Geology of an amber locality in the Hukawng Valley, Northern Myanmar

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Abstract

Amber ('Burmite') from the Hukawng Valley of Myanmar has been known since at least the 1st century AD. It is currently being produced from a hill known as Noije Bum, which was first documented as a source of amber in 1836.

Several geologists visited the locality between 1892 and 1930. All of them believed that the host rocks to the amber are Tertiary (most said Eocene) in age, and this conclusion has been widely quoted in the literature. However, recent work indicates a Cretaceous age. Insect inclusions in amber are considered to be Turonian–Cenomanian, and a specimen of the ammonite *Mortoniceras* (of Middle-Upper Albian age) was discovered during the authors' visit. Palynomorphs in samples collected by the authors suggest that the amber-bearing horizon is Upper Albian to Lower Cenomanian. The preponderance of the evidence suggests that both rocks and amber are most probably Upper Albian. This determination is significant for the study of insect evolution, indicating that the oldest known definitive ants have been identified in this amber [American Museum Novitates 3361 (2002) 72].

This site occurs within the Hukawng Basin, which is comprised of folded sedimentary (± volcanic) rocks of Cretaceous and Cenozoic age. The mine exposes a variety of clastic sedimentary rocks, with thin limestone beds, and abundant carbonaceous material. The sediments were deposited in a nearshore marine environment, such as a bay or estuary.

Amber is found in a fine clastic facies, principally as disk shaped clasts, oriented parallel to bedding. A minority occurs as runnels (stalactite shaped), with concentric layering caused by recurring flows of resin.

An Upper Albian age is similar to that of *Orbitolina* limestones known from a number of locations in northern Myanmar. One of these, at Nam Sakhaw, 90 km SW of Noije Bum, has also been a source of amber.
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Keywords: Hukawng valley; Southwest of Maingkwan; Lalawng village

1. Introduction

Amber (Burmite) from the Hukawng Valley of northern Myanmar appears in most inventories of world amber deposits, but there are few firsthand descriptions of the production locality. There has been a recent resurgence of interest, with papers by Tin (1999), Zherikhin and Ross (2000), Levinson (2001) and Grimaldi et al. (2002). However, none of these authors visited the site in person, and the most recent account of a field visit is by Chhibber (1934). Zherikhin and Ross (2000) note an important geological problem, in that earlier field geologists ascribed an Eocene age to the host sediments, while insect inclusions in amber appear to be Cretaceous.

The authors of this work spent two days (April 29 and 30, 2001) inspecting the current mining area. The objectives were to verify the source of the amber, and to obtain information on the geology and age of the host rocks.

The Hukawng Valley is situated in Kachin State, northern Myanmar (Fig. 1). The principal town is Tanai, situated on the 'Ledo Road' (constructed during World War II). The valley is a flat alluvial plain measuring about 80 km north–south by 50 km east–west, surrounded on all sides by hills. The amber mine occurs on the shoulder of a hill known as Noije Bum ('Banyan Mountain' in the Jingpaw language), about 20 km southwest of Tanai (Fig. 2). This is the first hill to rise above the plain in that direction, having a relief of about 250 m.

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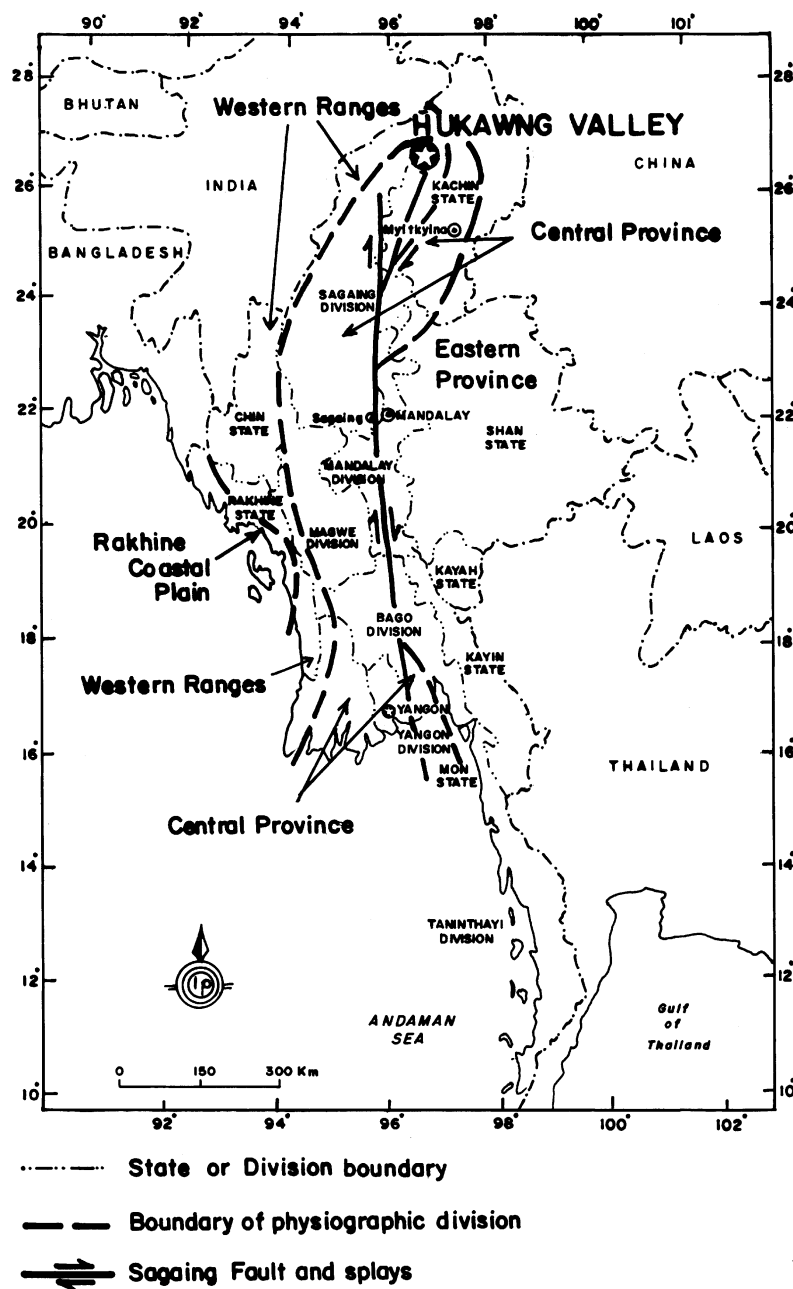
Fig. 1. Location of the Hukawng valley. The traditional physiographic/geologic divisions of Myanmar, and the Sagaing transcurrent fault with its splays, are also shown (see text for descriptions).

2. History of amber mining in the Hukawng Valley

2.1. History prior to 1995

A detailed history is beyond the scope of this paper, and the reader is referred to Zherikhin and Ross (2000) for an excellent account. The following summary is taken partly from their work. For studies of the fossil inclusions in this amber, prior to 2000, see Ross and York (2000).

Ancient Chinese sources indicate that the Hukawng Valley of northern Myanmar has been a source of amber since at least the 1st century AD (Laufer, 1906, summarised

by Fraquet (1987)). The first European to visit the amber localities in the Hukawng Valley was Capt. Hannay in 1836, who returned accompanied by Griffith, in 1837. Griffith described the location as a range of low hills, southwest of Meinkhoon (probably Maingkwan, Fig. 2). The site they describe is most probably the hill now known as Noije Bum.

