mudstone/claystone: greenish grey, laminae of coolly matter, gastropod preserved, bioturbation, calcareous nudule.	Lake	
										10	Coal, dull/carbonaceous mudstone greenish black.	Peat swamp	*Eugeissona miner* type, *Florschuetzia semilobata*
										40	Mudstone/claystone: greenish grey, laminae of coolly matter, gastropods preserved, bioturbation,calcareous nudule.	Lake	
										30-70	Sandstone associated with mudstone, siltstone :light greenish grey,very fine to fine sand, small bioturbation, calcareous concretion.	Lake delta	
	F2	50	100	65		100+	30+	60	30-100	50-60	Sandstone/conglomerate/mudston : yellowish brown-yellowish orange, poor sorted, subangular to subround, fining-upward sequence.	Braided stream	
										15	Mudstone/siltstone/sandstone very fine-grained: brown.	Fluviatile environment	
										90-100	Conglomeratic mudstone consist of quartz, phyllite fragments granule to pebble size, poor sorted, subangular.	Alluvial fan / fluviatile environment	
										50	Conglomerate consist of quartz, phyllite fragment granule to pebble size, poorly sorted, subangular, sand parting.		*Cephalomappa* type, *Echitriporites spinosus* , *Perfotricolpites digitatus*, *Florschuetzia semilobata*
	L1	100+	75	35	-	-	-	20	20-100	10	Carbonaceous mudstone/siltstone/sandstone (sapropelic)	Peat swamp	*Acacia type* , *Pediastrum* spp. *Botryococcus* spp
										35-100	Mudstone : light grey-greenish grey, laminae of coaly matter, gastropod preserved, highly sheared.	Deep lake	*Polygonum type*,
										65	Mudstone/siltstone/sandstone: light grey-greenish grey, partly conglomerate and sandstone.	Lake margin with thin fan	*Acrostichum aureum type*, *Terminalia type* *Leiospheridia spp*
	F1	-	34+	60+				80+	30-80+	34-40	Conglomeratic mudstone, clasts consist of quartz, phyllite fragments with granule to pebble size, poorly sorted, subangular.	Alluvial fan / fluviatile environment	
										40-60+	Conglomerate consist of quartz, phyllite fragment granule to pebble size, poorly sorted, subangular, sand parting		
											?-unknown	Fluvial?	
Pre-Tertiary											Silurian -Triassic basement.		

Figure 3. 4.9.1 Proposed depositional environment of the upper succession of Phrae Cenozoic basin in northern Thailand

3.6 Geological Resources

3.6.1 Coal

It is the known fact that a sedimentary basin is an area of the earth's crust that is underlain by the thick sequence of sedimentary rocks and possible associated geological resources. In Thailand coal commonly occurs in sedimentary basins which is absent from intervention of igneous and metamorphic rocks.

An attempt has, therefore, been made in the present study to focus some detailed study on the coal in the Cenozoic sedimentary sequence of the Phrae basin

The coal beds in the Phrae basin are relatively thin and their thicknesses are variable. Four coal beds including carbonaceous mudstone have been revealed from by drilling exploration. They were associated with the facies L1, L2, L3 and L4. Relatively thick coal beds of less than 2 meters in thickness occur in L2 and L3, in the western side of the basin. From the lithofacies analysis of each drill-hole it is interpreted that the coal beds were deposited in shallow lacustrine and peat swamp facies.

The core samples, which were collected from relatively thick coal bed, were analysed. Based on the analytical results, the general coal quality of the Phrae basin seems to be of high ash (26.8-61.1), high sulphur (3.67-8.94) and low heating value (1460-4090) (DMR, 1997) ash analysis indicates that the Fe_2O and CaO contents are relatively high, probably due to the sedimentary environments of high temperature and precipitation of Fe^{3+} and $Ca^{2+.}$ Also high ash and sulphur contents in coal mean their concentration from the result of strong decomposition of original peat under the environments of high temperature and dry climate. The coal rank has been determined as lignite. The results of the analysis are shown in Appendix

3.6.2 Clay minerals

From the drill-hole data, The potential clay minerals in the Phrae basin are associated with coal beds as underclays or between coal beds or the so called ball clay.

The thickness varies from 2 to14 metres, and the depth of deposit varies from 110 metres up to 550 metres. This clay deposits are generally classified as plastic to semi-plastic clay which are useful in ceramic industry. From the result of depths it is noted that the unit of clay deposit is too deep to be exploited for industrial clay.

CHAPTER IV

TECTONIC SEDIMENTATION AND BASIN EVOLUTION

From the analyses of subsurface geological data of the Phrae basin in terms of lithofacies, and environment of deposition, it is apparent that factors controlling deposition may be considered to have operated on two scales. The first one is a larger one on basinal scale, and the second one is smaller one on intrabasinal scale. On a basinal scale, sedimentation seems to have been controlled by a combination of structurally and compactionally induced subsidence, and depositional environment. On an intrabasinal scale, the post–depositional gravity faulting seems to have been controlled by a combination and extensional tectonic regime.

The evolution of the Phrae basin was initiated by the remnants of subtle graben style topographic low created by activation or reactivation of structural weaknesses. The two major fault-zones marking the boundary are parallel to the Uttaradit fault-zone in the northeast-southwest direction. These basinal faults were developed during the middle to the late Eocene Epoch as the result of the collision of Eurasia with Indian plate. The rate of subsidence, rate of deposition and depositional environment of the Phrae basin are controlled by the basinal faults. Beside, the basinal subsidence has strongly influenced on the thickness of sediments infilled.

The basin was formed as narrow and elongated northeast-southwest trending in-which the depocentre had changed from the western part in the early stage to the eastern part in the late stage during the development of the basin. So that in the early stage in the western part was undergone stronger subsidence than the eastern part. The synthetic, antithetic faults and the rollover anticline that were affected by syn-depositional tectonic movement still appeared as shown in Figure 3.2.4.2.

The intrabasinal faults are analysed in terms of syn-depositional and post–depositional faults with respect to various lithological sequences concerned. The intrabasinal fault has a direct effect on local subsidence, which indirectly controlled the nature of depositional environment, thickness of lithofacies, lithological characteristics.

After the tectonic activities especially faulting which marked the formation of the Phrae basin, the area continued to be tectonically active throughout Cenozoic Era as evidenced from the relatively thick succession in the basin and numerous of intrabasinal faults. The total thickness of the sedimentary sequence within the basin is approximately 1.5 kilometres as revealed by of the seismic survey data. From the detailed study and evidence from *Pediastrum* spp (the fresh water lacustrine algae) in the upper succession of the Phrae basin, the sediments in the Phrae basin are mainly non-marine clastics.

