Blueschists and Blue Amphibole Schists - Gneisses Associated with the Nan River Mafic – Ultramafic Belt, North Thailand

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Abstract. The discovery of an areally limited outcrop of blueschists in Huai Sak, near Ban Huai Lao, SE Nan Province in the early 1980s has not been followed up until now. This is despite these blueschists being used in many regional tectonic compilations as unequivocal evidence for the presence of a former subduction zone along the trend of the Nan river. We report additional structural information and mineral analyses for the Huai Sak blueschists and the discovery nearby, in Huai Phi Rong, of structurally similar schists containing the Na-Ca amphibole barroisite. In addition, we report the discovery in Huai Phi Rong of float samples, believed to be derived from a thrust sheet of serpentinite matrix melange, consisting of coarse schists and gneisses that contain a variety of blue amphiboles associated with garnet. EPMA analysis confirms these blue amphiboles to be variously riebeckite, glaucophane, winchite and barroisite.

1. Introduction

To date the only published reports of blueschists in Thailand are two short papers [1,2]. An exact location was not provided, as access to detailed topographic maps was restricted by the military. Sandra Barr (pers. comm.) confirmed that these blueschists were found in Huai Sak near Doi Puk Sung, some 3.5 km NE of the village of Ban Huai Lao, in the SE part of Nan Province (figure 1). Microprobe analysis showed the blue-amphibole to be ‘crossite’, an informal term for intermediate compositions between glaucophane and riebeckite, in an assemblage including much epidote and white mica. A second general location was provided [2], without chemical analyses, for a blueschist locality some 15 km west of Uttaradit. In his unpublished 1991 PhD thesis [3] on p.162, stated that “blueschists with quartzite intercalations have only been recognised in a small creek just south of Doi Puk Sung” and gave a grid reference for a location placing it in Huai Sak. He also provided 9 electron-microprobe analyses of blue amphiboles from 3 samples, confirming their crossite composition. Based on phase equilibria and the absence of lawsonite he estimated that “these blueschists have been formed at a pressure of approximately 7 kb and temperatures in the range of 390 to 450 °C”.

Here we provide preliminary results from a study of the general area around Ban Huai Lao, including the blueschists of Huai Sak and an exposure of barroisite schists in the nearby Huai Phi Rong (figure 1). In addition, we report the discovery of significantly higher-grade blue-amphibole bearing schists and gneisses,
found as float samples in Huai Phi Rong, variously containing glaucophane, riebeckite, barroisite, winchite, actinolite, hornblende, garnet and white mica.

The study area is part of the Nan River mafic – ultramafic belt (NMUB), long been considered to be part of an ophiolitic association marking the line of a major suture zone [4,5]. Recently it has become the received view that these mafic-ultramafics, their associated greenschists and relatively unmetamorphosed greywackes are the remnants of a back-arc basin rather than the main branch of the Paleotethys Ocean [6,7].

![Simplified geology map of the study area showing key localities (WGS84 coordinates).](image)

**Figure 1.** Simplified geology map of the study area showing key localities (WGS84 coordinates).

2. General geological setting

Structurally the area consists of a series of relatively thin thrust sheets composed of contrasting lithologies and metamorphic grades (figure 1). Only in a few places are the thrust faults exposed, although often they can be positioned in stream and road sections to within 5 – 10 m. The best example we have found is located in the south bank of Huai Kaeng Luang, at 0702464 mE 2026130 mN, where a thrust plane trending 080°/38°N places greenschist over serpentinite. Our general impression is that to the north of Huai Kaeng Luang most thrusts planes are subhorizontal, while to the south they dip moderately to the SW and NW, with the two areas being separated by a large ENE – WSW trending fault of unknown throw. Where a sense of displacement can be determined it is always, in a general sense, top to the south.

Space here precludes a detailed description of the various lithological units, which differ little from those identified by [1,2]. However, it should be noted that the structurally uppermost thrust sheet (orange coloured in figure 1) is composed of a melange with a sheared serpentinite matrix, previously noted by [3], within which there are blocks composed of lithologies that are exotic to the matrix. Those blocks identified so far are variously clastic sediments, peridotite, meta-gabbro, pyroxenite, andesite and chromite bearing serpentinites. It is believed that the high-grade blue-amphibole bearing rocks found as float in the bed of
Huai Phi Rong, discussed below, are derived from this melange, although as of yet no such lithologies have been found in-situ, probably due to their rarity and the poor overall exposure.

3. Blueschists in Huai Sak
The only significant exposures of blueschists located to date are in a 400 m section of Huai Sak, between 0703700 mE 2030500 mN and 0704100 mE 2030000 mN. This area is within the Sri Nan National Park and can only be legally accessed when accompanied by Forest Rangers. Permission for access is readily given by the regional Forestry Office. Although some previous workers [3] consider these blueschists to be exotic blocks within the serpentinite melange unit, we prefer to interpret this outcrop as a more or less coherent single thrust sheet, which is overlain by a separate thrust sheet of the serpentinite melange.