Dr Noetling of the Geological Survey of India was the first geologist to visit the area (in 1891–1892, Noetling, 1893). Some of his samples were examined by Otto Helm, who considered the amber to be a new mineral species, which he named 'Burmite'. Noetling considered the host rocks to be Miocene in age, because of lithological
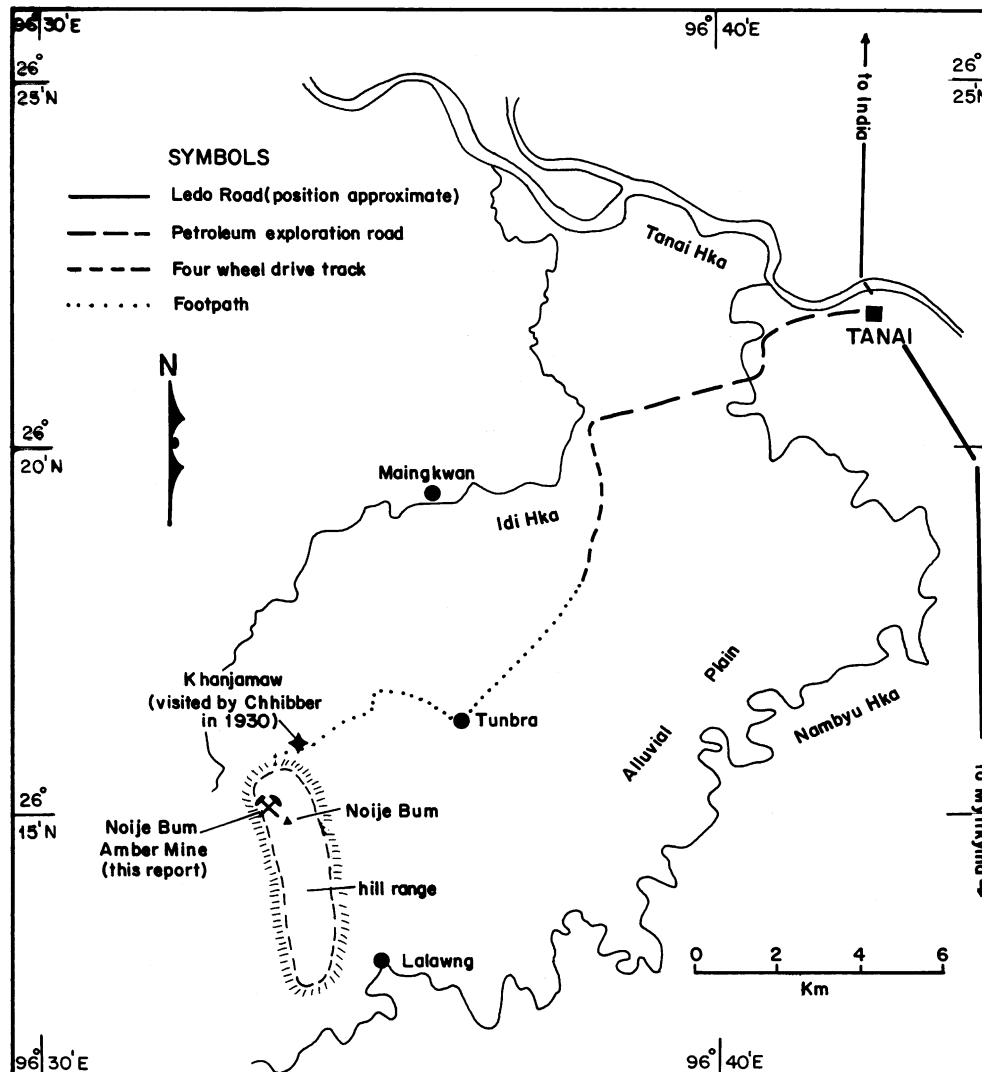
Fig. 2. Localities in the Hukawng Valley. Comparison with old reports indicates that the Noije Bum hill range has been the source of Hukawng Valley amber for at least the past 165 years (see text for discussion).

similarities with known Miocene formations (during this excursion he found a loose pebble containing an ammonite, but perhaps elsewhere in the Hukawng Valley). He described the amber location as a low hill range, southwest of Maingkwan (and therefore likely in the vicinity of the current mine). He was told that the principal mining area was at the south end of the range near Lalawng village (Fig. 2), but he did not go there.

Stuart (1923) was the first to propose an Eocene age for the amber-bearing sediments. On the eastern flank of the Noije Bum hill range, he observed pits dug for flint in a thin limestone layer. In the spoil piles he found a single piece of limestone containing 'numerous specimens of *Nummulites biarritzensis*', which he recognised as being Eocene in age. His map and description show that amber was not known from that location, but rather from blue clay 'on the western portion of the hills'. He concluded that the amber-bearing horizon underlies the *Nummulites* beds, but nonetheless forms part of an Eocene succession.

The best known description of the Hukawng Valley amber mines is that of Chhibber (1934), based on an inspection he made in 1930. He listed twelve production sites, ten of which were near the northern end of Noije Bum, with two others about 8 km to the west. Khanjamaw (Fig. 2), the principal mining site at that time, is now overgrown with jungle. The Noijemaw site was 'west of Noije Bum' and may be near the current mine. He reported that amber was produced from wells about one metre square, and up to 15 m deep, noting that amber from shallower levels was of inferior quality. These diggings and nearby stream sections exposed a sequence of carbonaceous sandstones and shales, with minor limestone and conglomerate beds. Amber was associated with very thin coal seams. Chhibber (1934) found *Nummulites* fossils in situ in a stream exposure (perhaps on the east flank of Noije Bum?), so concurred with the Eocene age proposed by Stuart (1923). However he apparently did not observe amber at that location.

Sahni and Sastri (1957) describe *Orbitolina* they found in samples collected by Stuart, from 'Amber mines 26°15′N, 96°25′E' (after Stuart (1923)). Examination of Stuart (1923) shows that the longitude is an error resulting from the inaccuracy of his map, and the rocks must have been collected from somewhere on the Noije Bum range. Sahni and Sastri (1957) concluded that these orbitolines were a previously undescribed species, which they named *Orbitolina hukawngensis*, and assigned 'a Cenomanian, and, in any case not older than Aptian' age. They credit Eames as being the first to describe *Orbitolina* from the area, but he believed that they were contained in derived clasts within Eocene sediments. In contrast, Sahni and Sastri (1957) concluded that a Cretaceous sequence with orbitolines occurs below the Tertiary rocks of the Hukawng Valley. Despite this, subsequent authors continued to accept the Eocene age of Chhibber (1934), and to overlook the possibility that the rocks may be Cretaceous.

Zherikhin and Ross (2000) summarise studies of Myanmar amber from the collection of the British Natural History Museum. They note the identification of 'five insect families or subfamilies that are not known later than Cretaceous elsewhere', although they do not rule out the possibility that the amber could be Tertiary. They suggest that if the sediments are Eocene, then Cretaceous amber was recycled and redeposited in them. As evidence, they note the occurrence of rounded pits on the surface of some amber pieces, which may have resulted from impacts during transport.

The Geological Survey of India reported amber production for the years 1898 through to 1940. Average annual production was about 1900 kg, with a maximum of nearly 11,000 kg in 1906. Recorded production stopped about 1941. The thriving trade in amber, and the manufacturing of jewellery have by now entirely disappeared, and the skills have been lost. The village of Maingkwan, reported to be a centre of the amber trade by Chhibber (1934), was abandoned in 1967 when most of its population moved to the new town of Tanai.

