STRATIGRAPHY AND PALAEONTOLOGY OF MID-CARBONIFEROUS SEQUENCES IN LOEI PROVINCE, THAILAND

SATHAPORN KAVINATE

A thesis submitted in partial fulfillment of the requirements for
the degree of Master of Science in Palaeontology
Mahasarakham University
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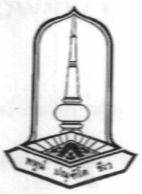

The examining committee has unanimously approved this thesis, submitted by Mr. Sathaporn Kavinate, as a partial fulfillment of the requirements for the Master of Science degree Program in Palaeontology at Mahasarakham University.

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Sathaporn Kavinate

ชื่อเรื่อง การลำดับชั้นหินและบรรพชีวินวิทยาของชั้นหินยุคคาร์บอนิเฟอรัสตอนกลาง ในพื้นที่จังหวัดเลย ประเทศไทย
ผู้วิจัย นายสถาพร กาวิเนตร
ปริญญา วิทยาศาสตรมหาบัณฑิต **สาขาวิชา** บรรพชีวินวิทยา
อาจารย์ที่ปรึกษา ผู้ช่วยศาสตราจารย์ ดร.มงคล อุดชาชน
Dr. Henri Fontaine
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บทคัดย่อ

หินตะกอนยุคคาร์บอนิเฟอรัสโผล่ปรากฏในหลายแห่งของประเทศไทย และมีการสะสมตัวในหลากหลายสภาพแวดล้อมบรรพกาล วัตถุประสงค์ของการศึกษาครั้งนี้ประกอบด้วย การศึกษาทางด้านธรณีวิทยา การสะสมตัวของหินตะกอน การลำดับชั้นหิน บรรพชีวินวิทยา เพื่อการตีสภาพแวดล้อมบรรพกาลของการสะสมตะกอน ในยุคคาร์บอนิเฟอรัสตอนกลางในพื้นที่จังหวัดเลย โดยกำหนดพื้นที่ศึกษาบริเวณพื้นที่ภูบ่อบิด อำเภอเมือง และพื้นที่ภูผาหม้อ อำเภอวังสะพุง จังหวัดเลย

ลักษณะธรณีวิทยาของทั้งสองพื้นที่สำรวจนั้นประกอบด้วยหินปูนเป็นส่วนใหญ่แทรกสลับกับหินดินดานตลอดแนว โดยการศึกษาครั้งนี้พบซากดึกดำบรรพ์สัตว์ไม่มีกระดูกสันหลังจำพวกหอยตะเกียง ปะการัง ไบรโอซัว และไครนอยด์ ซึ่งบ่งบอกถึงสภาพแวดล้อมการสะสมตัวบริเวณทะเลตื้น หรือไหลทวีป บริเวณภูบ่อบิด ส่วนใหญ่เป็นพบเป็นเลนส์ของหินปูนชั้นหนาที่แทรกสลับอยู่ในหินดินดาน พบซากดึกดำบรรพ์ปะการังจำพวก Tabulata และ Rugosa ซึ่งบ่งบอกอายุในช่วงสมัย Bashkirian ตอนปลาย และซากดึกดำบรรพ์ฟิวซูลินิด *Profusulinella* sp. และ สาหร่าย *Beresella erecta* บ่งบอกอายุอยู่ในช่วงสมัย Moscovian ตอนต้น ส่วนหินปูนบริเวณภูผาหม้อมีอายุในช่วงสมัย Moscovian ตอนต้น เนื่องจากพบซากดึกดำบรรพ์ สาหร่าย *Beresetta erecta* ฟอรามินิเฟอราขนาดเล็ก ได้แก่ *Geinitzina, Bradyina, Climacammina* และ*Endothyra* ฟิวซูลินิด *Profusulinella* sp. และปะการัง *Citronites citronoides* ตามที่มีการระบุชุดลักษณ์หินและบรรพชีวินวิทยา ทำให้ทราบว่าชุดหินภูบ่อบิดมีอายุแก่กว่าหรือมีการสะสมตัวของตะกอนทั้งตะกอนคาร์บอเนตรวมทั้งตะกอนเนื้อเม็ดก่อนชุดหินภูผาหม้อ

คำสำคัญ: ยุคคาร์บอนิเฟอรัสตอนกลาง, บรรพชีวินวิทยา, การเรียงลำดับชั้นหิน, จังหวัดเลย

TITLE Stratigraphy and Palaeontology of Mid - Carboniferous Sequences in Loei Province, Thailand

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ABSTRACT

Carboniferous sedimentary rocks are widely exposed in several areas of Thailand. They show a multitude of facets indicating that they have been deposited in very diverse environments. The purpose of this study was to investigate on the geology, sedimentology, stratigraphy, palaeontology and palaeoenvironment interpretation of Middle Carboniferous in Loei area. The materials were obtained from field work at Loei area especially Phu Bo Bit at Muang Loei and Phu Pha Mo at Wang Saphung Loei Provience.

The rocks from both section consisting of shale, limestone along with abundance and diverse invertebrate faunas; brachiopods, corals, bryozoans and crinoids are interpreted as having been deposited in shallow marine or shelf environments. At Phu Bo Bit, thick limestone lenses in shale contain microfossils, Tabulata and solitary Rugosa; they have been assigned to Late Bashkirian and fusulinaceans (*Profusulinella* sp.), algae *Beresella erecta*, have been assigned to Early Moscovian. The stratigraphic sequence of Phu Bo Bit extends from Late Bashkirian to Early Moscovian. The age of Phu Pha Mo limestone is Early Moscovian because of the occurence of algae (*Beresetta erecta)*, smaller foraminifera *(Geinitzina, Bradyina magna* Roth & Skinner and smaller *Bradyina, Climacammina, Endothyra),* a few fusulinaceans *(Profusulinetta* sp., *Citronites citronoides* Manukalova 1948, *Eoschubertetta* sp.). According to lithofacies and palaeontology identification, Phu Bo Bit section is older than Phu Pha Mo section. And the change of the carbonate to siliciclastic sedimentation on Phu Bo Bit section is active before carbonate accumulation on the Phu Pha Mo section.

Keywords: Mid - Carboniferous, Palaeontology, Stratigraphy, Loei Province

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CHAPTER 1

INTRODUCTION

1.1 Background

Thailand is a country with a wide spectrum of interesting geological settings. The country comprises rocks ranging in age from Precambrian to Quaternary. Various aspects of geology have long been studied in various parts of the country by a great number of researchers. One of the most fascinating areas in the upper part of northeastern Thailand is the Loei region where a lot of mineral commodities and fossils are known. This is mentioned in a number of publications on upper Paleozoic fossil and mineral deposits, both metallic and industrial, such as gold, copper, magnetite, manganese, barite, gypsum, coal, etc. (Fontaine *et al.*, 2005)

In the 1950s, the Department of Mineral Resources was very active in the geologic reconnaissance of the diverse mineral deposits of Thailand (Brown *et al.*, 1951), but it was also interested to extend its investigations to other geologic problems, for instance, it was eager to find good sections of sedimentary rocks, to study their fossils, and then, to distinguish biozones easy to correlate with the rocks of other countries (Sethaput, 1956).

Near Wang Saphung, Middle-Upper Carboniferous and Permian fossils were collected in a fair quantity. They were diverse and consisted of trilobites, foraminifera, conodonts, brachiopods and ammonoids described in many publications (Ishibashi *et al.*, 1997).

Until 1980 information on rocks older than Middle Carboniferous was very poor in Loei region. Fossils, supposed to be Devonian in age, had been mentioned as early as 1925, but at a single locality, without good identification and description (Fontaine *et al.*, 2005).

Due to the geological significance of the area, especially during the Silurian and Devonian periods through Carboniferous and Permian where significant geologic events occurred, many valuable documents of geological interest were published by various experts and researchers. Fontaine *et al.*, (2005) published an important work

about Stratigraphy, Paleontology and Sedimentology of the Loei Region, Northeast Thailand

The important regression observed in Pha Chom Nang Belt between Lower and Middle Carboniferous is more easily observed in Ban Sa Ngao Belt because of wider exposures of continental sediments.

Gypsum has been known in Loei-Wang Saphung area for a long time (Haworth *et al.*, 1966; Jacobson *et al.*, 1969). In 1995, an exploration of the gypsum was carried out by cored wells and geophysical techniques southeast of Wan Saphung; gypsum was found at different depths, from 7 m to more than 50 m (Utha-Aroon and Surinkum, 1995). A limestone bed was discovered above gypsum at a depth of 41 m. It was moderatedly rich in diverse Late Moscovian fossils including fusulinaceans (*Beedeina elegans* Rauser & Beliaev, 1940 and *Eostaffella lepida* Grozdilova & Lebedeva, 1950) and a fragment of a small solitary coral without dissepiments (Fontaine *et al.*, 1996). The gypsum appears to be slightly younger than the sediments with continental plants.

The Carboniferous is thus known in great detail in Northeast Thailand where important studies have been carried out during the last 35 years. Access to the outcrops is easy. Fossils are diverse and in abundance. In Northwest, Central and East Thailand, research has been more limited; it has been found differences in the sedimentation of these regions. In West and Peninsular Thailand, the tectono-sedimentary history of the Carboniferous is clearly distinct from the other parts of Thailand. Fossils are much less diverse. In Northern Thailand, the Carboniferous remains almost unknown. In the area of Uttaradit, Thanasuthipitak (1978) described a Carboniferous marine sedimentary sequence, about 2000 m thick, with an unconformity at the base of the Carboniferous and another unconformity at the top of the Middle Carboniferous. The Lower Carboniferous consisted of volcanogenic sediments, the Middle Carboniferous of flysch type sediments and the Upper Carboniferous of mollasse type sediments. No actual evidence was provided on the ages of these rocks (Fontaine *et al.*, 2005).

Table 1.1 Subdivision of the Carboniferous system according to the ICS geologic time scale 2012.

System	Subsystem/ Series	Stage	Age (Ma)
Permian	Cisuralian	Asselian	Younger
Carboniferous	Pennsylvanian	Gzhelian	298.9-303.7
		Kasimovian	303.7-307.0
		Moscovian	307.0-315.2
		Bashkirian	315.2-323.2
	Mississipplan	Serpukhovian	323.2-330.9
		Visean	330.9-346.7
		Tournaisian	346.7-358-9
Devonian	**Late**	**Famennian**	**older**

1.2 Purposes of the Research

The purposes of the research are to build a stratigraphic sequence of the Mid - Carboniferous in Loei area (Figure 1.1) using sedimentological and palaeontological data, to identify fusulinids and associate fossil for age discrimination and to reconstruct palaeoenvironment of the study area.

1.3 Scope of the Study

This study was carried out on the geology, sedimentology, stratigraphy, palaeontology and palaeoenvironment interpretation of Mid - Carboniferous in Loei area. The materials were obtained from field trip in Loei area especially at Na Duang coal mine; core log of gypsum drilling at Wang Saphung was also analyzed. Identification of the specimens was conducted at the Department of Mineral Resources.

1.4 Significance of the research

Our results allow a revision the geological map of this area and improve the basic knowledge about Middle Carboniferous palaeoenvironments, including continental and shallow marine environments, ancient coastlines and climates in Thailand, especially in the Loei area.

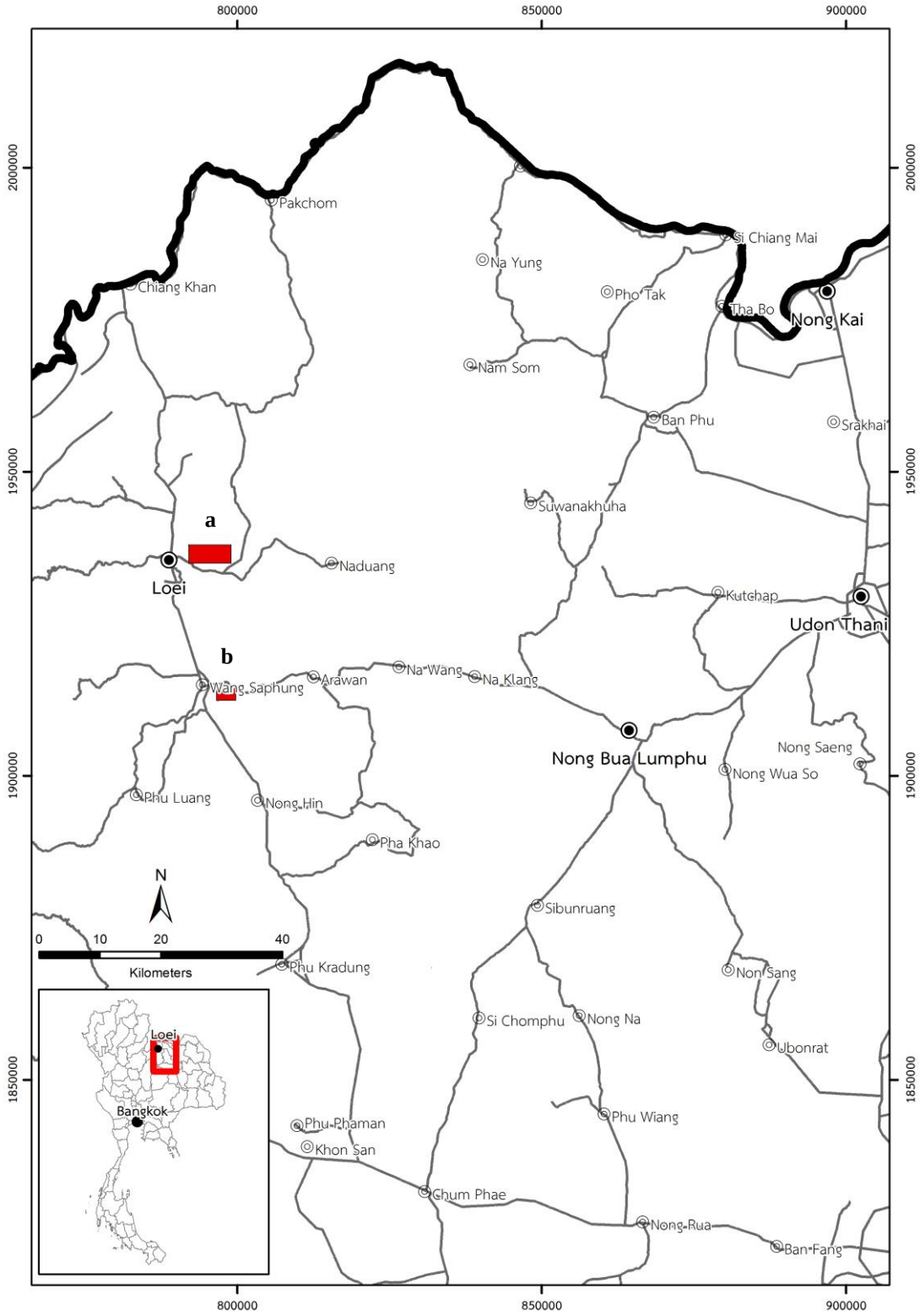


Figure 1.1 Location of the study area, (a) Phu Bo Bit Section and (b) Phu Pha Mo Section and its vicinity illustrating the network of the national and provincial highways.

1.5 Analysis and conclusion

The orientation of fossils was checked in outcrop on both vertical section and excavated site were analyzed. These results are combined with the analysis of lithologic composition, grain size, sorting and shape, sedimentary structures, indurations and type of cement. The results are shown in the lithostratigraphic columnar sections and were correlated with locality database. All these data were discussed and used for reconstruction of palaeoenvironment.

The study methodology employed in the present study can be summarized in Figure 1.2.

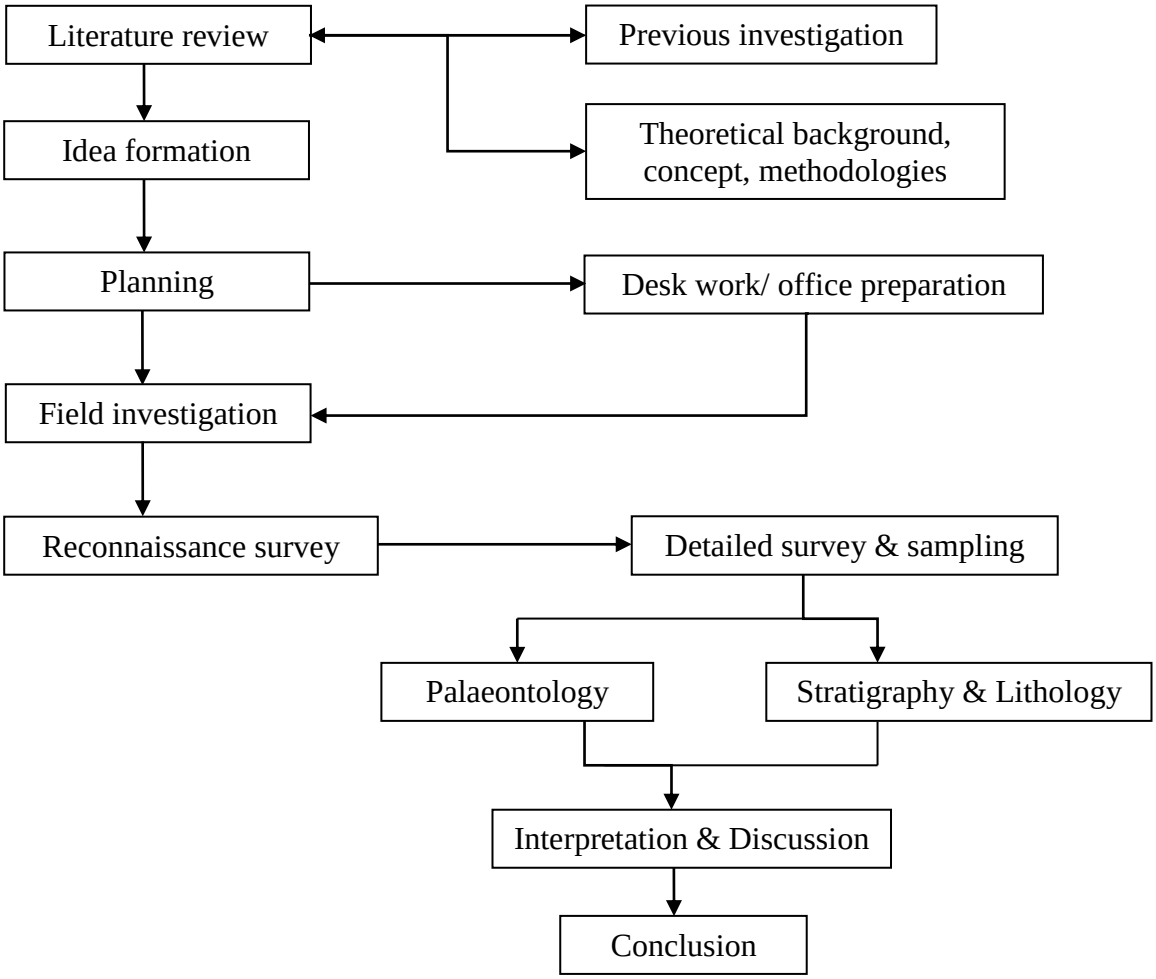


Figure 1.2 The study methodology.

CHAPTER 2

LITERATURE REVIEW

2.1 Statigraphy of Loei

2.1.1 Palaeozoic sedimentary rocks

The oldest Palaeozoic rocks in the study area are metasediments. They are quartzites and phyllites which make up a north-south trending escarpment in the middle of the map area (Figure 2.1 and 2.2).

The quartzite are light-to medium grey and mostly fine-to medium grained. They are often massive or from thick unit, but frequently they are distinctly and well bedded with light grey, slightly coarser grained layers alternating with fine-grained, medium grey layers a few centimeters thick. These well bedded quartzites are often intensely folded. Occasionally there are also layers of quartzitic conglomerate with pebbles a few centimeters in size. The phyllites represent regionally metamorphosed shales and siltstones. They display a streaked foliation and mostly have a grey or occasionally greenish-grey or reddish-grey colour, which may indicate that the regional metamorphic rocks include former redbeds, but a red colour could also have been caused by intense weathering of the phyllites.

The quartzites and phyllites were obviously affected by tectonic deformation and metamorphism much more intensely than all other rocks in the area; they are therefore regarded as the oldest rocks. The second oldest rocks for which a definite age is known are of middle-late Silurian age. Thus the Lower Palaeozoic metasediments are at least of middle Silurian in age but probably older, i.e. pre-Silurian.

Silurian-Devonian: The Silurian to Devonian sedimentary rocks consist of white, grey and yellowish-brown shale, reddish-brown fine-grained tuffaceous sandstone and siltstone, occasionally with lenses of light grey dolomitic limestone or bluish-grey crystalline limestone. They are sporadically exposed along some valleys in the eastern map area (sheets 5445 III and 5444 IV).

Sakagami and Nakornsri (1987) found several corals such as *Heliolites* sp. cf. *H. barrandei* (Hoernes), *Heliolites* sp. cf. *H. bohemicus* Wentzel, and *Favosites* sp. indet. in association with brachiopods in calcareous mudstones about 5 km south of Ban Nong or 5 km west of Ban Muang (sheet 5445 III). *Heliolites* is known from the middle

Silurian of several localities in Europe and Asia. *H barrandei* is known from middle Silurian to Lower Devonian. Encrinurid trilobites that occur together with the corals support a middle to Late Silurian age for the fauna.

Fontaine *et al.* (1981:5) found colonies of *Favosites* sp., *Heliolites* sp., and a few Stromatoporoidea in two small outcrops of black limestone about 2 km west of Ban Muang (loco T265 and T312-321, sheet 5445III). Fontaine (1990a) considered an Emsian-Eifelian age for these limestones west of Ban Muang. Limestones 2 km northwest of Ban Na Ngiu (loco T274-277 and T279-280, sheet 5445 III) mentioned by Fontaine (1990a:59) contain the coral *Favosites* and the algae *Renalcis*, suggesting an age of Silurian to Middle Devonian. Shales with thin lenses of silty and sandy limestone near Ban Na Khae (loco T2537-2540 and T2541-2545, sheet 5444 IV) yielded a fauna of brachiopods, corals and a trilobite, which Fontaine (1990a:59) interprets as Early to Middle Devonian (Emsian-Eifelian).

Devonian Chert: Chert is a hard, splintery, glass-like rock mostly dark grey in colour, but there are also light grey and rare reddish varieties. The chert is mostly well stratified in layers several ern to 10 em thick separated by mm-thick layers of mudstone and occasionally tuff. Pure chert consists almost entirely of cryptocrystalline quartz coloured by very small amounts of organic matter or iron oxide.

Chert occurs in huge masses in the western part of the map area (sheets 5345 II, 5344 I), where it forms long, north-south trending anticlinal cores of variable width. It is absent in the eastern part; whether it is concealed beneath younger rocks or whether it is missing completely is uncertain. It is unlikely that the chert was sedimented uniformly over the whole area; moreover there appear to be some facies changes. The westernmost occurrences of chert are less pure and are associated with a larger proportion of clastic material such as shales, siliceous shales and thick interbeds of quartzite, which may have originated from sandstone beds impregnated by siliceous solutions.

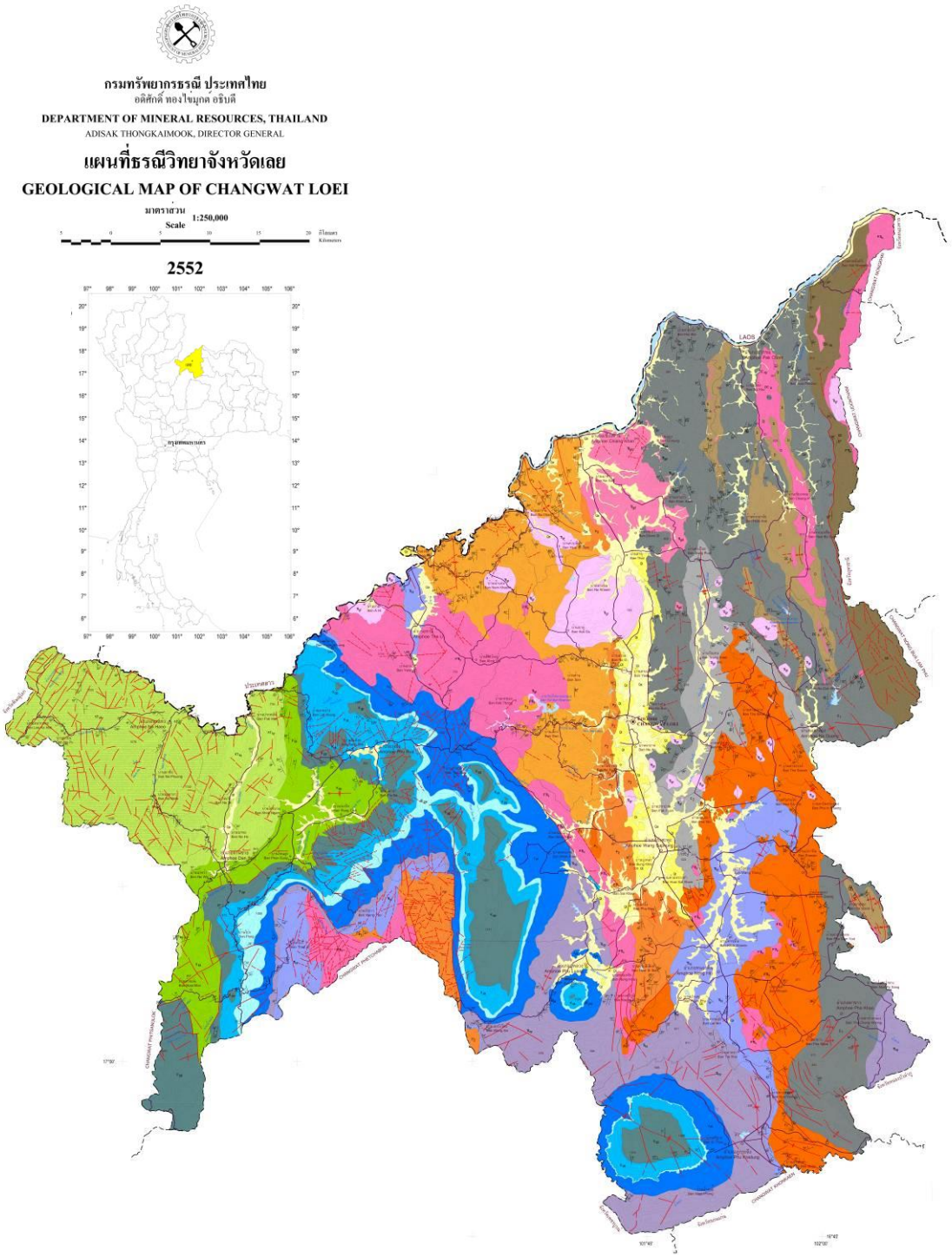
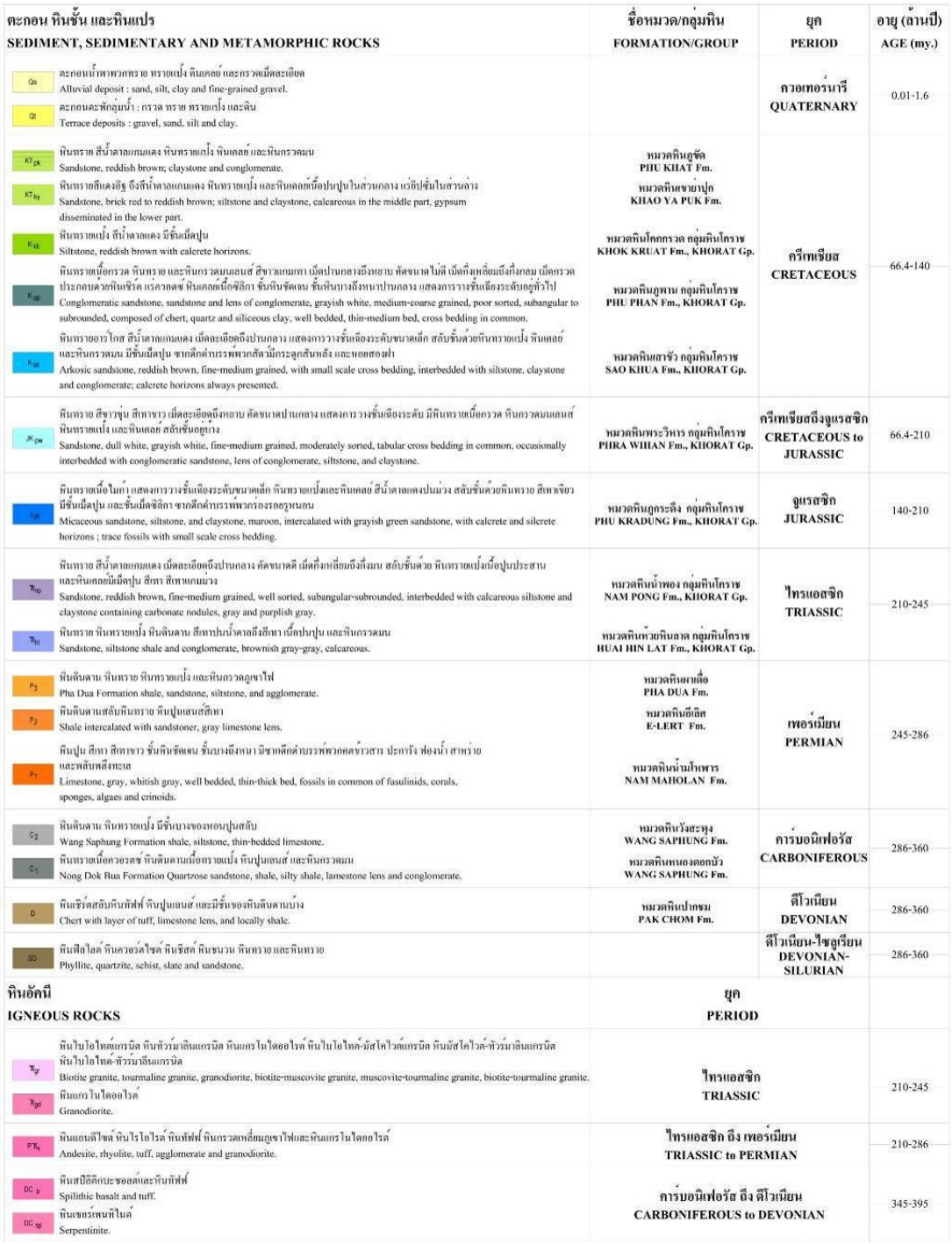


Figure 2.1 Geological map of Loei Province on the scale 1:250,000
(Department of Mineral Resources, 2009)

คำอธิบาย
EXPLANATION



ตะกอน หินชั้น และหินแปร SEDIMENT, SEDIMENTARY AND METAMORPHIC ROCKS	ชื่อหมวด/กลุ่มหิน FORMATION/GROUP	ยุค PERIOD	อายุ (ล้านปี) AGE (my.)
Qa ตะกอนน้ำพาพวกทราย ทรายแป้ง ดินเหลย์ และกรวดเม็ดละเอียด Alluvial deposit : sand, silt, clay and fine-grained gravel.		ควอเทอร์นารี QUATERNARY	0.01-1.6
Qt ตะกอนตะพักลุ่มน้ำ : กรวด ทราย ทรายแป้ง และดิน Terrace deposits : gravel, sand, silt and clay.			
KT_{pk} หินทราย สีน้ำตาลแกมแดง หินทรายแป้ง หินเหลย์ และหินกรวดมน Sandstone, reddish brown; claystone and conglomerate.	หมวดหินภูพัด PHU KHAT Fm.	ครีเทเชียส CRETACEOUS	66.4-140
KT_{ky} หินทรายสีแดงอิฐ ถึงสีน้ำตาลแกมแดง หินทรายแป้ง และหินเหลย์เนื้อปนปูนในส่วนกลาง แร่ยิปซั่มในส่วนล่าง Sandstone, brick red to reddish brown; siltstone and claystone, calcareous in the middle part, gypsum disseminated in the lower part.	หมวดหินเขาย่าปุก KHAO YA PUK Fm.		
K_{kk} หินทรายแป้ง สีน้ำตาลแดง มีชั้นเม็ดปูน Siltstone, reddish brown with calcrete horizons.	หมวดหินโคกกรวด กลุ่มหินโคราช KHOK KRUAT Fm., KHORAT Gp.		
K_{ph} หินทรายเนื้อกรวด หินทราย และหินกรวดมนเหลย์ สีขาวแกมเทา เม็ดปานกลางถึงหยาบ คัดขนาดไม่ดี เม็ดกึ่งมุมเหลี่ยมถึงกึ่งกลม เม็ดกรวดประกอบด้วยหินเชิร์ต แร่ควอตซ์ หินเหลย์เนื้อซิลิกา ชั้นหินหนาถึงหนาปานกลาง แสดงการวางชั้นเฉียงระดับอยู่ทั่วไป Conglomeratic sandstone, sandstone and lens of conglomerate, grayish white, medium-coarse grained, poor sorted, subangular to subrounded, composed of chert, quartz and siliceous clay, well bedded, thin-medium bed, cross bedding in common.	หมวดหินภูพาน กลุ่มหินโคราช PHU PHAN Fm., KHORAT Gp.		
K_{sk} หินทรายอาร์โกส สีน้ำตาลแกมแดง เม็ดละเอียดถึงปานกลาง แสดงการวางชั้นเฉียงระดับขนาดเล็ก สลับชั้นด้วยหินทรายแป้ง หินเหลย์ และหินกรวดมน มีชั้นเม็ดปูน ซากสัตว์และพืชกลุ่มกระดูกสันหลัง และหอยสองฝา Arkosic sandstone, reddish brown, fine-medium grained, with small scale cross bedding, interbedded with siltstone, claystone and conglomerate; calcrete horizons always presented.	หมวดหินเสาขัว กลุ่มหินโคราช SAO KHUA Fm., KHORAT Gp.		
JK_{pw} หินทราย สีขาวขุ่น สีเทาขาว เม็ดละเอียดถึงหยาบ คัดขนาดปานกลาง แสดงการวางชั้นเฉียงระดับ มีหินทรายเนื้อกรวด หินกรวดมนเหลย์ หินทรายแป้ง และหินเหลย์ สลับชั้นกันบ้าง Sandstone, dull white, grayish white, fine-medium grained, moderately sorted, tabular cross bedding in common, occasionally interbedded with conglomeratic sandstone, lens of conglomerate, siltstone, and claystone.	หมวดหินพระวิหาร กลุ่มหินโคราช PHRA WIHAN Fm., KHORAT Gp.	ครีเทเชียสถึงจูแรสซิก CRETACEOUS to JURASSIC	66.4-210
J_{pk} หินทรายเนื้อไมก้า แสดงการวางชั้นเฉียงระดับขนาดเล็ก หินทรายแป้งและหินเหลย์ สีน้ำตาลแดงปนม่วง สลับชั้นด้วยหินทราย สีเทาเขียว มีชั้นเม็ดปูน และชั้นเม็ดซิลิกา ซากสัตว์และพืชกลุ่มรอยรูหนอน Micaceous sandstone, siltstone, and claystone, maroon, intercalated with grayish green sandstone, with calcrete and silcrete horizons ; trace fossils with small scale cross bedding.	หมวดหินภูกระดึง กลุ่มหินโคราช PHU KRADUNG Fm., KHORAT Gp.	จูแรสซิก JURASSIC	140-210
Tr_{np} หินทราย สีน้ำตาลแกมแดง เม็ดละเอียดถึงปานกลาง คัดขนาดดี เม็ดกึ่งมนเหลี่ยมถึงกึ่งมน สลับชั้นด้วย หินทรายแป้งเนื้อปูนประสาน และหินเกลย์มีเม็ดปูน สีเทา สีเทาแกมม่วง Sandstone, reddish brown, fine-medium grained, well sorted, subangular-subrounded, interbedded with calcareous siltstone and claystone containing carbonate nodules, gray and purplish gray.	หมวดหินน้ำพอง กลุ่มหินโคราช NAM PONG Fm., KHORAT Gp.	ไทรแอสซิก TRIASSIC	210-245
Tr_{hl} หินทราย หินทรายแป้ง หินดินดาน สีเทาปนน้ำตาลถึงสีเทา เนื้อปนปูน และหินกรวดมน Sandstone, siltstone shale and conglomerate, brownish gray-gray, calcareous.	หมวดหินห้วยหินลาด กลุ่มหินโคราช HUAI HIN LAT Fm., KHORAT Gp.		
P_{pd} หินดินดาน หินทราย หินทรายแป้ง และหินกรวดภูเขาไฟ Pha Dua Formation shale, sandstone, siltstone, and agglomerate.	หมวดหินผาเดื่อ PHA DUA Fm.	เพอร์เมียน PERMIAN	245-286
P_{el} หินดินดานสลับหินทราย หินปูนแลนส์สีเทา Shale intercalated with sandstoner, gray limestone lens.	หมวดหินอีเลิศ E-LERT Fm.		
P_{mh} หินปูน สีเทา สีเทาขาว ชั้นหินหนาถึงหนา มีซากดึกดำบรรพ์พวกฟอสซิลข้าวสาร ปะการัง ฟองน้ำ สาหร่าย และพลับพลึงทะเล Limestone, gray, whitish gray, well bedded, thin-thick bed, fossils in common of fusulinids, corals, sponges, algaes and crinoids.	หมวดหินน้ำมหาโพธาร NAM MAHOLAN Fm.		
C_{sp} หินดินดาน หินทรายแป้ง มีชั้นบางของหอยปูนสลับ Wang Saphung Formation shale, siltstone, thin-bedded limestone.	หมวดหินวังสะพุง WANG SAPHUNG Fm.	คาร์บอนิเฟอรัส CARBONIFEROUS	286-360
C_{nb} หินทรายเนื้อควอรตซ์ หินดินดานเนื้อทรายแป้ง หินปูนแลนส์ และหินกรวดมน Nong Dok Bua Formation Quartzose sandstone, shale, silty shale, lamestone lens and conglomerate.	หมวดหินหนองดอกบัว WANG SAPHUNG Fm.		
D หินเชิร์ตสลับหินทัฟฟ์ หินปูนแลนส์ และมีชั้นของหินดินดานบ้าง Chert with layer of tuff, limestone lens, and locally shale.	หมวดหินปากชม PAK CHOM Fm.	ดีโวเนียน DEVONIAN	286-360
SD หินฟิลไลต์ หินควอร์ตไซต์ หินชิสต์ หินชนวน หินทราย และหินทราย Phyllite, quartzite, schist, slate and sandstone.		ดีโวเนียน-ไซลูเรียน DEVONIAN-SILURIAN	286-360
หินอัคนี **IGNEOUS ROCKS**	**ยุค** **PERIOD**		
TR_{gr} หินไบโอไทต์แกรนิต หินทัวร์มาลีนแกรนิต หินแกรโนไดออไรต์ หินไบโอไทต์-มัสโควิตแกรนิต หินมัสโควิต-ทัวร์มาลีนแกรนิต หินไบโอไทต์-ทัวร์มาลีนแกรนิต Biotite granite, tourmaline granite, granodiorite, biotite-muscovite granite, muscovite-tourmaline granite, biotite-tourmaline granite.	ไทรแอสซิก TRIASSIC		210-245
TR_{gd} หินแกรโนไดออไรต์ Granodiorite.			
PTR_{v} หินแอนดีไซต์ หินไรโอไรต์ หินทัฟฟ์ หินกรวดเหลี่ยมภูเขาไฟและหินแกรโนไดออไรต์ Andesite, rhyolite, tuff, agglomerate and granodiorite.	ไทรแอสซิก ถึง เพอร์เมียน TRIASSIC to PERMIAN		210-286
DC_{b} หินสปิลิติกบะซอลต์และหินทัฟฟ์ Spilithic basalt and tuff.	คาร์บอนิเฟอรัส ถึง ดีโวเนียน CARBONIFEROUS to DEVONIAN		345-395
DC_{sp} หินเซอร์เพนทินต์ Serpentinite.			