The deformation history of these blueschists appears to be remarkably similar to that of the barroisite schists from Huai Phi Rong, described below. D1 produced a strong, pervasive schistosity with alignment of elongate amphiboles, white mica and chlorite. S1 is axial planar to small rootless folds, outlined by quartz rich seams, with amplitudes ranging from a few mm to cm. D2 produced tight folds and associated crenulations, the largest observed has an amplitude of 40 cm. Only in a few places is there a weak axial planer S2 cleavage, more commonly S2 is a sporadically developed, spaced crenulation cleavage.

![Figure 2. Photomicrograph of blue-violet amphibole in blueschist from Huai Sak.](image)

Based on 10 thin sections of blueschist (figure 2), the general modal range of the assemblage is: blue amphibole 20 to 40%, epidote 30 – 55%, quartz 20 – 30% and white mica 10 – 20%. They contain minor amounts of feldspar, assumed to be albite, and titanite. Notably lawsonite and rutile are both absent. Optically (figure 2) the blue amphiboles clearly display the distinctive pale yellow to colourless, blue, lavender-violet pleochroic scheme distinctive of the Mg-riebeckite – glaucophane series. All samples collected to date have the same mineral assemblage:

Mg-riebeckite – epidote– chlorite – white mica – quartz ± Ca amphibole ± albite ± titanite
Table 1. EMPA analyses of selected specimens. 2020-4/5 blueschist from Huai Phi Rong. Others are float ‘exotic’ specimens. Barr – barroisite  Wine – Winchite  Rieb – riebeckite  Glauc – glaucophane  Hbd – hornblende  Act – actinolite.
EPMA analysis (2020-24/5 table1) shows that the blue amphibole is (riebeckite to Mg-riebeckite), with one analysed grain being winchite. The white mica is phengitic, with a very high Si a.p.f. of 3.45 – 3.47 and unusually high FeO and MgO contents, with 6 and 3 wt% respectively.

4. Barroisite schists in Huai Phi Rong

In Huai Phi Rong, between 0705500 mE 2028820 mN and 0705520 mE 2029035 mN, there is a 200 m or so, more or less continuous exposure of a unit of green-blue coloured schists, containing a large amount of amphibole. EPMA analysis confirms the amphiboles are variously barroisite (2019-124 table 1, figure 3.A), actinolite and hornblende. One specimen (2019-112 table 1, figure 3.B) contains a few crystals of glaucophane. Three mineral assemblages are recognised in thin section (note garnet and rutile are absent).

Barroisite – chlorite – muscovite - quartz – albite – epidote – titanite – haematite
Hornblende – actinolite – chlorite - quartz - albite – epidote – titanite – haematite
Barroisite – hornblende – chlorite - quartz – muscovite – epidote – titanite – haematite
Chlorite – muscovite – quartz – albite – epidote ± titanite ± haematite

Figure 3. Photomicrographs. Field of view (x40 – 3 mm x 100 – 1.2 mm).
This schist unit appears to be thrust bounded and around 25 m thick. Although the actual contacts are not exposed, they are marked by a notable increase in the intensity of shearing. It is underlain by a unit composed of partially serpentinised peridotite blocks set in a scaly textured, sheared serpentinite matrix, and overlain by a unit of mixed ultramafic and mafic lithologies, which are generally not serpentinised. The deformation history of this schist unit appears to be very similar to that of the blueschists found in Huai Sak. D1 is represented by a strong pervasive S1 schistosity that is axial planer to small, often rootless isoclinal folds, preserved in ruptured quartz rich bands, which range in amplitude from a few mm to a few cm. D2 produced tight folds, with amplitudes from a few cm to 25 m. There is no obvious S2 axial planer cleavage, rather the intermittent development of a spaced crenulation cleavage or dissolution cleavage.

5. High grade blue-amphibole schist / gneisses ‘exotic’ float samples in Huai Phi Rong

While conducting a drift mapping exercise for students in Huai Phi Rong a number of loose rocks were found that have well developed schist/gneiss textures and a distinctive silvery appearance from large plates of white mica. Informally we refer to these as float ‘exotic’ samples. When examined in thin section many such samples contain amphiboles with distinct blue colours (figure 3.C and D) which EPMA analysis shows to be barroisite or winchite. Other specimens contain large Ca amphibole grains with fringes and rims that are dark blue (figure 3.G), which EPMA confirms to be riebeckite. Some specimens show Ca-amphiboles or barroisite with fringes that have the light blue – violet pleochroism typical of Na-amphiboles (figure 3.H and I).