Another amber locality in northern Myanmar is of interest. Ngaw (1964) reported that amber was produced between 1948 and 1961, from a site near the Nam Sakhaw stream, 90 km southwest of Noije Bum (Fig. 3). This occurrence was also known in colonial times, as the notation 'amber mines' appears on the old 83-*O* topographic map. The amber is hosted by Cretaceous carbonaceous limestones, bearing *Orbitolina*; suggesting a similar age to Noije Bum (refer to Section 5).

2.2. History since 1995

The authors feel obliged to correct errors in two recently published works.

Tin (1999) describes the history, mining methods, geology, and other factors relating to Hukawng Valley amber. His descriptions are based largely on Chhibber (1934), and are outdated. For example, he states that 'from the latter half of February, the local people who have then gathered in their harvest, flock to the amber mines in great numbers'; this line is from Chhibber (1934), and is no longer correct. In reality, the mining company has been granted exclusive rights to the area by the Ministry of Mines, and no one else is working there. Tin (1999) accepted an Eocene age for these deposits.

In their otherwise excellent review, Zherikhin and Ross (2000), incorrectly state that access to this area is difficult as it 'remains controlled rather by the local clans and insurrectionsts than by the central government in Rangoon'. However, a peace agreement between the Myanmar government and the Kachin Independence Organisation (K.I.O.) came into effect in 1993. As a result, the national government now controls the region, in cooperation with the K.I.O.

Subsequent to the 1993 peace agreement, mining operations were undertaken in the period 1995–1997. This enterprise failed because the producers were unable to locate reliable markets.

In August 1999, the authors met some of the former miners, and purchased a small quantity of amber, which was sent to Davis in Canada. He noted the occurrence of microscopic insects within it, and forwarded the material to Dr Grimaldi in New York. Another local company recommenced mining in 2000, after which more amber was obtained and sent to Dr Grimaldi. In these two batches of amber, he and his co-workers have found hundreds of insect inclusions, and propose that they are Turonian–Cenomanian (Grimaldi et al., 2002).

Levinson (2001) briefly reports on the renewed commercial availability of Myanmar amber.

3. Regional geology

3.1. Synopsis of the geology of Myanmar

Myanmar can be divided into four north–south trending physiographic regions, which have traditionally been utilised for geological description as well. However there is no consensus on standard names for these belts. The following summary (based on Bender (1983)) employs the nomenclature shown on Fig. 1:

1. The Rakhine Coastal Plain is underlain by deformed Late Tertiary molasse sediments overlying Eocene to mid Miocene flyschoid rocks, with local mafic to intermediate dykes and plugs.
2. The Western Ranges consist principally of early Tertiary flysch, deformed into imbricate thrust zones. The eastern margin of the ranges is underlain by Triassic turbidities, Cretaceous and Tertiary sedimentary rocks, metamorphic rocks, and ultramafic rocks (dismembered ophiolites).
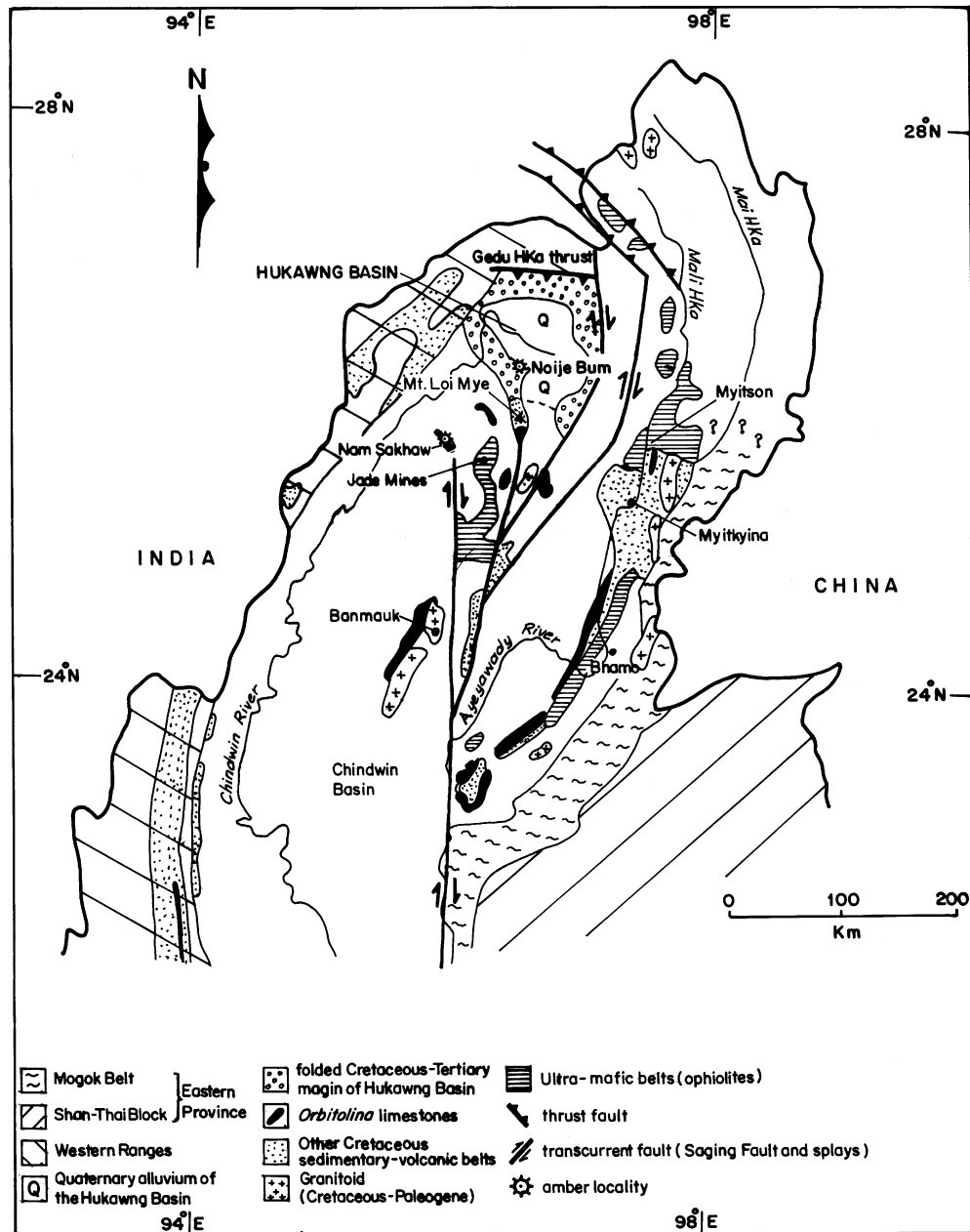
Fig. 3. Cretaceous geology of northern Myanmar. Other units and localities mentioned in the text are also shown. Based on Bender (1983), Mitchell (1993) and ESCAP (1996), and other sources.

3. The Central Province comprises a series of Cenozoic sedimentary basins, and intervening uplift areas. Sedimentary fill of Eocene, Oligocene, and Miocene–Quaternary clastic rocks is underlain by Cretaceous, and probably also older units. Basinal rocks are folded and faulted. Uplift areas consist of older sediments and crystalline rocks. The belt is bisected longitudinally by a discontinuous line of Mesozoic and Cenozoic igneous rocks (in part, the 'Inner Volcanic Arc').

