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Sedimentary facies of the late Middle Eocene Pondaung Formation (central Myanmar) and the palaeoenvironments of its Anthropoid Primates

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Abstract – The primate-bearing Pondaung Formation (northwestern part of central Myanmar) is mainly composed of cyclic sequences of sandstones and variegated clays that are divisible into 12 lithofacies and are grouped under seven facies associations. These established facies associations represent the deposition in a fluvio-deltaic environment. The anthropoid primate remains occur in swale-fill sediments, sometimes in carbonate nodules of pedogenetic origin and also, in small crevasse channel deposits of the upper part of the Pondaung Formation. The sedimentary facies associated to these anthropoid primates contribute to the understanding of their morpho-anatomic features. ***To cite this article: A.N. Soe et al., C. R. Palevol 1 (2002) 153–160.*** © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

Pondaung Formation / Eocene / fluvio-deltaic / swale-fill / anthropoid primates / Myanmar

Résumé – Faciès sédimentaires de la formation de Pondaung (fin Éocène moyen, Myanmar central) et paléoenvironnements des primates anthropoïdes. La formation de Pondaung affleure sur le piémont oriental des monts de Pondaung (Myanmar central). Elle se compose de séries sédimentaires cycliques, constituées d'une alternance de grès et d'argiles bariolées, qui peuvent être subdivisées en 12 lithofaciès, regroupés en sept associations de faciès. Ces environnements sédimentaires caractérisent un milieu fluvio-deltaïque. Les restes de primates anthropoïdes ont été découverts dans des sédiments de dépressions marécageuses, parfois à l'intérieur de nodules carbonatés d'origine pédogénétique et également dans de petits chenaux issus de la rupture de levées. Tous proviennent de la partie supérieure de cette formation. Les faciès sédimentaires associés aux fossiles de primates anthropoïdes contribuent à la compréhension de leurs adaptations morpho-anatomiques. ***Pour citer cet article : A.N. Soe et al., C. R. Palevol 1 (2002) 153–160.*** © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

formation de Pondaung / Éocène / fluvio-deltaïque / dépressions marécageuses / primates anthropoïdes / Myanmar

Version abrégée

La formation de Pondaung, qui affleure dans la partie nord-occidentale du Myanmar central (ancienne Birmanie), correspond à des dépôts fluviatiles [1]. Elle est intercalée entre deux formations marines, la formation de Tabyin à la base et celle de Yaw au sommet, datées respectivement de l'Éocène inférieur et supérieur. Les niveaux supérieurs de la formation de Pondaung ont livré une riche faune de vertébrés [2–8, 10] d'âge Bartonien (Éo-

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cène moyen supérieur). Parmi eux, trois formes distinctes de primates anthropoïdes, *Pondaungia cotteri*, *Amphipithecus mogaugensis*, *Bahinia pondaungensis* et *Myanmarpithecus yarshensis* témoignent de l'ampleur de la diversification de ce groupe en Asie. Les deux premières formes possèdent déjà un grand nombre de caractères dérivés, par rapport à leurs contemporains africains, qui suggèrent une origine asiatique plutôt qu'africaine des anthropoïdes modernes, Cercopithécoïdes et Hominoïdes. La formation de Pondaung correspond à des dépôts fluviatiles [11]. Quatre coupes distinctes y ont été levées, qui ont livré chacune des faunes de vertébrés et des restes d'anthropoïdes. Sept faciès sédimentaires distincts y ont été reconnus, (1) les chenaux fluviatiles sableux, (2) les petits chenaux et/ou les chenaux issus de la rupture de levées, (3) les dépressions marécageuses, (4) les dépôts de débordement, (5) les chenaux distributoires, (6) les marécages et (7) les pro-deltas.