Figure 2.2 Explanation of Geological map of Loei Province

(Department of Mineral Resources, 2009)

Devonian Limestone: Isolated patches of reef limestone, which are either of Devonian or Carboniferous age occur at many places in the western part of the map area. In most cases it is a medium or dark grey massive limestone, rather fine grained and lacking visible bedding. Occasionally it contains corals, both solitary and colonial. Some irregular streaky inclusions, apparently with lower solubility than the surrounding limestone, stand out on the weathered surfaces; they may be stromatoporoid structures. But apart from this the Devonian limestone in general is relatively homogeneous and not visibly different from similar limestones of other ages. The limestone often forms rugged cliffs which rise several tenths of meters above the surroundings. Other limestone occurrences are only a few tens of meters long and wide, and had to be exaggerated on the map in order to render them visible. They are often arranged in long, north-south trending rows, which may be several kilometers long. The Devonian limestone mostly occurs in close connection with chert the reef-limestone bodies lying at the flanks or on top of the chert anticlines. Where the chert is in contact with reef bodies, cm-thick beds of limestone alternate with medium grey chert beds (sheet 5344 I), or the limestone rests unconformably on folded chert.

The limestone bodies accumulated as smaller or larger patches of algal and stromatopora reefs, which grew in certain places for limited periods, occasionally also containing corals. The most important corals in the Devonian reef limestone identified by Fontaine (1990a) are *Phillipsastrea* sp. and *Heliolites* sp.. The genus *Phillipsastrea* lived around the Middle/Late Devonian boundary and is restricted to the period from middle Givetian to Frasnian. The genus *Heliolites* lived from Silurian until late Givetian time. If both genera of corals occur together the age of the rock can only be middle to late Givetian. Other corals emphasize an upper Givetian age. Only at places where no *Heliolites* is found a Frasnian age cannot completely be excluded.

Devonian-Carboniferous shale and greywacke: Shales make up by far the major part of the sedimentary rocks of the map area. They are predominantly black to dark grey, only in some central northern parts of the map area reddish shales locally occur also. The shales are more or less silicified and therefore hard or very hard when fresh. The bedding is rarely visible suggesting deposition was uniform. Moreover the bedding has been partially obscured by a streaky, uneven cleavage which dissects the

shales. Cleavage and bedding, as far as it can be seen, are often almost parallel or cross each other at a very acute angle, which makes the bedding even more indistinct.

Other rocks such as siliceous shale, chert, siltstone, sandstone, quartzite, greywacke, and conglomerate are frequently intercalated with the shales. Some of these intercalations are thick enough to be shown on the map; but very often they hardly extend far beyond a single outcrop. Silt and sandstone layers occasionally alternate with shale and give rise to a light and dark grey striping on the scale of a few centimeters.

Greywacke occurrences within the thick sequence of shale are locally large enough to be shown on the map. They are found mainly in a north-south trending strip in the center of the map area but they also occur in the northwest and southwest. The best outcrops are to be seen at the side of the road along the River Mekong near Ban Pak Niam 4.640-5. 180 km northeast of Pak Chom (loc. 18, sheet 5345 II).

In the shale layers between greywacke and conglomerate near Ban Pak Niam, small badly preserved plant remains are easily found, but the shale and greywacke contains almost no recognizable fossils. The plant remains are tectonically distorted and the organic matter has such a degree of coalification that determinable spores could not be extracted (Koch, 1986). Fontaine *et al.*, (1981) made almost the same experience but succeeded in identifying *Densosporites* sp., *Lycospora* sp., *Aucyrospora* sp., *Particulatisporites* sp., and *Endosporites* sp., which indicate a latest Devonian to very early Carboniferous age of the shale and greywacke.

Fontaine and Ingavat (1983) inferred that the greywacke and conglomerate occurrences are of stratigraphic significance, and are typical of the base of the Carboniferous. They compare the greywacke and conglomerates of the Loei province with conglomerates which, according to Baum *et al*., (1970), mark the base of the Carboniferous in northern Thailand.

Lower Caboniferous reef limestone: The lithology is similar to that of the Devonian and Upper Carboniferous reef limestone. In most cases they consist of medium or dark-grey massive limestone, rather fine-grained and without visible bedding. Some irregular streaky inclusions apparently with lower solubility than the surrounding limestone stand out on weathered surfaces; they may be stromatoporoid structures. At some places in the western part of the map area lenses and layers of an impure detrital limestone or calcareous sandstone with Lower Carboniferous fossils

indicate erosion and sedimentation of calcareous material during or shortly after the growth of the Lower Carboniferous reefs.

Apart from these exceptions the Lower Carboniferous limestone is rather homogeneous and not visibly different from similar limestones of other age. The limestone often forms rugged cliffs which may rise to over a hundred meters above the surrounding. Other occurrences of reef limestone are only a few tens of meters long and about the same thickness, and had to be exaggerated on the map in order to make them visible. They are mostly arranged in north-south trending rows, which may be several kilolmeters long; Fontaine (1990b) uses the term 'Pha Chom Nang Belt' for the occurrences of Lower Carboniferous reef- limestone about 14-24 km west of Pak Chom and 'Ban Sangao Belt' for those about 15 km east of Pak Chom (Sheet 5345 II). The Lower Carboniferous reef limestone is always embedded in shale and never occurs in association with chert. The north-south trending belts of limestone mark the positions of the main synclinal structures and are used to draw the border line between the Devonian and Carboniferous parts of the shale and greywacke sequence.

The limestone bodies accumulated as smaller or larger patches of algal and stromatopora reefs which grew at certain places for a limited period; they occasionally also contain a few corals. The most important corals in the Lower Carboniferous reef limestone, which were identified by Fontaine (1990b), belong to the genera *Arachnolasma, Aulakoninckophyllum, Caninia, Hetrophyllia, Hexaphyllia, Kueichouphyllum, Siphonodendron, Solenodendron, Yuanophyllum.* The corals, together with algae and foraminifera identified by Vachard (1990) fix the age of the Lower Carboniferous reef-limestone reasonably precisely. It cannot be older than middle Visean and reaches up to the latest Visean. Lower Serpukhovian cannot definitely be excluded, but growth of the reefs took place mainly during the middle and late Visean. Determinations carried out on conodonts by Stoppel (1986-87) confirm this age.

Upper Caboniferous reef limestone: The lithology is similar to that of the Devonian and Upper Carboniferous reef limestone. In most cases they consist of medium or dark-grey massive limestone, rather fine-grained and without visible bedding. Some irregular streaky inclusions apparently with lower solubility than the surrounding limestone stand out on weathered surfaces; they may be stromatoporoid structures. At some places in the western part of the map area lenses and layers of an

impure detrital limestone or calcareous sandstone with Lower Carboniferous fossils indicate erosion and sedimentation of calcareous material

Permian limestone : The Permian limestone in the Loei area consists of massive, grey and light grey crystalline limestone with chert nodules. In some p;aces it is layered and brecciated. The Permian limestone forms mountains showing karst features and steep cliffs, shich probably follow faults. The Permian limestone occurs in the central part of Loei area and strikes NW-SE. It has yielded fusulinids, corals and crinoids stems. The occurrence of *Verbeekina* suggests that the limestone in mid Permian in age.

2.1.2 Mesozoic

Mesozoic sediments were deposited only in continental environments. They are widespread outside the Loei area around the exposures of the Paleozoic sedimentary rocks; they rest unconformably upon these rocks. They build up a thick succession of non-marine rocks, exceeding 4000 m in thickness.

2.1.3 Cenozoic

Cenozoic does not deserve special comments. It is extremely restricted in the Loei area. Tertialry deposits remain unknown. Alluvial deposits belonging to Quaternary are restricted to a few very small areas, eapecially along rivers (Charoennpravat *et al*., 1976; Chonglakmani *et al.*, 1979). In the large flat areas, they are thin, commonly less than 4 m thick; because of that, they are not shown on the geological maps.

2.2 Geological setting

In Thailand, research on the Carboniferous started in 1889, when a Cambridge expedition to Southern Thailand discovered diverse fossils (Tabulate, bivalves, brachiopods, cephalopods, trilobites) at “Kuan Din So” in Phatthalung Province. In 1900, these fossils were considered Permo-Carboniferous in age in a brief report after a rough determination (cf. Fontaine *et al*., 2005). Later on, a more detailed examination of the material was carried out by Reed and the results were published in 1920, clearly indicating a Lower Carboniferous age. Also in 1899, limestone samples were collected in Central Thailand form Chon Daen area (Phetchabun Province) by Mr. W.M. Daly, working for the Forestry Department (Garrentt, 1924). They were sent to the British

Museum and did not contain fusulinaceans. They were considered Carboniferous in age because of the occurrence of small foraminifera, which actually display a large stratigraphic range. According to recent studies, the limestone of this area belongs to the Lower Permian, and maybe to the Upper Carboniferous at its base (Figure 2.3).

After the discoveries of 1899, the Carboniferous of Thailand was ignored for many years until, in 1960, two Visean corals collected east of Loei from the vicinities of Sa Ngao (*Siphonodendron*) and Pak Chom (*Heterocaninia*) were described by Hamada. In 1961, a new trilobite genus (*Thaiapis*) was found in shale near Wang Saphung in Loei Province. It was assigned a probable Middle or Upper Carboniferous age (see Fontaine *et al.*, 2005).

Bleakley *et al.*, (1965) (Overseas Geological Surveys) investigated lead-zinc deposits of Loei Province. They made an attempt to elucidate the stratigraphy of the region. The sediments were described and, according to their lithological facies, were divided into 3 types of rocks referred to the Upper Devonian-Lower Carboniferous, the Lower-Middle Carboniferous and the Upper Carboniferous-Permian, respectively. Palaeontological results were still very rare at that time; in addition to that, the similarity of lithologies of different ages did not help to establish a strong stratigraphy.

Later on, in Northeast Thailand, studies were focused mainly on the Wang Saphung area. They were organized by the Department of Mineral Resources and carried out with the collaboration of Japanese geologists; brachiopods, trilobites and microfossils were identified (see below).

In Rat Buri Province, “Lower Carboniferous” Fenestellidae (Sakagami, 1965, 1966) were found at Khao Noi (0.5 km east of the road from Rat Buri to Khao Yoi) and at Khao Khok (Tambon Huai Phai, Amphoe Muang). Because of their poor preservation and their wide stratigraphic distribution, they were considered of little value for precise stratigraphy (Toriyama *et al*, 1975).

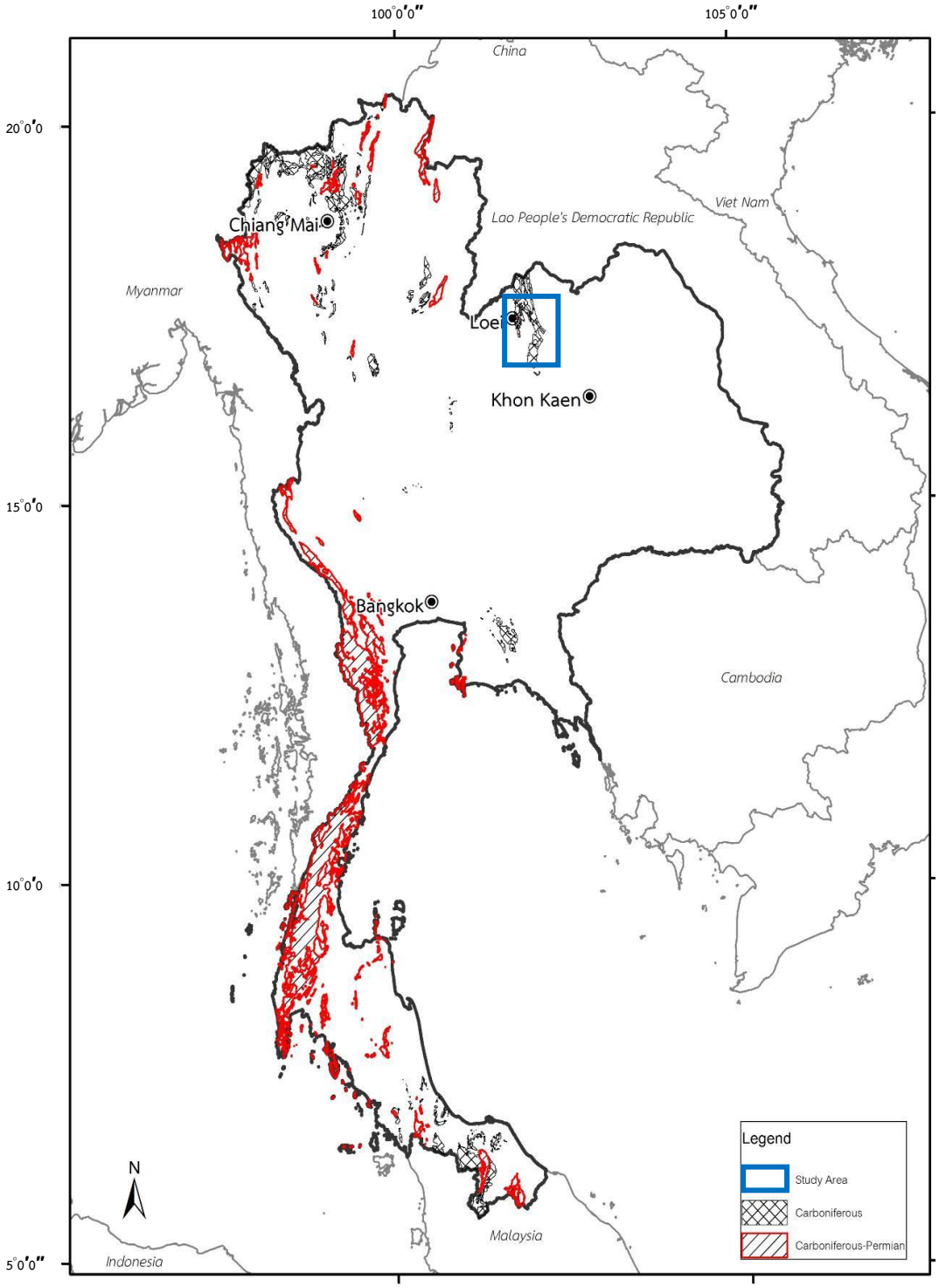


Figure 2.3 Index map of Thailand showing distribution of Carboniferous and Permo-Carboniferous rocks (modified after Geological Map of Thailand on 1:2,5000,000 scale, Department of Mineral Resources, 1992)

Upper Carboniferous (Lower Uralian) Fenestellidae were collected from pale green siliceous rocks near Petchabun (Sakagami, 1967). This information appears to be very interesting, but the geographic coordinates, indicated for this locality (16° 29’2l”N, 101° 53’18”E), are apparently erroneous (Fontaine *et al.*, 2005).

In southern Thailand, a Carboniferous (Visean) brachiopod was mentioned in Andaman Sea at Ko Kiang between Ko Adang and Ko Tarutao in Satun Province (Hamada, 1960). The material was poor and the identification rather difficult (Toriyama *et al.*, 1975). North of Chumphon, Lower Carboniferous Fenestellidae were reported by Sakagami (1971), an age assignment not fully accepted by Toriyama *et al.* (1975). An Early Carboniferous or more likely Middle Carboniferous brachiopod fauna was described from Ko Muk in the Andaman Sea (Hamada, 1960). It has been discussed by Waterhouse (1982), Shi and Waterhouse (1991) and Shi and Archbold (1995). Some previous generic assignments have not been accepted; the fauna has been considered Late Asselian to Early Sakmarian in age.

According to Toriyama (1984), Early Carboniferous fusuline faunas were still unknown in Thailand in 1984. Carboniferous was not clearly differentiated from younger or older systems at that time. Local stratigraphic names were used; they were based on regional studies, without precise lithostratigraphy and biostratigraphy in several areas (For instance, the Mae Hong Son Formation ranged from Silurian to Carboniferous). In 1983, a general information was: “Carboniferous sediments which are fossiliferous in the upper part occur in the environs of Loei and Phetchabun” (Bunopas, 1983, p. 42). In fact, species of Visean fusulines were mentioned in Loei area, for the first time in 1981 by Fontaine *et al.*. Middle and Upper Carboniferous fusulines were described in Northeast Thailand as early as 1972 (Igo, 1972). Lower Carboniferous fossils were known in Peninsular Thailand (Reed, 1920; Igo, 1973). In 1980, the most important studies on the Carboniferous paleontology had been carried out in Loei-Wang Saphung area. Elsewhere, a few localities had yielded Carboniferous samples, of which the age was sometimes debatable. In 1991, a book was published on the “Carboniferous corals of Thailand” (Fontaine *et al.*, 1991); new Carboniferous localities were described. Since then, other Carboniferous localities have been found (Fontaine *et al.*, 2003). Thailand is an attractive country for the study of the Carboniferous because of diverse faunas and floras as well as a great variety of

depositional environments. The Carboniferous seas extended to Laos and Vietnam. In these two countries, Carboniferous sedimentary rocks are widely exposed in several areas. In the past, an important orogenic phase was believed to have occurred during the Moscovian in these two countries, with a general stratigraphic break and large intrusion of granites. This point of view is no more accepted; a complete succession of the sediments through the Middle Carboniferous has been evidenced (Fontaine and Workman, 1978; Fontaine and Vachard, 1981).

Table 2.1 Stratigraphical distribution of Carboniferous limestone in Loei area

Age		**IMPORTANT FOSSILS**	**LOCALITIES**
Upper Carboni-ferous	Gshelian	Algae: *Connexia, Chuvashovia, Epimasto-pora, Eflugelia…*	Northwest of Pai, northwest of Pang Mapha, Ban Na Wai area
	Kasimovian	Foraminifers: *Triticites, Staffella, Schuber-tella, Schellwienia*	
Middle Carboni-ferous	Moscovian	Algae: *Dvinella, Beresella, Komia* Foraminifers: *Profusulinella, Fusulinella, Aljutovella, Neostaffella, Beedeina…* Corals :*Caninophtllum, Caninia, Yuano-phylloides, Multithecopora*	Ban Chabu, Ban Bo Khrai, Ban Mae Suya, Ban Pang Tong, Ban Mae Yan, Ban Na Wai areas
	Bashkirian	Algae: *Atractyliopsis* sp., *Velebitlla* n. Sp. aff. *Simplex*, Dasycladaceae indet., *Beresella*, rear *Ungdarella* Foraminifers: *Eostaffella, Millerella, Ozawainella, Profusulinella, Schubertella* Smaller foraminifera: *Climacammina, Globivalvulina, Bradyina, Tetrataxis,* Nodosariidae Fusulinaceans: *Profusulinella* spp., *Ozawainella* sp., *Staffella* sp., *Aljutovella* sp., *Pseudostaffella* sp. Corals: *Chaetetes, Caninia, Lublinophyllum, Ivanovia*	Ban Tat So Area, Ban Tham Pha Tang, Ban Sup, west of Ban Na Duang, Ban Na Charoen,
Lower Carboni-ferous	Serpukhovian	Algae: *Koninckopora, Windsoporella…* Foraminifers: *Eostaffella, Endostaffella, Endothyranopsis, Asteroarchaediscus, Vavulinella* Corals: *Arachnolasma, Kueichouphyllum, Solenodendron, Hexaphyllia, Syringopora...*	
	Visean		
	Tournaisian	Conodonts: *Apatognathus, Hindeodella, Neoprionodus* Radiolarians: *Entactinia variospina, Heleniforme laticlavium*	Ban Sa Kgao, Near Ban Pak Niem, Pphu Sang ak Chom,

Table 2.2 Stratigraphical distribution of Carboniferous limestone in Loei area (Fontaine *et al.*, 1991).

Localities	Pha Chom Nang area	Huai SaNhao, Khao Sam Nge	Phu Tham Pha Tang, Ban Tat So, Km 13, Pha Tha, Phu Bo Bit	Huai Nam Suai Section	Huai Pot, Ban Sup	Ban Pha Noi	Huai Lugng	Ban Na Charoen	Phu Ki Kai
Fossils	For. Cor. Al.	For. Cor.	For. Cor.	Corals	For. Brach.	For. Cor.	Brach.	For. Cor.	Corals
Authors	Fontaine et al 1981	Fontaine et al 1981, Fontaine 1989, Vachard 1989	Fontaine et al 1983, Fontaine 1989, Fontaine 1991, Vachard 1989	Fontaine et al 1991,	Igo 1972, Yanagida 1976	Igo 1972, Fontaine et al 1991	Yanagida 1976	Fontaine et al 1983	Fontaine et al 1991
Gzhelian									?
Moscovian									
Bashkirian									
Serpukhovian									
Visean									
Tournaisian									

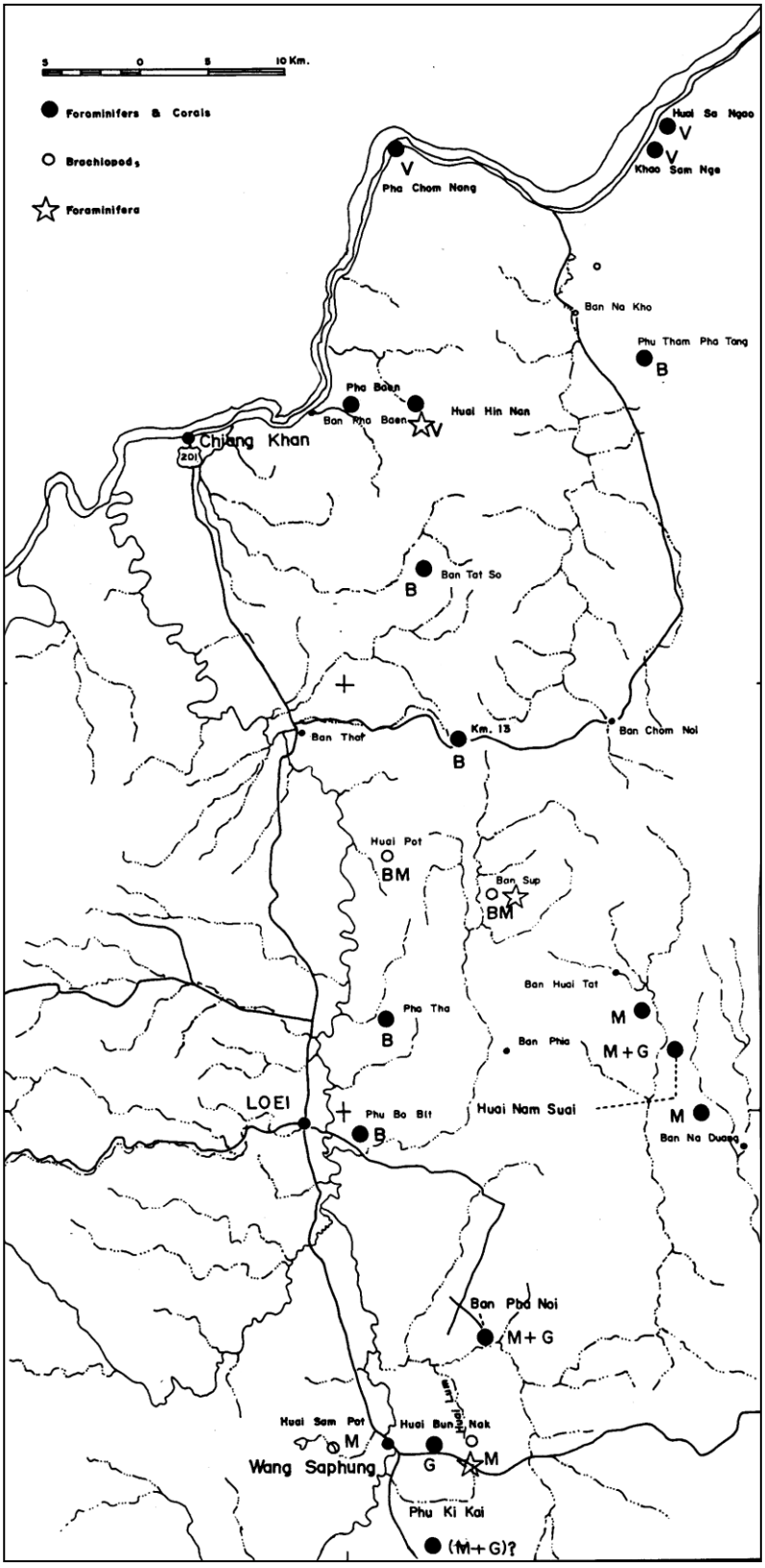


Figure 2.4 Carboniferous localities of Loei – Wang Saphung area
(Fontaine *et al.*, 1991)

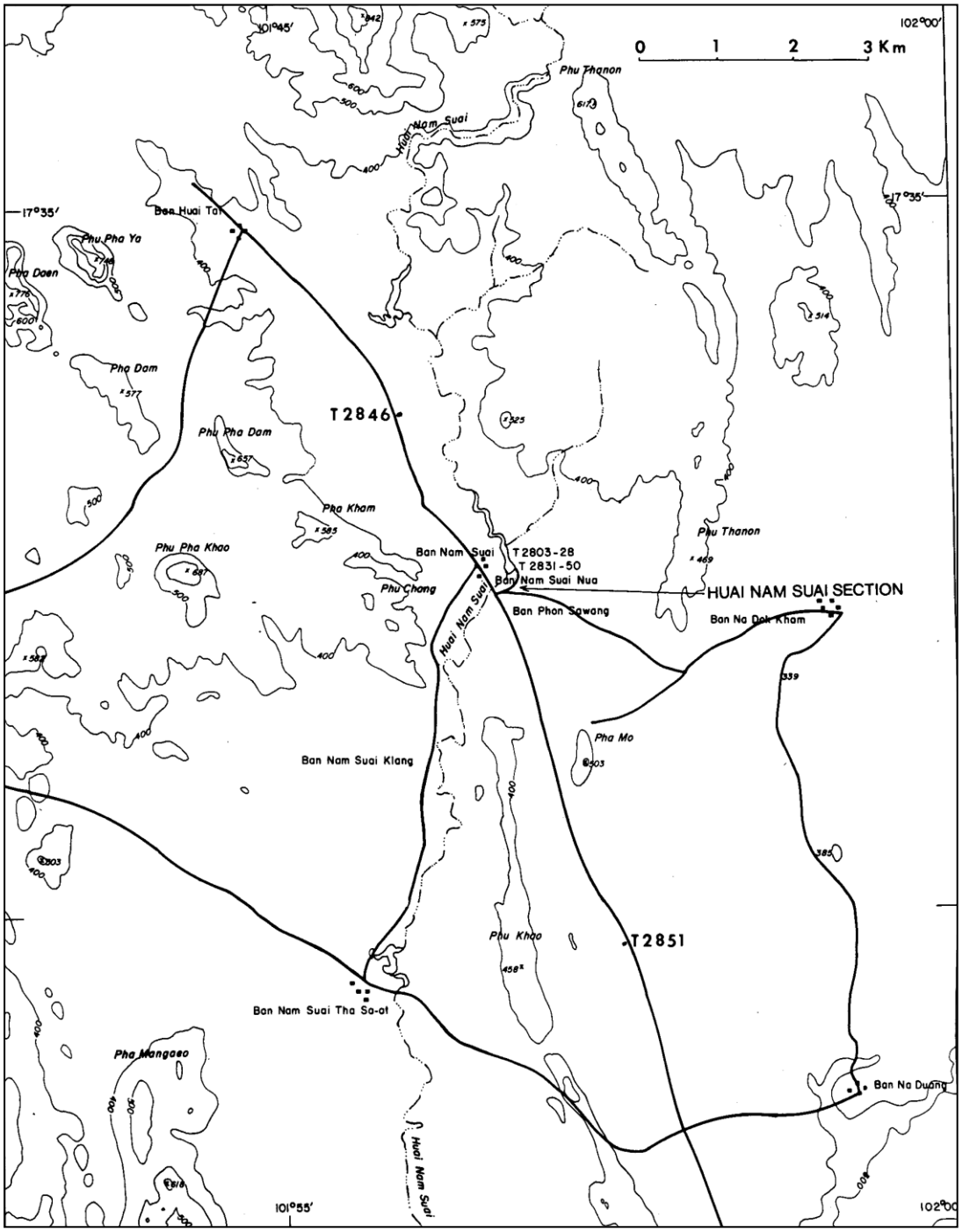


Figure 2.5 Huai Nam Suai area (Fontaine *et al.*, 1991)

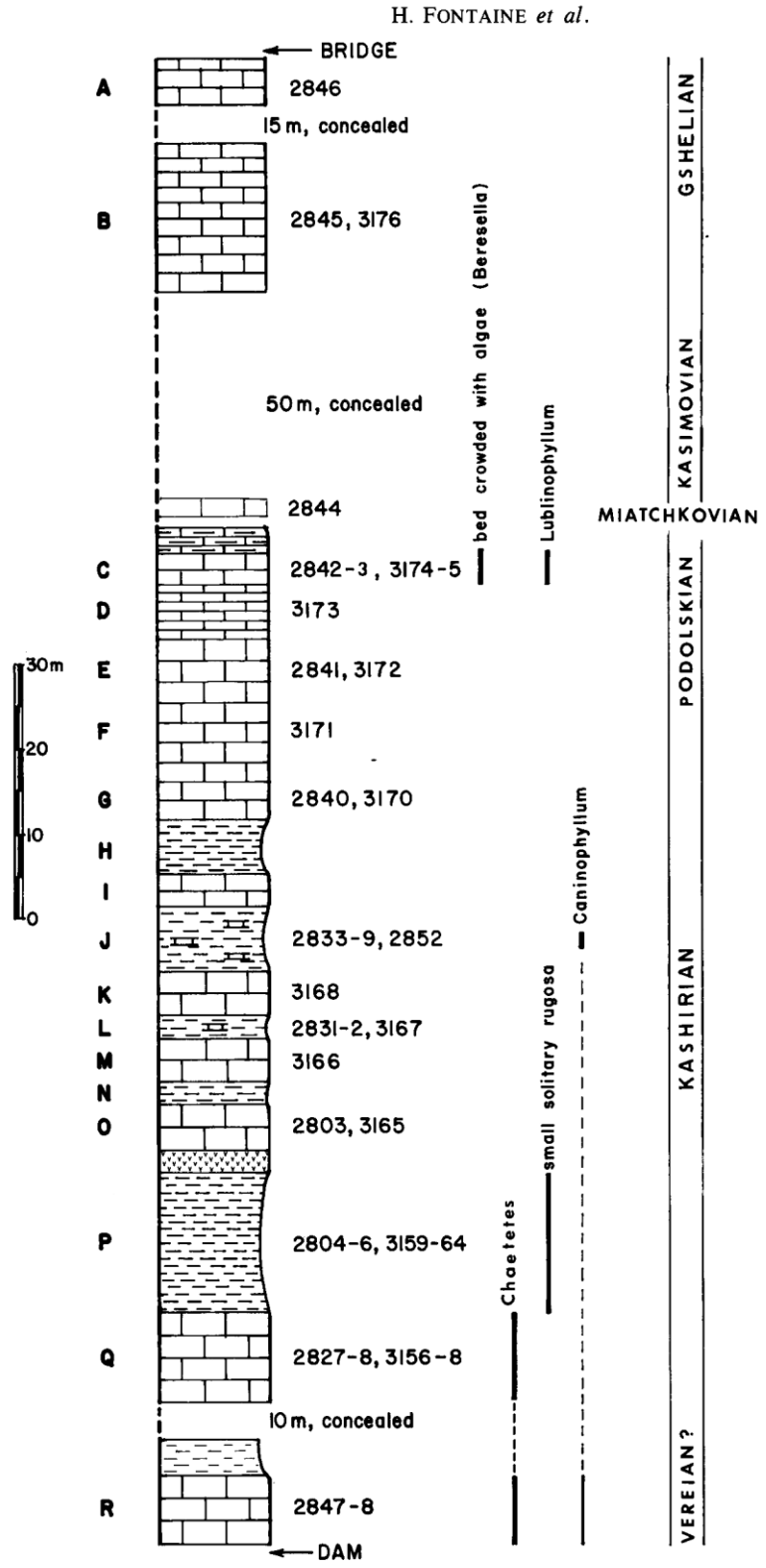


Figure 2.6 Columnar section of Huai Nam Suai. (Fontaine *et al.*, 1991)