4. The Eastern Province is underlain by sedimentary rocks representing a broad interval of geological time, from at least latest Proterozoic, through much of the Phanerozoic. Metamorphic, volcanic, and intrusive lithologies also appear, especially along the western margin (the Mogok Belt).

Mitchell et al. (2000) consider that Myanmar consists of three geological provinces: (1) 'a Western Province of mica schists and overlying predominantly oceanic rocks' (the Rakhine Coastal Plain, Western Ranges, and Central Province); (2) the Mogok metamorphic belt, of marble, gneiss, and granitoids (the western margin of the Eastern Province); and (3) the Phanerozoic 'Shan–Thai' block to the east (bulk of the Eastern Province) (Fig. 3). They

postulate two separate orogenies during the Mesozoic: (1) collision of a western, continental, block with an island arc to the east in early Jurassic; and (2) collision of the resulting complex with the Shan–Thai continent in mid-Cretaceous.

After the mid-Cretaceous orogeny, eastward subduction of oceanic crust continued (Mitchell et al., 2000). The Cenozoic sedimentary sub-basins of the Central Province were filled and deformed. The current geological setting of Myanmar reflects right-lateral displacement on the Sagaing Fault and its splays in northern Myanmar (Figs. 1 and 3). Total displacement on the fault since early Miocene has been estimated by various workers to be from more than 300 to 460 km, with a total northward movement on the west side of perhaps 1100 km since late Cretaceous (Mitchell, 1993).

Myanmar currently consists of the Asia plate to the east of the Sagaing Fault, and the Burma plate to the west. The Indian plate is colliding with Asia to the north, and subducting beneath the Burma plate to the east (Mitchell, 1993). Northward translation of the Burma plate is continuing, as evidenced by recurrent seismicity on the Sagaing Fault (Win, 1981).

3.2. Cretaceous geology of northern Myanmar

Sedimentary rocks that host the Hukawng Valley amber are now considered to be Cretaceous (refer to Section 5). Therefore the Cretaceous geology of northern Myanmar will be briefly reviewed in more detail, and shown on Fig. 3.

In general, Cretaceous marine sedimentary rocks become progressively younger from east to west, although overlaps occur. A skirt of Lower Cretaceous sedimentary rocks occurs along the western margin of the Eastern Province; including the Tithonian to Aptian Pyinyaung Buda Beds of Mitchell et al. (2000), and the Pan Laung Formation (described as Necomian by Chit (2000); and mid Jurassic to mid Cretaceous by Myint (2000)). Further west, Albian and/or Cenomanian limestones, bearing several species of *Orbitolina*, occur in the Central Province, and the eastern part of the Western Ranges. Upper Cretaceous (Campanian to Maastrichtian) units are present along the western boundary of the Central Province, and widely in the eastern part of the Western Ranges (e.g. Gramann, 1974).

Limestones carrying an *Orbitolina* fauna have been reported from various locations in northern Myanmar. They occur in a belt from south of Bhamo to north of Myitkyina, in the vicinity of Banmauk, in the jade mines region, in the upper Chindwin area, and in parts of the Western Ranges (Fig. 3). Chit (2000) states that the rocks are Albian to Cenomanian in age. According to Mitchell et al. (2000), the limestones were deposited in front of nappes resulting from an Aptian-mid Cretaceous orogeny.

Clegg (1941) described *Orbitolina* limestones from the defiles of the Ayeyawady (north and west of Bhamo, Fig. 3). He notes the occurrence of calcareous grits, sandstones, and shales; and of limestones bearing both foraminifera and large 'molluscs' (probably gastropods). The occurrence of a

northern continuation near the Ayeyawady confluence at Myitson has been confirmed by the present authors. Chit (2000) concludes that limestones from this belt (Taungbwet Taung Formation) represent a shallow lagoonal facies, and are Albian to Cenomanian in age. These units are associated with chert, basalt, and slate, tightly folded, and appear to overlie ophiolitic ultramafic rocks. Clegg (1941) considered that 'in every locality where Cretaceous sediments are exposed, peridotites, or serpentines their alteration product, are invariably found whilst dolerites and various pyroclastic rocks also occur'.

Discussing similar *Orbitolina*-bearing limestones near Banmauk (Fig. 3), Chit (2000) concludes that there was an abrupt change from lagoonal to shallow marine facies in Cenomanian time.

Occurrences of Cretaceous limestones also occur in the jade mines region and near Mt. Loi Mye (45 km south of Noije Bum, Fig. 3). The northernmost portion of the large ultramafic ophiolite body of the jade mines area, and a body of gabbro, occur there (Chhibber, 1934), and volcanic rocks are also present.

The amber and *Orbitolina*-bearing limestones at Nam Sakhaw lie on the western margin of this district, where Clegg (1941) observed associated calcareous sandstone, shale, and volcanic rocks. As at the Ayeyawady defiles, the carbonate units there are conspicuous: he recalled that the sheer cliff of Hpalamung Bum, 275 m high, 'when seen looming through the early morning mist from the low ground to the south is a most impressive sight'.

Jadeite-bearing ultramafic rocks occur in western Kachin State. A longer belt of ultramafites is exposed along the Ayeyawady River to the east (Fig. 3), and they also characterise the eastern margin of the Western Ranges. These are usually interpreted as dismembered ophiolites, although a complete ophiolite succession has not been described. Mitchell et al. (2000) state that they were emplaced as nappes during a lower Jurassic orogeny. Maung (2000) believes that the jade mines bodies are Cretaceous, while those in the Western Ranges are Triassic. In contrast, Hla (2000) believes that Western Ranges ophiolites were emplaced as late as the Cretaceous, while those in the Central Province may be Cretaceous to Eocene. Therefore a consensus on the age of these units has not been achieved.

The majority of the granitoid bodies indicated on Fig. 3 are described by Mitchell (1993) as being Late Cretaceous to early Eocene. More recently, Barley et al. (2000) reported ages of 120–80 Ma for I type granitoids in the Mogok Belt and Western Myanmar. They recognise an up to 200 km wide mid Cretaceous magmatic belt that extended along the entire continental margin from Tibet to Sumatra.

The Cretaceous sedimentary rocks described above were deposited prior to right-lateral displacements on the Sagaing Fault and its splays. If restored to their original position, they would form a narrower zone than at present, arrayed along the former continental margin (western edge of the Eastern Province). Maung (2000) concludes that the mid

Cretaceous sediments were laid down between a magmatic arc to the east, and a trench basin to the west. Sahni and Sastri (1957) note that a discontinuous belt of *Orbitolina* limestones extends from Myanmar, across Tibet, to Kashmir, northernmost Pakistan, and northern Iran.

3.3. Tectonic setting of the Hukawng Basin

Bender (1983) considers the Hukawng Basin to be one of the constituent sub-basins of the Central Province (his 'Inner Burman Tertiary Basin'). He postulates that low grade metamorphic rocks exposed to the south may represent basement, and states that aeromagnetic surveys suggest 5000 m of overlying sediments.