Les chenaux fluviatiles sableux (1/2) varient en épaisseur entre 2 et 8 m. Les séquences observées indiquent l'existence de dépôts de point bars de chenaux fluviatiles méandrants. Des surfaces d'érosion apparaissent dans les lithofaciès Se et St (Tableau 1), causées par la migration latérale des chenaux. L'absence de fentes de dessiccation et de traces de racines dans la partie inférieure de ces dépôts suggère la pérennité de l'écoulement. Ces chenaux renferment quelquefois une riche faune de vertébrés aquatiques, au sein de laquelle dominent les restes de poissons, de crocodiliens, de tortues et de quelques grands mammifères, comme les rhinocérotidés et les anthracotheriidés. Les petits chenaux et/ou les chenaux issus de la rupture de levées déposent de petits bancs de grès lenticulaires, dont l'épaisseur varie entre 0,5 et 3 m. Ils sont fréquemment interstratifiés avec des *mudstones* ferrugineux (Fm), qui peuvent contenir des empreintes de feuilles et des fragments de végétaux. La base micro-conglomératique d'un tel niveau a livré, dans la coupe de Pangan (Fig. 2A), un maxillaire fragmentaire de *Pondaungia cotteri*. Mais la majorité des restes d'anthropoïdes provient des dépressions marécageuses. Leur épaisseur peut varier entre 0,2 et 16 m et elles peuvent se prolonger sur des centaines de mètres. Elles renferment des dépôts détritiques fins, généralement rubéfiés et pédogénisés, montrant des bandes de couleur, dont certaines contiennent d'abondantes concrétions carbonatées, témoins du développement de sols peu évolués, mais également de l'existence d'une alternance de saisons sèches et humides. Les restes d'anthropoïdes sont disposés au sein de ces sédiments meubles, mais peuvent également être inclus dans des nodules carbonatés. Les restes d'anthropoïdes sont associés à des restes de vertébrés terrestres, comme des agamidés, des serpents, des crocodiliens, de petits ruminants et des créodontes. Dans certains niveaux, on note la présence d'abondants gastéropodes d'eau douce. Les autres faciès (4/5/6/7 [14, 17]) ne contiennent qu'exceptionnellement des restes de vertébrés.

En conclusion, les restes de mammifères et surtout d'anthropoïdes proviennent exclusivement de la partie supérieure de la formation de Pondaung, qui représente les dépôts d'une grande rivière qui formait des méandres [9, 12, 13, 18]. La section la plus épaisse, celle de Than-udaw, épaisse de près de 300 m, correspond à une dizaine de cycles fluviatiles. En certains endroits, les dépressions marécageuses peuvent atteindre une épaisseur considérable, sans doute en raison du rejeu de failles locales mineures. La rareté des stratifications entrecroisées en forme d'epsilon suggère, en outre, que la migration latérale des chenaux fluviatiles était réduite et que la plaine fluviatile évoluait vers l'aggradation. Les environnements sédimentaires contribuent donc à la reconstitution des paléoenvironnements et à la compréhension des adaptations morpho-anatomiques et alimentaires des anthropoïdes (molaires en forme de dôme, face courte et mâchoires puissantes) de cette formation.

1. Introduction

The Pondaung Formation exposed in the northwestern part of Central Myanmar (Burma) is mainly composed of fluviatile sediments (Fig. 1). It is also rich in vertebrate faunas, including anthropoid primates of late Middle Eocene age (Bartonian) [3], *Myanmarpithecus yarshensis* [15], *Pondaungia cotteri*, *Amphipithecus mogaungensis*, and *Bahinia pondaungensis* [2, 7, 8], associated with several land mammal remains, fishes, turtles, crocodiles, and agamid lizards. Among the mammals, anthracotheres [5], rhinoceroses [4], creodonts [6], and primitive ruminants [10] are the most abundant.

The study area is situated on the eastern foothills of Pondaung range, in Myaing and Pale townships. The rocks outcropping in the investigated area mainly consist of rock units of the Eocene age, the Tabyin, the Pondaung and the Yaw Formations. Both Tabyin and Yaw Formations are marine and attributed respectively to Early and Late Eocene [1]. The general geology, locations of the measured sections and fossil collecting localities of the Pondaung area are shown in Fig. 1.