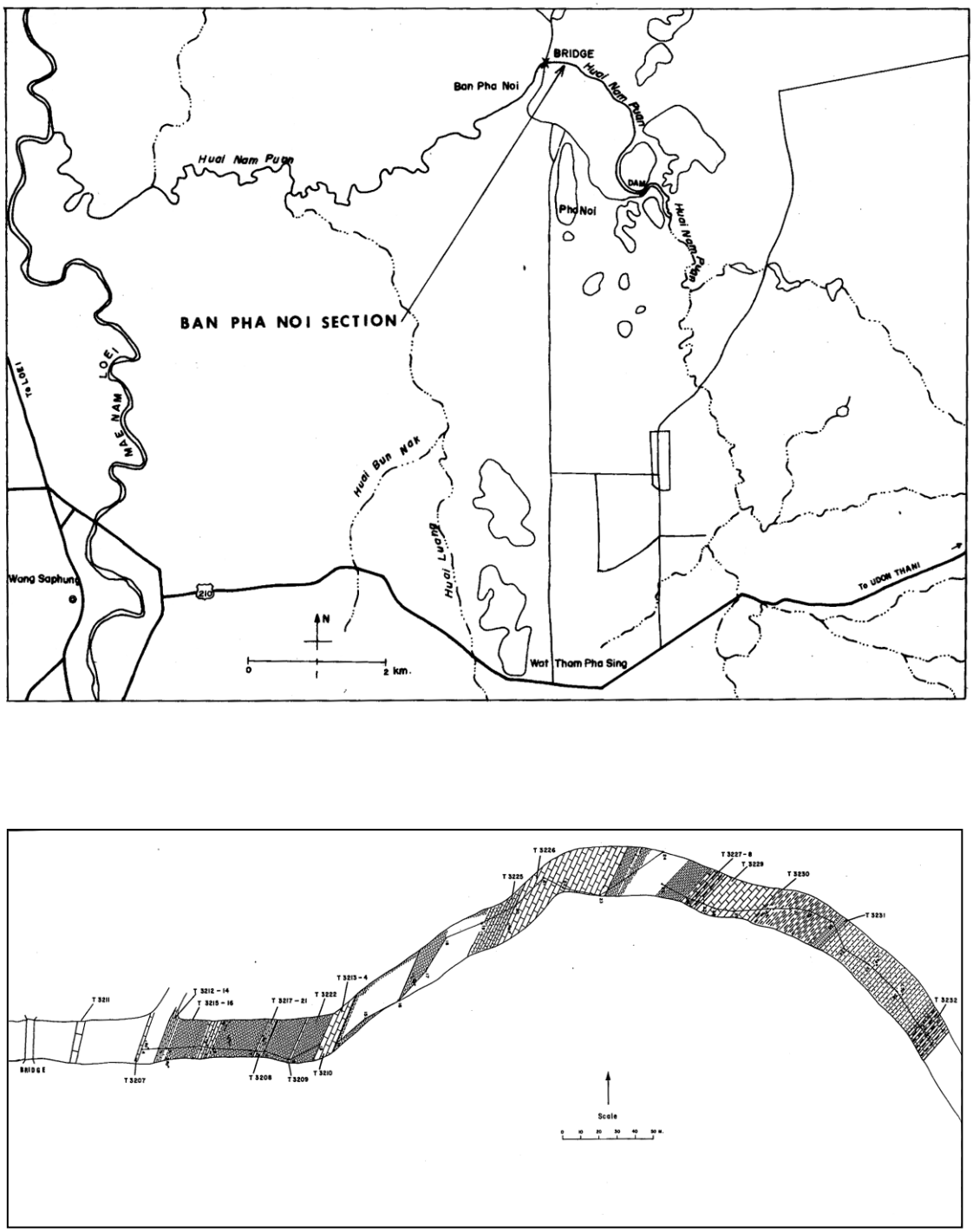


Figure 2.7 Ban Pha Noi section (Fontaine *et al.*, 1991)

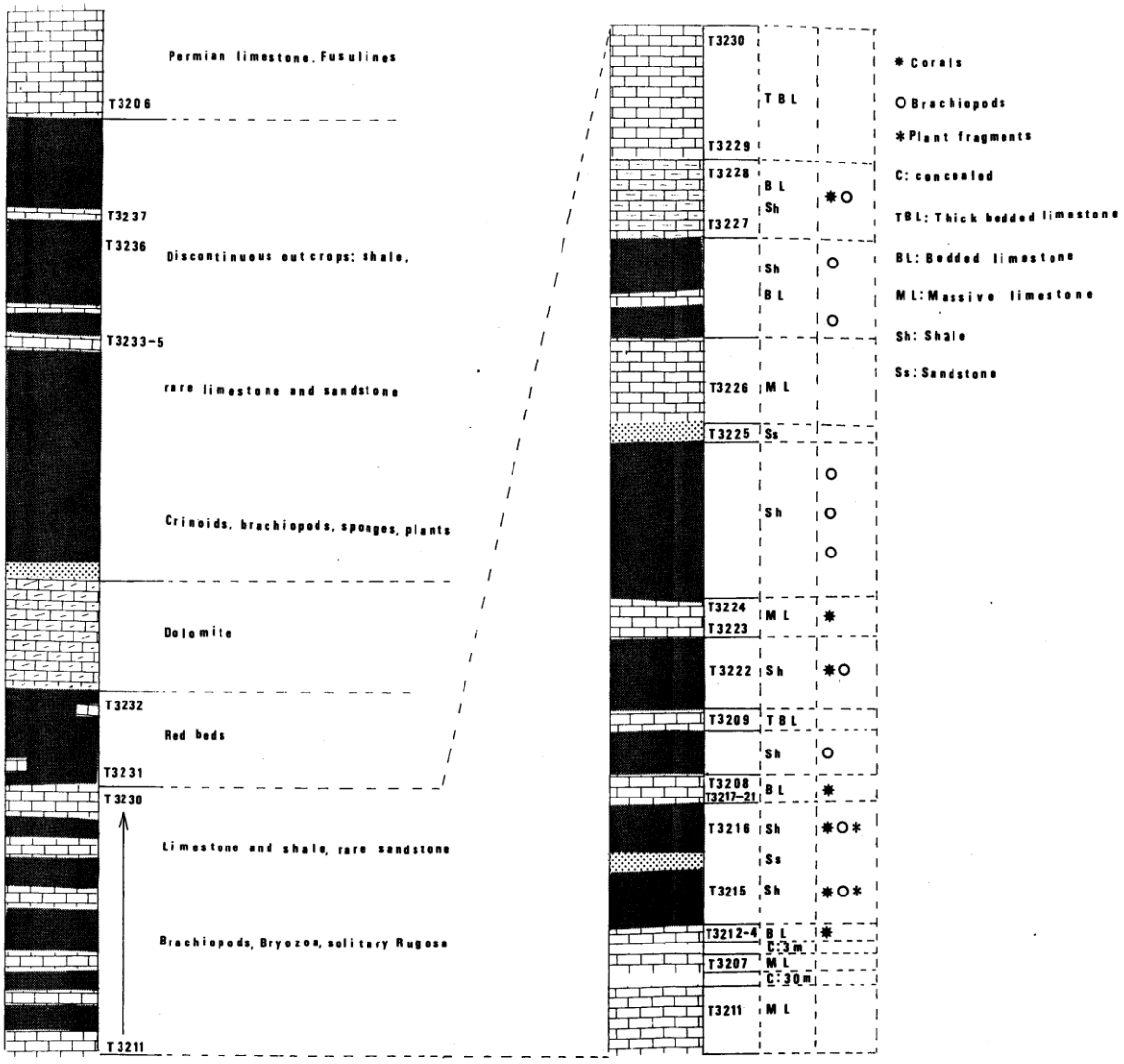


Figure 2.8 Columnar section of Ban Pha Noi section (Fontaine *et al.*, 1991)

2.3 Core log of gypsum drilling at Wang Saphung

Gypsum is known in Loei-Wang Sapung area for a long time (Haworth *et al.*, 1966; Jacobson *et al.*, 1969). It has been found by water wells drilled in the town of Loei and south of the town. It is associated with mudstone, shale and dolomitized limestone. Near Wang Saphung, the same sequence has also been observed. In the past, these rocks were tentatively placed within the Kanchanaburi Series, belonging to the Silurian-Devonian?-Early Carboniferous? (Brown *et al.*, 1951), although gypsum had not been reported elsewhere in these series (Jacobson *et al.*, 1969). In 1992, a water well found gypsum 2 km northwest of Loei at Nong Pak Kham, and about a year later, gypsum boulder were uncovered 1 km south of Wang Saphung. In 1995, an exploration of the gypsum was carried out by cored wells and geophysical techniques (Utha-Aroon and Surinkumm, 1995). A limestone bed was discovered above gypsum at a depth of 41 m. It was moderately rich in diverse Late Moscovian fossils including fusulinaceans (*Beedeina elegans* Rauser & Beliaev, 1940) and *Eostaffella lepida* Grozdilova & Lebedeva, 1950) and a fragment of a small solitary coral without dissepiments (Fontaine *et al.*, 1996).

The three wells from which the studied samples have been collected are located near Wat Non Sawang: they are in an east-west row: WP1 is to the west whereas WP2 and WP3 are respectively 100 and 500 m east of WP1. Gypsum is deep in the three wells, but is closer to the surface in other wells dug further south and a large gypsum anhydrite body has been found a kilometer south of WP3 between depths of 19.4 and 34.1 meters: see the contour map of the gypsum distribution in depth presented by Utha-Aroon and Surinkum (1995, fig 8)

WP1: A single sample from this well (2 thin sections T5076 and T5077) has been studied. It had been collected from a depth of 96.0 meters. It is a slightly and finely recrystallized micstone with some traces of shear. It contains a thin gypsum vein. A recrystallization in concentric layers suggests a stromatolite structure (T5077). No real fossil has been observed in all the thin sections. Small quartz crystals are occasionally present; they are not abundant and are due to diagenesis (Figure 2.10).

WP2; Three samples from this well (6 thin sections T5070 to T5075) have been studied. They had been collected at depths of 41.0, 51.2 and 56.1 meters (Figure 2.11).

At a depth of 41.0 meters (2 thin sections T5070 and T5071), limestone (wackestone) is relatively rich in diverse fossils consisting of the following taxa:

Calcispheres; *Eotuberitina retlingerae* Mikiukho Maklay 1958,
Tuberitina bulbacea Galloway et Hadton 1928

Pseudoalgae: *Claracrusta catenoides* (Homann, 1972)

Algae: *Gyroporella*? (Dasycladaceae)

Smaller foraminifer: *Climacammina* sp.
Globivalvulina sp.
Globivalvulina bulloides (Brady 1876)
Bradyina lepida Reitlinger 1950

Fusulinidae: *Ozawainella* sp.
Eostaffella lepida Grozdilova et Lebedeva 1950
Fusulina elegans Rauser et Beliaev 1940

Other fossils: Bryozoans (with Fenestellidae),
Gastropods, ostracods and crinoids.

Fusulina elegans is known by a single specimen: it indicates a Late Moscovian (Podolskian-Miatchkovian) age.

At a depth of 54.2 meters (3 thin sections T5072 and T5073), limestone (micstone to wackstone) contains only spongiostromids: other fossils are entirely absent. The nature of the limestone, the presence of abundant spongiostromids and the absence of other fossils indicate a strongly confined environment.

At a depth of 56.1 meters (3 thin sections T5074 and T5075), spongiostromids are less common. However, depositional environment is still confined. Limestone is a micstone. Fossil are few and consist of calcispheres (*Eotuberitina reitlingerae* Miklukho-Maklay, 1958), ostracods, brachiopods and gastropods.

WP3: A single sample has been studied: it had been collected from a depth of 40.3 meters (4 thin sections T5078 and T5079) (Figure 2.12). Limestone is wackestone to packstone. Fossils are common and display abundant traces of tiny borings. They consist of;

Smaller foraminifer: *Endothyra* sp.
Bradyina sp.
Tetrataxis sp.
Calcivertellidae
Hemigordius sp.

Other fossils: Brachiopods, bryozoans (with Fenestellidae), bivalves, gastropods, ostracods, crinoids and trilobites.

The trilobites and the Fenestellidae indicate clearly a Paleozoic age whereas some foraminifers focus on a Carboniferous-Permian age. *Hemigordius* is known form the late Moscovian to the late Permian in the Tethyan realm.

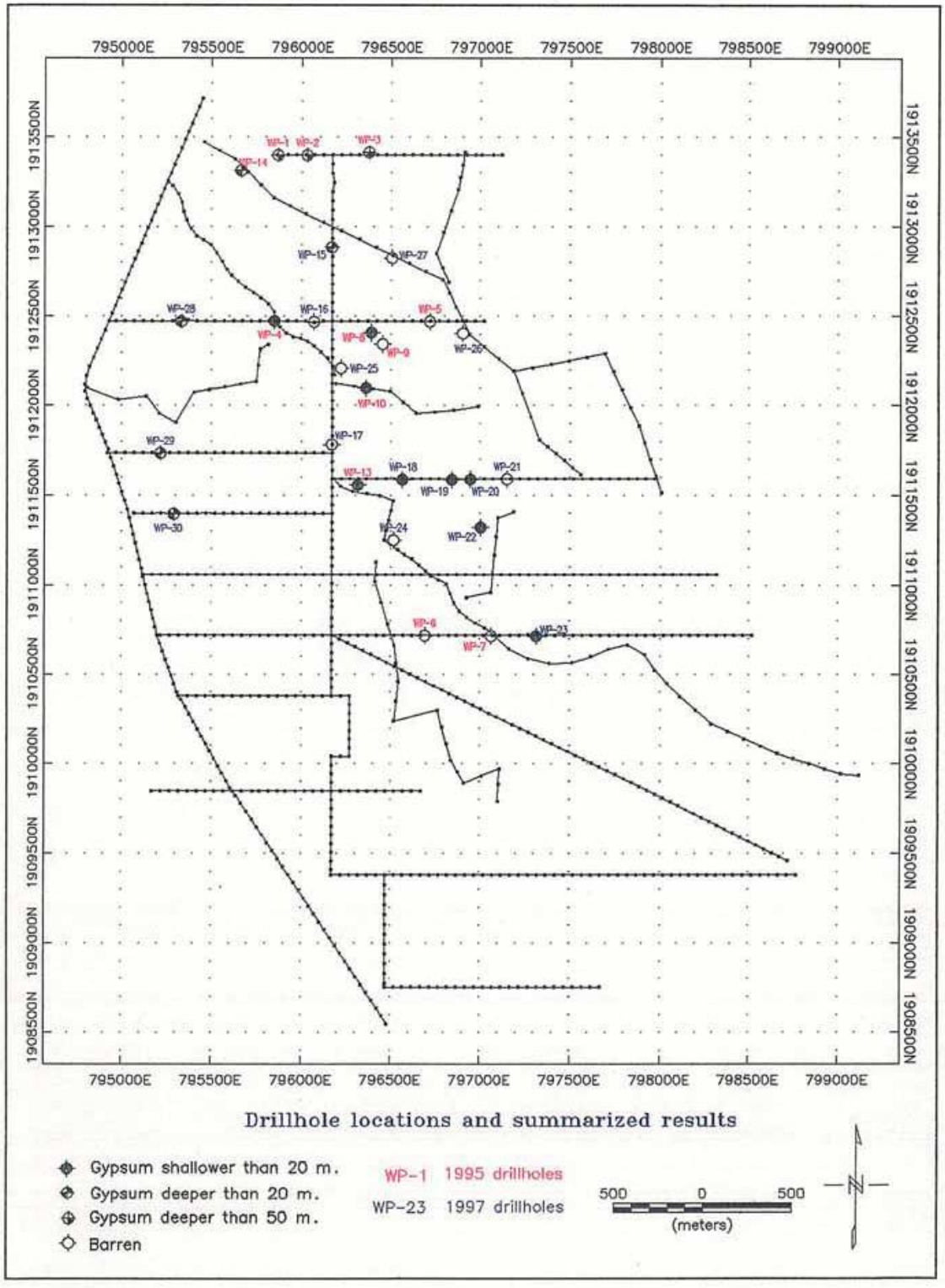


Figure 2.9 The drillhole locations of the gypsum exploration in the Wang Saphung area (Kuttikul *et al.*, 1997)

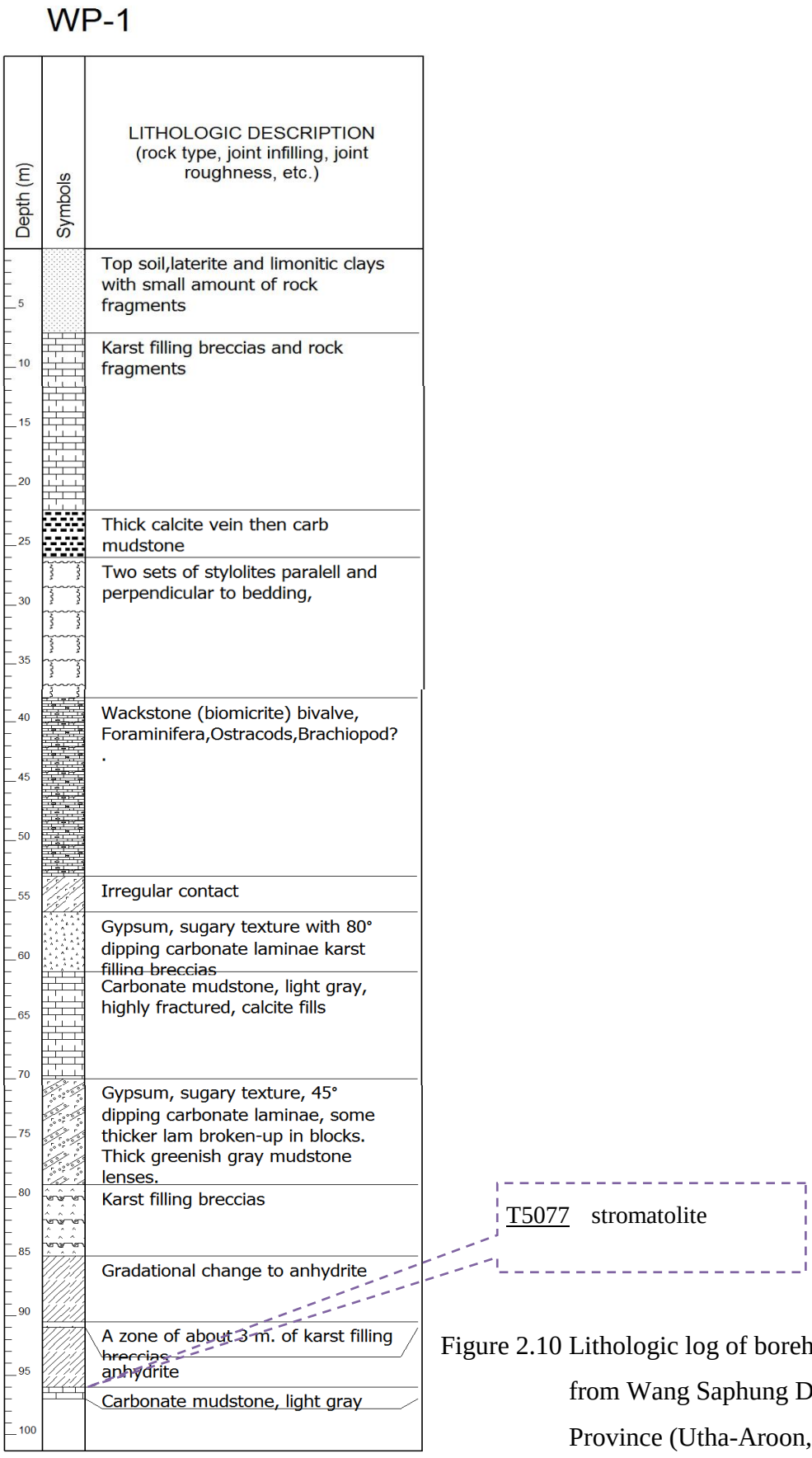


Figure 2.10 Lithologic log of borehole No. WP-1 from Wang Saphung District, Loei Province (Utha-Aroon, *et al.*, 1995)

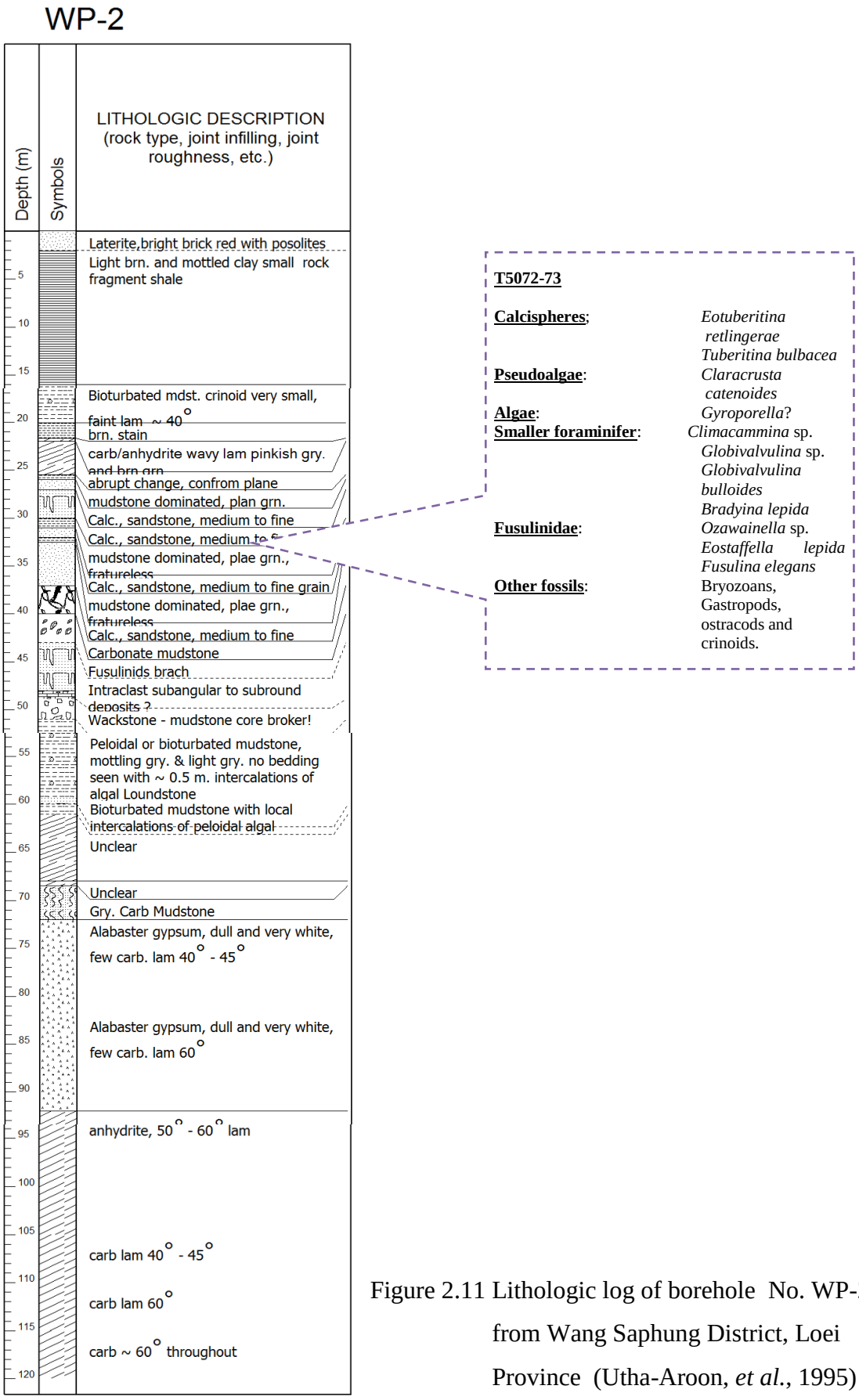


Figure 2.11 Lithologic log of borehole No. WP-2 from Wang Saphung District, Loei Province (Utha-Aroon, *et al.*, 1995)

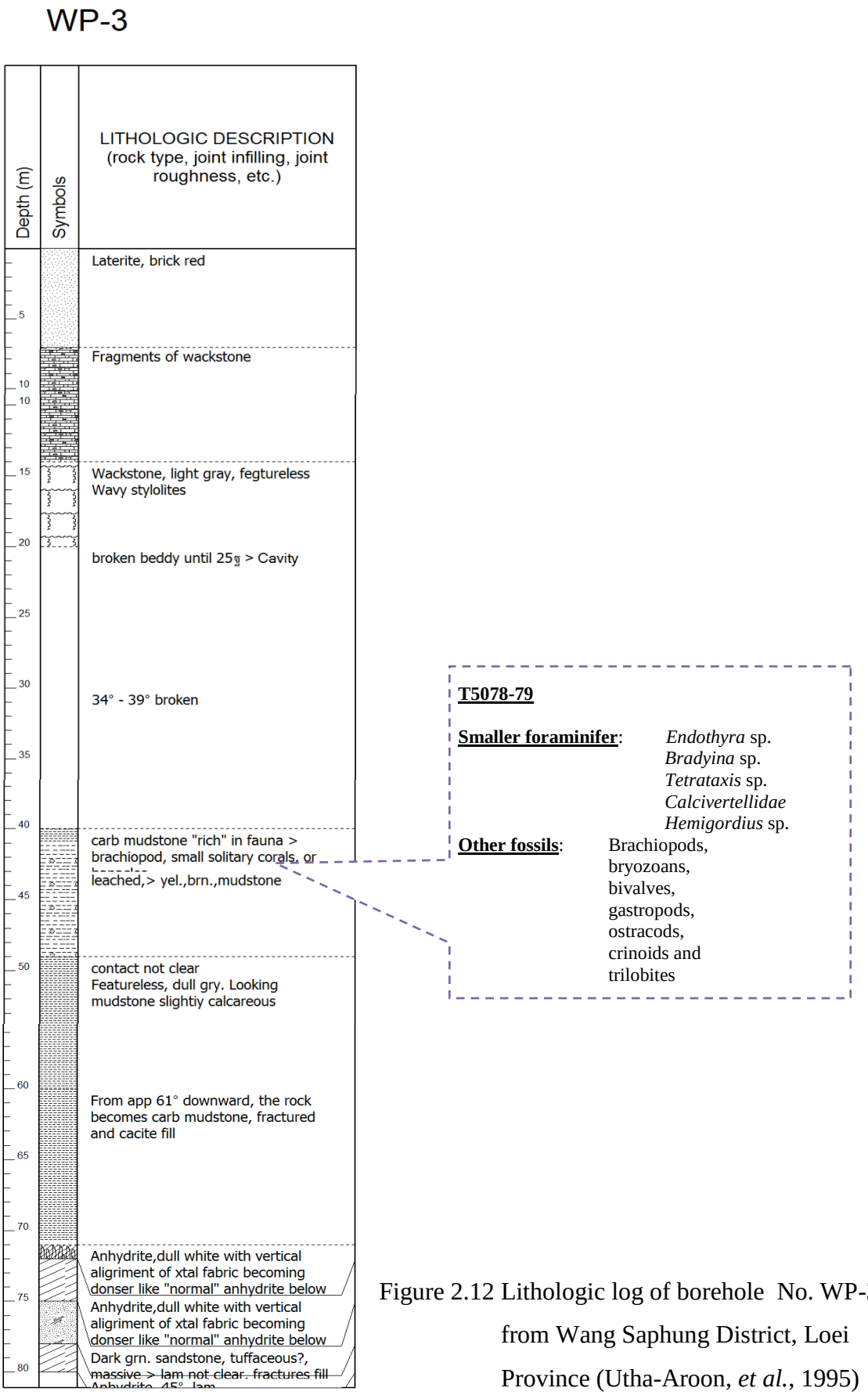


Figure 2.12 Lithologic log of borehole No. WP-3 from Wang Saphung District, Loei Province (Utha-Aroon, *et al.*, 1995)

2.4 Continental event

The important event mentioned in Pha Chom Nang Belt between Lower and Middle Carboniferous is more easily observed in Ban Sa Ngao Belt because of wider exposures of continental sediments.

About 6 km east of Ban Pak Niem and about 7 km south of Mekong River, a sequence of shale and sandstone contains a small coal deposit, which was investigated by core drillings in 1985-1986. This occurrence of coal is located about 60 km north of Ban Na Duang coal. Brachiopods in the shale indicated a near-coast marine environment; they suggested a Carboniferous to Permian age (Chairangsee *et al.*, 1990). This sequence unconformably overlies serpentinite. To the south, Chairangsee *et al.*, 1990 (bc. 71) mentioned plant remains in a Carboniferous shale east of Ban Pak Huai Na.

East of Ban Chom Noi and 1.5 km northwest of Ban Loeung (1743’07”N, 102200’02”E; locality 45 of fig. 2; samples T6968 to T6982), a weathered shale is exposed along a small road. It dips 30 towards the east. It is rich in plant imprints which have not been studied yet and seem to belong to the end of the Lower Carboniferous according to J. Broutin of Paris University. This outcrop is 10.5 km east of Ban Chom Noi and 11 km south-southeast of Ban Chiang Kiom. It is 27 km north of Ban Na Duang where similar fossil plants have been described (see the following paragraph). East of Ban Loeung, metamorphic rocks are widespread east of longitude 10201 ‘20’E.

Northeast of Ban Na Duang (locality 49 of fig. 2), a clastic sequence of shale, tuffaceous sandstone and siltstone contains lenses of anthracitic coal, which was exploited in the past. Plant leaves, roots, branches and trunks are visible in some beds. They consist of large frond fragments of *Eusphenopteris* associated with fragments of *Stigmaria, Lepidodendron, Adiantites, Archaeocalamites, Rhodeopteridium.* This flora indicates a Namurian B age and displays affinities with the floras of the regions located north of the paleotethys (Laveine *et al.,* 1993, 1994, 1999). Because of the other information on the stratigraphy of the region, the age should be restricted to a Serpukhovian-Lower Bashkirian age.

In conclusion, exposures of continental Carboniferous sediments appear to extend over a long distance from Mekong River to Ban Na Duang coal mine.

Table 2.3 These fossils indicate that the limestones of Wang Saphung and Na Duang area belong to a span of time from Bashkirian to Moscovian (Middle Carboniferous)

Fossil		**W***ang Saphung*	*Na Duang*
Calcispheres	*Eotuberitina retlingerae*	+	
Pseudoalgae	*Claracrusta catenoides*	+	
Algae	*Gyroporella*? *Tuberitina bulbacea*	+ +	
Foraminifers			
Small foraminifera	*Climacammina* sp., *Globivalvulina* sp., *Globivalvulina bulloides*, *Bradyina lepida*, *Calcivertellidae*, *Hemigordius* sp. *Tetrataxis* sp.	+ + + + + + +	
Fusulines	*Ozawainella* sp., *Eostaffella lepida*, *Fusulina elegans*, *Endothyra* sp., *Bradyina* sp.,	+ + + + +	
Corals			
Other fossil	bryozoans, gastropods, ostracods crinoids, and trilobite	+ + + + +	
Fossil plants	*Stigmaria*, *Lepidodendron*, *Adiantites*, *Archaeocalamites*, *Rhodeopteridium*.		+ + + + +

2.5 Sedimentology

1. Limestone classification

The main purpose of petrographic analyses of limestone is for depositional environment interpretation. In fact the most widely used classification are based on the concept of textural (fabric) maturity which is believed to concern to the energy level during the limestone deposition. The basis of the classification is given by many authors, however, Folk (1959) and Dunham (1962) systems are the most widely used. (Figure 2.13)

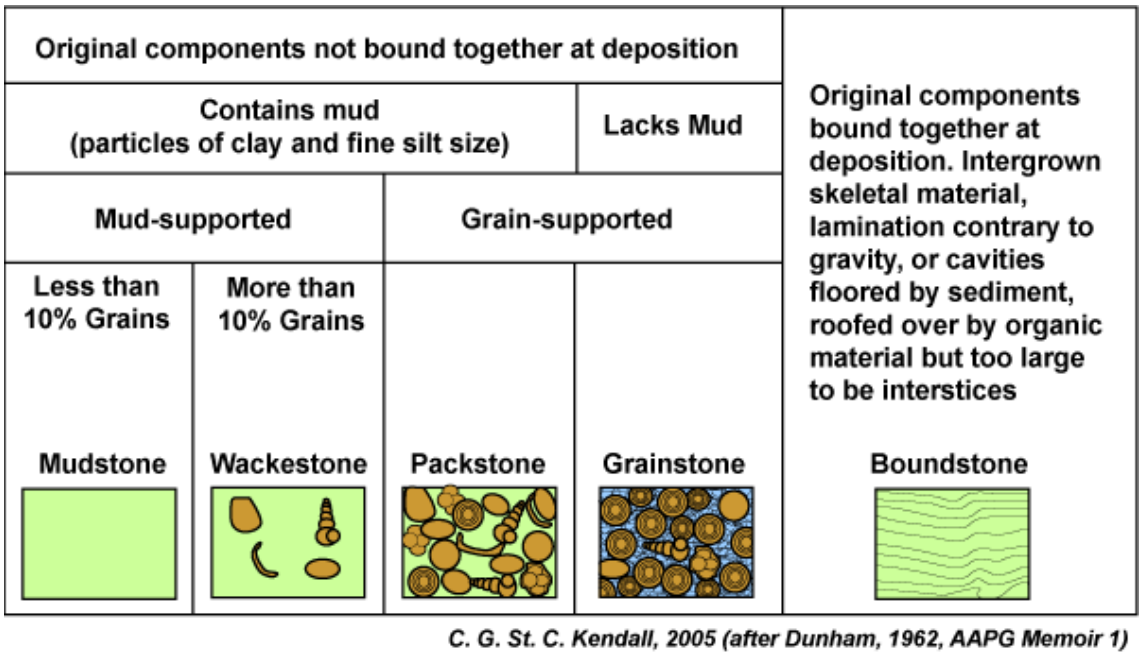


Figure 2.13 The classification of carbonate sedimentary rocks. These schemes are commonly used for description of limestone in the field and in hand specimen. above scheme after Folk (1959) and below scheme after Dunham (1962).