The palynological data suggested that the sedimentary sequence of the Cenozoic Phrae basin within the study area down to the depths of 850 metres was probably developed in the Early Miocene age as evidenced from *Florscheustia trilobata* and *Florscheudtia semilobata.*

Lithological data from the drilling exploration coupled with drill-hole geophysical data and the seismic data have led to the interpretation of sedimentary environments. There were possibly five tectonic events that caused movements during the evolution of the Phrae basin. This is suggested by five depositional cycles that are recognisable in the sedimentary succession and from seismic data characters.

The first depositional cycle is the lowermost part within the study area where sediments are represented by alluvial fan facies associated with braided fluviatile facies. The sequence is generally characterised by the association of coarse-grained and medium-grained clastic sediments of high energy. The basal conglomerate is well developed throughout the basin. It is interpreted that this unit was developed under the renewed tectonic activities, which led to the expression of positive features at the margin of the basin, reactivation of tilted faults. With respect to the surficial deposit, they indicate that the tectonic activity is still active nowadays. The western part of the Phrae basin is the relatively deeper depression zone as compared with the other areas. Towards the top of the sedimentary sequence, there was the wide spread of the relatively thick sequence of lacustrine sedimentary facies, believed to be associated with the increases structural activities, especially the reactivation of existing major faults, which culminated a depression of limnic condition. The sedimentary sequence deposited during this period is characterised by fine-grained clastics, coal and carbonaceous mudstone. It is interesting to note that, from the first sedimentary cycle in the lower part of the sedimentary succession up to the forth sedimentary cycle are the repeating cycle of fluvio-lacustrine facies in alternation with alluvial fan facies within the study area, the depositional cycle was initially dominated by alluvial fans, fluviatile environment changed to lake margin in which mudstone partly with sandstone and conglomerate, to deep lake environment in which gastropods are very common and changed to peat swamp. The broad pattern of sedimentary facies of the Cenozoic sequence within the basin reveals that the facies are generally widespread through out the basin. On the topmost part of this sequence the fifth part of sedimentary cycle of fluviatile environment were deposited. These lines of evidence indicate that the major faults in both western and eastern margins have been intermittently reactivated throughout the basin filled history.

Besides, the sedimentation pattern, sedimentary environment and sedimentary facies of the Cenozoic sequence are further complicated by a series of intrabasinal faultings both syn-post-depositional origins induced by the activities especially of growth faults. Local subsidence and uplifting are also recognised from the pattern vertical and lateral facies changes, which are believed to be partially responsible by the differential, post-depositional, compactional induced subsidence, and tectonic faulting.

In conclusion, amongst one of the important controlling factors on sedimentation is the faulting and/or subsidence of both tectonically controlled and compactionally induced origins. The geological evolution of Phrae basin in terms of tectonic sedimentation is summarised and presented in Table 4.1

Table 4.1 Tectonic sedimentation of the upper sucession of the Phrae basin (cont.)

Tectonic activities	Sedimentation / Erosion	Facies	Thick-ness(m)	cycles
Slow subsidence	Sedimentation under fluviatile condition	Fluviatile		5
Rapid subsidence due to faulting	Alluvial fan sedimentation	Alluvial fan	15-200	
Rapid subsidence due to faulting	Sedimentation under fresh- water lake condition	Lacustrine	20	4
Moderate subsidence	Formation of the moderately-subsiding peat swamp silting up of the lake	Peat swamp	10	
Rapid subsidence due to faulting	Sedimentation under fresh- water lake condition	Lacustrine	50-140	
Moderate subsidence	Formation of the moderately-subsiding peat swamp silting up of the lake	Peat swamp	20	
Slow subsidence	Fluviatile sedimentation	Fluviatile	15-20	
Slow subsidence	Fluviatile sedimentation under braided stream	Braided fluviatile	100	
Rapid subsindence due to faulting	Alluvial fan sedimentation	Alluvial fan	35-100	
Slow subsidence	Fluviatile sedimentation	Fluviatile	50-70	

Table 4.1 Tectonic sedimentation of the upper sucession of the Phrae basin (cont.)

Tectonic activities	Sedimentation / Erosion	Facies	Thick-ness(m)	cycles
Moderately subsidence	Formation of the moderately-subsiding peat swamp	Peat swamp	20	3
Moderately subsidence	Sedimentation under fresh- water lake condition	Lacustrine	(10-50)	
Moderately subsidence	Formation of the moderately-subsiding peat swamp	Peat swamp	(10-20)	
Rapid subsidence due to faulting	Sedimentation under fresh- water lake condition	Lacustrine	(40-100)	
Moderately subsidence	Formation of the moderately-subsiding peat swamp	Peat swamp	(10-30)	
Moderately subsidence	Sedimentation under fresh- water lake condition	Lacustrine	(30-35)	
Rapid subsidence due to faulting	Sedimentation under fresh- water lake condition with the association of marginal lacustrine character of sand layer	Lacustrine	10-150	
Slow subsidence	Fluviatile sedimentation	Fluviatile	40	
Rapid subsidence due to faulting	Alluvial sedimentation	Alluvial fan	40-90	
Slow subsidence	Fluviatile sedimentation under braided stream	Braided fluviatile	40-80	
Rapid subsidence due to faulting	Alluvial sedimentation	Alluvial fan	100	

Table 4.1 Tectonic sedimentation of the upper sucession of the Phrae basin (cont.)

Tectonic activities	Sedimentation / Erosion	Facies	Thick-ness(m)	cycles
Rapid subsidence due to faulting	Sedimentation under fresh- water lake condition	Lacustrine	70	2
Moderately subsidence	Formation of the moderately-subsiding peat swamp silting up of the lake	Peat swamp	10	
Moderately subsidence	Sedimentation under fresh- water lake condition	Lacustrine	15-20	
Moderate subsidence	Formation of the moderately-subsiding peat swamp silting up of the lake	Peat swamp	10	
Moderate subsidence	Sedimentation under fresh- water lake condition	Lacustrine	40	
Rapid subsidence due to faulting	Sedimentation under fresh- water lake condition with the association of marginal lacustrine character of sand layer	Lacustrine	30-70	
Slow subsidence	Fluviatile sedimentation under braided stream	Braided fluviatile	60	
Slow subsidence	Fluviatile sedimentation	Fluviatile	15	
Rapid subsidence due to faulting	Alluvial fan sedimentation	Alluvial fan	50-100	

Table 4.1 Tectonic sedimentation of the upper sucession of the Phrae basin (cont.)

Tectonic activities	**Sedimentation / Erosion**	**Facies**	Thick-ness(m)	cycles
Moderate subsidence	Formation of the moderately-subsiding peat swamp	Peat swamp	10	**1**
Rapid subsidence due to faulting	Sedimentation under fresh- water lake condition	Lacustrine	35-100	
Rapid subsidence due to faulting	Sedimentation under fresh- water lake condition the association of marginal lacustrine character of sand layer	Marginal Lacustrine	65	
Block-faulting and the formation sub-basin	Brosion of basement rocks/Alluvial sedimentation	Unconformity / Alluvial fan	80+	

CHAPTER V

CONCLUSION

Previous investigations in the Phrae basin have been carried out for decades. Most previous works aimed at investigating the potential of coal and petroleum (DMR, 1967 and 1970; Piyasin, 1972; Austhai, 1976; Maneenai and others, 1987; PTT, 1992, Ban Pu, 1994; DMR, 1995). This research has paid particular attention to study detail lithofacies in terms of characterisation and classification. Due to the limitation of subsurface data, the attention in this research has only emphasised on the upper succession of the Phrae Cenozoic basin. The result of this research shows the more understanding in the evolution of the basin using those lithofacies classification and interpretation.