2. Lithofacies associations

Twelve lithofacies have been classified (Table 1, facies codes modified from Miall [11]) on the basis of sedimentary structures, lithology and fossils. Four sections with their lithofacies columns have been established (Figs. 2 and 3). Seven facies associations were distinguished with respect to their lithology, facies successions and bed geometry (Table 2). They are sandy fluvial channel, small fluvial channel and/or

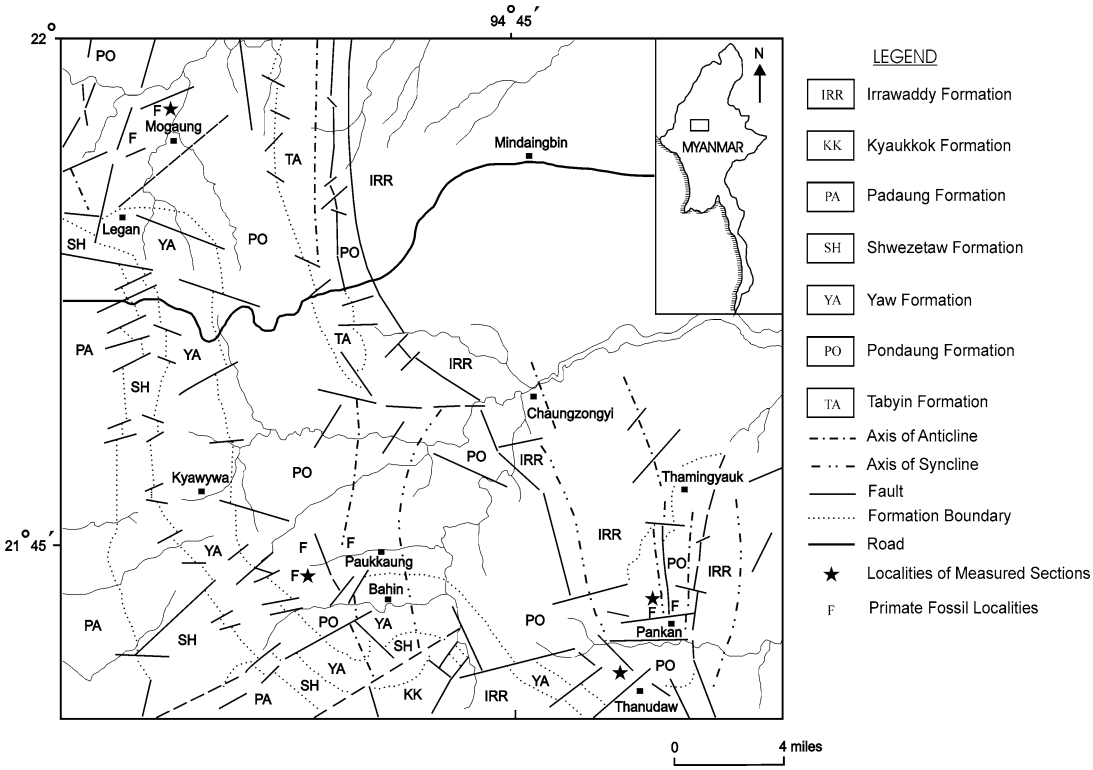

Figure 1. Geological sketch showing the locations of measured sections and fossil collecting localities of the Pondaung area (after [16], modified).

Figure 1. Carte géologique montrant la localisation des coupes mesurées et des localités fossilifères de la région de Pondaung (d'après [16], modifiée).

crevasse channel, swale-fill, overbank, distributary channel, marsh, and prodelta.