Sedimentary (and lesser volcanic) rocks underlie hills that surround the central alluvial plain of the Hukawng Valley, with bedding trends and fold axes parallel to the basin margins. The map of ESCAP (1996) shows the Hukawng Valley with areas of Eocene rocks around the west, north, and east sides, and Miocene rocks on its southwest and southeast margins. However, the amber-bearing sediments are Cretaceous, and not Eocene as previously believed (this paper). In addition to the Noije Bum area, Chhibber (1934) reported an amber locality on the eastern margin of the valley, suggesting that a Cretaceous sequence may occur there as well. The authors believe that more of the 'Tertiary' units may in fact be Cretaceous. These areas are indicated on Fig. 3.

The interpretation of Bender (1983), Fig. 22) indicates a NNE-plunging anticline at Noije Bum. He states that Cenomanian limestone occurs in the crest of this fold and another to the west, but does not say how he arrived at this conclusion. He interprets the remaining rocks, including those that host the amber, to be of early Tertiary age. A large package of folded rocks occurs to the northwest, west, and south of the amber locality on his map.

Along the northern margin of the Hukawng Basin, and in the Western Ranges beyond, fold axes and bedding trends have turned to an east–west orientation. Studies of landforms by Mitchell et al. (1978) and Bender (1983), and the present authors, suggest that the northern boundary of the basin may be a north vergent thrust fault exposed along Gedu Hka (river). South of the river there is a remarkable cuesta-shaped ridge, about 60 km long, with the scarp face on the north side. The eastern end of this thrust appears to be connected to a splay of the Sagaing Fault (Fig. 3). Stuart (1923) reported a Cretaceous–Eocene unconformity where his traverse passed Gedu Hka; he mentions no fault but his observation of serpentinite bodies below the contact suggests that one must be present.

Deformation of the Hukawng Basin most probably resulted from the continuing collision of India with Asia, and its subduction beneath the Burma plate (initiated in latest Eocene time). The Himalayan boundary is marked by southwest vergent thrusts to the northeast of the valley (Fig. 3).

4. Noije bum amber mine

4.1. Mining operation

The site resembles a small open pit mine, with all excavation by manual methods. A work force of about 60 men was present during the time of the visit. They had stripped overburden from an area measuring about 120×30 m^2 (Figs. 4–6), and were producing amber from the unweathered rocks thus exposed. The site straddles a ridge, with the slope on the north side averaging about 13°. Deep shafts, as described by Chhibber (1934), are not required, probably because on this steeper slope, the weathered layer is thinner. The current mining method produces good, easily accessible exposures, and the authors have probably had a more extensive view of unweathered bedrock than any of the earlier workers.

4.2. Lithology and sedimentology

A variety of clastic sedimentary rocks, with thin limestone beds, and abundant coaly and carbonaceous material, was recognised at the site. Chhibber (1934) describes the rocks as being blue in colour, but in the authors' opinion they are more nearly medium green, greyish green, or rarely blue–green. Weathered rocks are mainly tan brown with some shales being reddish. They have been subdivided into four or five units, as shown on Fig. 4, and briefly described below:

The fine clastic facies consists of fine or very fine-grained sandstone (grains usually 0.1 mm or less), with beds of finer clastics (silt, shale), interbeds of grey micritic limestone a few centimetres thick, and coal laminations usually about 1–2 mm thick. The coal horizons, although thin, are laterally persistent, and carbonaceous material is abundant in this unit. This facies is always thin bedded or laminated, and even parallel lamination is the predominant internal sedimentary structure. The unit is usually about 1 m thick. The amber is associated with this facies.

Limestone beds, about 6–8 cm thick, occur within the fine clastic facies. This rock is medium grey in colour, micritic, and typically of massive appearance. It often contains fine fragments or strands of coalified plant material. Rounded coarse sand or granule-sized clasts are sometimes present at the base.

The medium clastic facies consists largely of sandstone, with grain sizes usually 0.4 mm or less (fine to medium sand). It often assumes a 'salt and pepper' appearance under the hand lens. As mapped on Fig. 4, it is a somewhat heterogeneous unit, containing beds of siltstone, shale, and conglomerate that are too thin to be shown separately. Shale chips are sometimes observed within the sandstone. Coalified plant fragments occur on bedding surfaces. The unit most commonly displays massive bedding or even parallel lamination, but tabular cross beds were observed locally. Beds are usually 10–80 cm thick. Locally,
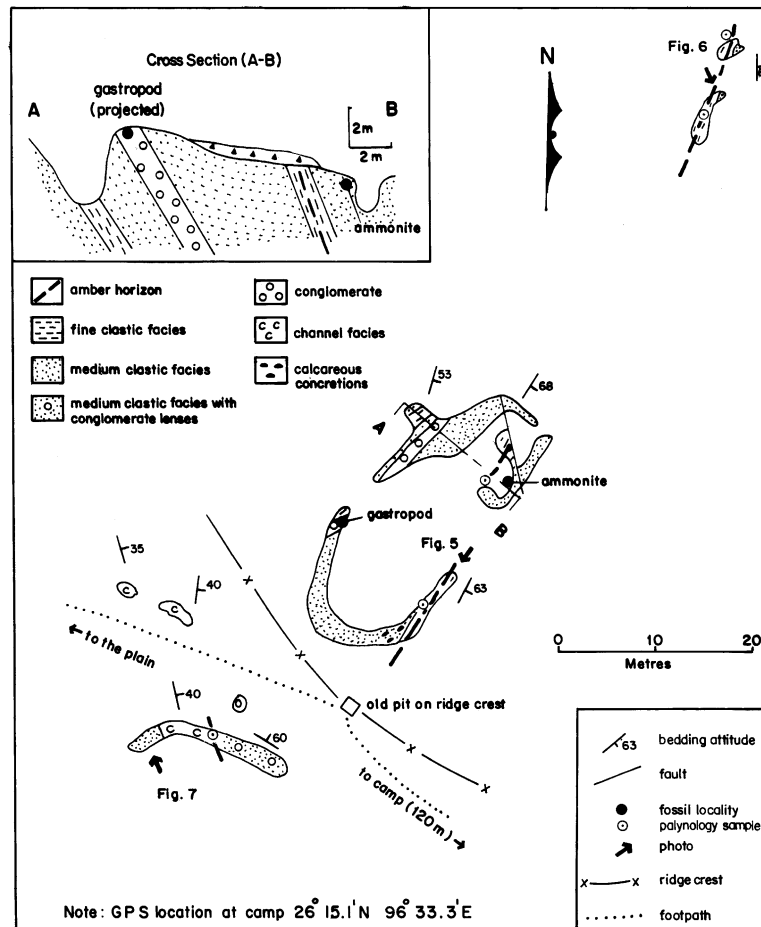
Fig. 4. Geology map of the Noije Bum amber mine, as it appeared on April 29–30, 2001. See text for descriptions.

calcareous concretions are present, consisting of limestone, chert, and other rocks, armoured by precipitated calcite. Fig. 7 shows an unusually thin-bedded (4–8 cm) sandstone sequence.

Thin sections of medium sandstone indicate that lithic clasts predominate, with lesser quantities of feldspar and quartz. Lithic clasts include chert, andesite, basalt, quartzite, micritic limestone, and serpentinite, with actinolite schist noted in one specimen. Plagioclase occurs in 0.25–0.4 mm grains, and quartz clasts are about 0.2 mm in dimension. The texture is immature, being poorly sorted, with only incipient rounding of clasts. The cement is coarsely crystalline calcite, and the rock effervesces vigorously in dilute hydrochloric acid. This is a calcareous lithic sandstone.