Phrae basin is an intermontane basin located in Changwat Phrae, northern Thailand. The importance of the Phrae basin is basically owing to coal deposits, which has been explored by private companies and the Department of Mineral Resources. The area has been selected for the present study under reason that the Phrae basin has been partially explored notably, drilling exploration, geophysical exploration so that the subsurface geological information are available for detailed study.

The study area is mainly confined within the southern part of the basin covering an area of approximately 300 square kilometres with altogether 12 drill-holes of depth range from 354 to 850 metres, the drill-hole data is supplemented with wireline geophysical logs of the following parameters, namely, gamma ray log, caliper, and density. Besides, there is altogether 156 line– kilometres from 9 survey lines of seismic reflection survey data, the palynoflora study supplied by the PTT Exploration & Production Plc. with emphasis on the geological age determination is available for the present study and analytical results of 10 samples coal.

The scope of the present investigation covers the preparation of the geological map of the basin and neighboring area, the drill-chart of 12 primary reference drill-holes including the detailed examination of core samples logical, 4 geological cross-sections, 4 two-way time structural contour maps, 1 fence diagram and several lithostratigraphic columns have been prepared to serve as the baseline information for the analysis of Cenozoic sedimentary sequence in the Phrae basin.

It is concluded that the Phrae basin began to from Early Miocene time by the relative movement of the Mae Ping fault zone and the Uttaradit fault zone respectively to the order of time. This is mainly due to the fact that the Cenozoic period marked the resume instability of block and strike-slip faulting. The collision of India and Eurasia plates during the Himalaya Orogeny in Eocene to Early Miocene is regarded to be responsible for the formation of grabens in the northern part of Thailand which are expressed geomorphologiacally as intermontane basin.

The Phrae basin is considered to be an intracratonic basin where sedimentary sequence in this basin records initial isostatic subsidence followed by a thick sedimentary-infill history. Based on the seismic survey data, the total thickness of the sedimentary sequence within the basin is approximately 1,500 metres

The study area is focussing upon the upper sedimentary succession of the southern part of the Phrae basin. Evidences from the subsurface exploration and palynology data indicate that the oldest sediments is of Neogene age as deduced from *Florscheustia trilobata* and *Floscheutia semilobata*. The Cenozoic sedimentary sequence in the basin is entirely non-marine clastics as evidenced from *Pediastrum* spp (the fresh-water lacustrine algae) with total thickness of approximately 850 metres in the deepest drill-holes of the study area.

The Cenozoic sequence can be generally subdivided into nine main units. The lowermost unit is represented by alluvial fan facies/fluviatile facies. Lithologically, the unit beginning with conglomerate at the base and passing upward into conglomeratic mudstone.

The second unit lies unconformably on the lowermost unit of the thick sequence of mudstone with some conglomerate content, it is the product of fresh-water lake with some influence of alluvial fan facies evidenced from conglomerate. The upper part of this unit is consisting of carbonaceous mudstone and coal bed, this part was deposited in the relatively low-energy condition of peat swamp environment of the marginal subfacies of lacutrine facies, some influences of alluvial fan facies are present in this subunit.

The third unit is characterised by the thick sequence of conglomerate and passing upward to conglomeratic mudstone interbedding with sandstone and conglomerate, this part was deposited in the high-energy condition of alluvial fan environment/fluviatile environment. Above the alluvial fan facies is represented by the lithological unit of mudstone interbedded with siltstone and sandstone, this unit was deposited under the fluviatile environment. The uppermost part of this unit is characterised by the lithological unit of sandstone dominated with conglomerate and layers of clay interbedding. This part is believed to be the product of braided fluviatile system.

The forth unit lies conformably on the third unit with an abrupt change in lithological characteristics to mainly fine-grained clastic sedimentary rocks of marginal lacustrine facies and interrupted by some conglomerates of alluvial fan facies. Laid on the top of the marginal lacustrine facies is the sedimentary unit comprising of two cycles of fresh-water lake deposits, characterised by thick sequence of mudstone within the lower part and grading upward in to peat-swamp deposits characterised by the sequence of carbonaceous mudstone with coal bed on the upper part. The uppermost part of the second unit characterised by a thick sequence of mudstone with partly sandstone, it is believed to be the product of sedimentary deposits of influx of fluviatile sediment into fine-grained fresh-water lake deposit.

The fifth unit characterised by sequence of conglomerate of alluvial fan system/fluviatile system above the alluvial fan system is the lithological unit of sandstone dominated with the layers of mudstone and conglomerate interbedded. This unit was deposited in braided fluviatile environment. The sequence that laid down upon the braided fluviatile system is consists of thick sequence of coarse-grained clastic sedimentary rocks of conglomerate and conglomeratic mudstone and sandstone. They are the products of sedimentary deposits of proximal alluvial fan system. Interbedding of mudstone and siltstone of fluviatile deposit represent the uppermost part of this unit.

The sixth unit overlies conformably the fifth unit. Lithologically, the lower part of the unit is characterised by thick sequence of claystone with some beds of medium-grained clastics. There are some conglomerates interbedding with this sedimentary unit. This sedimentary unit was deposited under a relatively upper flow regime of marginal zone on lake-deltaic environment with some influences of conglomerate of alluvial fan facies. The upper part of the sixth unit, the is characterised by repeating of three-cycles of sedimentary deposits beginning with thick sequence mudstone, claystone passing upward into the association of finer terrigeneous sediments including silt, carbonaceous mudstone and coal bed, it is noted that, there are three repetitions of fresh-water lake deposit and grading to peat swamp deposits in this part.

The seventh unit overlies conformably the sixth unit. Lithologically the unit is characterised by fine-to medium-grained clastic sediments, consisting of mudstone interbedded with siltstone, the unit is considered to be deposited in fluviatile environment. In the middle part of this unit, the lithology is consisting of thick sequence of coarse-grained clastic sedimentary rock of conglomeratic mudstone interbedded with conglomerate and sandstone. There are the products of sedimentary deposits of proximal alluvial fan system. Above the alluvial fan facies is the sedimentary sequence of dominant sandstone interbedded with conglomerate and thin layer of mudstone, this part is the braided fluviatile facies. Interbedding of sandstone, mudstone and siltstone of fluviatile facies represent the upper most part of the seventh unit.