2.1. FA 1. Sandy fluvial channel

This facies association is characterised by the lithofacies Se, St, Sp, Sh, Sr, Fl, and Fm (Table 1; Figs. 2 and 3). They show typically fining upward grain size and associated changes in sedimentary structures. Some fragmented large mammalian remains, bone fragments of turtles, fishes, teeth of crocodiles, and some teeth and jaw fragments of vertebrate fossils embedded in these sediments.

The facies association is interpreted as the channel associated with point bars deposits of mixed load meandering river. Basal erosional surface of the lithofacies (Se) and (St) results from the lateral migration of erosional thalweg. The lack of mudcracks and root traces in the lowermost portion of the channel deposits suggests perennial river flow.

2.2. FA 2. Small fluvial channel and/or crevasse channel

This facies association constitutes the lithofacies St, Sr, Sm, Sl and Fm (Table 1; Figs. 2 and 3). The lithofacies (Fm) that occurs at the top of some sections shows well-preserved leaf impressions and plant remains. A fragmented maxilla of *Pondaungia*, some teeth and small bone fragments of mammals, small bone fragments of turtles, teeth of crocodiles and fishes occur in these sediments.

This facies association is interpreted as resulting from the coexistence of small meandering channel and crevasse splays that extend across the natural levee into the flood plain and that were capped by muddy sediments. The muddy sediments correspond to flood basin deposits of muddy and swampy conditions.

2.3. FA 3. Swale-fill

This facies association is classified by the lithofacies (Fsc) with minor or local distribution of lithofacies (Sm) (Table 1; Figs. 2 and 3). The lithofacies (Fsc) is laterally persistent in outcrops and reveals different colour patches and display colour bands. The amount of mud is generally greater than that of silt. Anthropoid primate jaws and maxilla, *Pondaungia*, *Amphipithecus*, *Bahinia* and *Myanmarpithecus* were discovered in these sediments and, sometimes, in the carbonate nodules. Bones, teeth and jaw fragments of various vertebrates were also discovered in these sediments. Some sections show an exceptional amount of gastropods. Moreover, calcareous nodules, which correspond to poorly developed palaeosoils, are sometimes abundant. Pedogenic carbonate concretions develop by leaching processes, indicating seasonality of climates.

Table 1. Lithofacies of the upper part of the Pondaung Formation.

Tableau 1. Lithofaciès de la partie supérieure de la formation de Pondaung.

Facies	Texture (grain size)	Lithology	Bed thickness	Sedimentary structures	Boundaries	Other characteristics
1. Se: Scoured surfaces with intraformational conglomerate	medium- to coarse-grained	ferruginous, reddish to dark brown gritty sand matrix, with sandstone, poorly sorted, mud and igneous pebble clasts	0.25–3.25 m	incipient pebble imbricated	sharp, erosional	pebble size decrease upward
2. St: Trough cross-bedded sandstone	medium- to coarse-grained	yellowish brown to light grey lithic sandstone; subangular to subrounded, slightly micaceous; poorly sorted	0.5–17 m	moderately to well preserved trough cross-beds in sets up to 1 m thick; individual sets range from 2.5 cm to 5 cm; and also, small trough cross-beds in sets up to 15 cm thick and the lamination sets vary from 2 to 5 mm, grouped with set size decreasing upward	sharp, erosional	pebbles within the cross lamination (vary from 1 to 3 cm), mudstone intraclasts, plant debris, oblate calcareous concretion embedded with fossil wood; occurrence of fragmented vertebrate fossils on foresets
3. Sp: Planar crossbedded sandstone	medium- to coarse-grained	yellowish brown to buff, subrounded to rounded lithic sandstone; poorly sorted	0.5–3 m	vaguely tabular cross-beds; some with mud drapes	sharp, erosional (sometimes gradational)	rare pebble; commonly intercalated with mud layers
4. Sh: Laminated sandstone with silt patches	fine- to medium-grained	reddish to yellowish brown lithic sandstone; subangular to subrounded, ferruginous and buff coloured silt patches	0.5–6 m	parallel lamination	sharp, erosional (sometimes gradational)	syneresis cracks occur on the bedding
5. Sr: Ripple crosslaminated sandstone	fine sand and silt	very fine-to fine-grained lithic sandstone and buff coloured silt	0.1–1 m	horizontal, wavy and ripple lamination	sharp, erosional	
6. Sl: Low angle crosslaminated sandstone	fine- to medium-grained	light grey to ash grey, sandstone, moderately sorted	0.3–0.6 m	low angle cross-beds; wavy lamination	sharp, erosional	interbedded with ferruginous mudstone
7. Sm: Massive sandstone	fine- to coarse-grained	yellowish brown to dark grey lithic sandstone; moderately sorted, micaceous, widely emplaced igneous granules	0.2–4 m	apparently massive	sharp	occurs as lenticular units interbedded with mudstone; fossil wood and mud clasts are also present; syneresis cracks; coal seams are intercalated in some places
8. Fl: Laminated fine sand and silt	very fine sand and silt	yellowish brown sand, and buff colour silt	0.1–4 m	horizontal lamination	sharp, gradational	very thin peat layers; ferruginous sand layers; sand filled burrows
9. Fsc: Laminated siltstone and mudstone	silt and mud	purplish grey, reddish brown silt and variegated clay (Colour vary from light bluish grey, light grey, grey, purplish red, reddish brown, yellowish brown, buff)	0.2–16 m	slightly laminated	sharp (sometimes gradational) nonerosional	vertebrate fauna; gastropod shells; caliche nodules; rare gypsum