2. Standard Microfacies Types

With the aid of sedimentological as well as paleoecological data, the microfacies types of limestones of various ages can be combined into major types which reflect the depositional and ecological conditions in a certain sedimentary environment (Flugel, 2004). The major types or Standard Microfacies Types (SMF Types) have often proved useful as a basis for considering depositional environments by Flugel (2004) as show in Figure 2.14

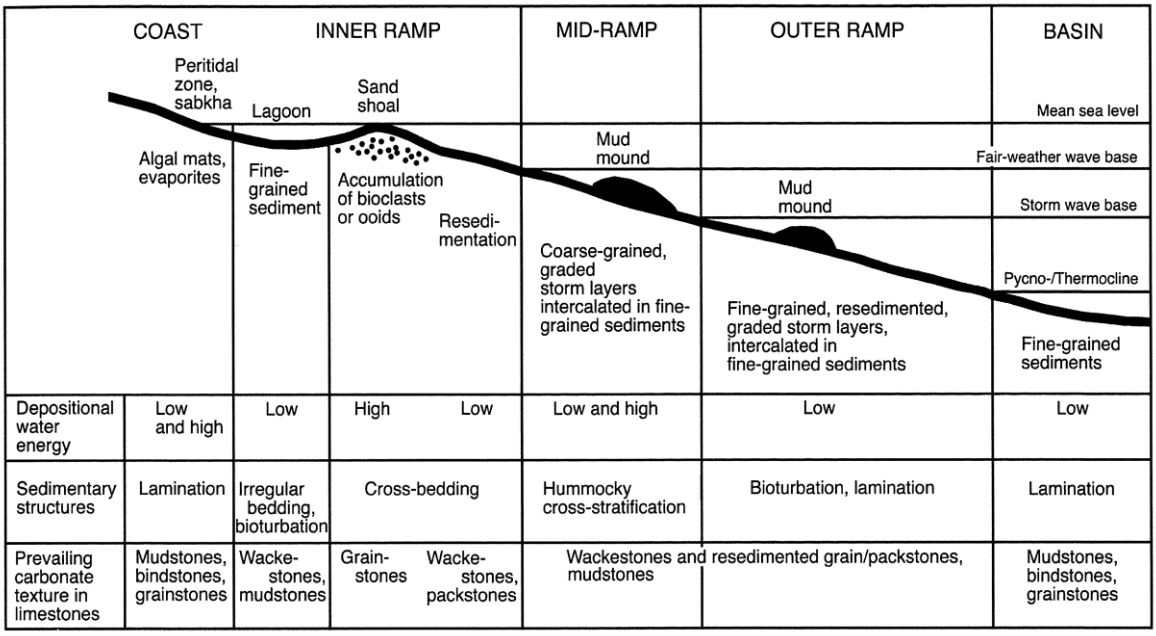


Figure 2.14 Generalized subdivision of carbonate ramps (Flugel, 2004).

2.6 Morphology of fusulinid

Many textbooks contain valuable information on the morphology of fusuline. Particularly useful ones include Moore and others (1964) and Boardman and others (1987). They are considered and concluded to this part as follows:

The fusuline tests are mostly fusiform, globular or subsylindrical in shape (Figure 2.15) and coiled around an axis. The tests of many different genera are similar in the external appearance, but the internal structure may be quite dissimilar. Classification on internal shell features can be determined from thin sections or polished slices. Two sections are indispensable which cut through the beginning chamber. They disclose most internal features of the shell. One of these slices bisecting the shell with parallel to the axis of coiling and including the center of the proloculus, is called an axial section. The other, slices through the test with vertical to the axis of coiling and passing the proloculus, is called a sagittal section. A section parallel to the axis of coiling but not through the initial chamber is a tangential section. A section vertical to the axis of coiling but no passing the proloculus, is called a parallel section. Sections cut in directions neither parallel to the axis of coiling nor normal to it are referred to oblique section.

Fusuline growth starts with a minute sub-sphercal initial chamber called the Proloculus (Figure 2.15) Chambers are added around the proloculus with an axis of coiling to form a coiled test. The outer or upper wall of test encloses the chamber, is called spirotheca (Figure 2.16). Shell increases in size by secretion at the outer margin of the shell, forming new chambers. Parition between chambers, commonly consisting of previous outer wall is called septum. As each chamber is added, the last formed septum becomes the antetheca. Septal pore (Figure 2.15 - 2.18) is the small perforation in septum and antetheca. The external view of shell is devided by shallow closely spaced meridional grooves, external furrow which mark the position of the septa. Folding or corrugation of septum and antetheca transverse to the axis of coiling, are septal fluting. The septa are essentially plane in many of the primitive fusulines. They evolve fluting in more complex forms and chamberlets develop where opposing folds touch and partly divide the chambers. Cuniculus is tunnel-like passageways between alternate chamberlets formed by strong septal fluting. Resorbed area at base of septa in

the central part of fusuline is tunnel (Figure 2.16-2.18). Choma is a ridge of dense calcite which deposited beside the tunnel.

Many fusulinids resemble grains of wheat; the internal structure, however, is very complex and distinctive. The shell consists of a series of chambers formed about a central longitudinal axis. Complex patterns in the number and arrangement of internal walls and deposits are present and aid in classification and the working out of evolutionary relationships.

Members, especially of the Fusulinacea, are excellent index fossils for determining ages and correlating Upper Mississippian to Permian strata (Figure 2.19). In some places fusulinaceans may be so abundant as to be a significant component of limestone.

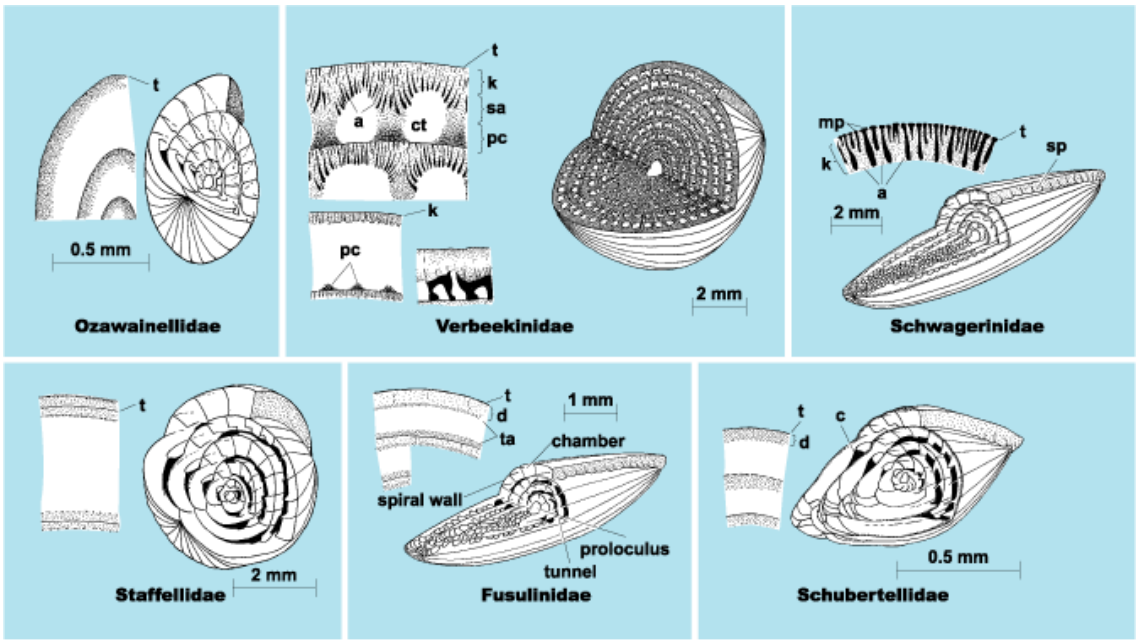


Figure 2.15 Diagram of fusulines test showing structure features (Moore, 1964).

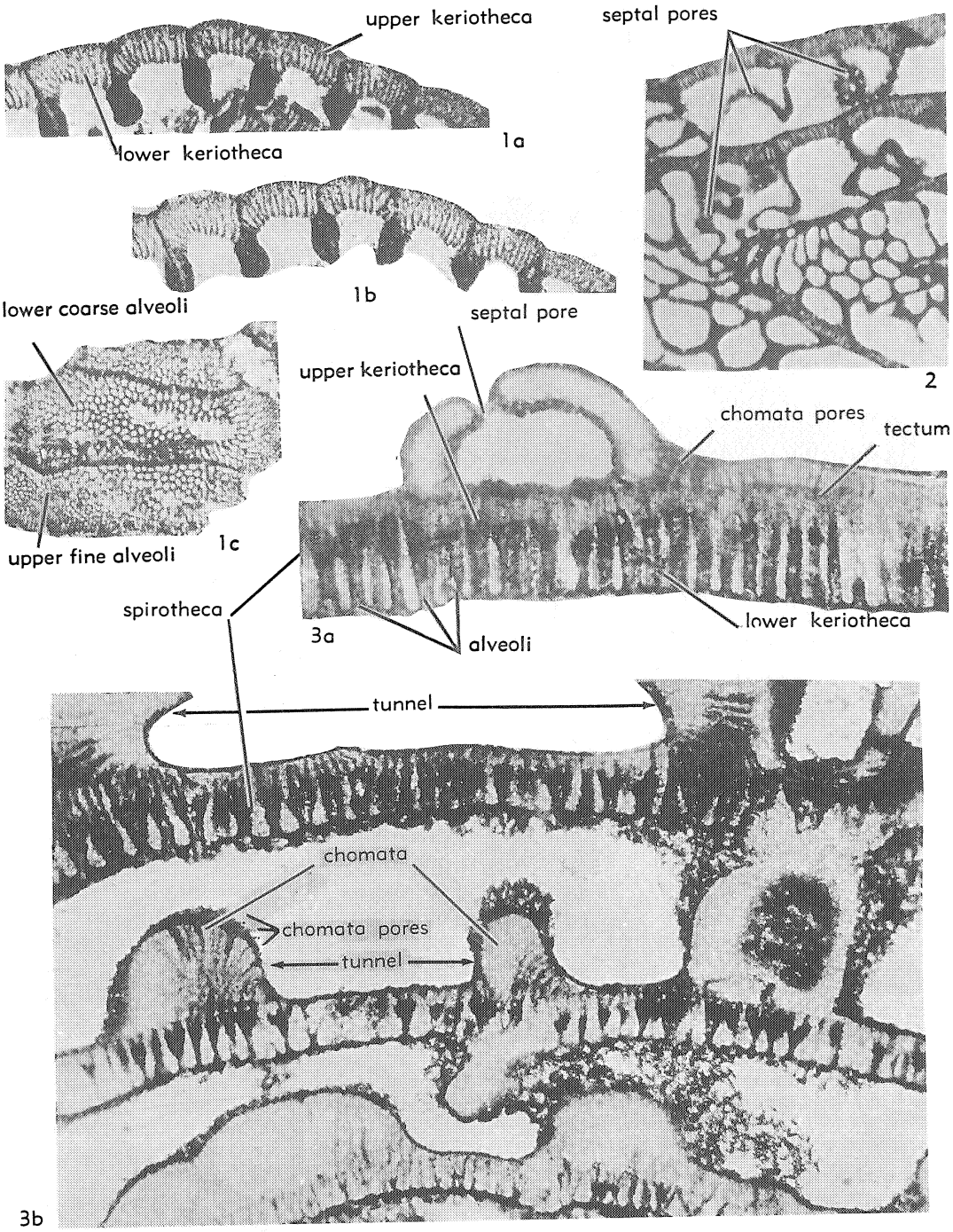


Figure 2.16 Spirotheca and septal structures of fusulinaceans (Moore, 1964).

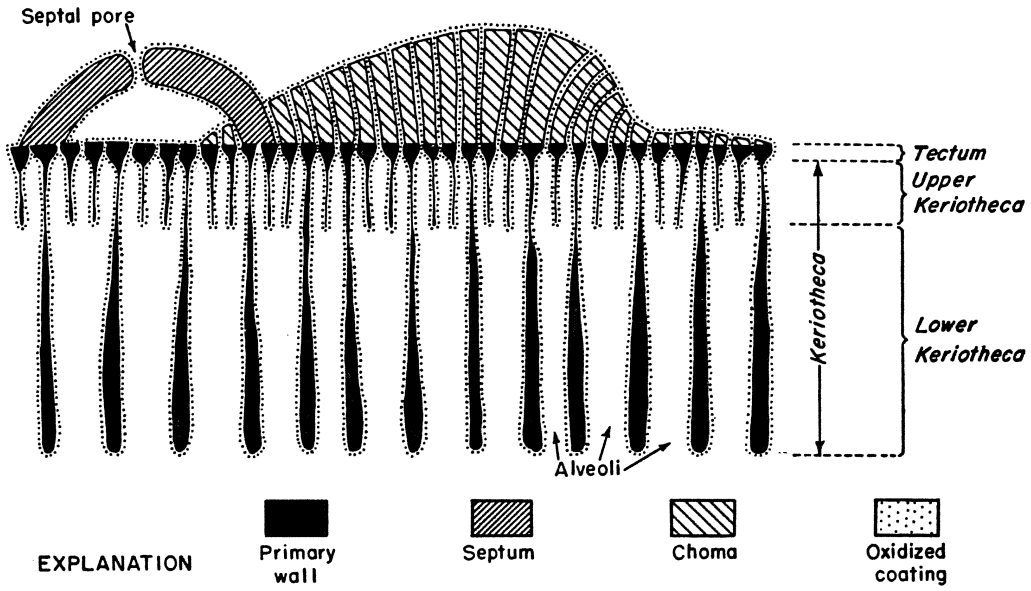


Figure 2.17 Diagram of spirotheca showing pendant-like walls of alveoli, choma and septal pore of *Schwagerina campensis* THOMPSON, L.Perm. (Moore, 1964).

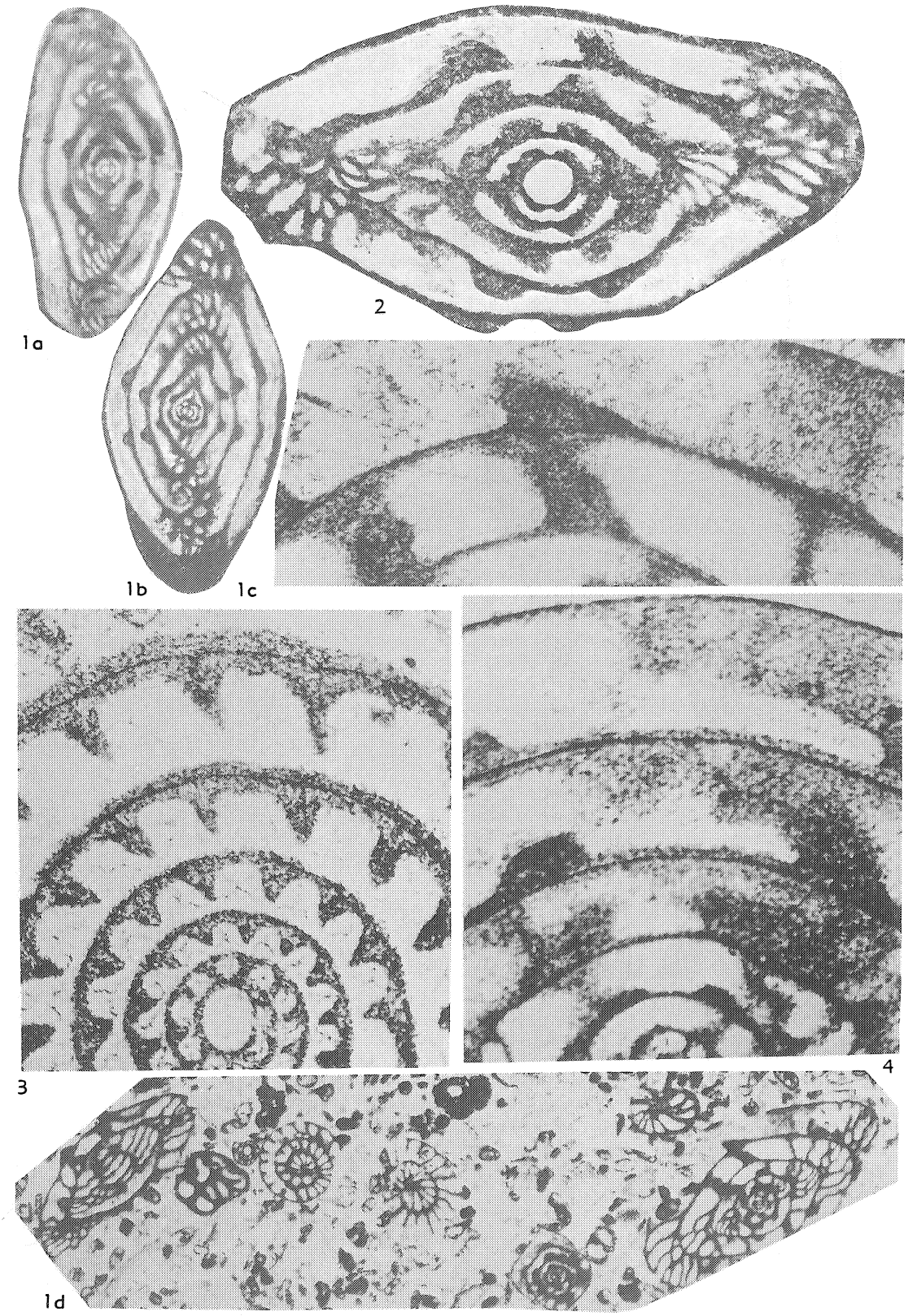


Figure 2.18 Fusulinidae (Fusulininae; 1-4, *Profusulinella*). (Moore, 1964).

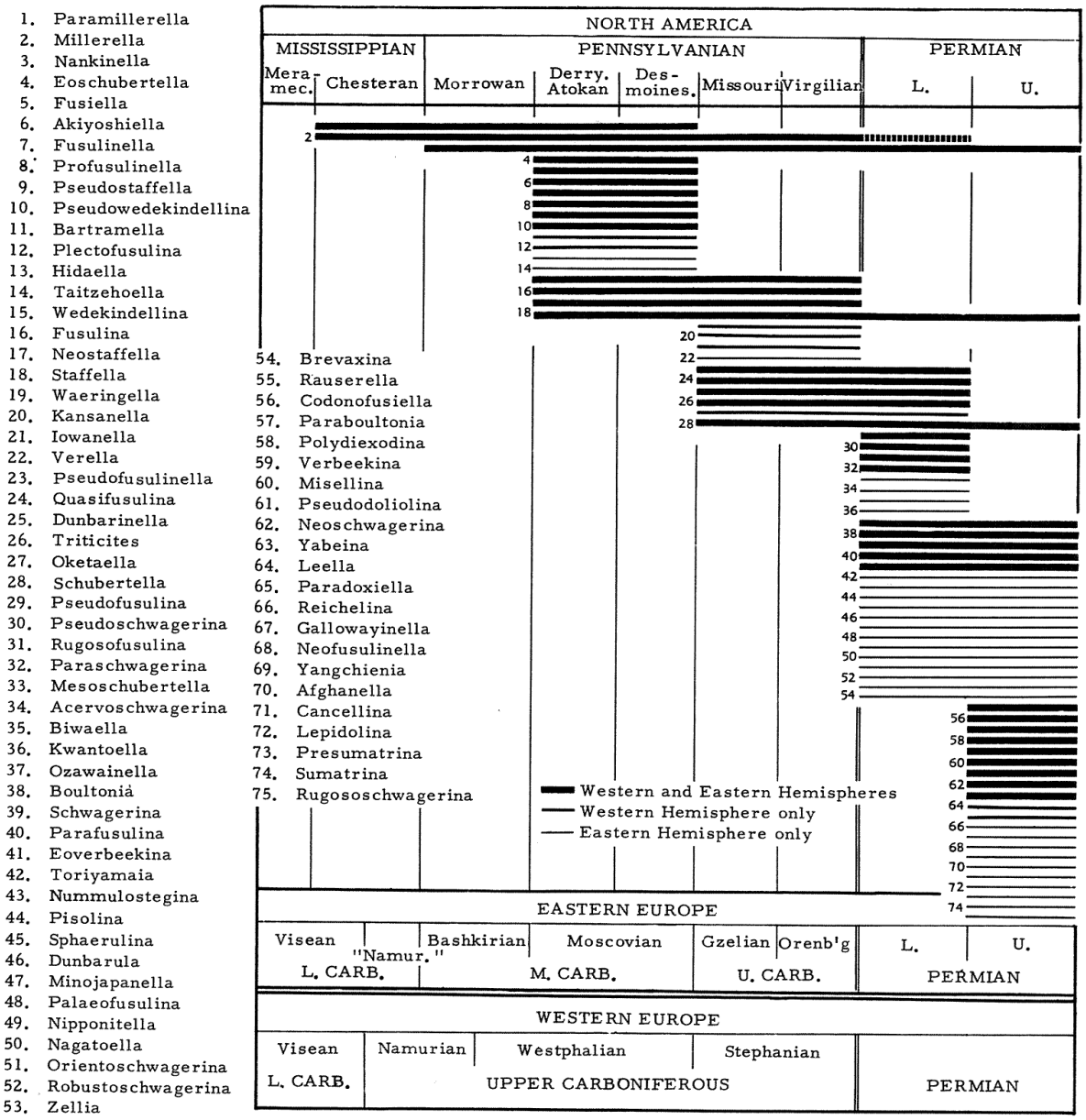


Figure 2.19 Stratigraphic distribution of fusulinacean (Moore, 1964).

CHAPTER 3

METHODOLOGY

3.1 Study localities

The study area is located in Loei Province, in northeastern Thailand, between 101° 30’ to102° 30’ E and 16° 45’ to18° 15’ N (Figure3.1). It covers topographic map on the scale 1: 50,000 Series WGS84 (39 Map sheet). This study contains two main localities including the Phu Bo Bit and Phu Pha Mo in the east of Loei and Wang Saphung, respectively (Figure 3.2).

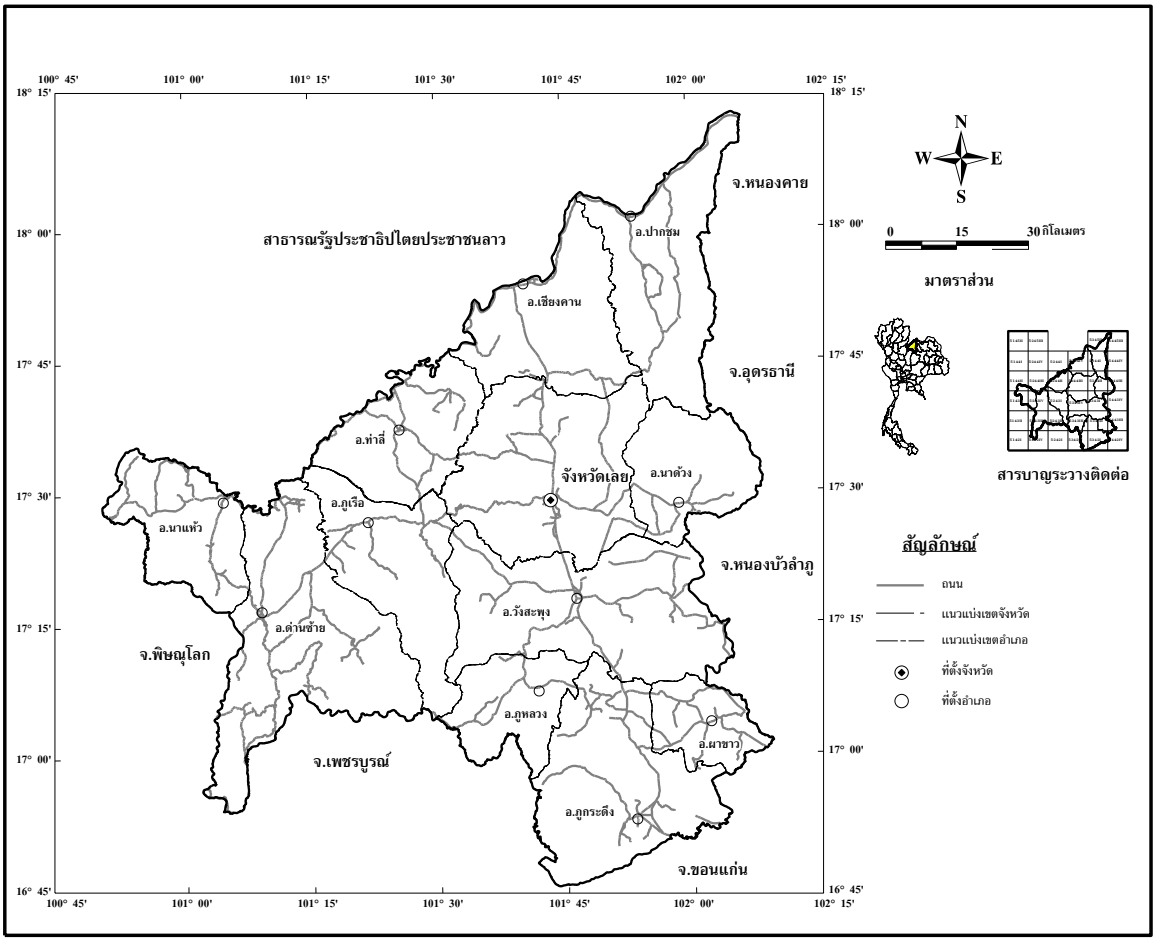


Figure 3.1 Topographic map Index of the study area on the scale 1: 50,000 by ArcGIS.

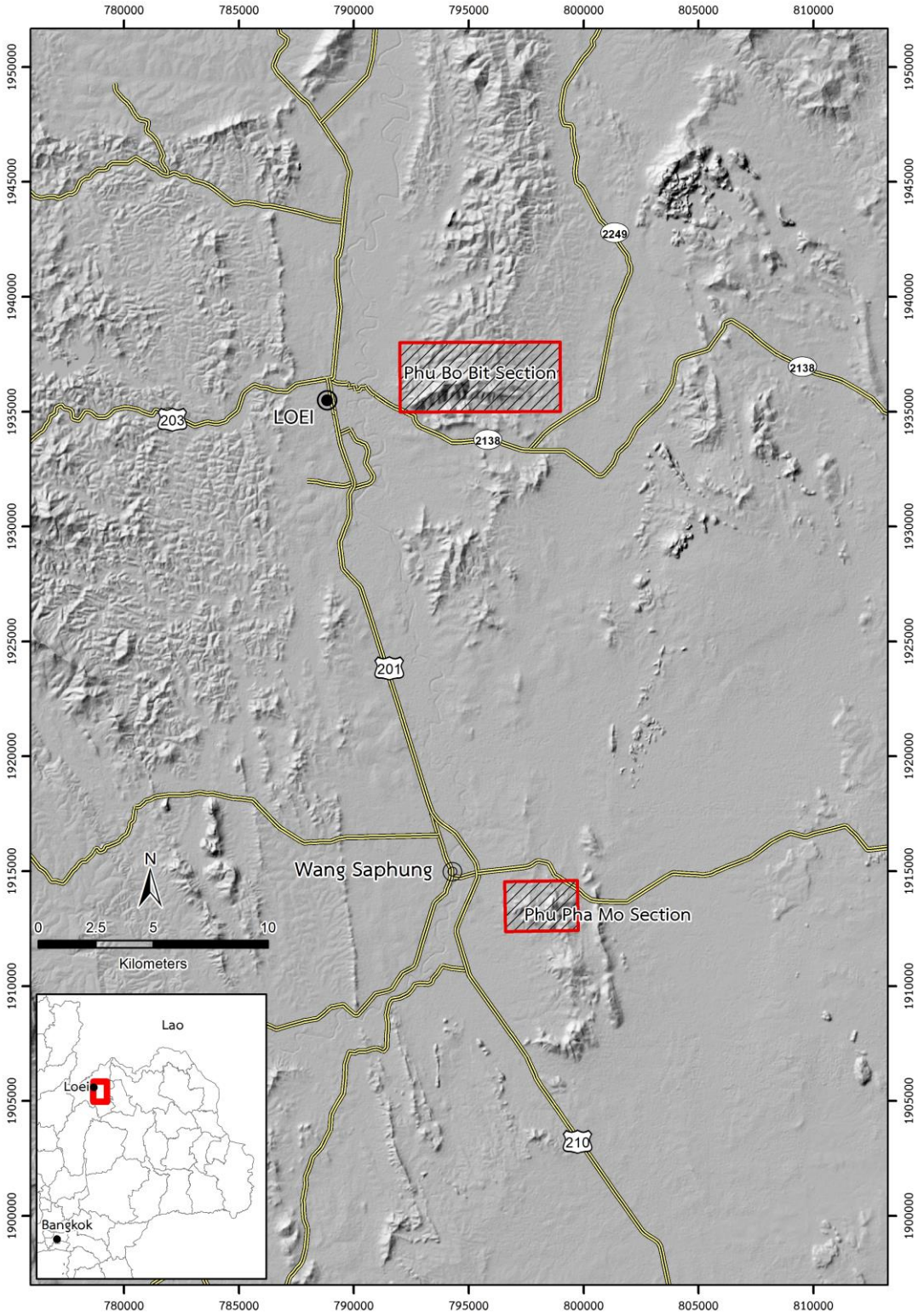
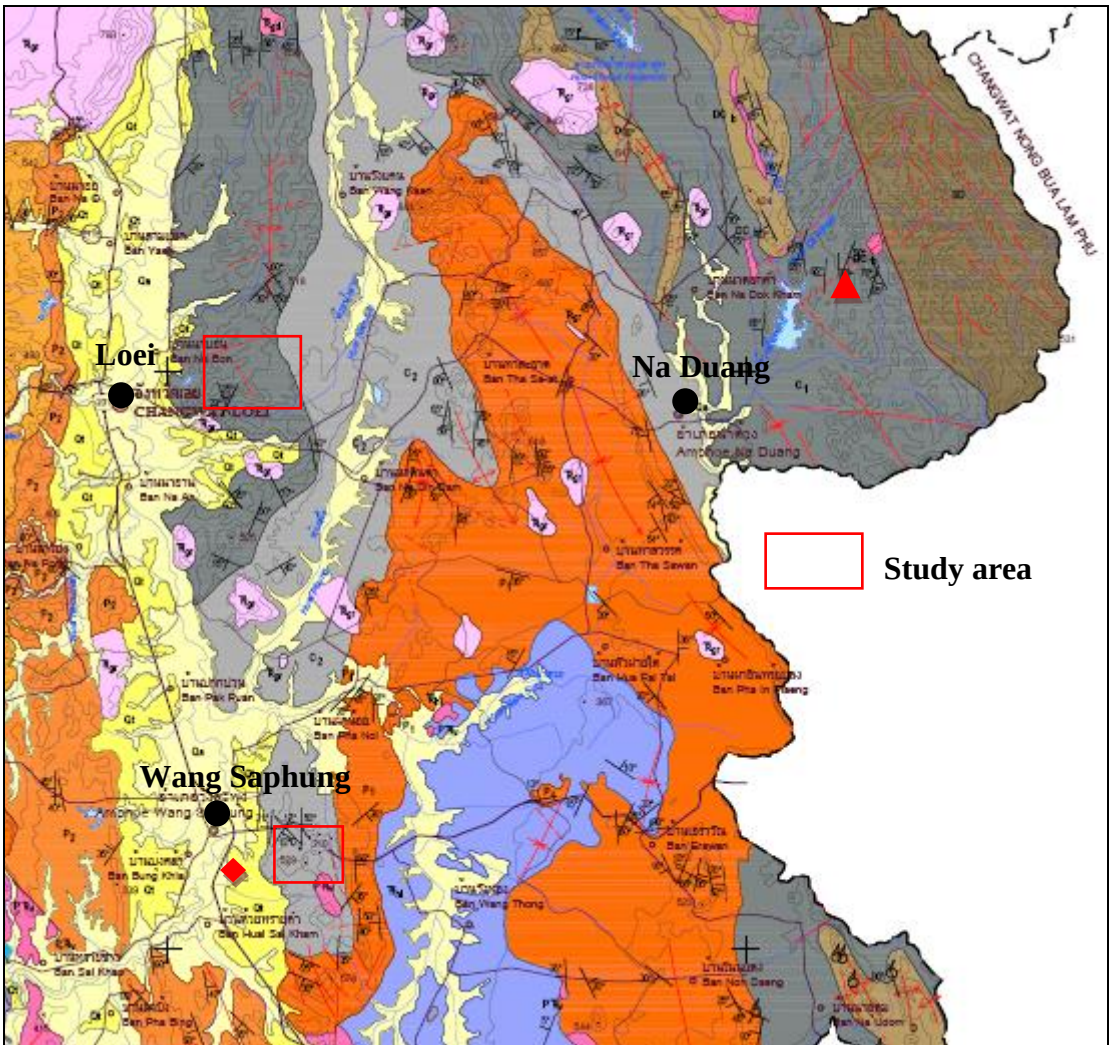


Figure 3.2 Topographic map of the study area and its vicinity by ArcGIS.



EXPLANATION

คะคอน หินชั้น และหินแปร SEDIMENT, SEDIMENTARY AND METAMORPHIC ROCKS	ชื่อหมวด/กลุ่มหิน FORMATION/GROUP	ยุค PERIOD	อายุ (ล้านปี) AGE (my.)
P_3 หินดินดาน หินทราย หินทรายแป้ง และหินกรวดภูเขาไฟ Pha Dua Formation shale, sandstone, siltstone, and agglomerate.	หมวดหินผาเดื่อ PHA DUA Fm.	เพอร์เมียน PERMIAN	245-286
P_2 หินดินดานสลับหินทราย หินปูนเลนส์สีเทา Shale intercalated with sandstoner, gray limestone lens.	หมวดหินเอ็เลิต E-LERT Fm.		
P_1 หินปูน สีเทา สีเทาขาว ชั้นหินหนาปานกลางถึงหนา มีซากดึกดำบรรพ์ของฟิวลินิด ปะการัง ฟองน้ำ สาหร่าย และหลับตีงทะเล Limestone, gray, whitish gray, well bedded, thin-thick bed, fossils in common of fusulinids, corals, sponges, algaes and crinoids.	หมวดหินน้ำไหหาร NAM MAHOLAN Fm.		
C_2 หินดินดาน หินทรายแป้ง มีชั้นบางของหินปูนสลับ Wang Saphung Formation shale, siltstone, thin-bedded limestone.	หมวดหินวังสะพุง WANG SAPHUNG Fm.	คาร์บอนิเฟอรัส CARBONIFEROUS	286-360
C_1 หินทรายเนื้อควอรตซ์ หินดินดานเนื้อทรายแป้ง หินปูนเลนส์ และหินกรวดมน Nong Dok Bua Formation Quartzose sandstone, shale, silty shale, limestone lens and conglomerate.	หมวดหินหนองดอกบัว WANG SAPHUNG Fm.		
D หินเชิร์ตสลับหินทัฟฟ์ หินปูนเลนส์ และมีชั้นของหินดินดานบ้าง Chert with layer of tuff, limestone lens, and locally shale.	หมวดหินปากชม PAK CHOM Fm.	ดีโวเนียน DEVONIAN	286-360
SD หินฟิลไลต์ หินควอร์ตไซต์ หินชิสต์ หินชนวน หินทราย และหินทราย Phyllite, quartzite, schist, slate and sandstone.		ดีโวเนียน-ไซลูเรียน DEVONIAN-SILURIAN	286-360
หินอัคนี IGNEOUS ROCKS	ยุค PERIOD		
TR_{gr} หินไบโอไทต์แกรนิต หินทัวร์มาลีนแกรนิต หินแกรโนไดออไรต์ หินไบโอไทต์-มัสโอไวต์แกรนิต หินมัสโอไวต์-ทัวร์มาลีนแกรนิต หินไบโอไทต์-ทัวร์มาลีนแกรนิต Biotite granite, tourmaline granite, granodiorite, biotite-muscovite granite, muscovite-tourmaline granite, biotite-tourmaline granite. TR_{gd} หินแกรโนไดออไรต์ Granodiorite.	ไทรแอสซิก TRIASSIC		210-245

Figure 3.3 Geological map of study area (Department of Mineral Resources, 2009)

3.2 Field work

Field work consists in collect data, preparation for field survey, collect of fossil;

Planning and collecting.