The eighth unit, underlies Quaternary alluvial deposits which is characterised by the thick sequence of fine-grained clastic rocks, showing repetition of two cycles of sedimentary deposits beginning with the association of fine terigeneous sediments including silt, carbonaceous mudstone and coal bed, passing upward to thick sedimentary sequence of mudstone and claystone. It is not that, there are two repetitions of peat swamp deposits passing into fresh-water lake deposit in this part.

The topsoil deposit with the association of very fine sand and lateritic soils represents the uppermost sedimentary unit. Under the topsoil is the association of sedimentary unit of clay and fine-to coarse-grained clastic sediments. The sediments are represented by unconsolidated clay with some pebbles. It is the products of alluvial fan. Below the alluvial fan facies is the lithological unit of dominant sand with interbedding layer of mud, this unit was deposited under the fluviatile environment of braided system. Under the braided fluviatile facies is the sedimentary association of sand, silt and clay, this part is the product fluviatile environment.

The sedimentary sequence of the Cenozoic Phrae basin within the study area has been classified into five depositional cycle of fluvio-lacustrine facies from the lower part towards to the top of the basin as shown in Table 4.1. Each depositional cycle was initially dominated by alluvial fans, fluviatile environment, changed to lake margin in which mudstone partly with sandstone and conglomerate, to deep lake environment and changed to peat swamp. The lower part of the succession is thickening westwardly, whereas the upper part of the succession is thickening eastwadly

The coal beds in the Phrae basin are relatively thin and their thicknesses are variable. Drilling exploration has revealed four coal beds including carbonaceous mudstone. They were associated with the facies L1, L2, L3 and L4. A relatively thick coal bed of less than 2 metres thick occurs in L2 and L3, in the western side of the basin. The coal samples collected from relatively thick coal bed were analysed. The general coal quality of the Phrae Basin seems to be high ash 26.80-61.1), high sulphur (3.67-8.94) and low heating value (1460-4090) (DMR, 1997) as shown in Appendix

The potential clays minerals in the Phrae basin are associated with coal beds as underclays or between coal beds The thickness varies from 2 to14 metres, and the depth of deposit is varies from 110 metres up to 550 metres. These clay deposits are generally classified as plastic to semi-plastic clay, which are useful for ceramic industry.

The basin form is narrow and elongated in the northeast-southwest trend with the change in depocentre during Neogene deposition from the western part in the early stage to the eastern part in the late stage. In the early stage in the western part was more relatively stronger subsided than the eastern part. The intrabasinal faults are analysed in terms of syn-depositional and post–depositional faults with respect to various lithological sequences concerned. The intrabasinal fault has a direct effect on local subsidence, which indirectly controlled the nature of depositional environment, thickness of lithofacies, lithological characteristics.

Lithological data from the drilling exploration coupled with drill-hole geophysical data and the seismic data have led to the interpretation of sedimentary environments. There were possibly five tectonic events that caused movements during the evolution of the Phrae basin. This is suggested by five depositional cycles that are recognizable in the sedimentary sequence and from seismic data characters. It is noted that, from the first sedimentary cycle in the lower part of the sedimentary succession up to the forth sedimentary cycle are the repeating cycles of fluvio-lacustrine facies within the study area, the depositional cycle was initially dominated by alluvial fans, braided stream, changed to lake margin in which mudstone partly with sandstone and conglomerate, to deep lake environment in which gastropods are very common the broad pattern of sedimentary facies of the Cenozoic sequence within the basin reveals that the facies are generally widespread through out the basin. The top most of this sequence is the deposits part of the fifth of sedimentary cycle of fluviatile environment. These lines of evidence indicate that the major faults in both western and eastern margins have been intermittently reactivated throughout the basin filled history.

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APPENDIX

Analytical Results of Sampled Coal Beds

(DMR, 1997)

DH	sample	analytical sample			as received		as analysed basis								
No	No	from	to	thick	TM	SM	M	ASH	VM	FC	(FR)	HV	TS	S ash	S comb
4/38	1	407.20	408.70	1.50	16.5	6.8	10.4	56.1	23.3	10.2	0.44	1640	4.94	0.77	4.17
2/39	2	257.80	258.60	0.80	27.5	14.4	15.3	25.6	38.2	20.9	0.55	3360	6.62		
3/39	3	298.50	299.30	0.80	33.4	23.9	12.5	45.4	29.5	12.6	0.43	2370	7.82		
3/39	4	590.80	591.40	0.60	23.4	13.6	11.3	43.9	27.8	17.0	0.61	2800	6.81	0.67	6.14
3/39	5	591.70	592.00	0.30	27.7	16.1	13.8	26.8	33.7	25.7	0.76	4090	5.52	1.18	4.34
1/40	6	130.90	131.35	0.45	35.3	28.3	9.8	61.1	19.5	9.6	0.49	1460	3.67		
1/40	7	131.70	132.00	0.30	32.1	25.1	9.3	49.7	25.4	15.6	0.61	2210	8.94		
1/40	8	274.50	275.90	1.40	15.2	4.0	11.7	32.5	33.2	22.6	0.68	3540	5.80		
2/40	9	301.60	303.20	1.60	27.7	18.6	11.2	59.0	20.4	9.4	0.46	1570	4.47		
2/40	10	403.70	405.00	1.30	18.7	8.5	11.1	51.2	25.6	12.1	0.47	2310	6.08		

DH	sample	dry basis											
No	No	ASH	VM	HV	TS	Ssulf	Spy	Sorg	C	H	O	N	S
4/38	1	62.6	26.0	1830	5.51	1.69	2.54	1.28	19.0	2.02	11.17	0.54	4.65
2/39	2	30.2	45.1	3967	7.82								
3/39	3	51.9	33.7	2709	8.94								
3/39	4	49.5	31.3	3157	7.68	0.89	4.73	2.06	30.3	2.45	9.84	1.00	6.92
3/39	5	31.1	39.1	4745	6.40	0.80	3.94	1.66	47.0	3.55	11.78	1.54	5.03
1/40	6	67.7	21.6	1619	4.07								
1/40	7	54.8	28.0	2437	9.86								
1/40	8	36.8	37.6	4009	6.57								
2/40	9	66.4	23.0	1768	5.03								
2/40	10	57.6	28.8	2598	6.84								

DH	sample	dry ash free basis										HGI	ash fusion temp C		
No	No	CV	C	H	O	N	S	HC	OC	NC	SC		DT	ST	FT
4/38	1	4896	50.8	5.40	29.89	1.44	12.45	128	44	2	9	100	1085	1230	1255
2/39	2	5685													
3/39	3	5629													
3/39	4	6250	60.0	4.85	19.47	1.98	13.71	97	24	3	9	81	1070	1130	1155
3/39	5	6886	68.2	5.15	17.10	2.23	7.31	91	19	3	4	58	1060	1080	1090
1/40	6	5017													
1/40	7	5390													
1/40	8	6344													
2/40	9	5268													