Table 1. (Continued.)
Table 1. (Suite.)

Facies	Texture (grain size)	Lithology	Bed thickness	Sedimentary structures	Boundaries	Other characteristics
10. Fm: Massive mudstone	mud	reddish brown mudstone, ferruginous	0.5–1.75 m	massive, mottled and moderately bioturbated	sharp, nonerosional	well-preserved leaf impressions; plant fragments
11. Ss: Thinly laminated sandstone and clay	medium sand and clay	dark grey, medium grained sandstone and clay	0.4–0.8 m	horizontal and wavy lamination (laminations vary from 2–4 mm thick)	wavy base (sometimes sharp)	peat layers are sandwiched in these laminations, asymmetrical current ripple are noticed on the upper bedding plane
12. Fc: Thinly laminated clay and silty clay	clay, silty clay	reddish brown, silty clay and bluish grey clay, with tiny plant debris, moderately bioturbated	0.35–10.5 m	parallel laminations (laminations thickness range from 1 to 2 mm)	gradational, sharp	peat layers or coal seams are intercalated; thin mudstone beds are also present but rare; fragmented shell remains are also present

This facies association represents the swale-fill deposits that correspond to muddy sediments. The sandstone layer may be interpreted as distal splay sediments.

2.4. FA 4. Overbank

Overbank facies association contains the lithofacies Sh, Sr, Sm, Fl, and Fm (Table 1; Figs. 2 and 3). They show the coarsening upward sequence in some places. Sand-filled burrows and fossil trails are fairly observed on the upper bedding of the laminated sandstones. Thin laminations of oxidised, reddish brown sand layers are intercalated with siltstones in some places.

The facies associations of (Sm, Fm and Sr) and (Fl, Fm and Fl) represent the overbank deposits. The upward coarsening and laminated sandstones, with fossil trails alternating with massive mudstones, indicate flood plain deposits. The lithofacies sequence of (Fl and Sr) may be considered as representing levee deposits.

2.5. FA 5. Distributary channel

This facies association is composed of clastic sequences, showing the repeated cycle of upward coarsening grain size. It comprises the lithofacies St, Fl, Sm, Ss, Sr, and Fc (Table 1; Fig. 3). The coals and plant debris occur in these sediments.