After the review of literature, the first step involved mainly data collection in order to get new information about the study area and relevant information for subsequent step.

Field survey

Field investigation, geological map and sample collection. The lithostratigraphic columnar section has been carried out into two steps, notably, the reconnaissance field investigation and detailed field investigation. (see Figure 3.3, 3.4, 3.5 and 3.6)

The geography, general stratigraphy, and more detailed information on Carboniferous sequences in Loei area have been studied. A geological map was established and paleontological samples.

Description of a rock unit should include colour (fresh and weathered); lithologic composition; grain size, sorting and shape; sedimentary structures; indurations; type of cement; fossil content and pedogenic features. The nature of the contacts bounding a unit is extremely important to understand the palaeoenvironment. Contacts are most often characterized as erosional (underlying beds or structures are truncated), sharp (no truncations but knife – edge change in lithology) or gradational. The geometry of a rock unit (lenticular, tabular, wedge - shaped) should be determined whenever possible. Field descriptions can be augmented by detailed petrography.

3.3 Laboratory work

In the laboratory, all collected rock specimens were slab-cut and polished for megascopic observation of sedimentological features. And thin sections of limestone have been prepared for petrographic and palaeontologic identifications. They will provide the ages and depositional environments of the rocks under study.

Petrography: This study mainly investigates the area of Loei. The limestones were sampled to make thin sections for petrography.

Paleontology: Identification of fossil; algae, foraminifers and corals which was conducted at the department of mineral resources (DMR).

CHAPTER 4

RESULTS

4.1 Sedimentology and stratigraphy

The discussion is focus on lithology and lithofacies based on the field investigation, and laboratory studies. This study contains two main localities including the Phu Bo Bit and Phu Pha Mo in the east of Loei and Wang Saphung, respectively. Details on sedimentology and stratigraphy of these sections are below (Figure 4.1).

4.1.1 Lithology of the Phu Bo Bit section

The overall rock unit of the Phu Bo Bit section were mapped from two measured sections oriented approximately in the east-west direction and the traverses are shown in Figure 4.2. The total distance of traverses was about 5 km. long and rock samples were collected for detailed petrographic study. The representative sedimentary sequence of section of the Phu Bo Bit sction is shown in Figure 4.3. From the results of field observation, there are 2 rock units. The description of each unit is presented in ascending order as follows:

A hill 2 km east of Loei, thick limestone lenses in shale contain microfossils, Tabulata and solitary Rugosa; they have been assigned to Upper Bashkirian (Fontaine and Suteethorn, 1988; Fontaine, 1990; Fontaine *et al*., 1991, Fontaine *et al*., 2005).

Along the northern foot of Phu Pho Bit, a section of shale, calcareous mudstone, argillaceous limestone, limestone and sandstone is well exposed along the road from Ban Na Bon (5 km south of Pha Tha) to Ban Phia. It is rich in fossils at many levels: foraminifera, solitary Rugosa with and without dissepiments, *Chaetetes,* bryozoans, brachiopods, gastropods. Beds dip towards East. Samples have been collected from west to east.

At the first locality (fig. 4.2; 793900E, 1937300N*;* samples T7795 to T7797), variously argillaceous limestone and calcareous mudstone.

At the second locality (fig. 4.2; 794300E, 1937500N; samples T7641 to T7650), a dark grey limestone is associated with shale and sandstone.

At the third locality (fig. 4.2; 794200E, 1937500N; samples T7798 to T7801), 2.3 km east of Ban Na Bon, limestone beds in shale.

At the fourth locality (fig. 4.2; 794800E, 1937700N; sample T7802), shale starts to be prominent.

At the fifth locality (fig. 4.2; 796300E, 1937400N; samples T7803 to T7805), 3.5 km east of Ban Na Bon, lenses of small black limestone occur in the shale. Limestone is packstone.

At the sixth locality (fig. 4.2; 797100E, 1936300N; sample T7806), sandstone beds appear in the shale.

At the seventh locality (fig. 4.2; 797900E, 1936100N; samples T7807 to T7812), small limestone (wackestone to packstone) lenses in shale

South of Phu Bo Bit, a few hills are built up by shale, siltstone, sandstone, limestone lenses and igneous rocks. Brachiopods locally occur in shale. Limestone is recrystallized at some places. Elsewhere, it is difficult to find fossils useful for stratigraphy.

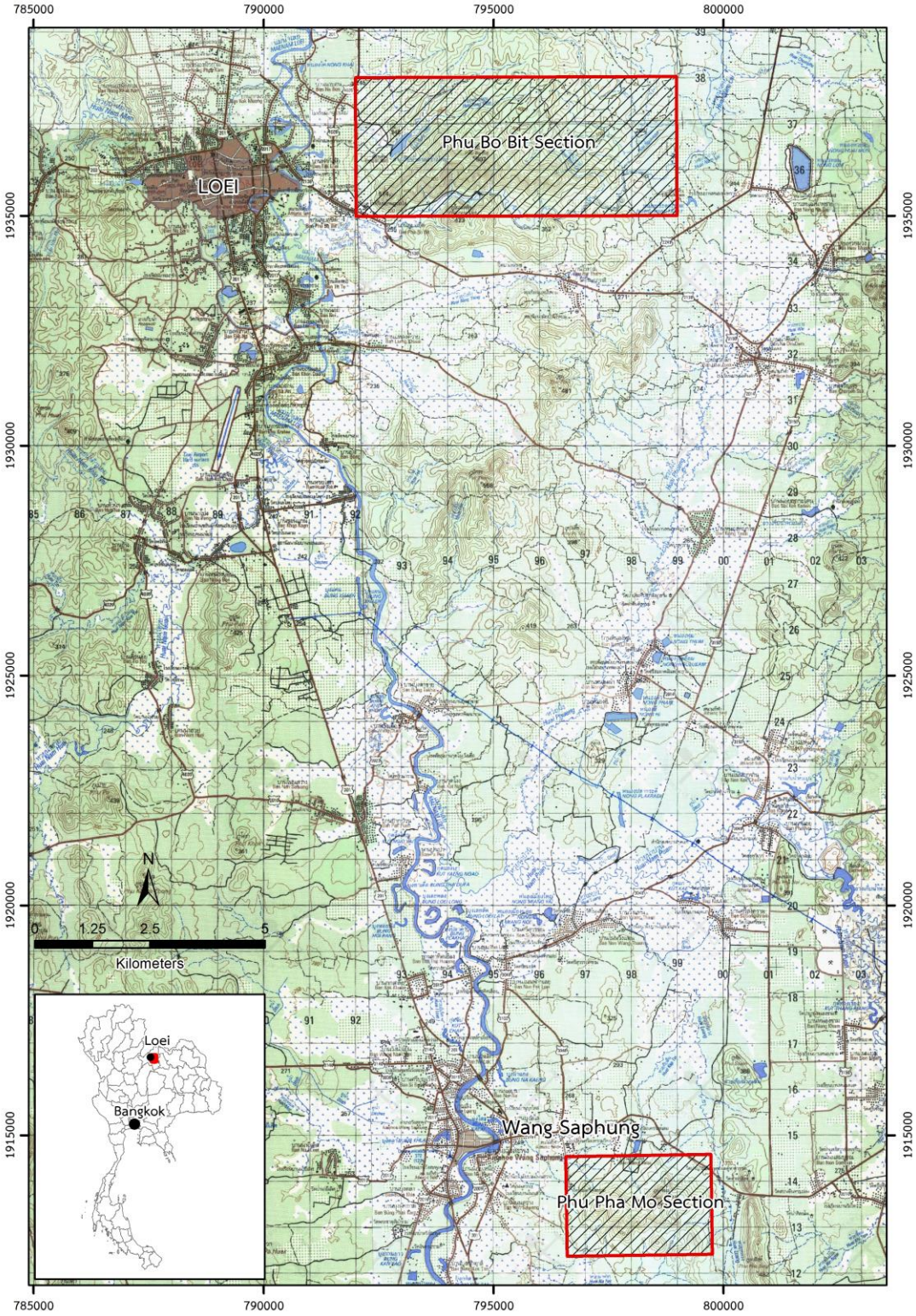


Figure 4.1 Topographic map of the study area and its vicinity. (Royal Thai Survey Department, 1999)

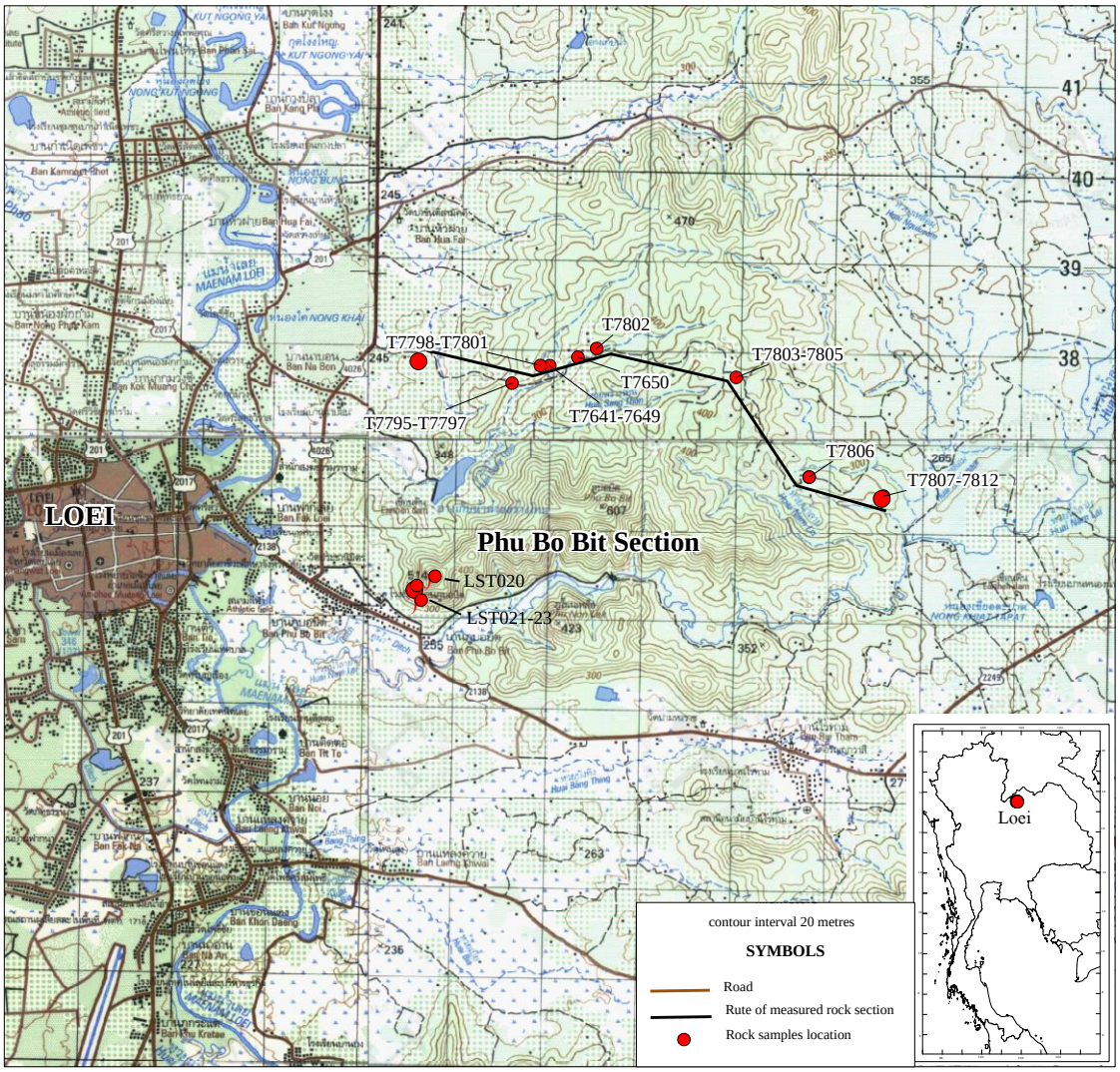


Figure 4.2 Topographical map showing Phu Bo Bit section located to the east of Muang district, Loei Province; Map sheet Amphoe Wang Saphung (5343 I) and Ban Sup (5344 II) of the 1:50,000. (Royal Thai Survey Department, 1999)

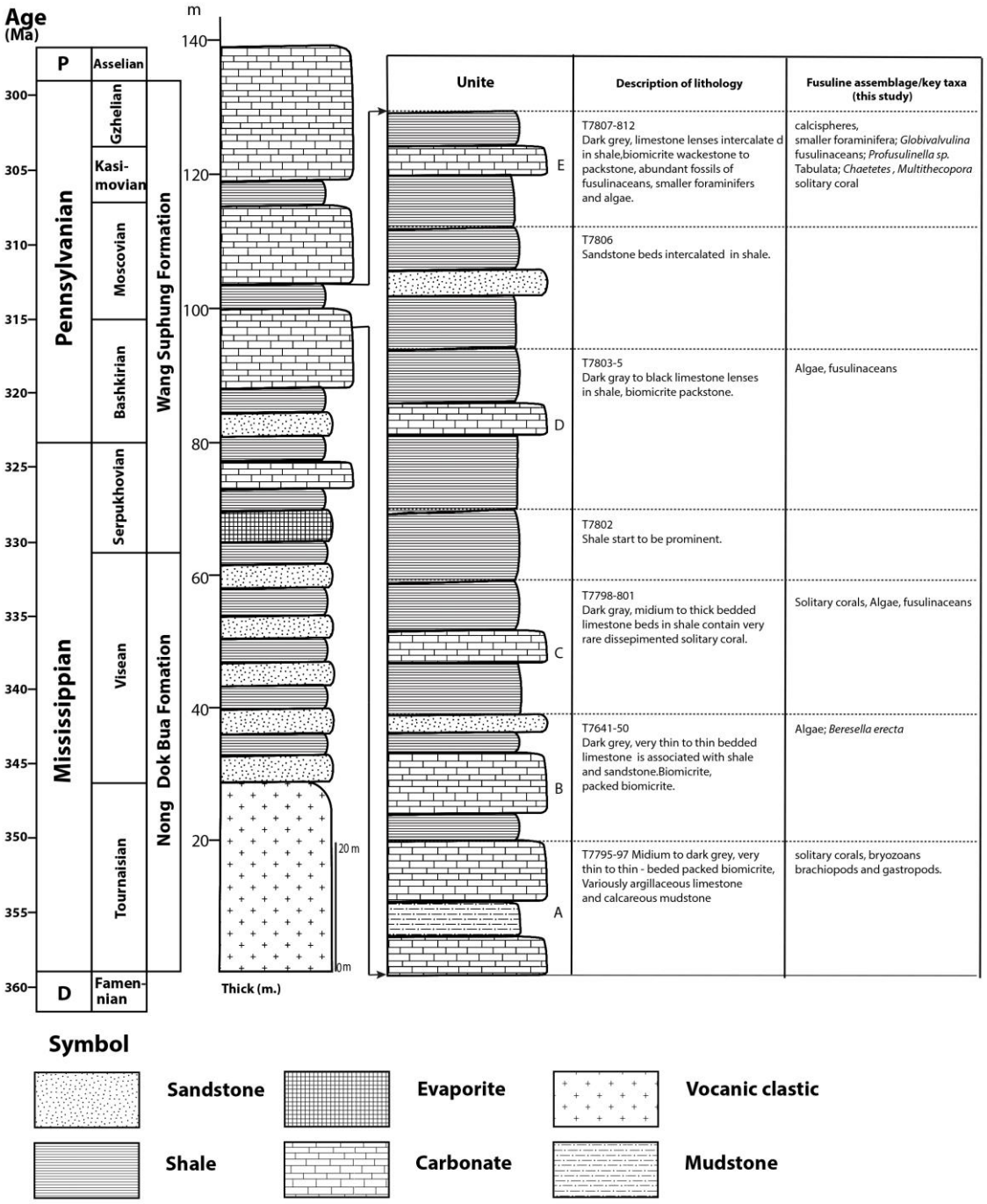


Figure 4.3 Lithostratigraphy of Phu Bo Bit.

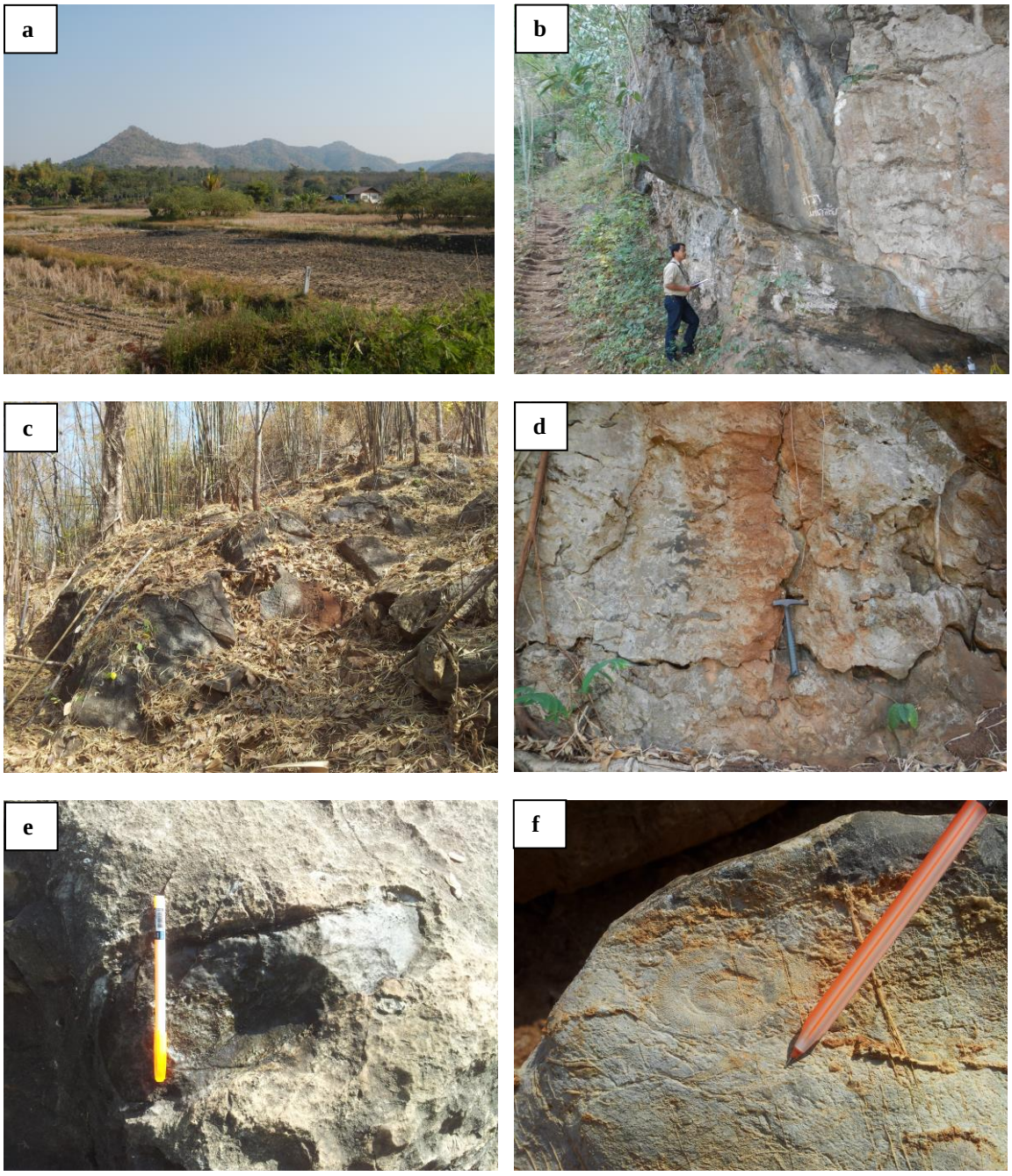


Figure 4.4 Field photograps showing view from south of Phu Bo Bit (a), intercalation of limestone and shale layers (b), very thick bedded to massive limestone (c, d), the massive coral (e) and solitary coral (f) at Phu Bo Bit section.

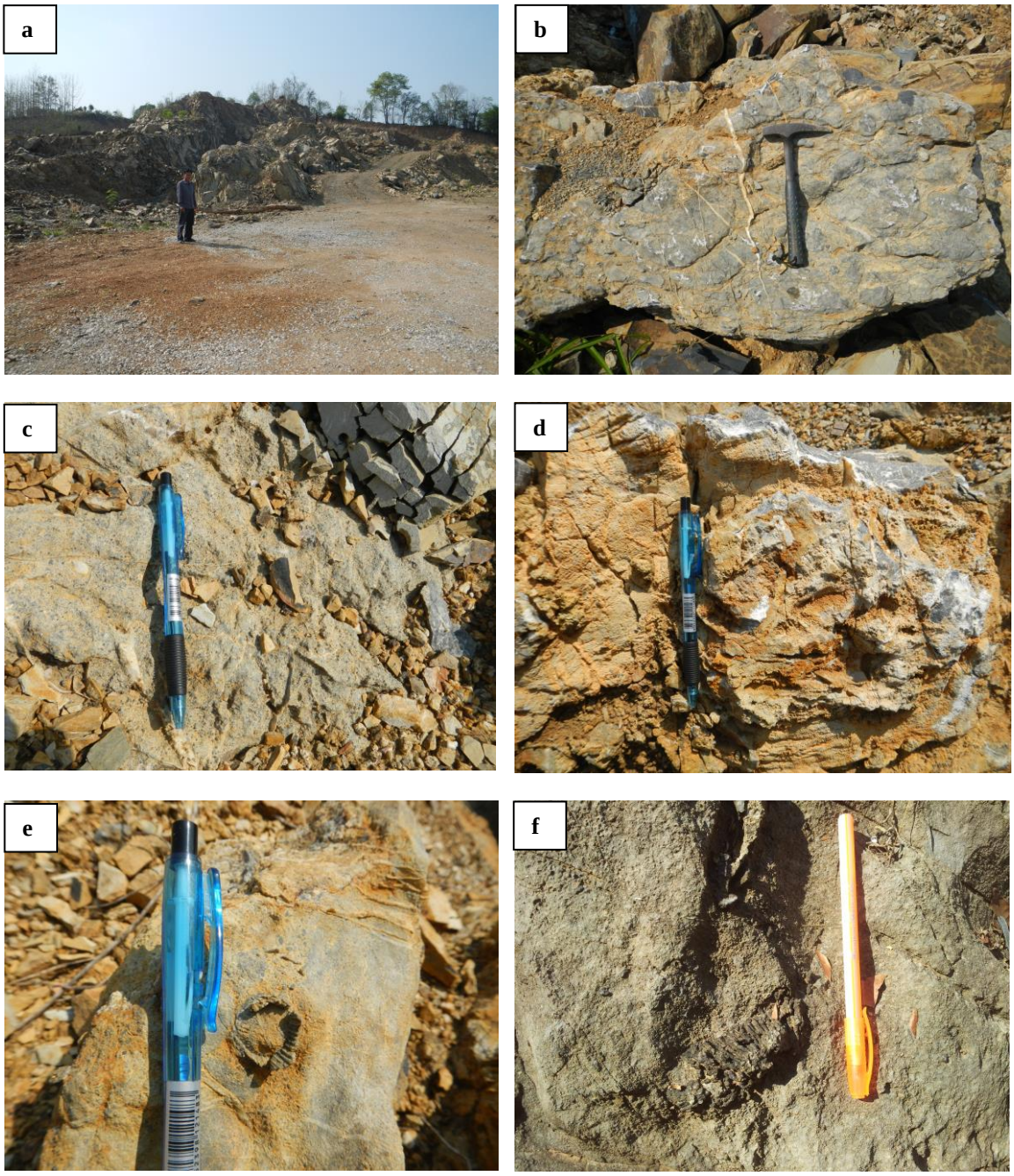


Figure 4.5 (a) A quary near the foot hill of Phu Bo Bit.; (b, c, d) A close-up outcrop of limestone of Phu Bo Bit section., (e) solitary Rugosa, (f) Tabulata

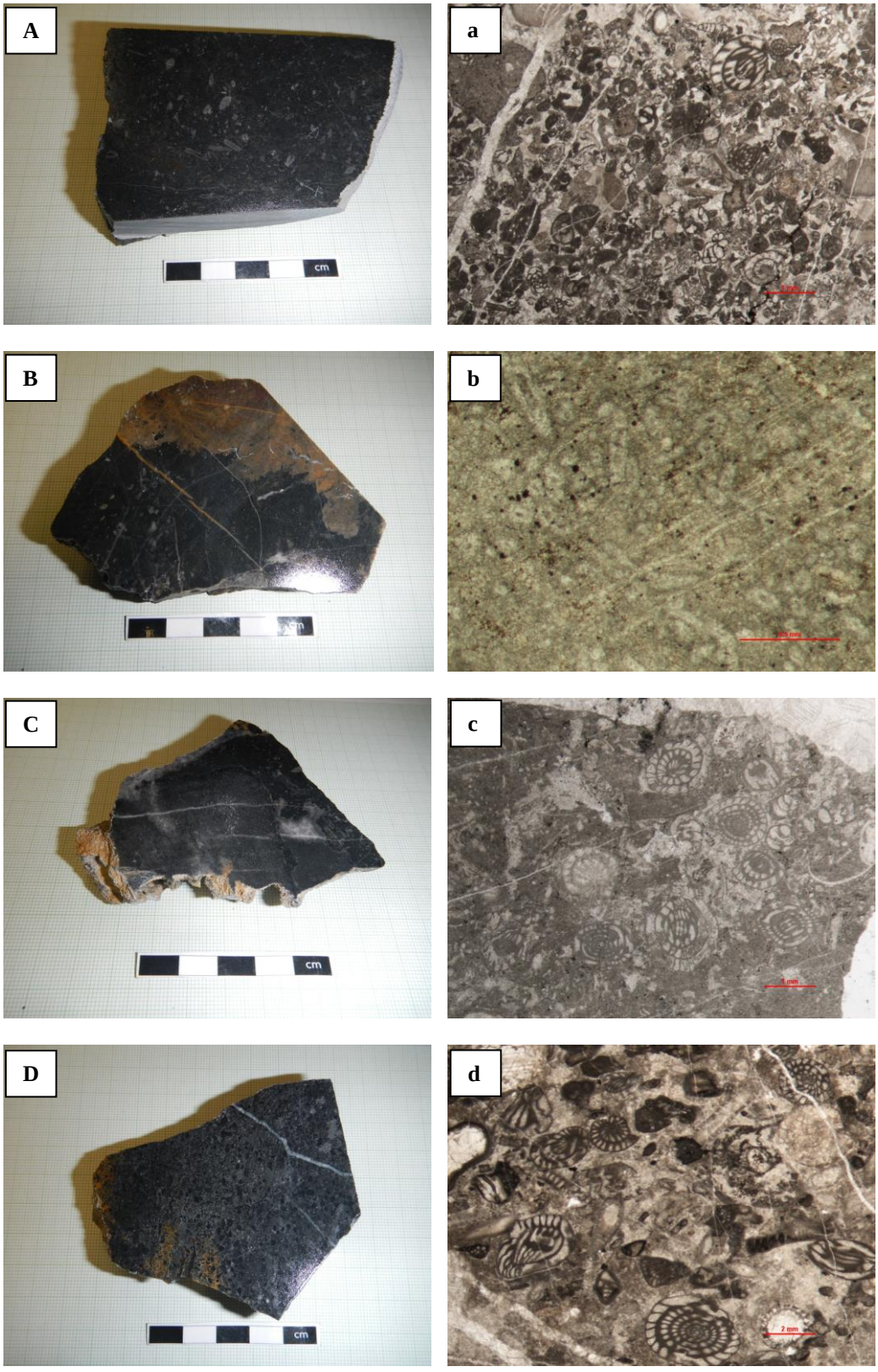


Figure 4.6 **A,a**: A rock slab and photomicrograph of sample no. LST18, **B,b**: A rock slab and photomicrograph of sample no. LST021, **C,c**: A rock slab and photomicrograph of sample no. LST016, and **D,d**: A rock slab and photomicrograph of sample no. LST015 from Phu Bo Bit section.

4.1.2 Lithology of the Phu Pha Mo section

A hill 3 km southeast of Wang Saphung (fig 4.5; 797033E, 1914049N; samples T7586 to T7591, LST010 to LST014 and LST024 to LST032), consists of shale and sandstone with some limestone interbeds. Consisting of a grey packstone.

The overall rock unit of the Phu Pha Mo section were mapped from a measured sections and the traverses are shown in Figure 4.7. The total distance of traverses was about 1 km. long and about 50 rock samples were collected for detailed petrographic study. The representative sedimentary sequence of section of the Phu Pha Mo sction is shown in Figure 4.8. From the results of field observation. The description of rock unit is presented in ascending order as follows:

The unit is characterized by the succession of thin-to thick –bedded dark gray to black limestone and limestone with nodular and thin-bedded chert intercalation. Limestone are mostly fine-grained and black in colour. Moderately to poorly sorted skeletal, poorly sorted packed biomicrite, biosparite are generally recognized. Fossil of relatively abundant algae, fusulinaceans, and smaller foraminifers are identified.

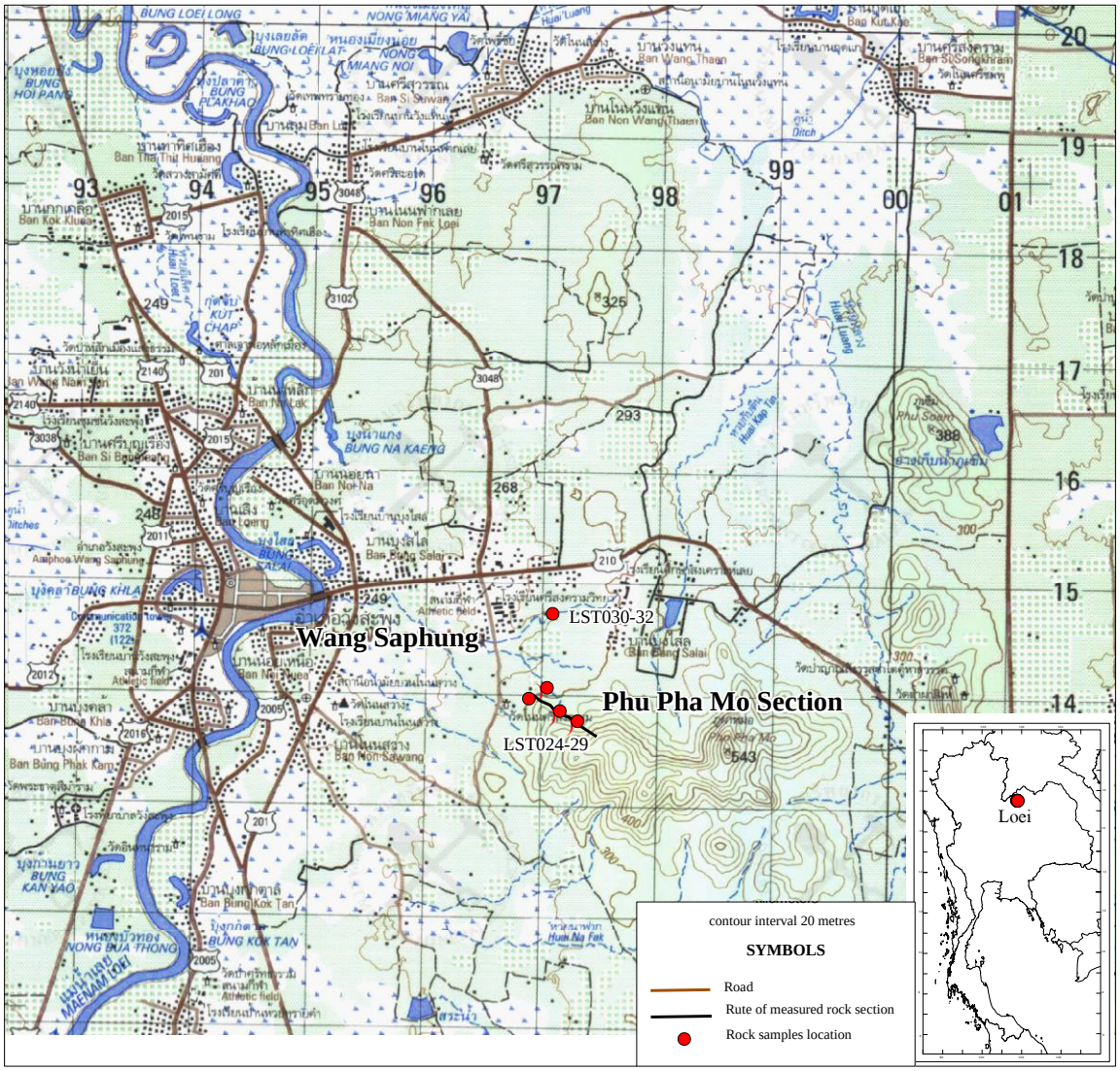


Figure 4.7 Topographical map showing the Phu Pha Mo section, Wang Saphung district, Loei Province; Map sheet Amphoe Wang Saphung (5343 I) of the 1:50,000. (Royal Thai Survey Department, 1999)

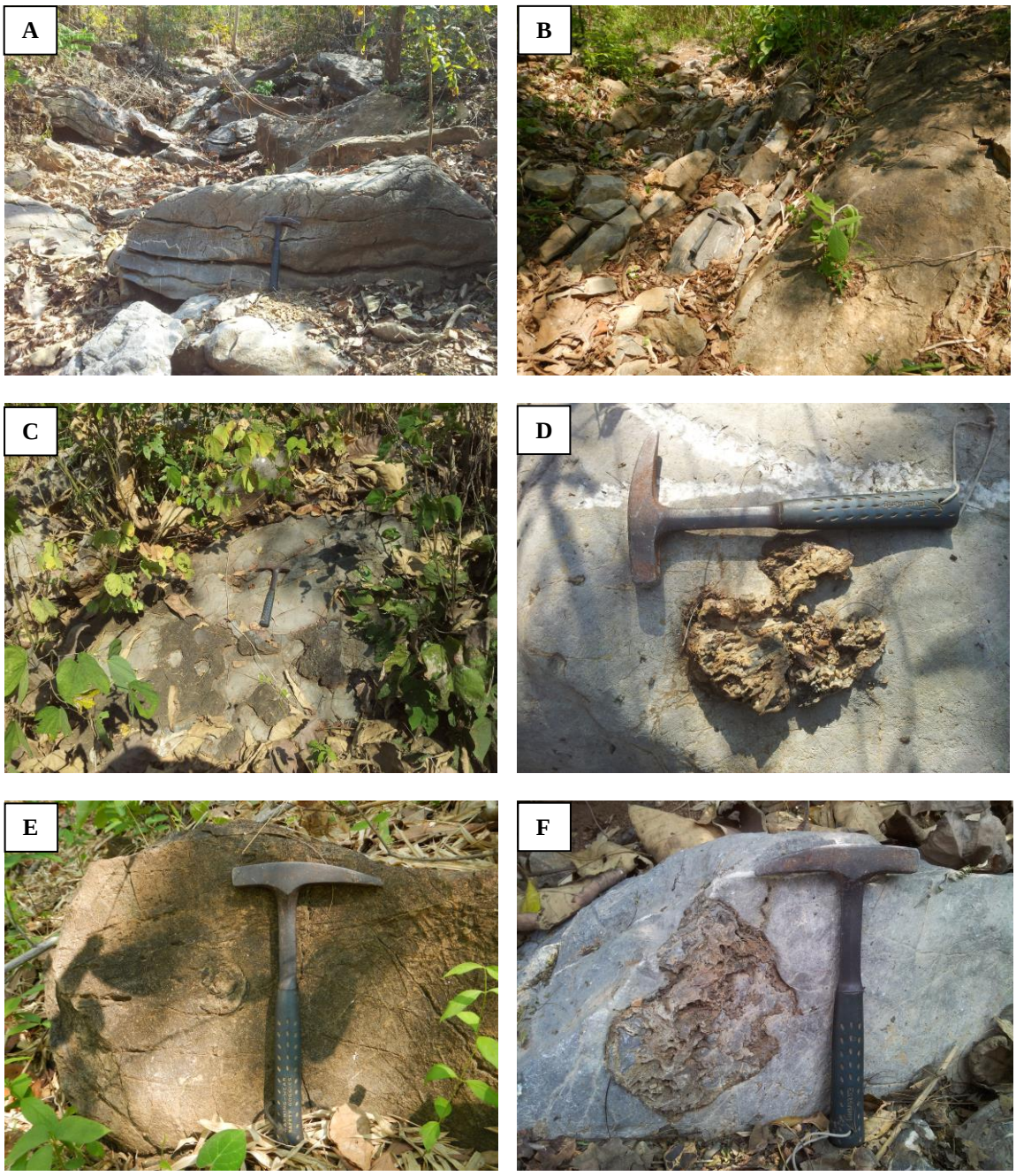


Figure 4.8 Field photograps showing outcrop bedded limestone (A, B),and limestone with chert nodule (C), Tabulata (D), amonoid (E), and massive Rugosa (F) at Phu Pha Mo section.