DH	sample	ash analysis as oxide												ASTM class	
No	No	Si	Al	Fe	Ca	Mg	Na	K	S	P	Ti	Mn	Ig loss	Btu lb	Class
4/38	1	46.7	26.60	13.02	2.84	1.52	0.75	3.10	3.05	0.08	0.48	0.04	1.82	6148	Lig B
2/39	2													6684	Lig A
3/39	3													4965	Lig B
3/39	4	43.6	22.98	19.73	3.49	1.52	0.95	2.66	3.41	0.20	0.40	0.02	1.04	7270	Lig A
3/39	5	34.4	14.18	27.03	8.36	1.66	1.55	1.64	9.61	0.81	0.41	0.03	0.32	8122	Lig A
1/40	6													3423	Lig B
1/40	7													4709	Lig B
1/40	8													9238	subC
2/40	9													4595	Lig B
2/40	10													7600	Lig A

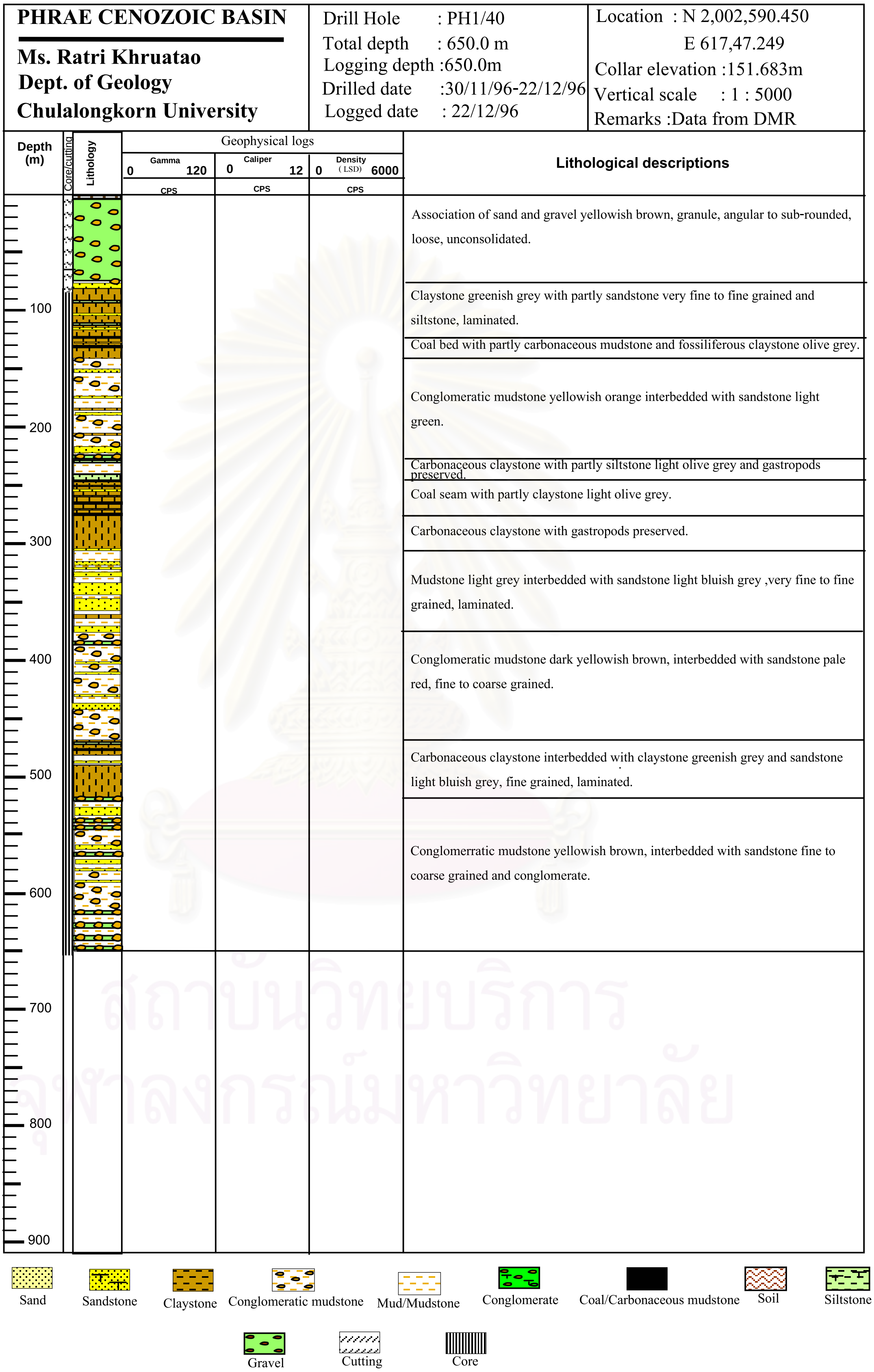


Figure A The geological drill-chart of drill-hole number PH1/40