The facies associations of Ss, Sm, St, and Ss, Sr and St, Fc, St correspond to small-scale coarsening-upward sequences. In some places, the lithofacies sequence of (Sm and Fl) represents a fining upward sequence. They represent the sediments deposited by the distributary channels in a delta plain. The lithofacies sequence of (Ss, Sr/Sm and St) indicates that sediments were deposited in the unidirectional current of the distributary channel. Coals and plant debris also indicate intermittent sub-aerial exposures.

2.6. FA 6. Marsh

This facies association is characterised by the lithofacies (Fc), with minor distribution of (Sm) (Table 1; Fig. 3). It also comprises the lithofacies St, Fl and Fc. Peat layers or coal seams are examined in these sediments.

This lithofacies assemblage suggests that sediments were deposited under the delta marsh environment. They were deposited in the quiet conditions that prevailed, with peat swamps colonising the inter-channel areas [14]. The lithofacies sequence of Fl and Sm, intercalated with coal seams and clay patches, correspond to the sediments deposited under the levee deposit. The lithofacies sequence of St and Fl indicates the smaller scale crevasse channels.

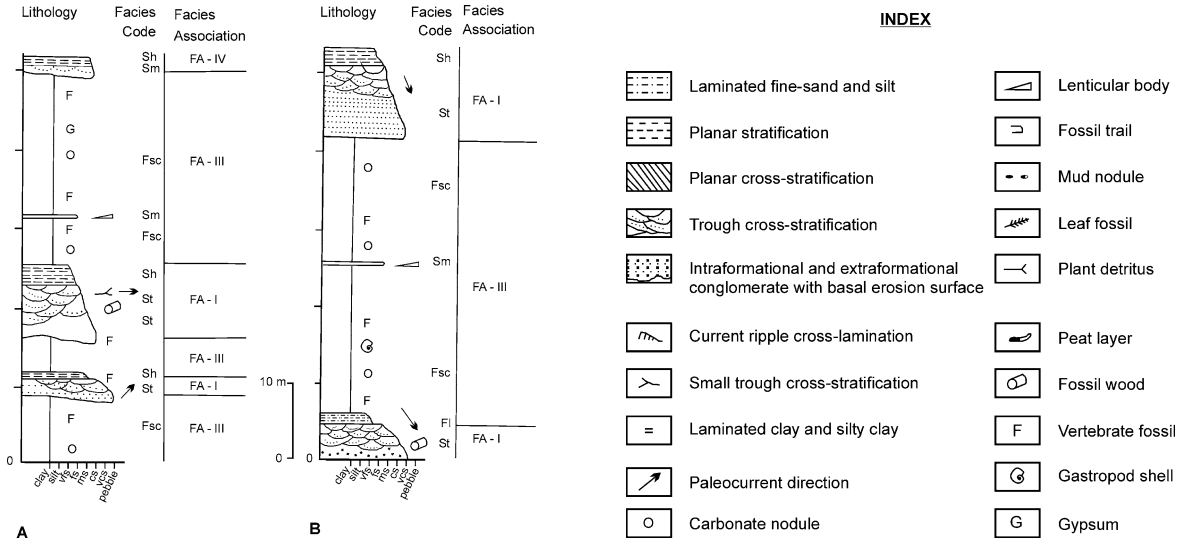

Figure 2. Measured sections of Pangan area (A) and Mogaung area (B).
Figure 2. Coupes mesurées des régions de Pangan (A) et de Mogaung (B).