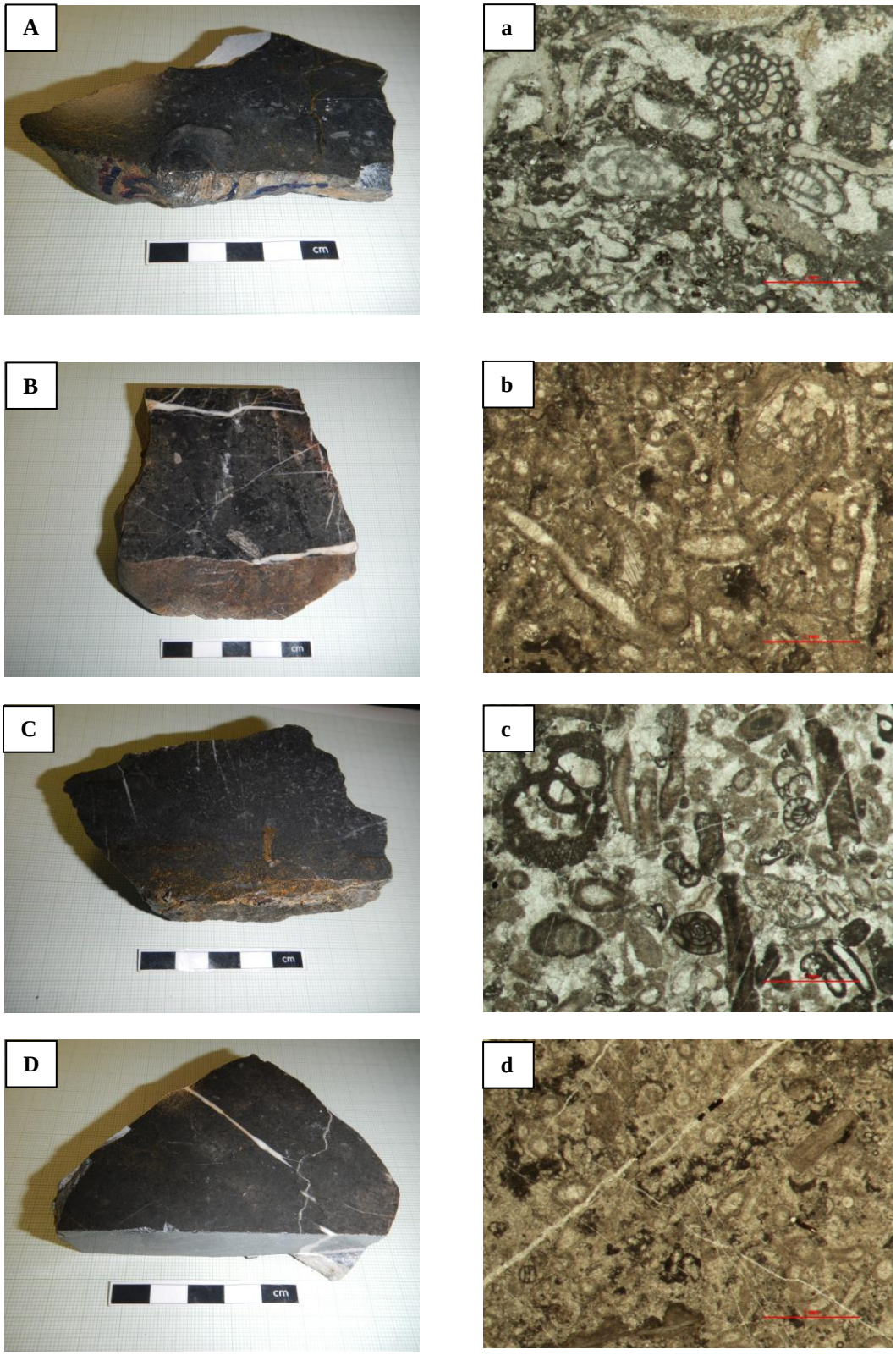


Figure 4.9 **A,a**: A rock slab and photomicrograph of sample no. LST031, **B,b**: A rock slab and photomicrograph of sample no. LST029, **C,c**: A rock slab and photomicrograph of sample no. LST032, and **D,d**: A rock slab and photomicrograph of sample no. LST026 from Phu Pha Mo section.

4.2 Palaeontology

4.2.1 Phu Bo Bit section, it is rich in fossils at many levels: foraminifera, solitary Rugosa with and without dissepiments, *Chaetetes,* bryozoans, brachiopods, gastropods. Beds dip towards the East. Samples have been collected from west to east.

At the first locality (fig. 4.1; 793900E, 1937300N*;* samples T7795 to T7797), variously argillaceous limestone and calcareous mudstone contain diverse fossils: dissepimented solitary corals, bryozoans, brachiopods and gastropods. Fragments of algae and fusulinaceans are rare and poorly preserved.

At the second locality (fig. 4.1; 794300E, 1937500N; samples T7641 to T7650), a dark grey limestone is associated with shale and sandstone. It is locally very rich in fossils. Algae *(Beresella erecta* Maslov & Kulik 1956) are commonly in great abundance; they are similar to those found at Phu Pha Mo (see below) and to those of the Moscovian limestone exposed in a pond at Ban Na Duang (Fontaine and Suteethorn, 2000b). Other fossils are rare: smaller foraminifera (Nodosariidae), fusulinaceans, dissepimented solitary corals and crinoids.

At the third locality (fig. 4.1; 794200E, 1937500N; samples T7798 to T7801), 2.3 km east of Ban Na Bon, limestone beds in shale contain very rare dissepimented solitary corals. Algae are still in abundance; fusulinaceans are very rare.

At the fourth locality (fig. 4.1; 794800E, 1937700N; sample T7802), shale starts to be prominent.

At the fifth locality (fig. 4.1; 796300E, 1937400N; samples T7803 to T7805), 3.5 km east of Ban Na Bon, lenses of small black limestone occur in the shale. Limestone is packstone, again very rich in tubular algae; it contains rare fusulinaceans (T7805).

At the sixth locality (fig. 4.1; 797100E, 1936300N; sample T7806), sandstone beds appear in the shale.

At the seventh locality (fig. 4.1; 797900E, 1936100N; samples T7807 to T7812), small limestone (wackestone to packstone) lenses in shale contain calcispheres, smaller foraminifera *(Globivalvulina),* scattered and poorly preserved fusulinaceans *(Profusulinella* sp.), *Chaetetes, Multithecopora,* solitary corals with and without dissepiments. The shale is locally rich in brachiopods.

The solitary corals with dissepiments belong to *Caninophyllum.* They are about 3 cm in diameter, with 40 to 44 major septa and extremely short minor septa. Dissepiments are arranged in about 8 rows. Other solitary corals are small, 5 to 6 mm in diameter. They display a columella and they probably belong to *Amygdalophylloides. Chaetetes* consists of 2 species: a species with corallites 0.6 mm in diameter, the other species with corallites 0.4 mm in diameter. The corallites of *Multithecopora* are 1.5 mm in diameter. East of that locality, the topography is flat and only rare outcrops of shale are visible at ground surface. The section exposed at the northern foot of Phu Bo Bit extends from Late Bashkirian to Early Moscovian.

4.2.2 Phu Pha Mo section, It contains algae *(Beresetta erecta* Maslov & Kulik 1956, *Ungdaretla uratica* Maslov), calcispheres *(Eotuheritina),* smaller foraminifera *(Geinitzina, Bradyina magna* Roth & Skinner and smaller *Bradyina, Ctimacammina, Endothyra),* a few fusulinaceans *(Profusulinetta* sp., *Citronites citronoides* Manukalova 1948, *Eoschubertetta* sp.), solitary corals and crinoids. It is commonly packed with fragments of algae and must he considered algal mound. The algae do not build a true framework, the mound appears to be -imply an accumulation of algal debris. Among fusulinaceans, *Citronites* is interesting. It is known in the Lower Moscovian, it is a small form close to *Beedeina* and a transition to *Aijutovetla.* The solitary corals are small, hornshaped, 12 to 22 mm in diameter near the calice. They are dissepimented corals, belonging to Cyathopsidae *(Caninia,* without columella and with a short cardinal septum in an open fossula) and Geyerophyllidae *(Kionophyttum,* with a solid axial structure and lonsdaleoid dissepiments; probably to *Amygdatophyltoides,* with a slightly more complex columella and sporadic lonsdaleoid dissepiments). Geyerophyllidae were already known in Loei region, at Pha Tha and near Ban Pha Noi (Fontaine *et al.,* 1991). Corals are far less important than the algae. They are only scattered solitary Rugosa and cannot suggest reef building. The age of Phu Pha Mo limestone is Early Moscovian (most probably Vereyan) because of the occurence of *Profusutinella* with *Citronites citronoides.*

4.2.3 Systematic Palaeontology

Systematic description of Fusulinids

Phylum PROTOZAO

Class SARCODINA

Order FORAMINIFERIDA Eichwald, 1830

Suborder FUSULININA – Wedekind, 1937

Superfamily FUSULINACEA – Moller, 1878

Family PSUDOSTAFFELLIDAE – Putria, 1956

Subfamily FUSULINELLINAE – Staff and Wedekind, 1910

Genus *Profusulinella* – Rauser and Beliaev, 1936

Profusulinella sp.

1982 *Profusulinella rhombiformis* – Fontaine *et al.*, p. 52 (N.F.)

(Plate 1 Figure A1-A2, A4-A7, Plate 2 Figure B1-B3, from the Phu Bo Bit section and plate 3 Figure C10, Plate 4 Figure D2, D6, Plate 5 Figure E3 from the Phu Pha Mo section)

Description Shell minute, inflated fusiform to subellipsoidal, with bluntly rounded poles. Mature specimens possess 4-6 volutions and measure from 0.9 to 1.25 mm in length and from 0.5-1 mm. in diameter. Tunnel rather narrow, about half as high as chambers. Chomata massive and wide.

Age/Remark Carboniferous, late Bashkirian to early Moscovian.

Occurrence Phu Bo Bit, Sample LST015, LST016, LST017, LST018, Phu Pha Mo, Sample LST031.

Family OZAWAINELLIDAE – Thompson & Foster, 1937

Genus *Ozawainella* – Thompson, 1935

Ozawainella sp.

(Plate 1 Figure A7, Plate 2 Figure B1-B3, from the Phu Bo Bit section and plate 3 Figure C10, Plate 4 Figure D2, D6, Plate 5 Figure E3 from the Phu Pha Mo section)

Description Shell umbilicate to spherical or elongate, evolute in early forms, involute or irregularly uncoiled in later ones, axis of coiling short or long, first few volutions discoidal, others spherical to unevenly elongate; spirotheca composed of

tectum with upper and lower tectoria in early forms but diaphanotheca occurring below tectum and above lower tectorium in later ones; septa plane; shell generally planispiral but may be asymmetrical, discoidal in at least part of shell with coiling axis in shortest diameter; tunnel singular (*1929)

Age/Remark Late Mississippian – Late Permian.

Occurrence Phu Bo Bit, Sample LST016, LST018, Phu Pha Mo, Sample LST031.

Superfamily ENDOTHYRACEA – Brady, 1884

Family ENDOTHYRIDEA – Brady, 1884

Subfamily ENDOTHYRINAE – Brady, 1884

Genus *Endothyra* – Phillips, 1846

Endothyra sp.

(Plate 1 Figure A7, from the Phu Bo Bit section and plate 5 Figure E5 from the Phu Pha Mo section)

Description Test enrolled, partially involute, plane of coiling changes during growth, turning through 30^0 – 90^0 , may turn gradually as in plectogyral coiling, or abruptly nearly 90^0 , few chambers to whorl, whorls few; wall calcarour, with 2 layers, thin dark outer layer (tectum) and thicker, fibrous alveolar, inner layer (diaphanotheca); partial recrystallization may result in granular appearance, secondary deposits in form of nodes, rigdes, or forward directed hooks secreted on chamber floors; external aperture not always evident, but interiomarginal, equatorial to asymmetrical slit may be present, relatively large intercameral foramina in same position.

Age/Remark Late Devonian (Famennian), Early Carboniferous – Permian.

Occurrence Phu Bo Bit, Sample LST016, Phu Pha Mo, Sample LST032.

Family ENDOTHYRIDEA – Brady, 1884

Subfamily BRADYININAE – Reytlinger, 1950

Genus *Bradyina* – Moller, 1878

Bradyina sp.

(Plate 3 Figure C6, and plate 4 Figure D2 from the Phu Pha Mo section)

Description Test free, robust, planispiral, involute; few chambers and whorls; chamberlets or canals formed by converging septal lamellae or infolding of outer wall to

form septa, chamberlets extending into umblical region; wall calcareous, microgranular, perforate, with distinct radial lamellae; primary interiomarginal aperture, with additional large areal pores forming cribrate aperture, and supplementary septal pores opening into septal chamberlets.

Age/Remark Early Carboniferous – Late Carboniferous.

Occurrence Phu Pha Mo, Sample LST029, LST031 and LST032.

Family PALAEOTEXTULARIIDAE – Galloway, 1933

Genus *Climacammina* – Brady in Etheridge, 1873

Climacammina sp.

(Plate 5 Figure E6, from the Phu Pha Mo section)

Description Test biserial or may become uniserial; wall granular calcareous, with inner layer and thin adventitious coating; aperture simple or multiple.

Age/Remark Carboniferous – Permian.

Occurrence, Phu Pha Mo, Sample LST032.

Family BISERIAMMINIDAE – Chernysheva, 1941

Genus *Globivalvulina* – Schubert, 1921

Globivalvulina sp.

(Plate 1 Figure A6, from the Phu Bo Bit section)

Description Test biserial, involute; aperture at inner border of septal face.

Age/Remark Early Carboniferous – Permian.

Occurrence, Phu Bo Bit , Sample LST016.

Systematic description of Algae

Order BERESELLALES – Maslov and Kulik, 1956

nomen translat. herein

Family BERESELLACEAE – Maslov and Kulik, 1956

nomen translat. H. Termier *et al.*, 1977 see also G. Termier *et al.*, 1977, p. 141 (ex tribe)

orth mut. Shuysky, 1985 (ex Beresellidae)

(non Deloffre, 1987, nec Shuysky, 1987, nec Deloffre, 1988)

Tribe Bereselleae Maslov and Kulik, 1956

Genus *Beresella* – Makhaev, 1937 ex Maslov and Kulik, 1956

Beresella erecta

Beresella erecta– Maslov and Kulik, 1956

(Plate 1 Figure A3, Plate 2 Figure B5, from the Phu Bo Bit section and plate 3 Figure C1,C7, Plate 4 Figure D1, Plate 5 Figure E1, E4, E6 from the Phu Pha Mo section)

Description Cylindrical microproblematic algae, undivided but with internal diaphragms more or less numerous according to the. The tubular undivided skeletons are occasionally bifurcated, and have an outer surface smooth or finely costulate, and a internal cavity. In between, the re-entrants, darker rings, are finely canaliculate. The canalicules are blind, because they are overlain by a continuous external yellow layer. (Vachard, 1991, fig 4.4) can occupy the entire central cavity.

Age/Remark Carboniferous, late Bashkirian to Orenburgian (acme in Moscovian).

Occurrence Phu Bo Bit, LST015, T7589, Phu Pha Mo, Sample LST026, LST032.

Table 4.1 Generic level of major fossil groups observed in the Phu Bo Bit Section and Phu Pha Mo Section. These fossils suggest Bashkirian - Moscovian (Middle Carboniferous) of the studied sections.

Age		Fossils		Phu Bo Bit	Phu Pha Mo
Mid - Carboniferous	Moscovian	Algae	*Beresella* sp.		+
			Ungdarella sp.		+
		Foraminifer	*Profusulinella* sp.	+	+
			Citronites sp.		+
			Eoschubertella sp.		+
		Small foraminifera	*Geinitzina* sp.		+
			Bradyina sp.	+	+
			Climacammina sp.	+	+
			Endothyra sp.	+	+
		Corals	*Caninophyllum* sp.	+	
			Caninia sp.	+	+
			Multithecopora	+	+
	Bashkirian	Algae	*Beresella* sp.	+	+
			Ungdarella sp.		+
		Foraminifer	*Profusulinella* sp.	+	+
			Eostaffella sp.	+	+
			Ozawainella sp.	+	
		Small foraminifera	*Climacammina* sp.	+	+
			Globivalvulina sp.	+	
			Bradyina sp.	+	+
			Endothyra sp.	+	+
		Corals	*Chaetetes* sp.	+	+
			Multithecopora sp.	+	+
			Caninia sp.		+
		Other fossil	brachiopods	+	+
			bryozoans	+	+
			gastropods	+	+
			ostracods	+	+
			crinoids	+	+
			trilobite	+	

4.3 Microfacies analysis

Outcrop observations are combined with detailed microfacies studies comprising the description and interpretation of the sedimentary facies as well as the occurrence and composition of the biota. The investigations form the basis for the reconstruction of two fundamentally different depositional settings.

4.3.1 Selective microfacies recognition and interpretation

Thin-section observation are served as the basis for describing carbonate texture, and identifying allochemical constituents. The facies are defined on the bases of lithology, allochemical constituents, texture, and fossil associations in order to reconstruct their depositional environment. The carbonate facies are named following the carbonate rock classification either developed by Folk (1959, 1962) or Dunham (1962) and also Embry and Klovan (1971). Additionally the fabric characteristics are complementary. These selective microfacies are summarized in Table 4.2

Table 4.2 Summary the microfacies types identified in the study area

Microfacies	**Lithological characteristic**	**Depositional environments**
I Algal lamination	Very thin-laminae, algal decayed, detrital quartz grains	Shallow subtidal.
II Pelmicrite	Decret peloids, fine fossil fragments	Subtidal zone of inner shelf, low-water energy.
III Sparse biomicrite	Poorly sorted, floating grain, micrite matrix	Subtidal and/or subwave base of the shelf sea close to the shore
IV Packed biomicrite	In-situ deposition of unfragment fossils, micrite matrix, fragmental fossils, intraclasts, carbonaceous matter	Subtidal zone below the active wave base.
V Biosparite	Intraclasts, fragmentals and unfragment fossils, lumped pellets, poorly to moderately sorted	Intertidal to near shore subtidal above the wave base

4.3.2 Depositional environment

The carbonate rocks in the study area are recognized into six microfacies based on limestone classifications those developed either by Folk (1959, 1962), or Dunham (1962), and Embry and Klovan (1971) as well as carbonate textures. Excluding crystalline microfacies, the packed biomicrite, sparse biomicrite, biosparite, pelmicrite and algal- lamination are present in decreasing order of abundant. These microfacies representing carbonate facies develop under influent from low to high energy water in subtidal to intertidal regims. (Figure 4.10, and Table 4.2)

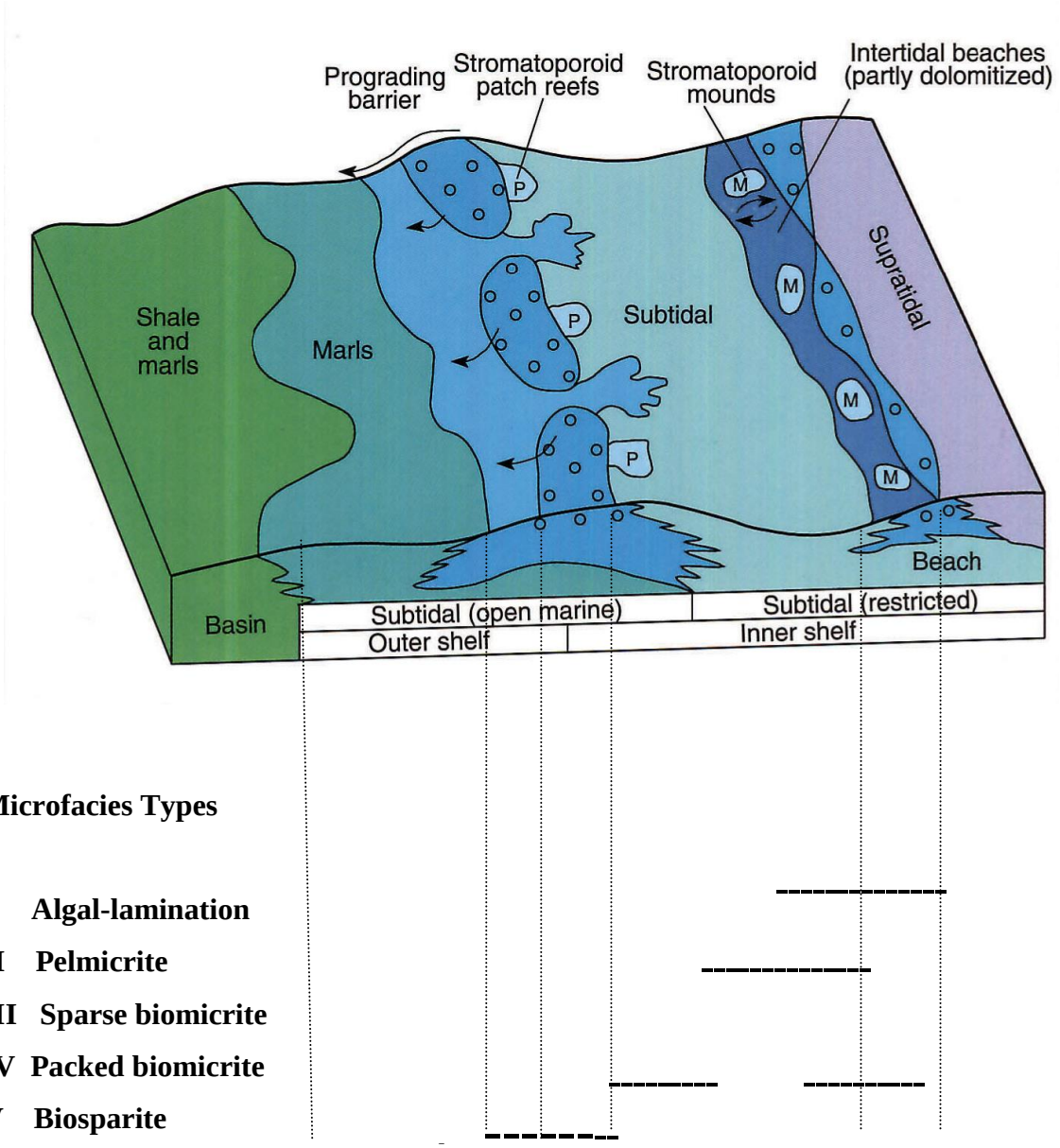


Figure 4.10 Reconstruction palaeoenvironment of the study area showing, marine depositional environments. (Richard, 1989)

CHAPTER 5

CONCLUSION

5.1 Conclusion

According to this thesis study, on the geology, sedimentology, stratigraphy, palaeontology of the two main localities including the Phu Bo Bit section and Phu Pha Mo sections in the east of Loei and Wang Saphung towns, revealed that

1. At Phu Bo Bit, thick limestone lenses in shale contain microfossils, Tabulata and solitary Rugosa; they have been assigned to Late Bashkirian and fusulinaceans (*Profusulinella* sp.) *Beresella,* have been assigned to Early Moscovian. The stratigraphic sequence of Phu Bo Bit extends from Late Bashkirian to Early Moscovian.

2. The age of Phu Pha Mo limestone is Early Moscovian (most probably Vereyan) because of the occurence of *Profusutinella* with *Citronites citronoides.*

3. According to lithofacies and fossil identification, Phu Bo Bit section is older than Phu Pha Mo section. And the change of the carbonate to siliciclastic sedimentation on Phu Bo Bit section is active before carbonate accumulation on the Phu Pha Mo section. The high sea level in Bashkirian age has been suggested as the major time of carbonate built up of the Phu Bo Bit , but the younger, the Moscovian age is the major time for carbonate built up of the Phu Pha Mo.

4. The rocks from both section consisting of shale, limestone along with abundance and diverse invertebrate faunas; brachiopods, corals, bryozoans and crinoids are interpreted as having been deposited in shallow marine or shelf environments.

5.2 Suggestion

The history of the Carboniferous of northeast Thailand is turning to be more complicated than what was thought previously. So far, the answer is difficult, a more intensive study has to be carried out.

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Appendix

Appendix A
List of Illustrations

EXPLANATION

PLATE 1: FIGURE A

Phu Bo Bit Section

Late Bashkirian to Early Moscovian

Figure A1 – *Profusulinella* sp. Sample LST015.

Figure A2 – *Profusulinella* sp. Sample LST015.

Figure A3 – *Beresella* sp. and *Profusulinella* sp. S. Sample LST015.

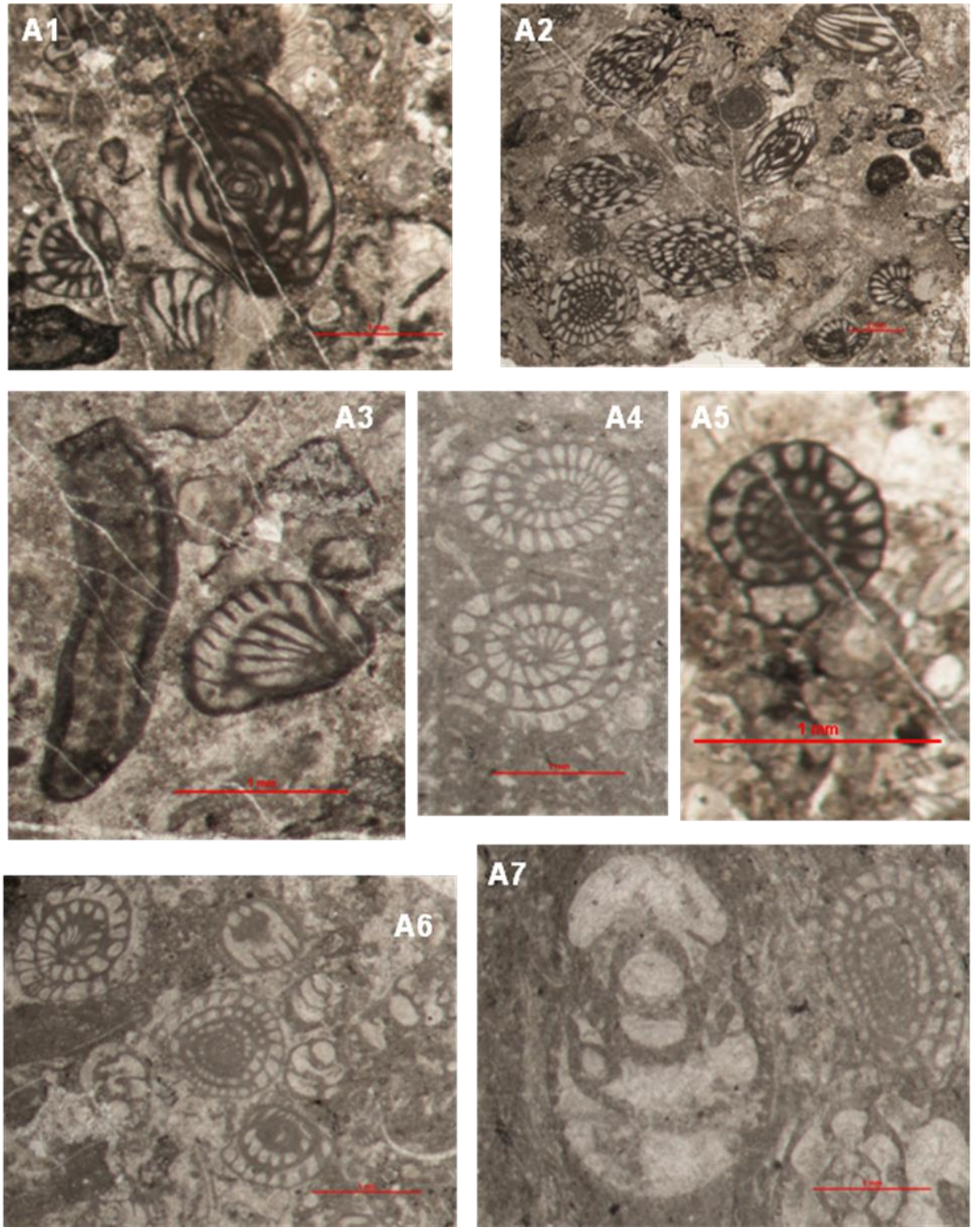
Figure A4 – *Profusulinella* sp. Sample LST016.

Figure A5 – *Profusulinella* sp. Sample LST015.

Figure A6 – *Profusulinella* sp. and *Globivalvulina* sp. Sample LST016.

Figure A7 - *Profusulinella* sp. and *Ozawainella* sp. Sample LST016.

PLATE 1



EXPLANATION

PLATE 2: FIGURE B

The section exposed at the northern foot of Phu Bo Bit.

Late Bashkirian to Early Moscovian

Figure B1 – *Profusulinella* sp. Sample LST017.

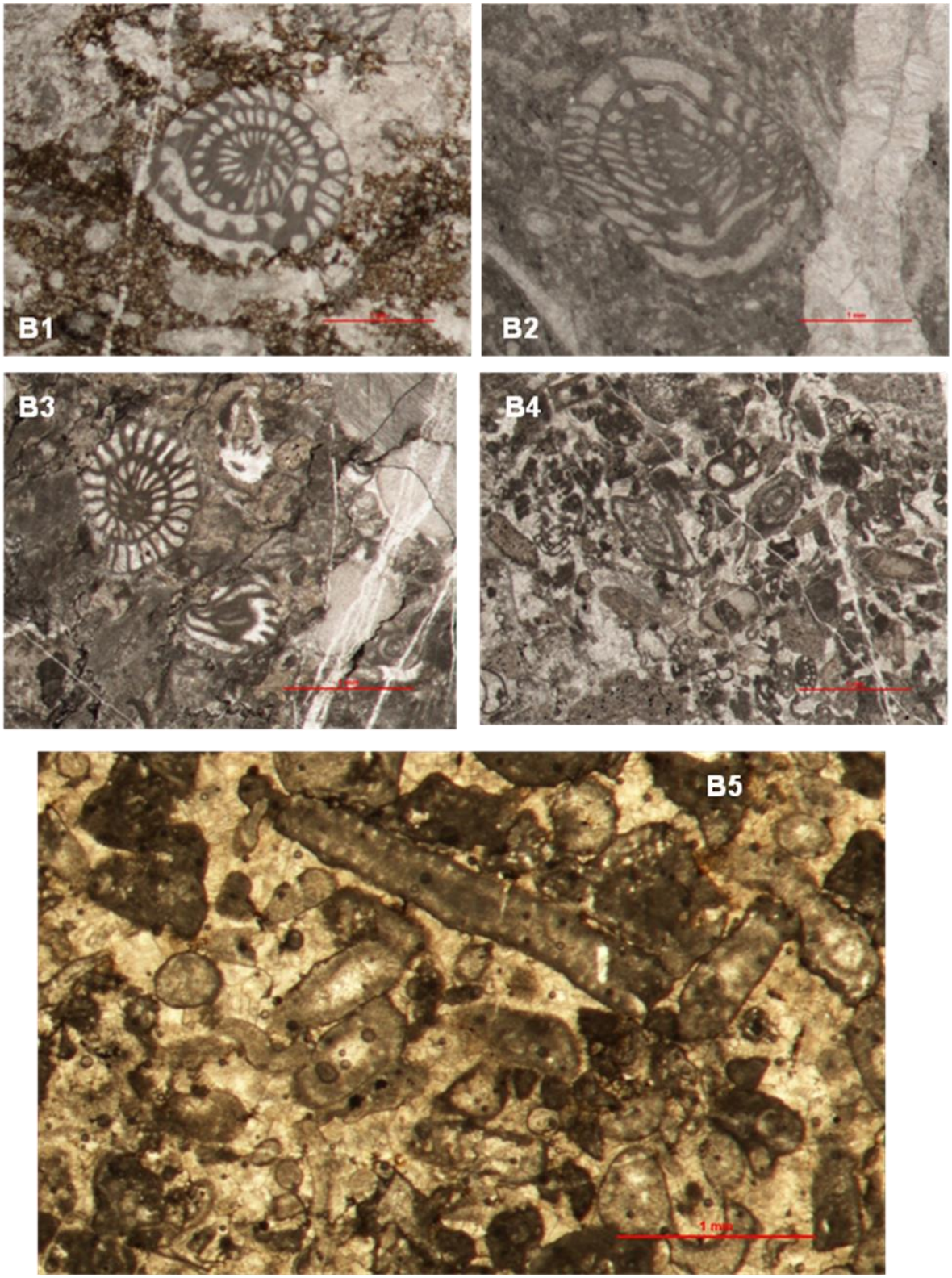
Figure B2 – *Profusulinella* sp. Sample LST016.