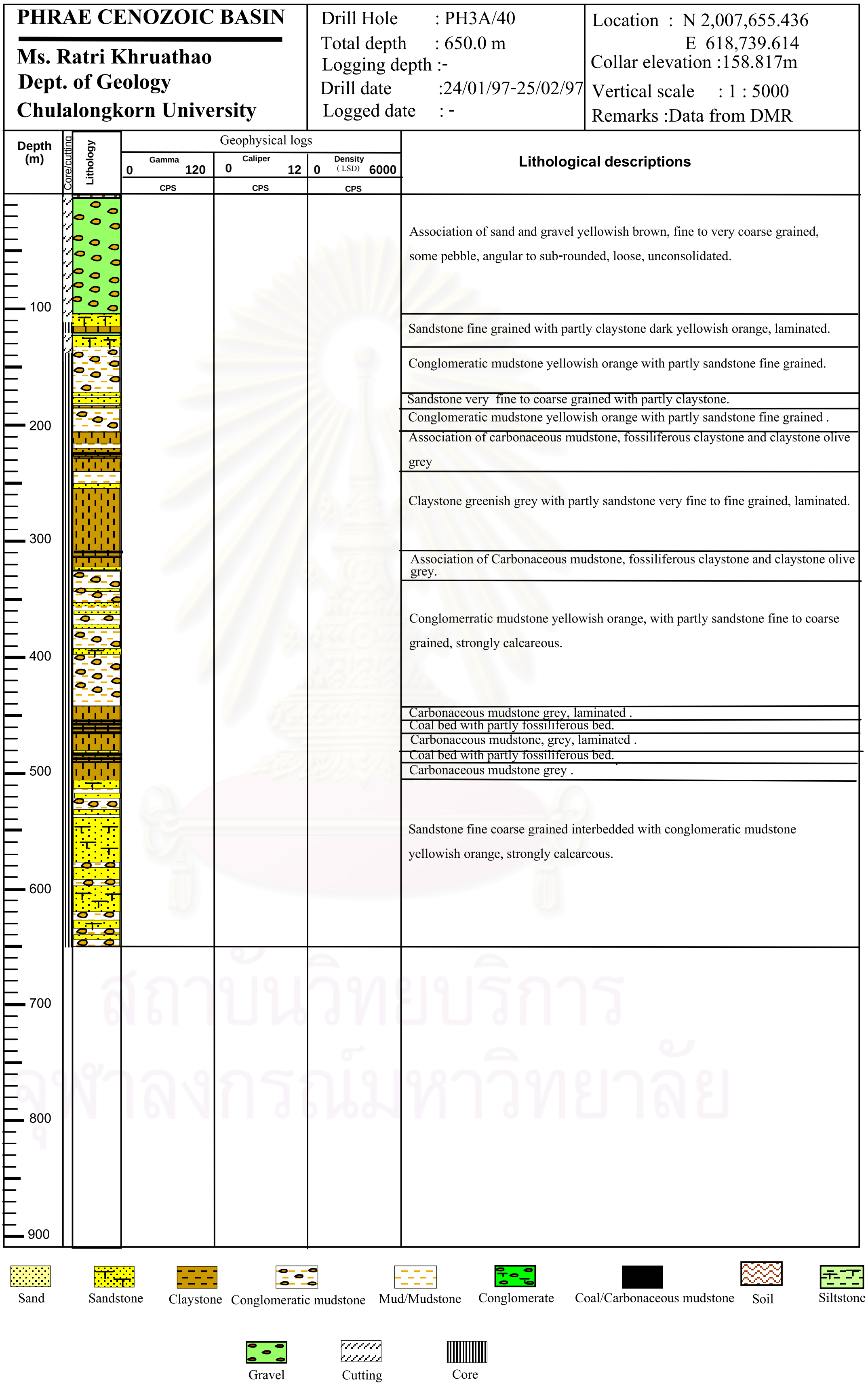


Figure B The geological drill-chart of drill-hole number PH3A/40

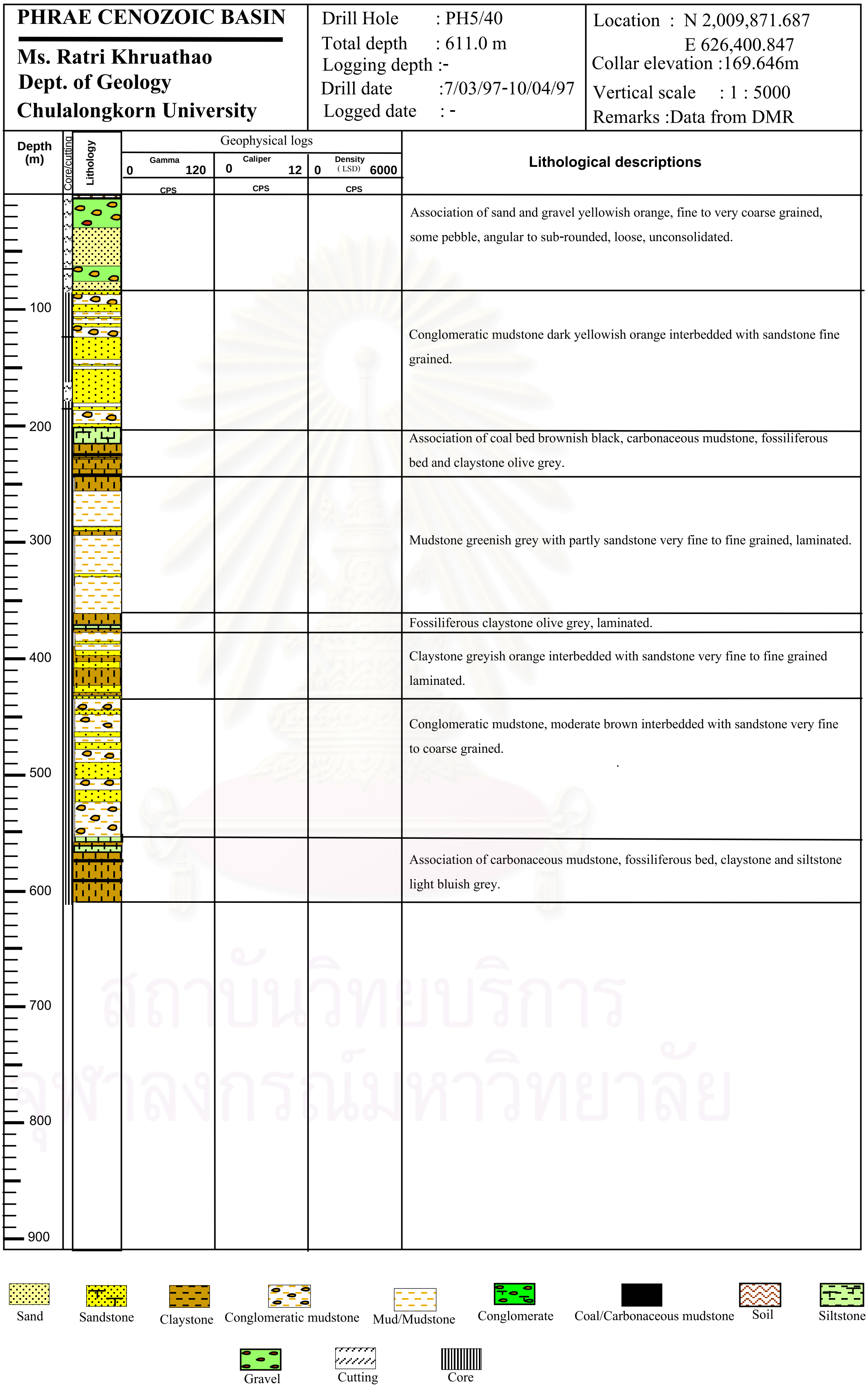


Figure C The geological drill-chart of drill-hole number PH5/40

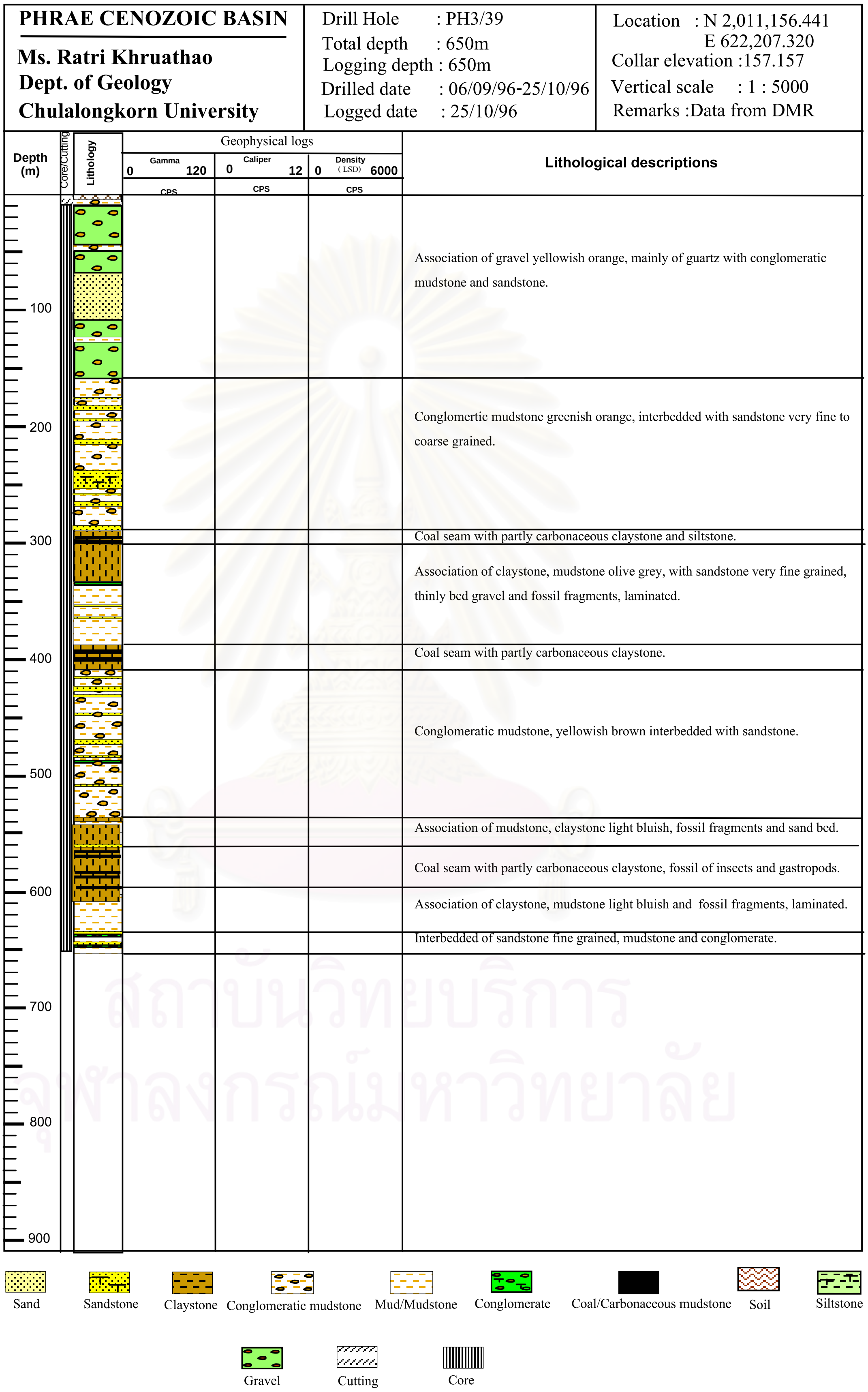


Figure D The geological drill-chart of drill-hole number PH3/39

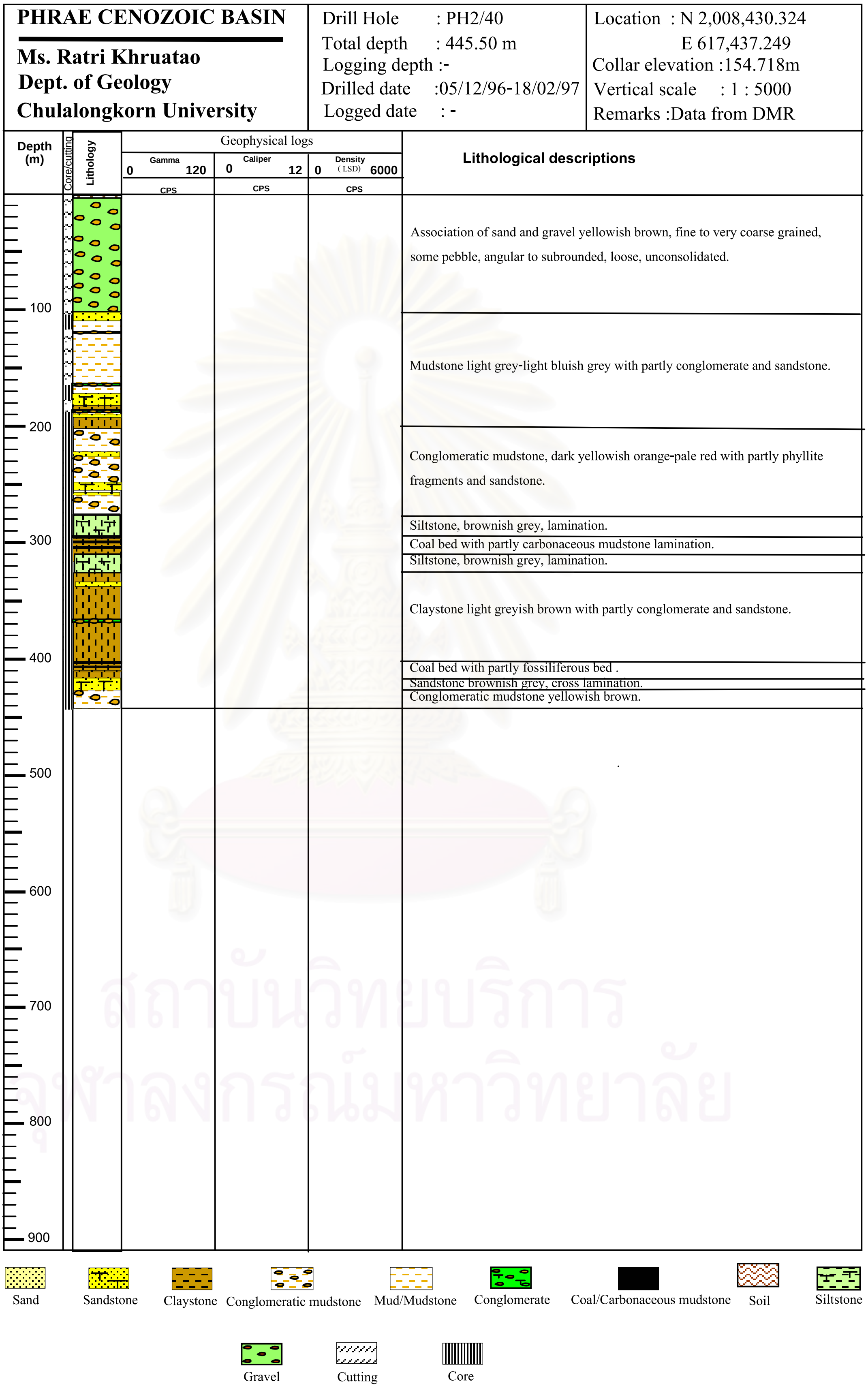


Figure E The geological drill chart of drill-hole number PH2/40

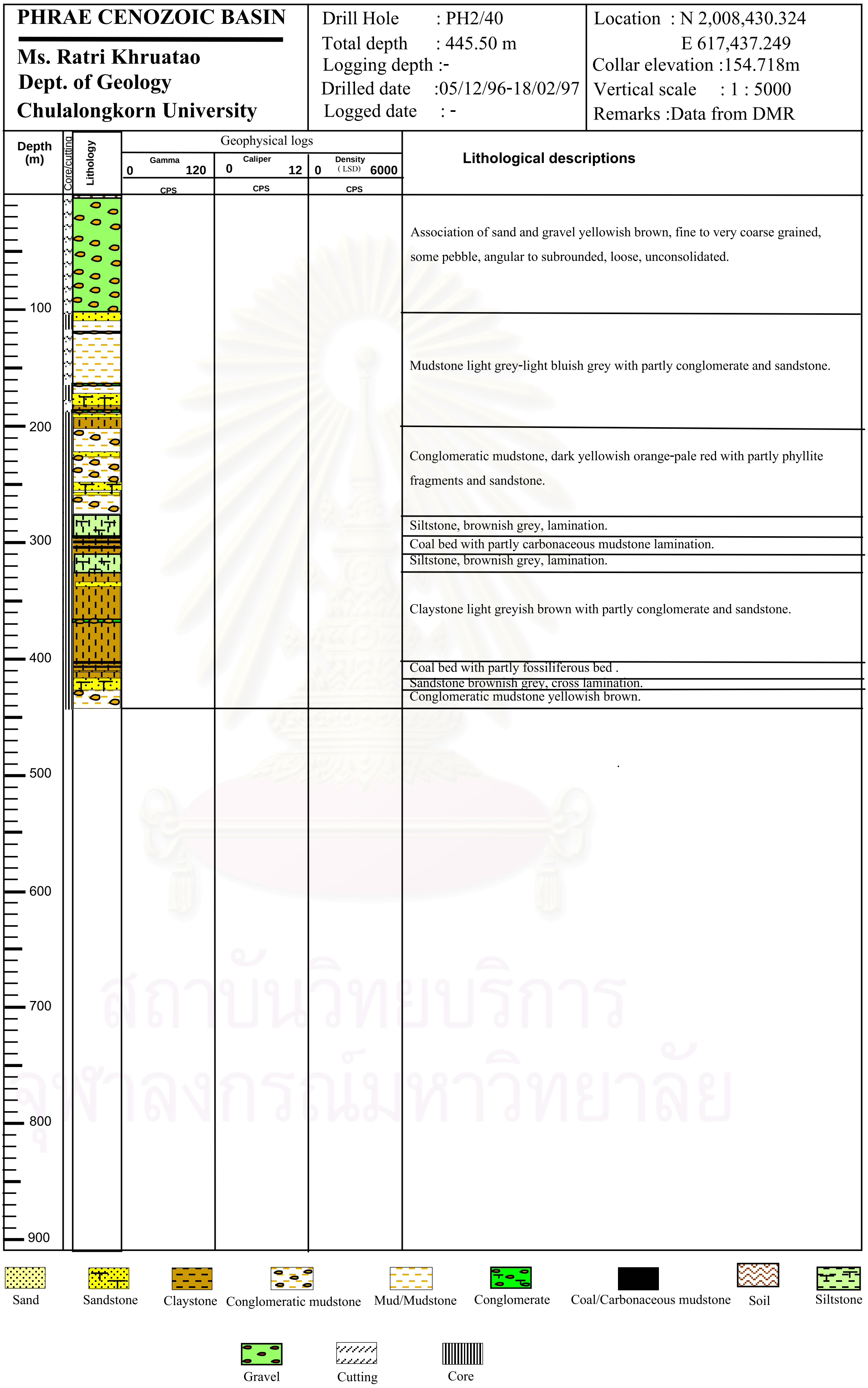
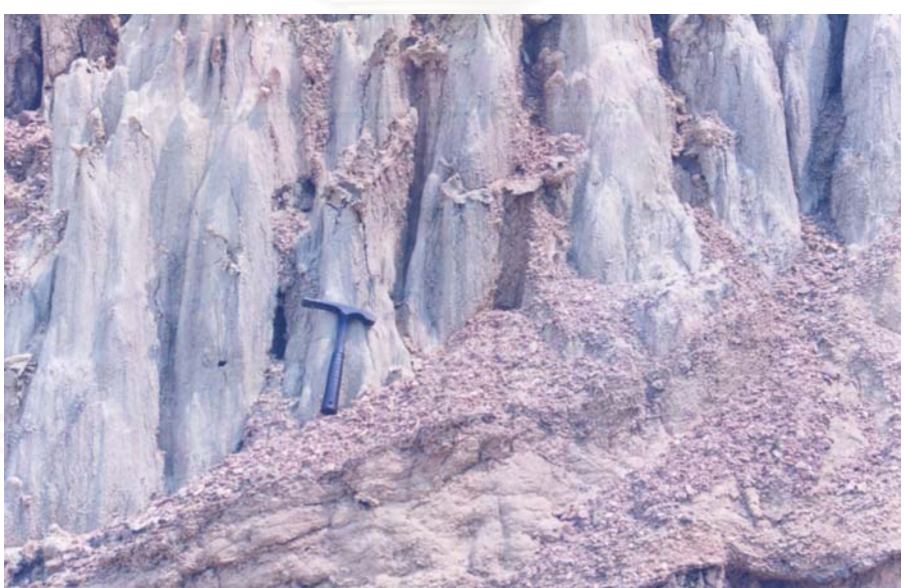


Figure E The geological drill chart of drill-hole number PH2/40

FigureF. Outcrop of Phrae basin, fault (LookingnN20E), 6 2 2 8 1 0 4 E 2 0 0 1 1 2 1 N