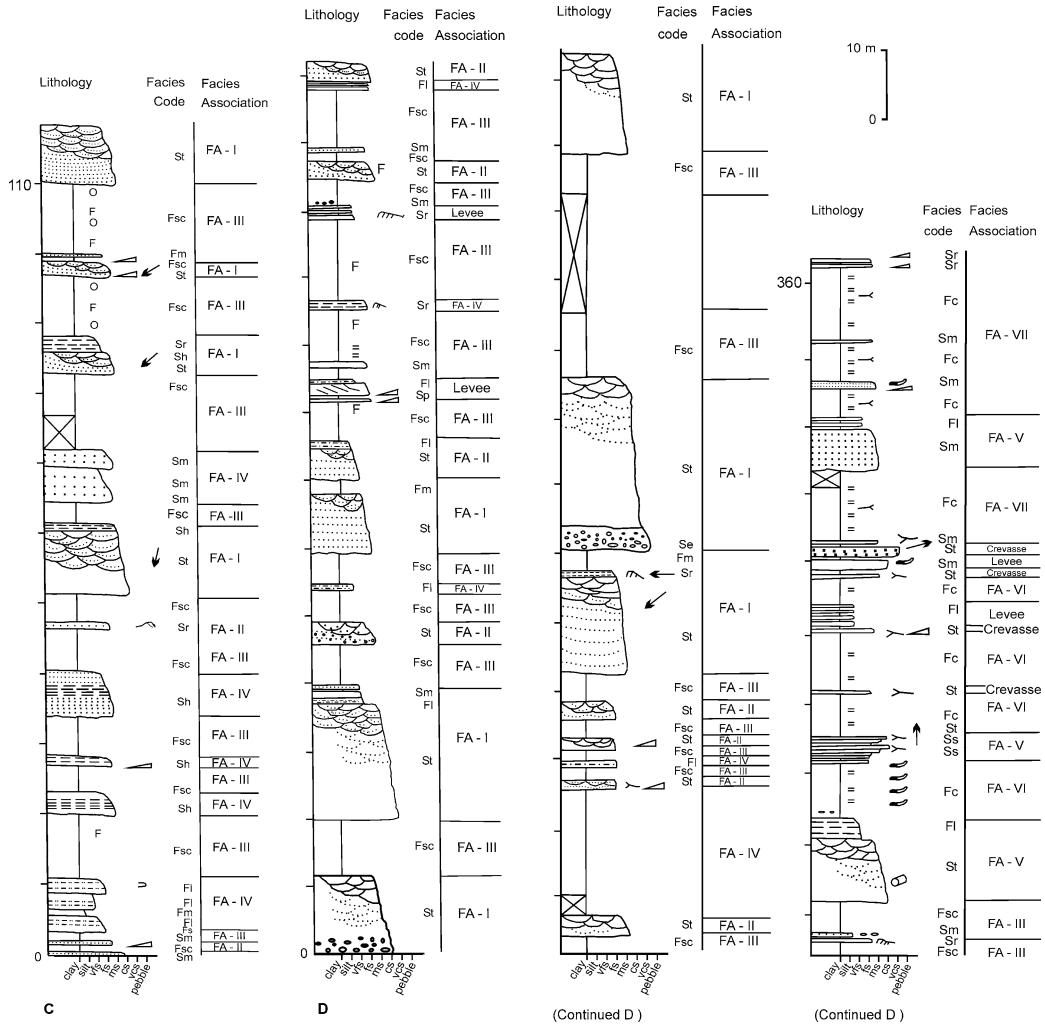

Figure 3. Measured sections of Bahin area (C) and Than-U-Daw area (D).
Figure 3. Coupes mesurées des régions de Bahin (C) et de Than-U-Daw (D).

Table 2. Facies associations of the upper part of the Pondaung Formation.

Tableau 2. Associations de faciès de la partie supérieure de la formation de Pondaung.

Facies association	Interpretation	Facies	Thickness
1	sandy fluvial channel	Se, St, Sp, Sh, Sr, Fl, Fm	2–18 m
2	small fluvial channel and/or crevasse channel	St, Sr, Sm, Sl, Fm	0.5–3 m
3	swale-fill	Fsc, Sm	1–16 m
4	overbank	Sh, Sr, Sm, Fl, Fm	1.5–7.5 m
5	distributary channel	St, Fl, Sm, Ss, Sr, Fc	2–12 m
6	marsh	Fc, St, Fl, Sm	3.5–8 m
7	prodelta	Fc, Sm, Sr	4–10.5 m

2.7. FA 7. Prodelta

This facies association mainly consists of thinly laminated clay and silty clay (Fc) that comprise abundant tiny fragments of plant detritus and fragmented shell remains. It is also marked by layering due to differences in both colour and grain size. Weak to moderate bioturbations are also observed. The lithofacies Sr and Sm are present as well.