Figure B3 – *Profusulinella* sp. Sample LST018.

Figure B4 – *Ozawainella* sp. (center and center right), Sample LST018.

Figure B5 – *Beresella* sp., longitudinal section and transverse section of *Beresella* . Sample T7589.

PLATE 2



EXPLANATION

PLATE 3: FIGURE C

The western side of a hilll 3 km southheast of Wang Saphung, Phu Pha Mo

Early Moscovian

Figure C1 – *Beresella* sp. Sample LST026.

Figure C2 and C3 – Transverse section and longitudinal section of solitary Rugosa, apparently belonging to *Caninia*. Sample LST028.

Figure C4 and C5 – Poorly preserved fasciculate Tabulata, transverse section and longitudinal section, apparently belonging to *Multithecopora* sp., Sample LST029.

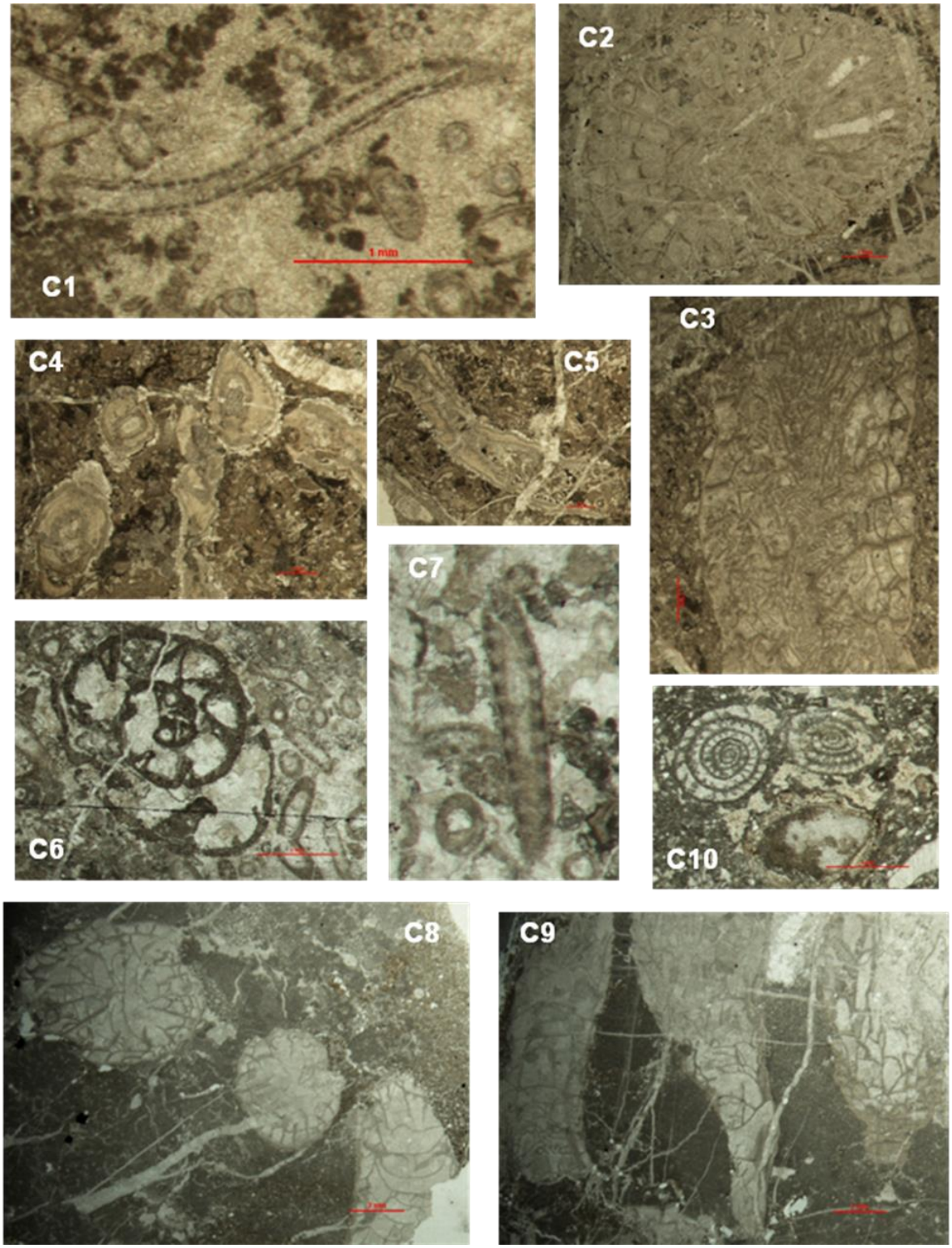
Figure C6 – *Bradyina* sp. Sample LST029.

Figure C7 – *Beresella* sp. Sample LST032.

Figure C8 and C9 – Transverse section and longitudinal section of fasciculate Rugosa Sample LST030.

Figure C10 – *Profusulinella* sp., Sample LST031.

PLATE 3



EXPLANATION

PLATE 4: FIGURE D

The western side of a hilll 3 km southheast of Wang Saphung, Phu Pha Mo

Early Moscovian

Figure D1 – *Beresella* sp. Sample LST026.

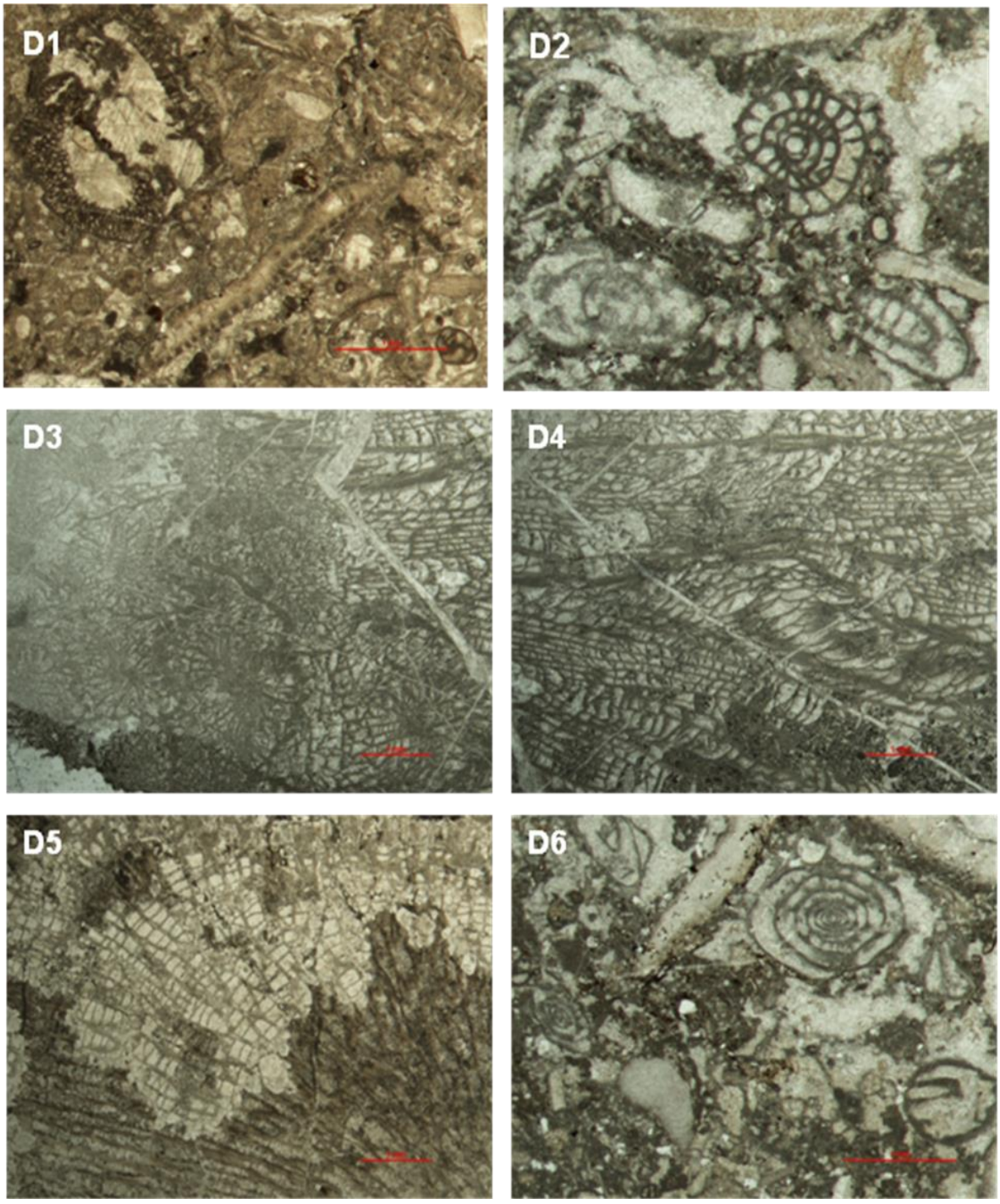
Figure D2– *Profusulinella* sp. and *Bradyina* sp. (bottom left) Sample LST031.

Figure D3 and D4 –Transverse section and longitudinal section massive coral, , Sample LST011.

Figure D5 – *Chaetetes* sp. Sample LST010.

Figure D6 – *Profusulinella* sp. and *Ozawainella* sp. (left) Sample LST031.

PLATE 4



EXPLANATION

PLATE 5: FIGURE E

The western side of a hilll 3 km southheast of Wang Saphung, Phu Pha Mo

Early Moscovian

Figure E1 – *Beresella* sp. (center), *Profusulinella* sp. (bottom center) and *Bradyina* sp. (top left) Sample LST032.

Figure E2 – Longitudinal section of solitary Rugosa Sample LST031.

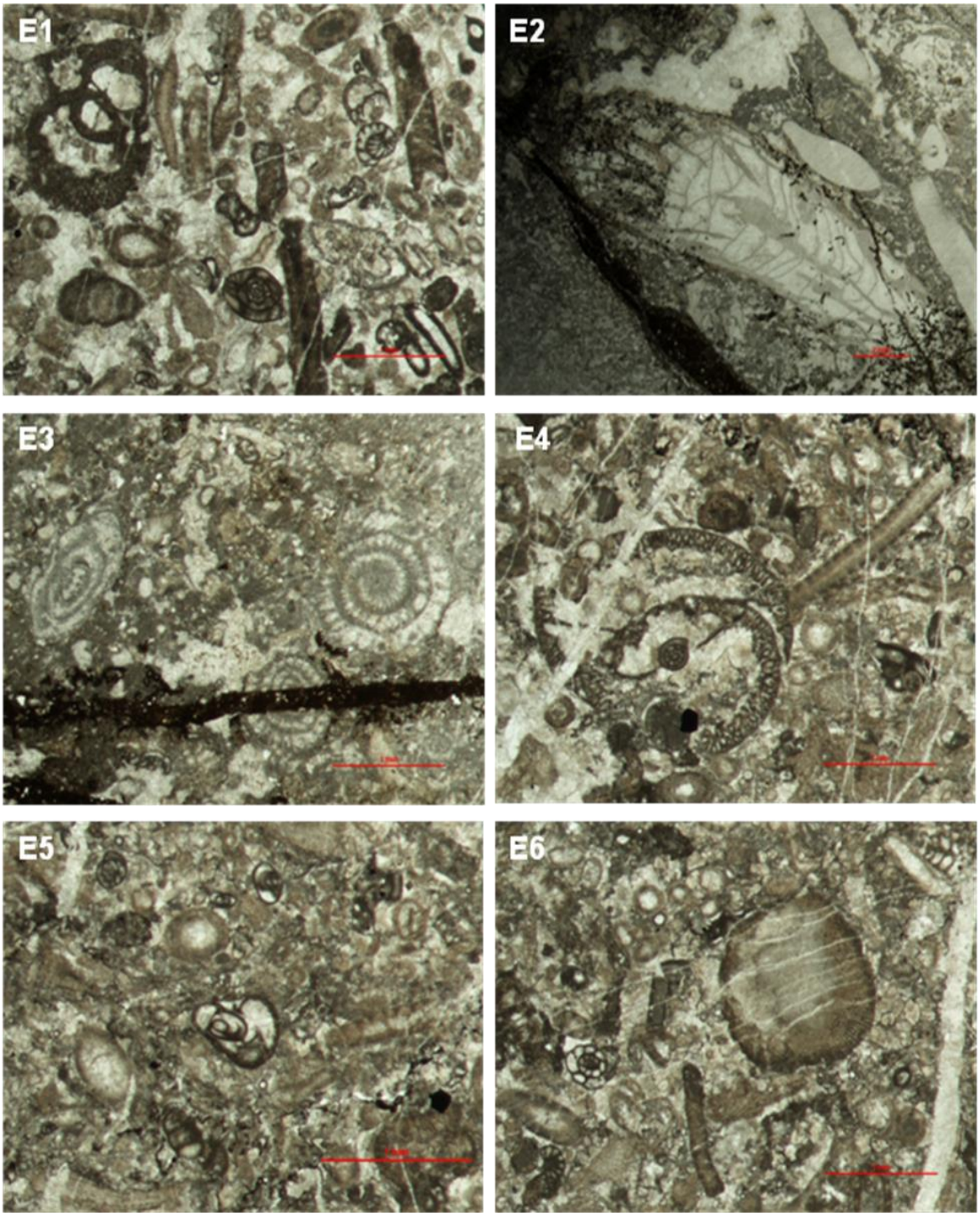
Figure E3 – *Profusulinella* sp. and *Ozawainella* sp. (left) Sample LST031.

Figure E4 – *Beresella* sp. (right), and *Bradyina* sp. (left) Sample LST032.

Figure E5 – *Endothyra* sp. (center) and *Beresella* sp. Sample LST032.

Figure E6 – *Beresella* sp., and *Climacammina* sp. (top right) Sample LST032.

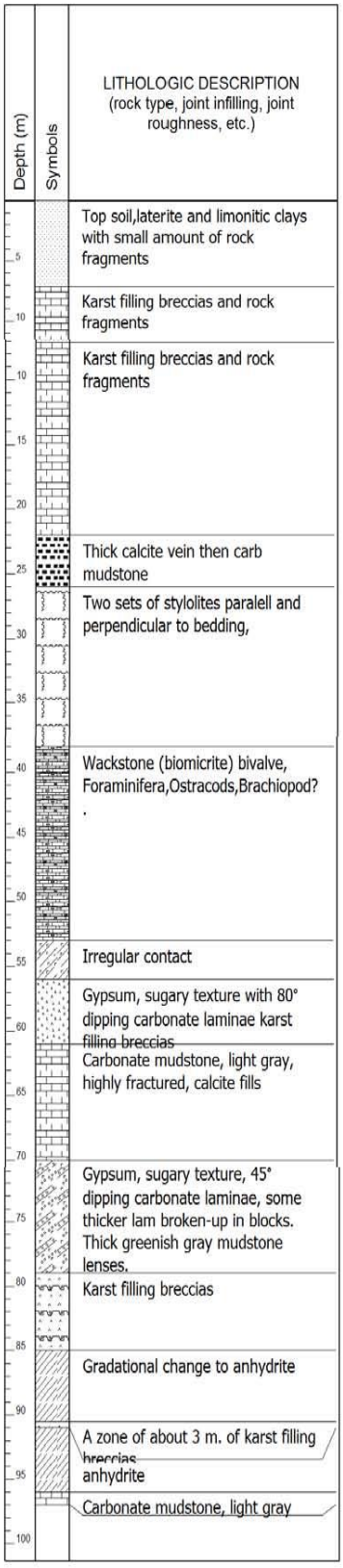
PLATE 5



Appendix B

The drillhole logging of the gypsum exploration in the Wang Saphung area (Utha-Aroon, *et al.*, 1995)

WP-1



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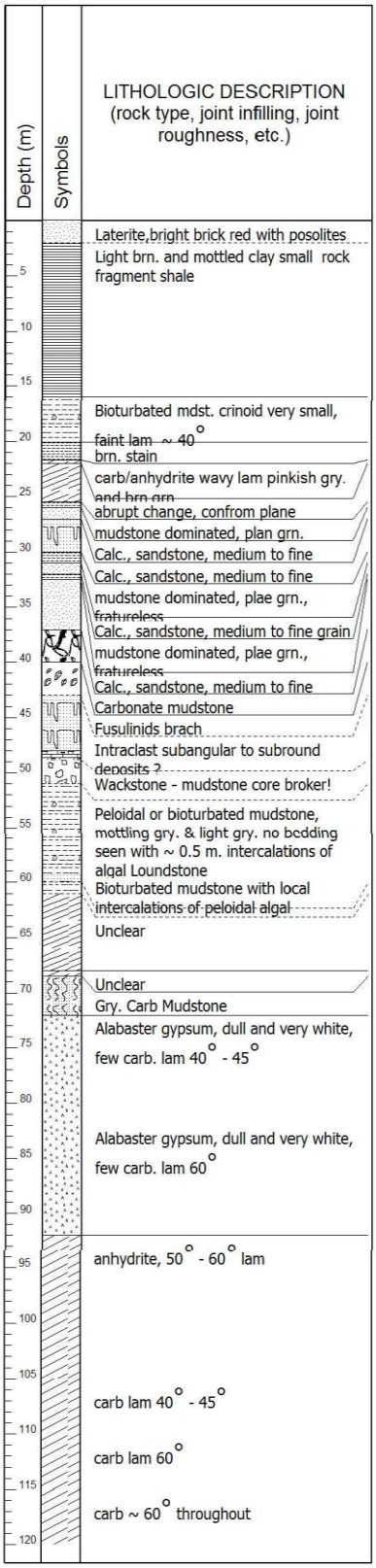

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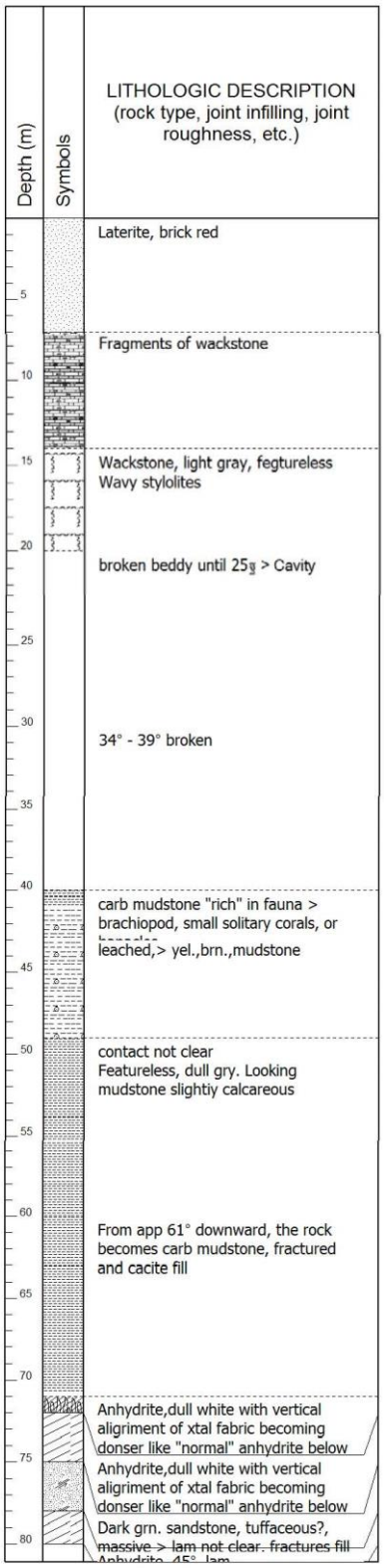

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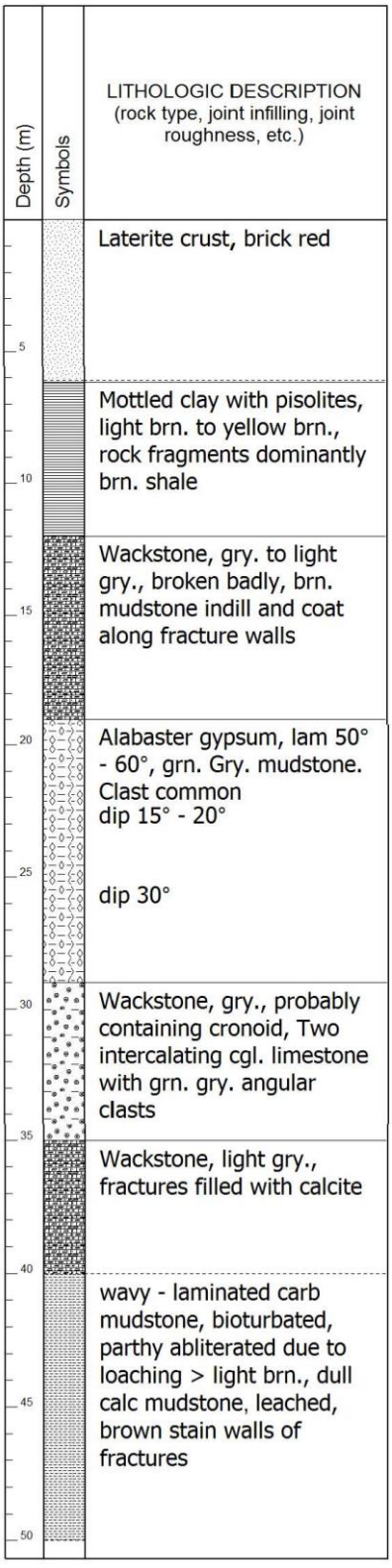

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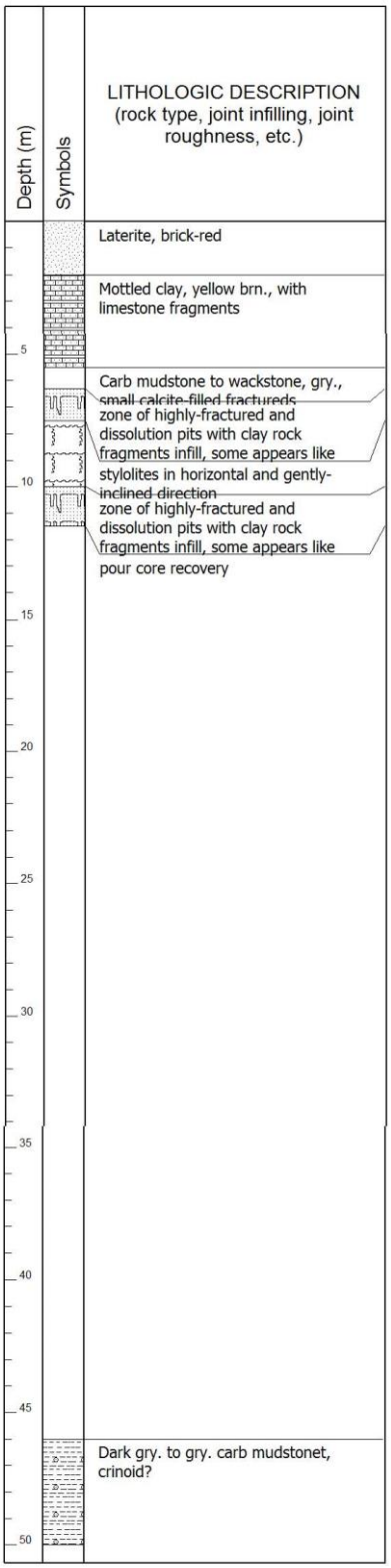

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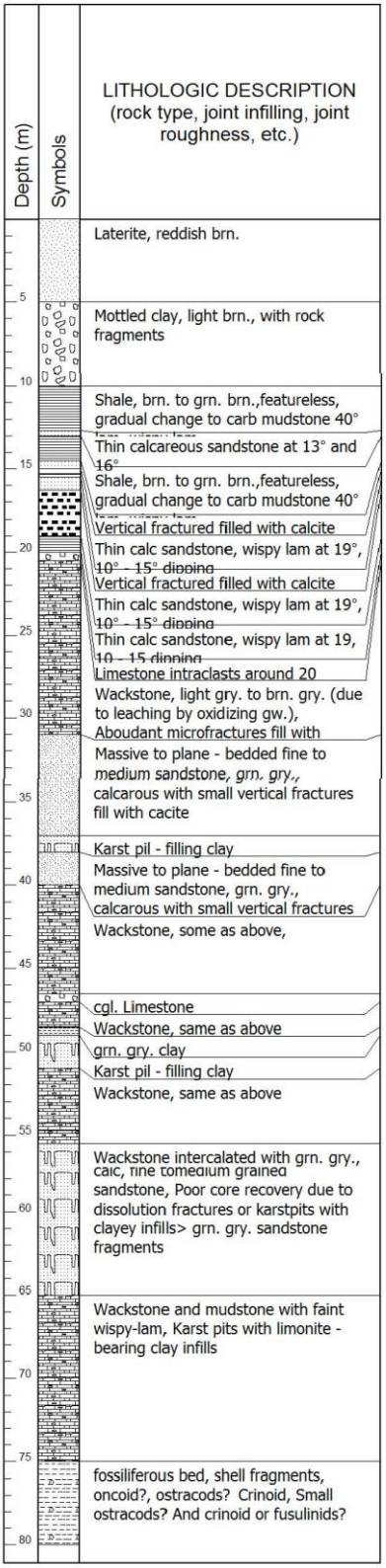

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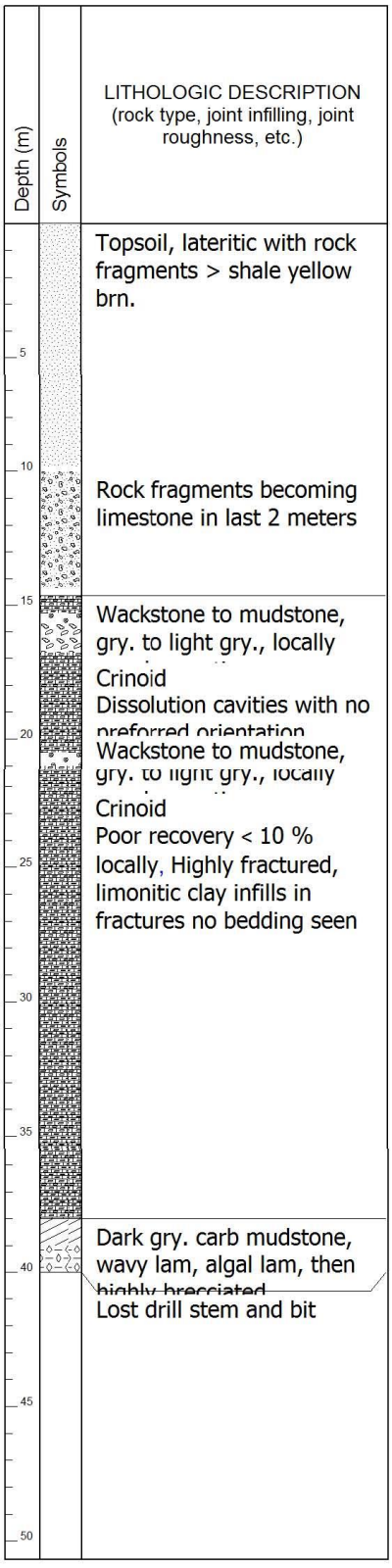

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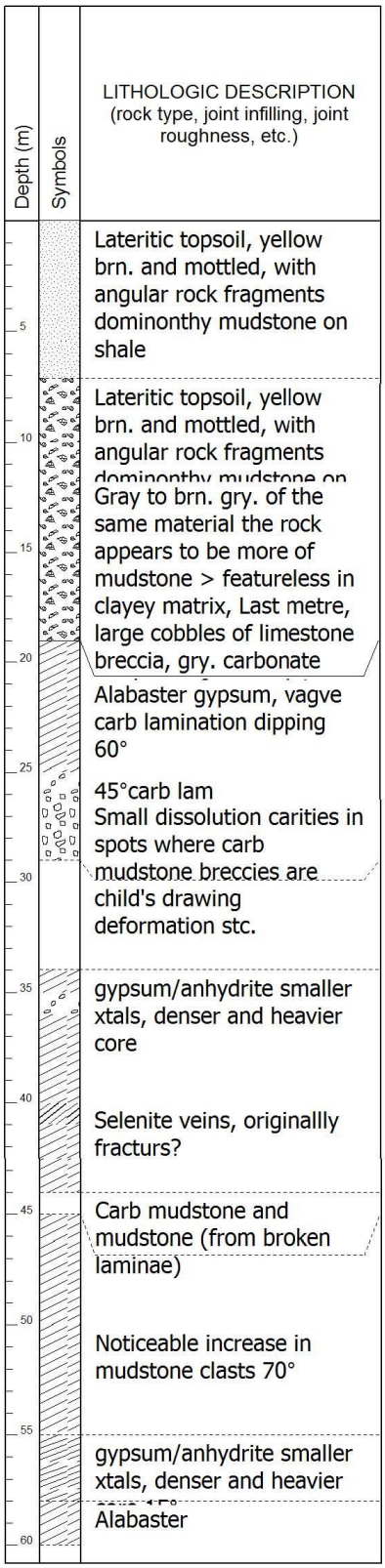

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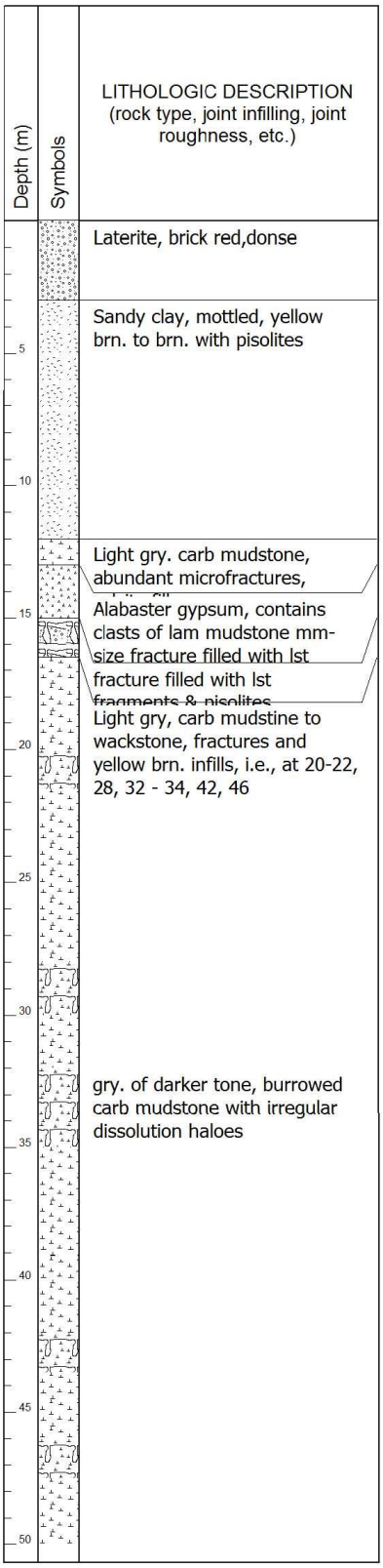

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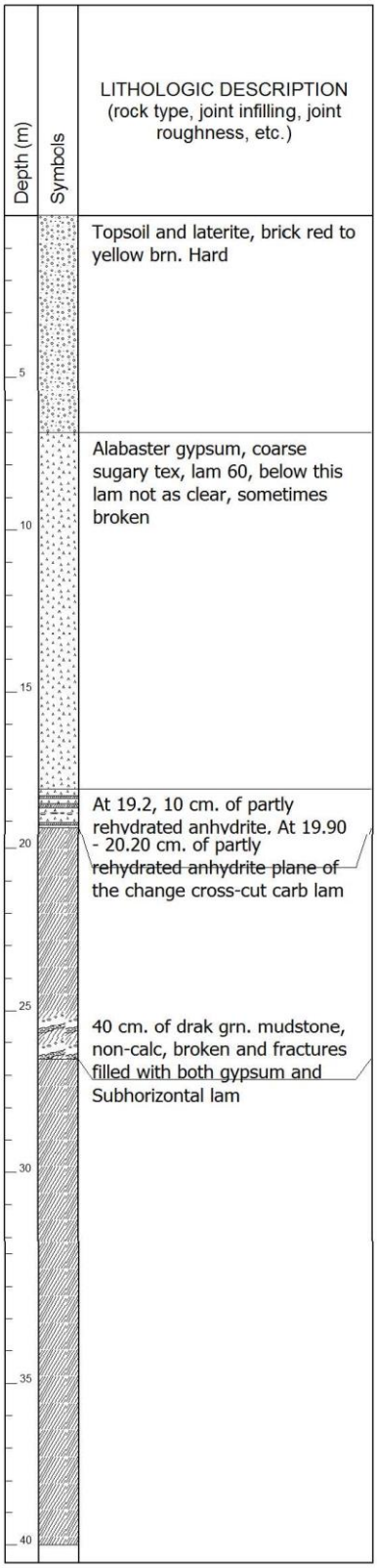

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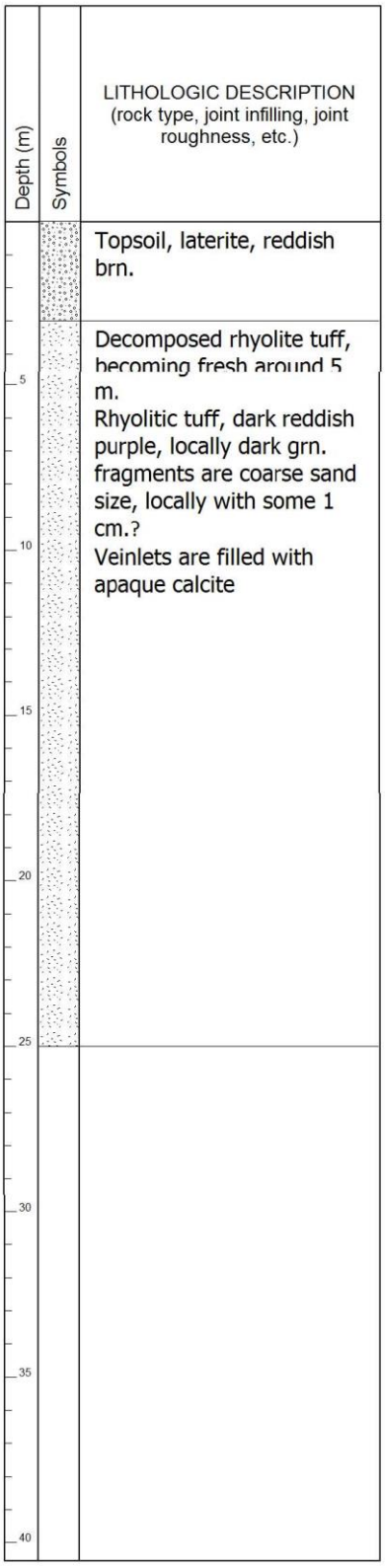