FigureG. Outcrop of Phrae basin,calcareous in lacustrine facies (LookingnN10E), 628104E,2001121N

FigureH. Outcrop of Phrae basin,fault(LookingN40E), 621308E,1993799N

FigureI. Outcrop of Phrae basin,contact lacustrine facies with fulviatile facies(LookingnN30E), 627026E,1999240N

BIOGRAPHY

Miss Ratri Khruathao was born in Chiang Rai in 1966, she studied at Thonguitayakom school for the pre-university education in Chiang Rai between 1979 and 1984. She graduated with the B.Sc. in Geology from Chiang Mai University in 1989. After graduation, she worked with the Hancig Co., Ltd. for one year, her assignment was in the field of ore deposits especially the chromite and manganese at Changwat Uttaradit and Changwat Nan. In 1990, she worked with the Sinpatanalung Co., Ltd. for 9 months her assignment were in the field of various ore deposits especially the stibnite deposit in Amphoe Mae Sot, Changwat Tak. In 1991, she was employed by C&S Engineering Supply, her responsibility was on the foundation work. At present, she has been worked with the Siam Tone Company Ltd. Her position is the maintenance manager. She has been working at Siam Tone Company, Ltd. since 1991. She has spent 7 years for geotechnical works including foundation, soil improvement, water well, investigation, grouting for bridge and dam project, before piling work.