The fine-grained muddy sediments of clay and silty clay indicate prodelta deposits. The facies association Sr and Sm was deposited under the river floods of high current velocities, which are efficient in transporting large quantities of coarser sediments (sands) over large distances into the sea [17].

3. Depositional environments

The upper part of Pondaung Formation records two major depositional environments: the channel deposits associated with the overbank deposits and the fluvial-dominated deltaic deposits. These environments are recognised from the nature and distribution of facies associations. The interpretation regarding the various fluvial and deltaic environments are in agreement with those mentioned by Walker and Cant [18], Reineck and Singh [13], and Reading [12].

The cyclic pattern of sandstones and variegated clays were deposited by the repeated lateral migration of a meandering channel associated with point-bars and swale-fills. At least ten fluvial cycles have been recognised in a measured section of some 300 m in the Than-udaw area, located about 13 km NNW of Myaing (Fig. 3d). The general paucity of epsilon-shaped cross bedding of sandstones suggests that the lateral migration of channels was minimal and that the floodplains were aggrading (e.g., [9]). The overbank environments are the area of fall-off in the level of turbulence and fine-grained sediments were deposited. Crevasse splay deposits interbedded with muddy sediments frequently occur in the examined area. They indicate that the formation of a broad flood plain was well developed.

The uppermost part of Pondaung Formation, which is transitional to the overlying Yaw Formation, is regarded as representing fluvial-dominated deltaic sedimentation. This environment is recognised by the delta plain and prodelta deposits. The delta plain consists of distributary channels, smaller crevasse splay lobe, interdistributary channel area and deltaic marsh. The prodelta environment is closely associated with the prograding delta system and it is the seaward extension of the delta front.

4. Conclusions

The upper part of the Pondaung Formation was deposited in a fluvio-deltaic environment, which was interpreted from seven distinct facies associations recognised in the present study. The sandy fluvial channel, small fluvial channel and/or crevasse channel, swale-fill and overbank facies associations represent the deposition on an alluvial plain in which mixed load meandering channels and overbank deposits are predominant. The other three facies associations, distributary channel, marsh and prodelta, indicate that sediments were deposited in delta plain and prodelta. The anthropoid primates are found predominantly in the swale-fill sediments, in the loose sediment or sometimes inside the carbonate nodules. Bones, teeth and jaw fragments of mostly terrestrial animals, including anthracotheriids, rhinocerotids, small ruminants, rodents, agamid lizards, turtles, and crocodiles, vertebrae of snakes and of fishes were collected from these sediments. In some other places, fragmented large mammal remains, bone fragments of turtles, fishes and crocodiles are embedded in the trough cross-bedded sandstones and mud pebble conglomerates that were deposited in the sandy fluvial channels. A maxilla of *Pondaungia cotteri*, some teeth and small bone fragments of mammals, turtles, fishes and crocodiles occur in thin, lenticular, basal lag conglomerate beds of the small crevasse channel sediments. The sedimentary environments described hereby can contribute to the palaeoenvironmental reconstructions

relative to these anthropoid primates. They may also help to understand their locomotory adaptation, diet, and morphological specialisations. Short faces, short and very elevated lower jaws are characteristics of Amphipithecidae [7]. These characters are also indicative of a diet consisting of hard food like seeds and nuts, rather than of young leaves and fruits. Additional data are nevertheless necessary to fully understand the evolution of these earliest Southeast Asian Eocene anthropoids.

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