A conglomerate horizon was noted in several exposures. Clast size generally decreases from south to north, ranging from cobbles near the footpath, to granules near the northern end of the outcrop. The bed is typically 1–2 m in thickness. A thin conglomerate bed was also observed in the north-ernmost pit, and lenses appear in the medium clastic facies south of the footpath. The conglomerate carries clasts of a distinctive pale buff, pale grey, or pale green saccharoidal limestone, carrying traces of pyrite, quite unlike the grey

micrite found in the fine clastic facies. It also carries pebbles of chert, mudstone, serpentinite, and volcanic rocks, but no quartz, no plutonic, and few if any metamorphic clasts. In some examples it is a matrix-rich grit, and in others it is clast supported. Sorting tends to be poor, but the clasts are rounded. The authors observed numerous small broken bivalve shells and a gastropod in this bed.

Rocks of the 'channel facies' occur in the southwest corner of the area, demonstrating distinctive sedimentary structures. Beds, about 75–125 cm thick, noticeably fine upwards. Coarser portions of the beds are either massive bedded or display tabular cross beds, and finer ones are laminated. Trough cross bedding was also noted. Lenticular beds occur as medium sand lenses within much finer material. Channel scours are common, with layering in underlying beds decisively truncated. These sediments are also carbonaceous, and coaly plant fragments on bedding surfaces are ubiquitous.

4.3. Amber

Amber is found within a narrow horizon in the fine clastic facies. However, of two such beds shown on Fig. 4, only one produced amber.

Fig. 5. A view of the open pit. Miners in the foreground are excavating the amber seam (dark coloured rock). See Fig. 4 for location.

Fig. 6. Test shaft. The dark coloured rocks at bottom are the amber horizon. Location shown on Fig. 4.

Most amber occurs as discoid clasts, with a wide range in sizes. These are thickest in the centre, tapering to rounded edges. The diameter to thickness ratio of the disks is usually in the range 2.4:1–3.0:1, with rarer flat examples up to 5:1. Sizes range from small chips a few millimetres in dimension, to others several centimetres in diameter. They are not perfectly symmetrical, and irregularities are usually present. Pitted surfaces, as described by Zherikhin and Ross (2000) are not ubiquitous. The disks are oriented parallel to bedding (Fig. 8).

A minor proportion of the amber occurs as runnels, resembling small stalactites, with round cross-sections, perhaps 1 cm in diameter, but sometimes larger. These often show concentric layering, probably resulting from repeated flows of resin. The shape of these ambers appears not to have been modified by transportation, except that they were broken into shorter lengths. Fossil insects are more common in runnels than in disk-shaped amber clasts. Ross (1998) explains the origin of this phenomenon: "The resin is exuded as blobs or stalactites, which drip and flow down the trunk of the tree. Often, as it exudes, insects become trapped and engulfed in the sticky material. The resin eventually falls to the ground and… fossilises into amber."

The amber is typically reddish brown in colour, with various shades of yellow, orange, and red also occurring. These colours range from pale to dark, and it can vary from perfectly transparent, through translucent, to opaque. Inclusions of organic matter (vegetation), are common, but not always present. Insect fossils, which are mostly microscopic, occur at about 46 per kilogram of the current product (Grimaldi et al., 2000).

Thin white calcite veinlets, usually 1 mm or less, but up to 4 or 5 mm in width, are commonly observed in the amber. Their density varies considerably, with some examples being nearly free of them, and others packed with veinlets. They are a major factor in determining gem quality, and many pieces are ruined by their presence.

Among the amber produced by the miners is one example which has a bivalve shell embedded in its surface. The valve measures 18 mm long, and 13 mm wide. It is oriented with the convex side embedded to its full height of 6 mm in a piece of amber that is 50 mm in maximum dimension. The concave side of the shell faces away from the amber and carries sandstone matrix. It appears to have been embedded in the amber while the latter was in a plastic condition.

Fig. 7. A view of the thin bedded nature, and dip of the rocks. Located on Fig. 4.

4.4. Structural geology

Rocks at this site are oriented right way up, as evidenced by channel scours, graded beds, and cross beds.

North of the ridge crest, bedding attitudes are quite uniform, with NNE strikes, and dips of 50–70° to the E or SE (Fig. 4). South of the crest, the strikes turn to the SSE or SE, and dips flatten to the 35–60° range. This suggests that the site is on the northwest limb of a northeast-plunging syncline. Chhibber (1934) reported that rocks in this region exhibit 'tightly compressed anticlinal and synclinal folds'. The relationship of this fold to the large anticline at Noije Bum, interpreted by Bender (1983), was not determined.

A minor fault was noted in the central part of the site (Fig. 4). It has a conspicuous gouge zone, but apparently no great displacement. Its attitude is 168°/60° NE. Bedding has been contorted where it intersects the fine clastic unit. The other fine clastic bed (near point 'A', Fig. 4) also exhibits contorted bedding and slickensides.

Thin calcite veins occur not only in amber, but also within the sedimentary host rocks. Joints and fractures hosting the veins would have opened after consolidation of the rocks, in response to deformational or lithostatic stresses. Perhaps the brittle nature of the amber was responsible for a greater density of fractures.

4.5. Paleontology

Several macrofossils were located by the workmen in the course of mining, and others were recovered during this

Fig. 8. Amber in matrix, within the fine-grained, laminated facies. The largest amber disk, indicated by the pencil, measures 27 × 10 mm. Two smaller pieces appear to the right. Note the oval cross-sections of the discoid amber clasts, and their orientation parallel to the lamination. Collected from the pit shown in Fig. 6.

visit. These include one ammonite, five gastropods, and numerous fragments of bivalve shells.

While the authors were inspecting the site, miners working nearby discovered an ammonite fossil. They immediately brought it to the authors, and were able to indicate the exact location in which it was found. It was collected from a massive sandstone bed, about 2 m stratigraphically above the amber layer (Fig. 4). This is close to the minor fault, but both the amber and the fossil are in the footwall. It appears not to have been recycled from older sediments because it is not abraded or rounded, and it was found in sandstone rather than conglomerate. It is identified as *Mortoniceras* (Dr Win Swe, pers. commmun. 2001). Wright et al. (1996) state that this ammonite genus is restricted to Middle Albian–Upper Albian.

Prior to the field visit, the workmen found four gastropods. These have extremely high conical shapes, and are quite large, being 50–70 mm or more in height (the largest was broken) and up to 38 mm in diameter at the base. They have not been positively identified, but are possibly Nerineid gastropods, which have been reported from rocks of similar age elsewhere in Myanmar (e.g. Bender, 1983, p. 88). The authors discovered another gastropod shell (possibly a different species) in the conglomerate bed (Fig. 4).

Broken shell fragments of small bivalves occur in the conglomerate. These are white, calcareous, with a pearly lustre, and some are striated. The largest measures 18 mm in maximum dimension, but most are 10 mm or less. They have not been further identified.

Several samples were submitted to Dr Davies for palynological study (Davies, 2001a,b). These included three sample sets: (1) two pieces of amber; (2) four samples of sediment found associated with (adhering to) pieces of amber; and (3) five chip samples of the host sediments. Sample sets (1) and (2) were selected from material purchased from the miners. They yielded only 'impoverished assemblages', and were not definitive. One sample of associated sediment (set 2) was found to contain several Late Campanian palynomorphs, but Davies (2001b) considers that this material probably results from contamination.