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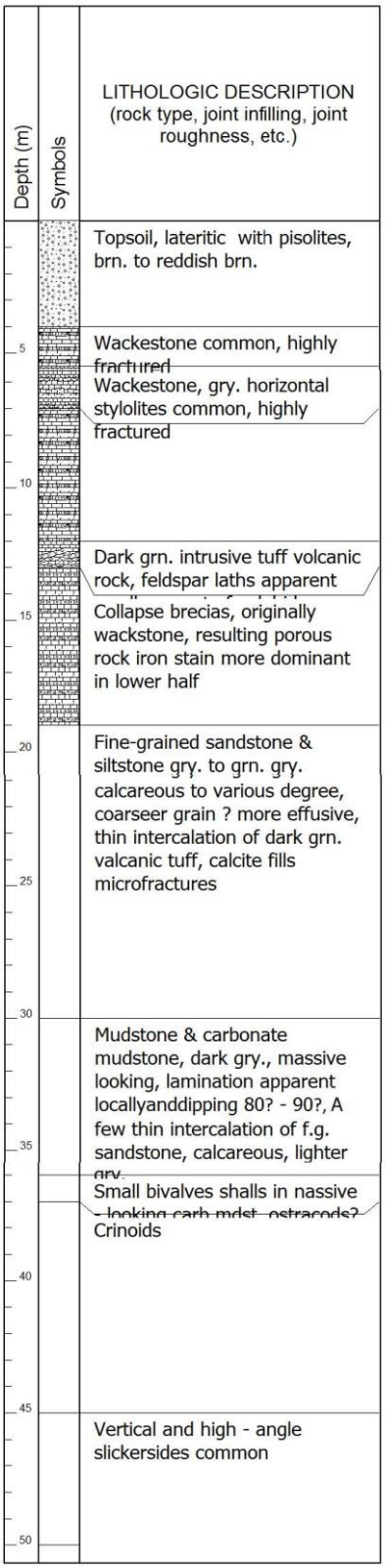

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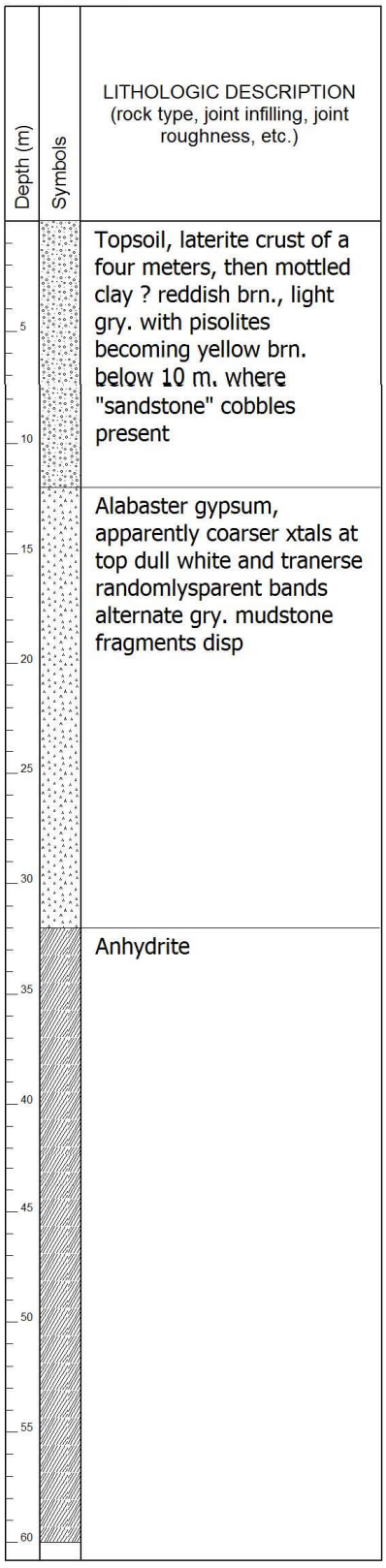

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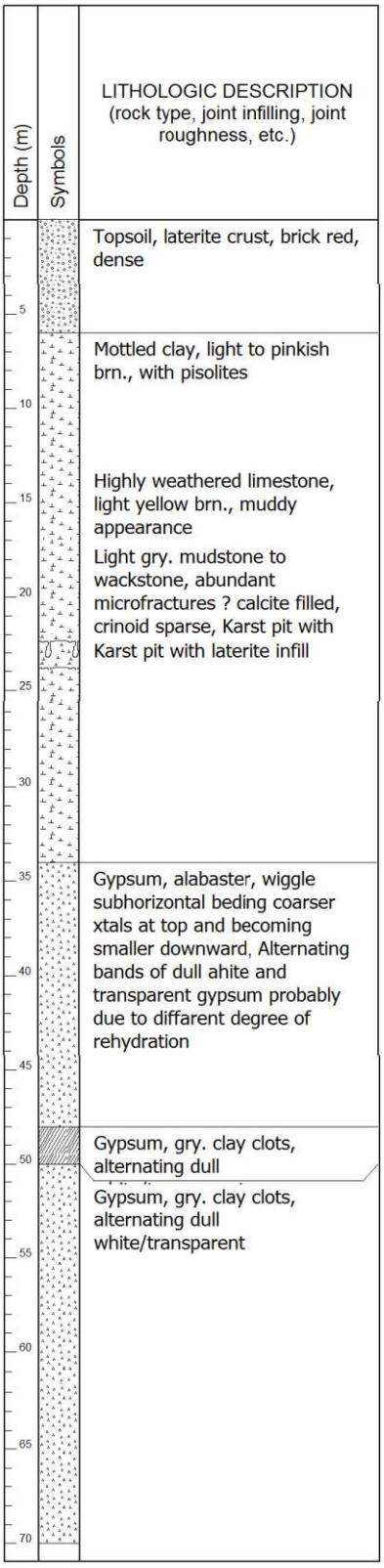

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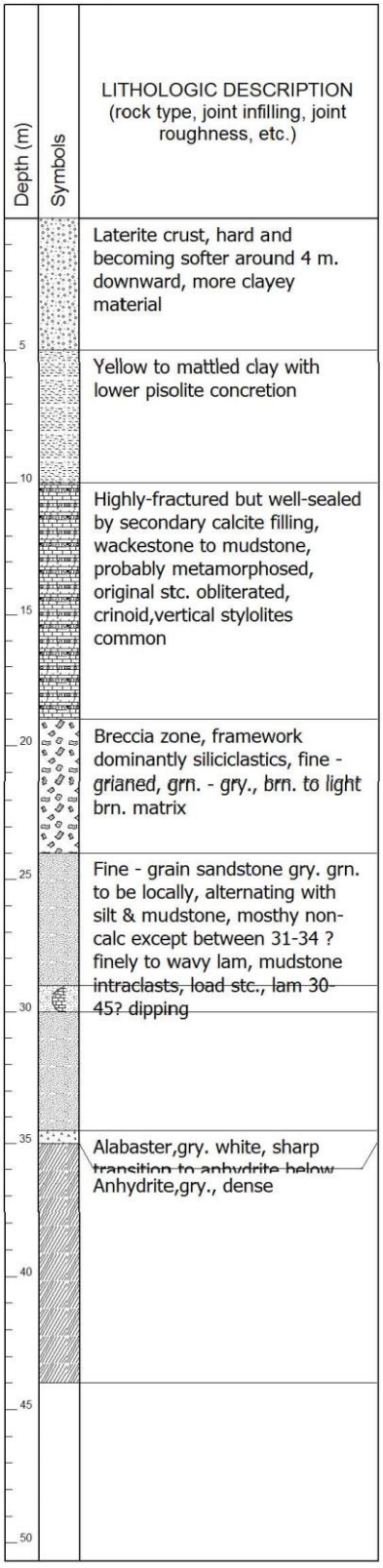

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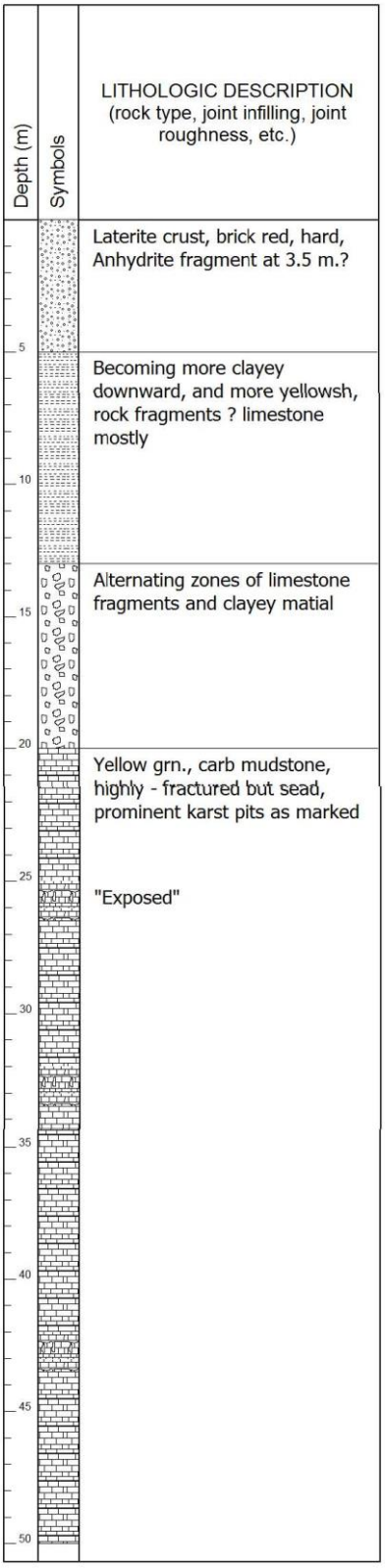

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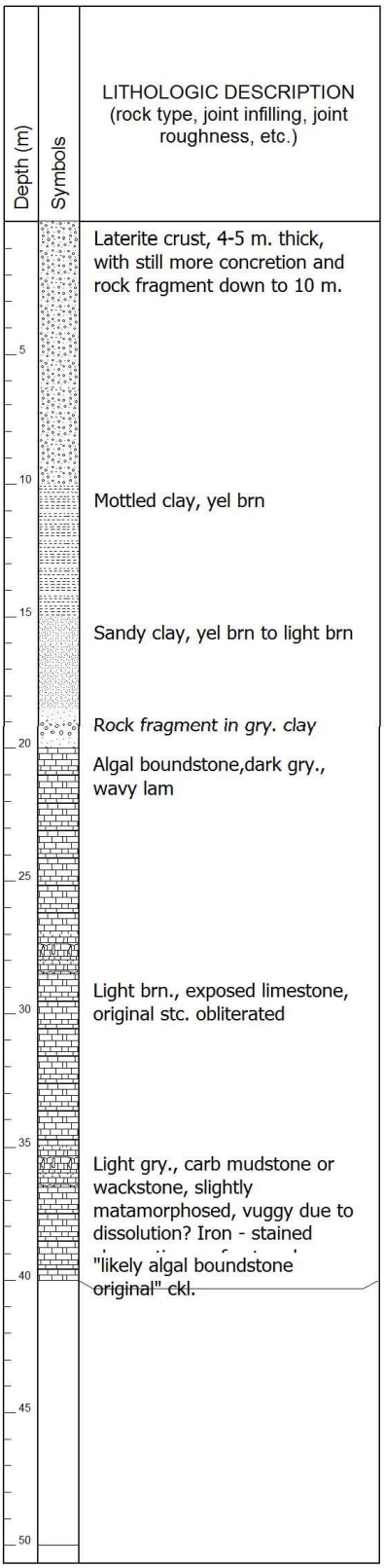

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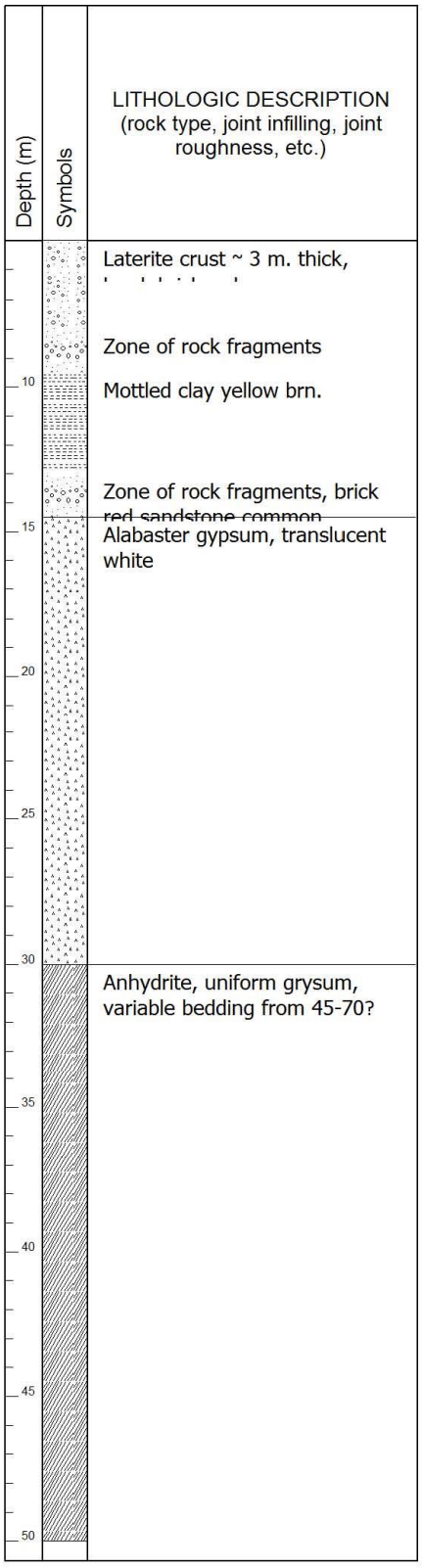

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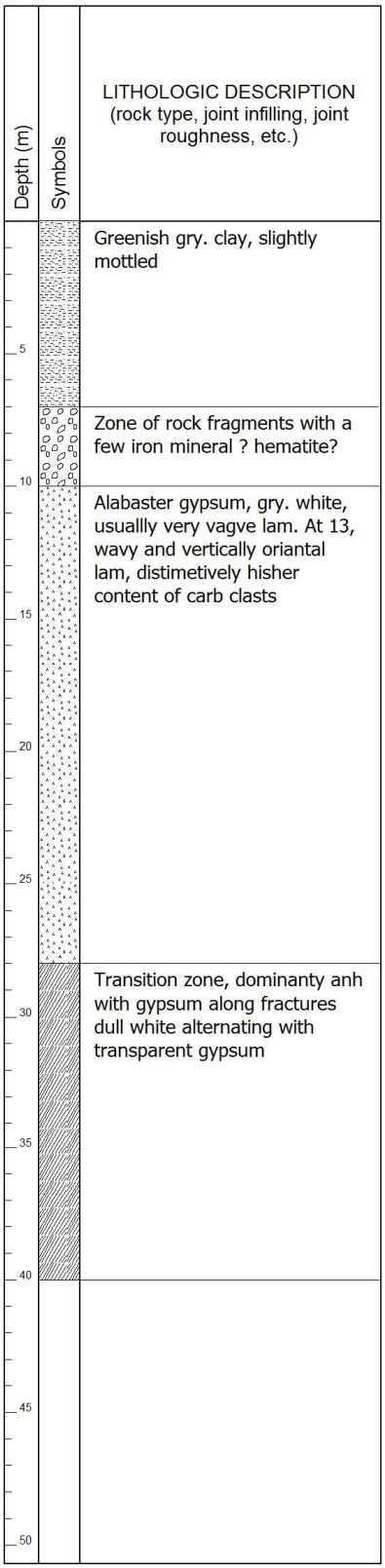

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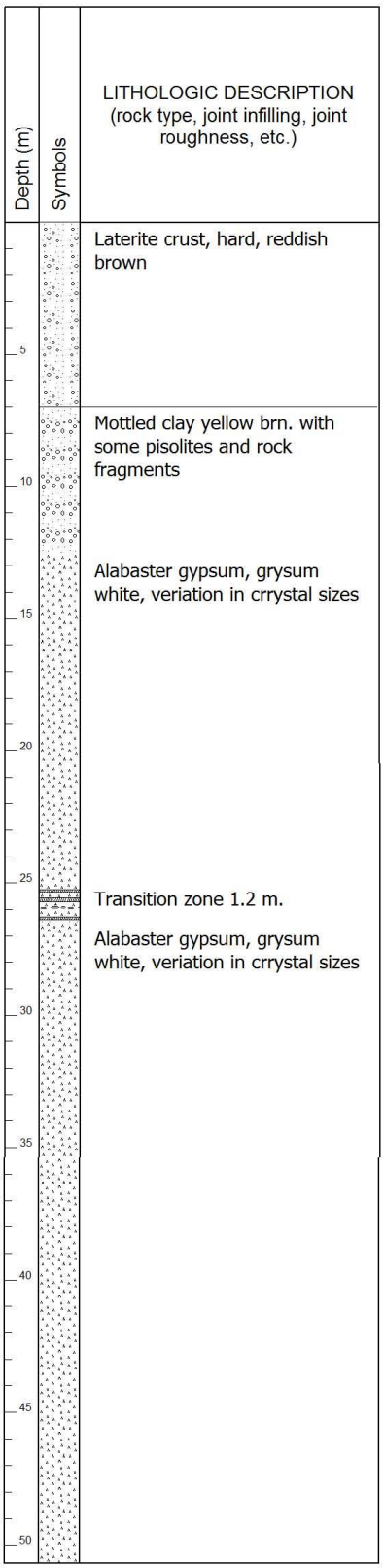

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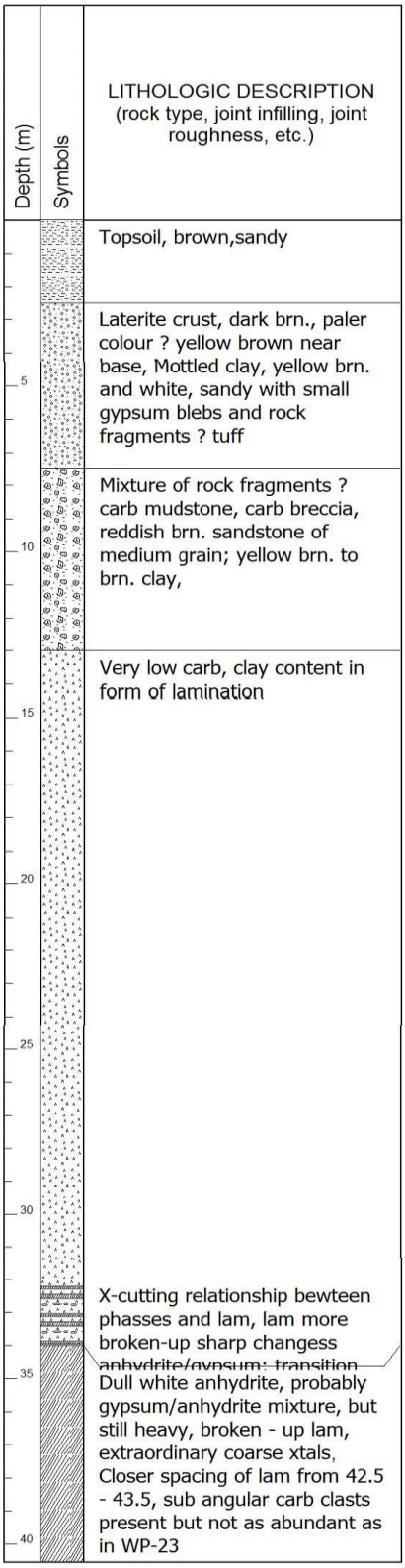

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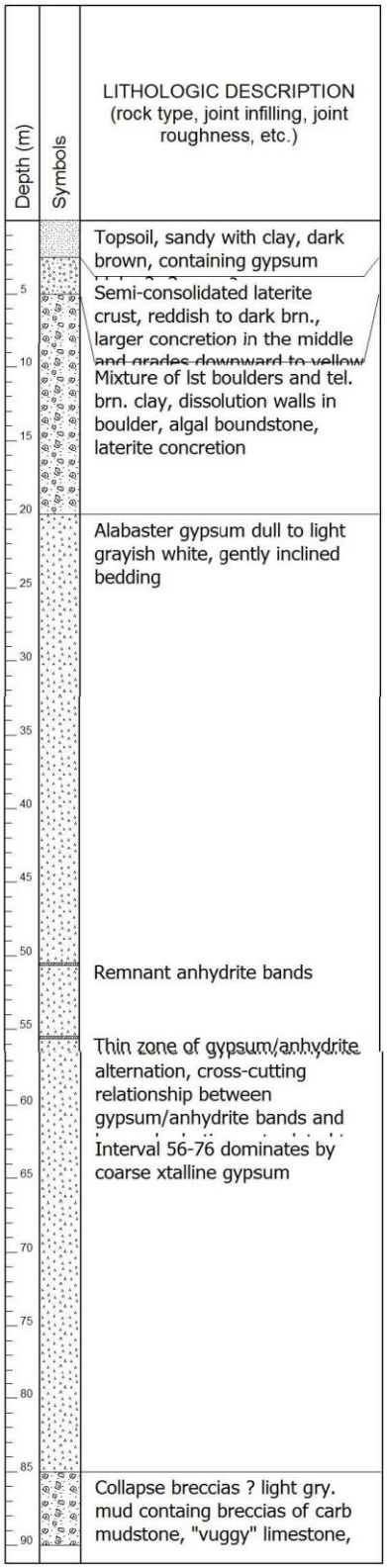

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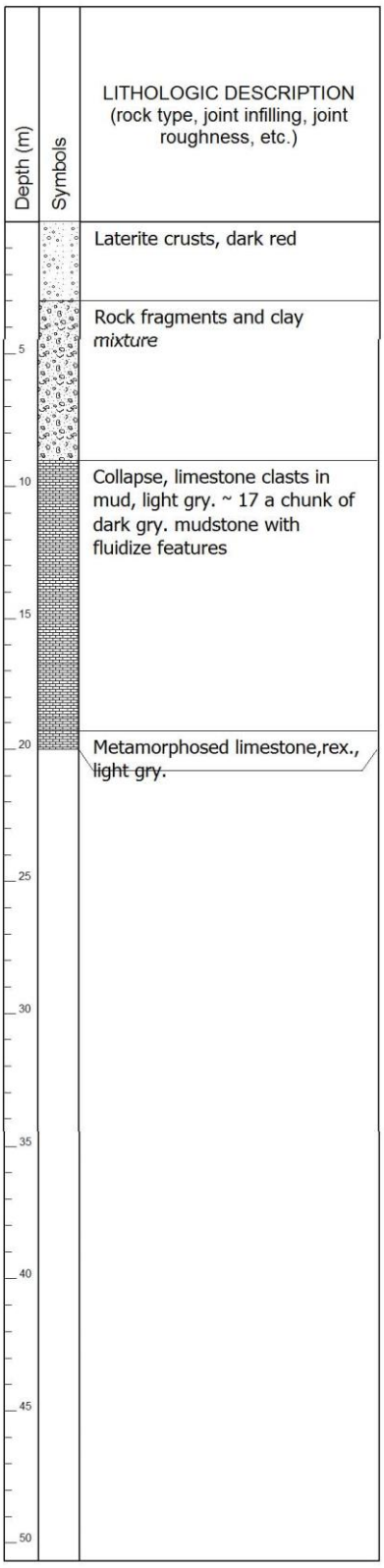

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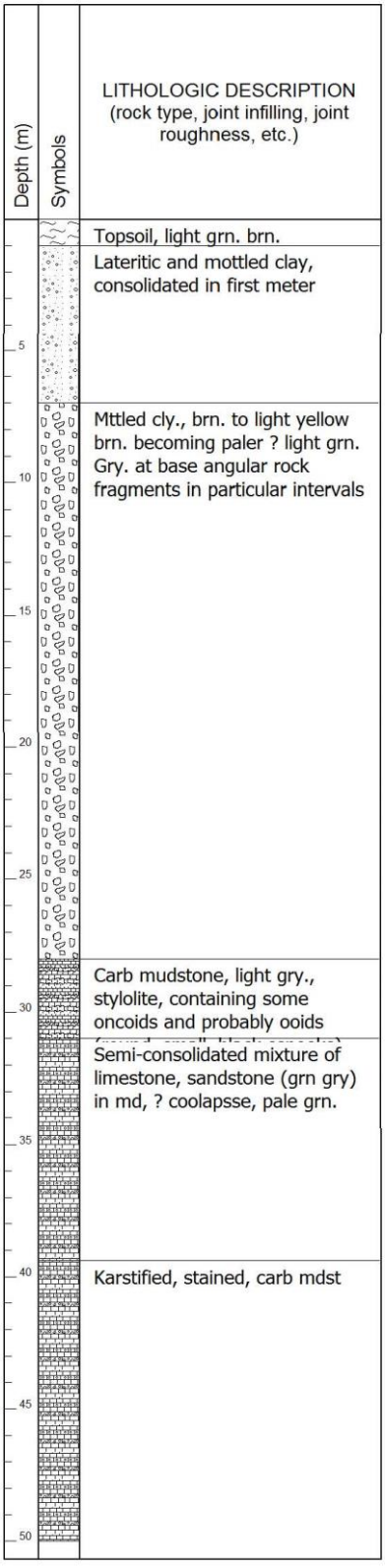

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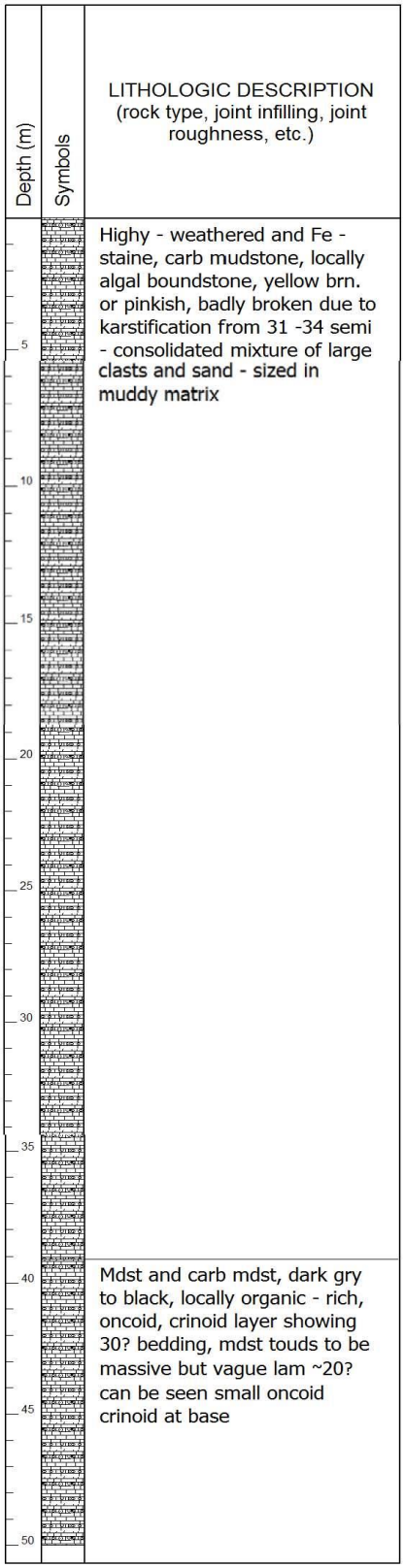

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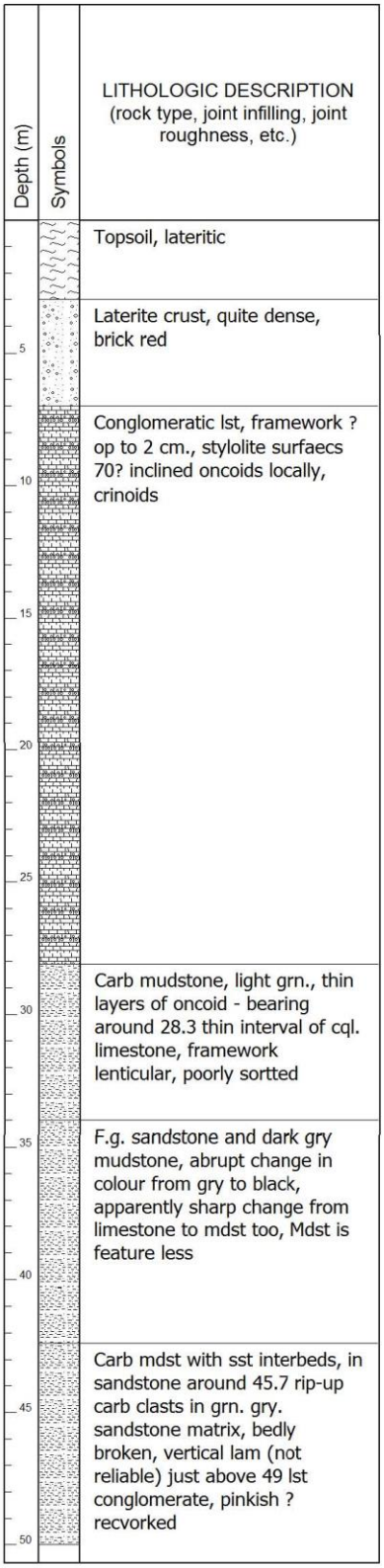

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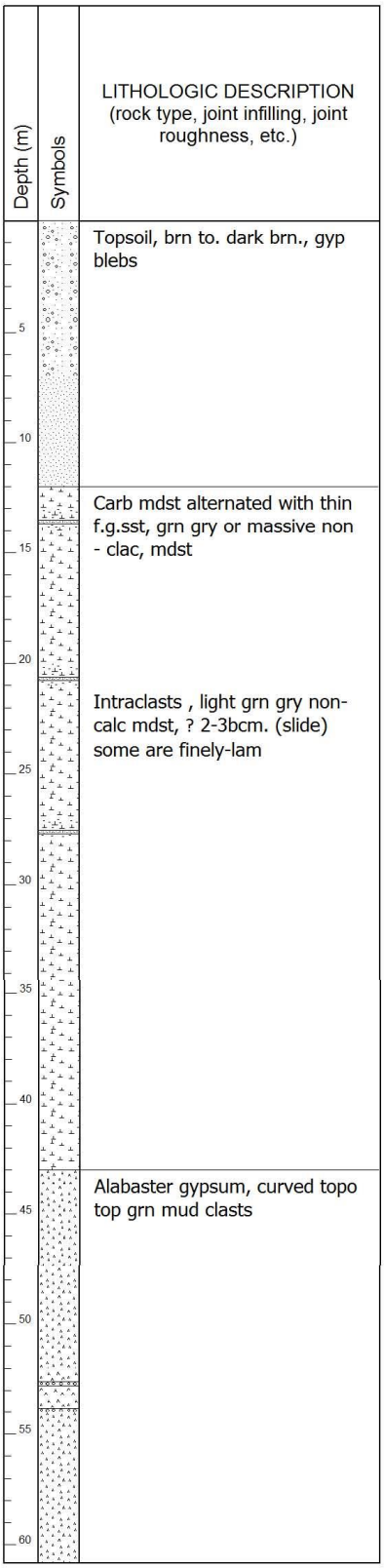

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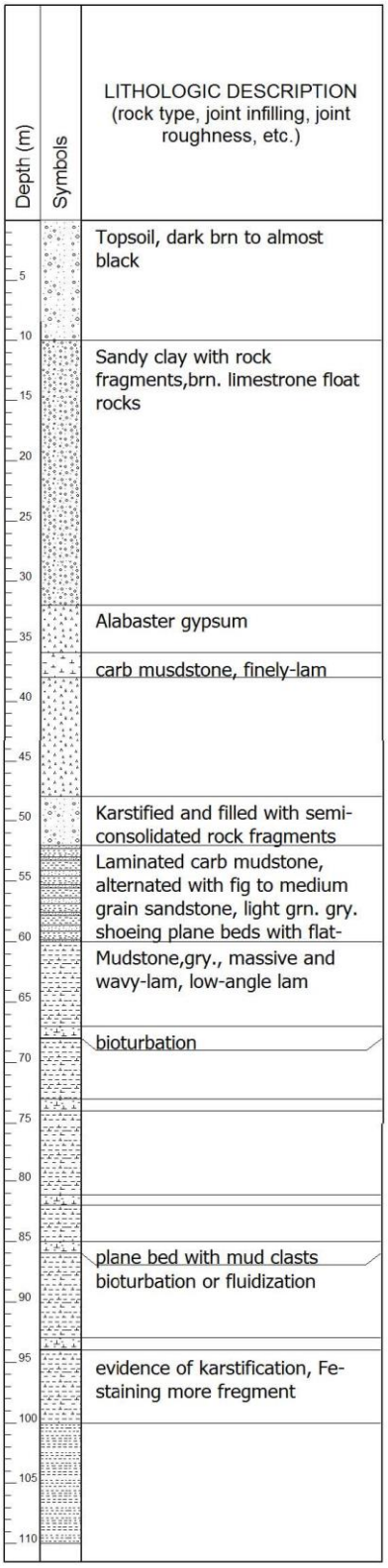

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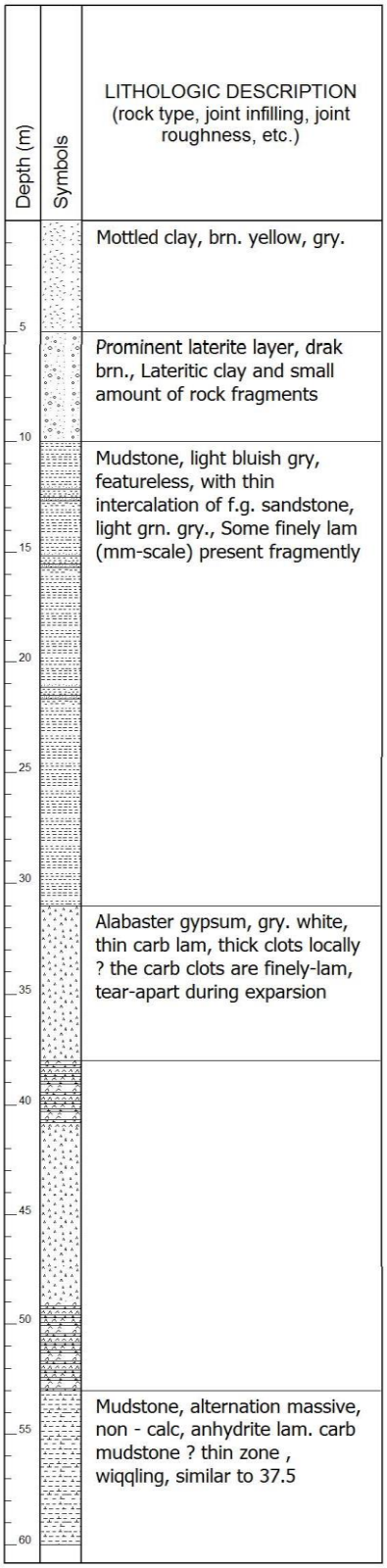

Biography

Biography

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Research output

Fontaine H, Kavinate S, Hoang TT and Vachard D. (2012). Permian Limestone of Peninsular and Western Thailand in Khao Yoi, Chaam and Thong Pha Phum Areas. *Nat. Hist. Bull. Siam Society.* Bangkok, 58, 39-47.

Fontaine H, Hoang TT, Kavinate S, Suteethorn V and Vachard D. (2013). Upper Permian (Late Changhsingian) marine strata in Nan Province, northern Thailand. *Journal of Asian Earth Sciences*. 76(2013), 115-119.

_____. (2013). Wide Extension of Carboniferous Limestone in Northwest Thailand with an Interesting Stratigraphy. *Journal of The Geological Society of Thailand (GST)*. Special Issue, 65.