The third palynology sample set consisted of chip samples of host rock, collected by the authors from the amber horizon (located on Fig. 4). The objective was to determine the age of the sediments in which the amber occurs. This set yielded variable results with 'low to good palynomorph recovery'. Davies (2001b) identified microfossils derived from dinoflagellates, algae, angiosperms, gymnosperms, pteridophytes, and bryophytes. The most common palynomorphs were *Araucariacites australis* (65 examples), *Sequoiapollenites* sp.(48), *Taxodiaceaepollenites hiatus* (12), and *Clavatipollenites rotundus* (11). On the basis of assemblages including *Spinidinium* sp., *Liliacidites kaitangataensis*, *Liliacidites dividuus*, *Crybelosporites striatus*, *Crybelosporites punctatus*, *Corollina*

spp., *Collarisporites* sp., *C. rotundus*, *Cupuliferoidaepollenties parvulus*, *Parvisaccites rugosus*, *Eucommiidites minor*, *Pustulipollis* sp., *Palmaepollenites* sp., *Scupisporis* sp., and *Phimopollenites augathellaensis*, Davies (2001b) considered a late Albian to early Cenomanian age to be most likely. He further states that "These assemblages are similar to those described from the Albian of the district south of the Songhua River, China, described by Yu (1983)". At that location, 'The overlying sediments of the Cenomanian and Turonian are marked by an increase of more advanced angiosperm pollen, which are not present in the Burmite samples'. Davies (2001b) concludes that the assemblages found in the five samples of set (3) 'indicate that the age of the amber is most likely late Albian to early Cenomanian'.

As noted above, fossil inclusions of insects also occur in amber from Noije Bum. Although both Cretaceous and Eocene foraminifera have been reported from the vicinity, only 'foraminiferal liners' identified by Davies (2001b) have been recognised during this study.

5. Discussion

5.1. Correspondence to sites visited by Chhibber (1934)

The lithologies described by Chhibber (1934) correspond very well to rocks observed in this study, and his Khanjamaw locality is only 1.5 km distant. He also mentioned amber at a location called Noijemaw, located 'west of Noije Bum' which could be the same site as the current mine. It is probable that the same stratigraphic unit occurs at all these locations.

5.2. Age of the amber and its host rocks

The conclusion of Chhibber (1934), that the amber bearing rocks of the Hukawng Valley are of Eocene age, has been widely quoted. Examples from the geological literature include Ngaw (1964), Bender (1983), ESCAP (1996) and Tin (1999). Zherikhin and Ross (2000) accept an Eocene age for the sediments, while considering the amber to be Cretaceous. The Eocene age is also reported in general treatises on amber, such as Rice (1980) and Fraquet (1987). However, recent data indicate that both rocks and amber are Cretaceous, probably Upper Albian.

There is no doubt that the amber is Cretaceous. Zherikhin and Ross (2000) report that insects in amber collected from the Hukawng Valley are most probably from that period. Grimaldi et al. (2002), after much detailed study, consider that they are Turonian–Cenomanian. In subsequent correspondence, Grimaldi states that the age could possibly be as old as Upper Albian (pers. commun., 2002).

The age of the host sediments requires further consideration. If the amber is Cretaceous, there must have been an emergent landmass of that age, which would have shed sediments into adjacent seas. However the amber could also

have been recycled into younger sediments. Stuart (1923) and Chhibber (1934) reported rocks carrying the Eocene foraminifer *Nummulites*, although not in direct association with amber. Sahni and Sastri (1957) showed that limestones bearing *Orbitolina*, of probable Cenomanian age, occur in the area, but their relationship to the amber horizon is unclear. The question of whether the amber horizon belongs to an Eocene or to a Cretaceous succession was answered by the discovery of an ammonite specimen during the authors' visit. The ammonite *Mortoniceras* indicates Middle Albian–Upper Albian (Wright et al., 1996). This age is supported by Davies (2001b) who concluded that palyno-morph assemblages, in samples collected by the authors, are Upper Albian to Lower Cenomanian.

In the Western Ranges and Rakhine Coastal Plain of Myanmar, Tertiary flyschoid sediments carry exotic blocks of Cretaceous limestone (olistoliths). Of marine Cretaceous fossils reported from these two provinces, Gramann (1974) remarks that 'many if not all have been derived from exotic blocks' (however he located bona fide Cretaceous succes-sions in the eastern part of the Western Ranges). Bender (1983) also describes this phenomenon. To the authors' knowledge, exotic Cretaceous fossils or olistoliths have not been reported from the Tertiary basins of the Central Province, including the Hukawng Basin. In any case, this is not likely to be true of Noije Bum, as all of the above results (ammonite, palynology, and insect fossils) indicate a generally mid-Cretaceous age. The ammonite did not appear to be abraded, and palynology provides particularly compelling evidence. The most reliable set of palynology samples (set 3) was collected by the authors specifically for this purpose, and provided a consistent set of results.

The proposed age of the amber itself, based on insect inclusions, is slightly younger than that of the host rocks, as determined by the ammonite and palynology. This is clearly impossible, as while the amber could be older (through recycling), it cannot be younger. The preponderance of the evidence suggests that both rocks and amber are most probably Upper Albian.

This period, the uppermost Lower Cretaceous, and the lowermost Upper Cretaceous, has great significance for the evolution of both plants and insects. It saw the radiation of angiosperms, and the origins and development of insect pollination. Insects that engage in pollination first appeared at this time. Grimaldi (pers. commun., 2002) writes that "The rare ants found in this amber would be the oldest definitive fossils known of this extremely important group. Prior to this, the oldest known were Turonian, also in amber". The Turonian amber occurrences are in New Jersey, USA, described by Grimaldi et al. (2000).

It appears that neither M. Stuart nor H.L. Chhibber was familiar with *Orbitolina*. Stuart failed to identify it in specimens he collected from the amber mines (Sahni and Sastri, 1957). Chhibber (1934) did not report it from limestones of the jade mines region, which he mistakenly considered to be Paleozoic; Clegg (1941) noted that

Orbitolina is commonly present in those exposures. Stuart (1923) and Chhibber (1934) were both positive in their identifications of *Nummulites*, so it may be assumed that they were correct on that count. However had either encountered *Orbitolina* beds, he would not have recognised the fossil, nor appreciated its Cretaceous age.

It is likely that a Cretaceous–Eocene unconformity occurs in the vicinity. Assuming that the identifications of *Nummulites* by Stuart (1923) and Chhibber (1934) are correct, it might be found on the eastern flank of the Noije Bum hill range. Recognition of Cretaceous rocks has been hampered by poor bedrock exposure, a paucity of ammonites in the sequence, the unfamiliarity of early workers with *Orbitolina*, and a belief that any Cretaceous fossils must be derived and recycled. In retrospect, it is clear that more significance should have been attached to the ammonite found by Noetling in 1891–1892.

5.3. Depositional environment

The ammonite and some of the microfossils indicate a marine setting. The depositional area must have been nearshore, because of the abundance of amber, coalified plant fragments, and common coal laminations in the fine clastic facies. Davies (2001b) states that the dinoflagellates he identified (*Alterbidinium minor*, *Cleistosphaeridium* sp., *Spinidinium* sp., *Cribroperidinium* sp. operculum, *Sentusi-dinium* spp., *Palaeohystrichophora isodiametrica* cf., *Silici-sphaera ferox*, *Tehamidinium* sp.) are typical of inner neritic to littoral environments. A marine environment is also indicated by his recognition of organic-walled foraminiferal liners and zynemataceous algae. Coal seams thicker than a few millimetres, and large portions of trees, etc. were not observed in the field, suggesting that the fossil vegetation was transported a certain distance from its place of origin.

A regional study of the sedimentology and stratigraphy has not been made, and it is difficult to draw conclusions from only one exposure. Deltaic environments should include non-marine sediments, and rooted plant fossils, which were not recognised at Noije Bum, and the conglomerate bed is not typical of deltas (Miall, 1979). A barrier island environment appears to be excluded as these generally consist of clean sands (Reinson, 1979). Several characteristics of a lagoonal environment, as elucidated by Reinson (1979) were observed. These include the presence of interbedded sandstone, siltstone, shale, and thin coal facies; and sand bodies that can be interpreted as washover sheet deposits, and channel fill deposits. However, the occurrence of conglomerate does not fit his lagoonal model.

A nearshore marine setting (bay, lagoon, or estuary), proximal to a river outlet, may be the best explanation. Such an environment is described by Clifton (1983), from a study of the estuary at Willapa Bay, Washington. The estuarine deposits there include 'a complicated array of sand, mud, and gravel', including lag deposits consisting of shells, wood fragments, pebbles, and mud clasts. He lists several

criteria that may be employed to distinguish among subtidal, intratidal, and supratidal deposits. When applied to Noije Bum, these suggest a subtidal deposit as (1) there are widespread lag deposits; (2) there are laterally extensive beds of shale interbedded with fine-grained sand; (3) fossil root systems were not observed; and (4) mud cracks were not observed.

Based on a paleogeographic map, Zherikhin and Ross (2000) postulated that the Noije Bum vicinity was 350 km from the nearest land during the Cenomanian (slightly later than the Upper Albian age proposed for the amber horizon). Their conclusion is contradicted by the identification of a nearshore environment in this study. Whether the adjacent landmass was the Asian mainland or an island has not been determined.

Terrigenous pollen derives from a forest of *A. australis* (related to the Norfolk pine), *Sequoiapollenites* (similar to *Sequoia*), and several angiosperm species, all indicating a 'humid warm temperate climate' (Davies, 2001b). Swamps vegetated with *Taxodiaceaepollenites* probably occurred along the shore (Davies, 2001a).

5.4. Significance of the observed clast lithologies

The calcareous nature of the clastic sediments recalls the descriptions of Clegg (1941) of similar rocks along Ayeyawady River, and in the jade mines area. At Noije Bum, limestone cobbles in the conglomerate, and micrite clasts in the sandstones, indicate that carbonate bedrock was present in the source area. The identification of pollen of *Taxodiaceaepollenites*, which inhabits coastal swamps, commonly on calcareous bedrock (Davies, 2001a), suggests that limestone may have occurred along the shoreline.

The association of clasts of limestone, chert, andesite, basalt, serpentinite, and actinolite schist, is similar to lithologies found in the Cretaceous Bhamo–Myitkyina belt (Fig. 3). The rather coarse plagioclase clasts may originate from mafic intrusive rocks, which are also known from the above association. Most of these lithologies are also found in the vicinity of Mt Loi Mye, some 45 km south of Noije Bum (Fig. 3). This is an immature assemblage, typical of what may be found in orogenic belts, and may reflect a mid Cretaceous orogeny proposed by Mitchell et al. (2000).

The presence of serpentinite clasts indicates that emplacement of ultramafites must have preceded the deposition of these sediments (i.e. they are not younger than Albian). The jade mines ophiolite belt extends to the southern margin of the Hukawng Basin.

Granitoid clasts are absent, so the suite of Cretaceous felsic plutons either was not present in the source area, or had not yet been emplaced/exposed. There is also no sign of the micaceous schist lithologies from the presumed basement to the Hukawng Basin (Bender, 1983). The quartzite clasts could possibly be derived from that source, however. Quartz is a minor component of the sandstones, and was not recognised among the larger conglomerate clasts, emphasising the immaturity of these sediments.

Thin micrite beds found within the fine clastic facies may result from erosion of coastal carbonates, during periods when clastic input from further inland was low. They carry plant fragments of obvious detrital origin.

5.5. Origin and deposition of amber

The authors note that both the Araucariaceae (especially genus *Agathis*) and the *Taxodiaceae* have been identified as sources of Cretaceous amber elsewhere (e.g. Grimaldi et al., 2000; Poinar and Milki, 2001). Palynomorphs of genera from both families were identified in samples collected from the amber horizon at Noije Bum (Davies, 2001b).

Chhibber (1934) quotes specific gravities of 1.034–1.095 for Hukawng Valley amber, which is slightly denser than sea water. Therefore it may be expected together with fine clastic sediments, and/or associated with other low density material, such as waterlogged wood or plant fragments. The Noije Bum amber may have been deposited with wood and plant material, in fine clastic sediments along the floors and banks of tidal channels (as for wood fragments observed by Clifton (1983)), or in washovers adjacent to channels.

The amber may have been deposited originally as copal, an intermediate stage in the transformation of resin. Ross (1998) states that the change from copal to amber may occur after deposition in marine sediments. At Noije Bum the amber and its host sediments are of approximately the same age, so it was deposited while relatively young. A bivalve shell found embedded in amber suggests that the latter was soft when deposited.

The mechanism that produced the discoid shape of most amber clasts is unclear. The runnels appear not to have been modified by transport and deposition, so the disks may similarly reflect their original morphology. Perhaps the runnels collected on tree trunks, and the disks as pools on the ground surface. Alternatively, the disk shapes could have resulted from abrasion during transport. The occurrence of conglomerate in the sequence indicates that the amber may have passed through a high energy environment, in contrast to the low energy facies in which New Jersey amber occurs (Grimaldi et al., 2000), for example.

5.6. Further work required

Clearly, much remains to learn about the geology of the amber mines region. The earlier reports of *Nummulites* in some limestones should be confirmed, the *Orbitolina* beds relocated, and the Cretaceous–Eocene unconformity delineated. The stratigraphy, sedimentology, paleontology, and structural geology of the region all need to be further elucidated.

6. Conclusions

Noije Bum in the Hukawng Valley has been the principal source of amber in Myanmar for at least the past 166 years, and probably for very much longer.

The conclusion of Chhibber (1934) that the amber is hosted by Eocene sediments has been widely quoted in the literature. However, recent work indicates a Cretaceous age. Insect inclusions in amber are interpreted to be Turonian–Cenomanian, and a specimen of the ammonite *Mortoniceras* (of Middle or Upper Albian age) was discovered during the authors' visit. Palynomorphs in samples collected by the authors suggest that the amber-bearing horizon is Upper Albian to Lower Cenomanian. The preponderance of the evidence suggests that both rocks and amber are most probably Upper Albian. This determination is significant for the study of insect evolution, and if correct, indicates that the oldest known definitive ants have been identified in this amber (Grimaldi et al., 2002).

This Upper Albian age is similar to that of *Orbitolina* limestones which are known from a number of locations in northern Myanmar. One of these, at Nam Sakhaw, has also been a source of amber. Therefore presently unknown amber deposits could occur in other mid-Cretaceous sediments as well.

The recognition of Cretaceous rocks at Noije Bum indicates that rocks of this age may be more widely distributed in the Hukawng Valley than previously believed.

Acknowledgments

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