| Texture          | Specimens | Ca  | Barr | Winc | Reib | Blue | Gnt | Wnc | Stlp | Alb | Kfd | Epit | Chl | Cbr | Rut | Apat | Zirc | Cpg |
|------------------|-----------|-----|------|------|------|------|-----|-----|------|-----|-----|------|-----|-----|-----|------|-----|-----|
| Non foliated     | 2019-99   | X   |      | X    | X    | X    | X   | X   | X    | X   | X   |
|                  | 2019-101**| X   | X    | x    | x    | x    | X   | X   | X    | X   | X   |
| Foliated         | 2019-10** | X   | r    | X    | x    | x    | x   | X   | x    | X   | X   |
|                  | 2020-14   | X   | r    | X    | x    | x    | X   | X   | x    | X   | X   |
| Sheared - mylonite | 2019-99  | X   | X    | X    | X    | X    | x   | X   | X    | X   | X   |
|                  | 2019-101**| X   | X    | X    | X    | x    | x   | X   | x    | X   | X   |
|                  | 2019-102**| X   | X    | X    | X    | x    | x   | x   | x    | X   | X   |
|                  | 2020-13   | X   | X    | X    | X    | x    | x   | x   | x    | X   | X   |
| Segregated schist | 2019-11**| X   | X    | X    | X    | X    | X   | X   | X    | X   | X   |
|                  | 2019-12**| X   | X    | X    | X    | x    | X   | X   | X    | X   | X   |
|                  | 2020-14   | X   | x    | X    | X    | X    | x   | X   | X    | X   | X   |
|                  | 2021-17   | X   | x    | X    | X    | x    | x   | X   | X    | X   | X   |
|                  | 2021-22   | X   | x    | X    | X    | x    | x   | X   | X    | X   | X   |
|                  | 2020-15   | X   | x    | X    | X    | x    | x   | X   | X    | X   | X   |
|                  | 2020-16   | X   | x    | X    | X    | x    | x   | X   | X    | X   | X   |
|                  | 2020-20   | X   | x    | X    | X    | x    | x   | x   | x    | x   | X   |
|                  | 2020-24   | X   | x    | X    | X    | x    | x   | x   | x    | x   | X   |
|                  | 2020-28   | X   | x    | X    | X    | x    | x   | x   | x    | x   | X   |
|                  | 2021-21   | X   | x    | X    | X    | x    | x   | x   | x    | x   | X   |
|                  | 2021-24   | X   | x    | X    | X    | x    | x   | x   | x    | x   | X   |

** EMPA: Ca-amphibole, Barr. - barroisite, Winc. - winchite, Reib - riebeckite, Glau - glaucophane, Blue - blue amphibole (R = rim)

Figure 4. Mineral assemblages in all float ‘exotic’ samples from Huai Phi Rong.

Over three field seasons we have collected 31 float ‘exotic’ specimens of various types. Although found along the entire length of Huai Phi Rong, they become more abundant and larger upstream from the outcrop of the barroisite schists described above. We have yet to find any of these types of schists/ gneisses in place. We suspect that they are derived from ‘exotic blocks’ weathering out from the thrust sheet of serpentinite melange which crops out across the watershed above Huai Phi Rong. No similar float samples have been found in any other stream section.
The various mineral assemblages in these specimens are summarised in figure 4, where they are grouped according to the deformation textures observed in thin section. One of these groups (6 specimens) has shear to mylonite textures, including C-S structures, mica and amphibole fish, together quartz ribbons and garnets that have been fractured and drawn out into elliptical shapes (figure 3.E and F).

6. PT conditions of metamorphism

Mineral chemistry analyses were obtained using an electron probe microanalyzer (JEOL JXA-8530F Plus EPMA) equipped with five wavelength dispersive X-ray spectrometers (WDS) and an energy dispersive spectrometer (EDS). Operating conditions were 15 kV accelerating voltage, 10 nA beam current, ~1-5 μm beam diameter (depending on mineral species), with counting times of 20 seconds. The EMPA analyses were conducted at the Institute of Earth Sciences - NAWI Graz Geocenter, University of Graz, Austria.

Based on garnet – amphibole – plagioclase thermobarometry [8] and EPMA analyses of garnet – amphibole pairs from 6 float ‘exotic’ specimens obtained in 2019, a series of PT estimates have been generated (figure 5). A further 25 such float ‘exotics’ specimens collected in 2020 – 21 await EPMA analysis. It is apparent from the compilation in figure 5 that the estimated temperatures are a little higher that would be expected for the formation of blueschists under the various corresponding pressures. As discussed later, we believe that this reflects the initial metamorphism of these particular float ‘exotic’ specimens under upper greenschist – lower amphibolite conditions, before they later entered the transition zone into the blueschist facies.

![Figure 5. Compilation of PT estimates from garnet – amphibole pairs in ‘exotic’ float samples.](image)

None of the assemblages found in the float ‘exotics’ are suitable for conventional geobarometry. The main problem being that all of the plagioclase feldspar is almost pure albite. However, it is noted that most of the ‘exotic’ samples contain rutile and no titanite, while the blueschists and barroisite schists only contain titanite. This indicates the float ‘exotics’ were metamorphosed at significantly higher pressures, probably in the order of at least 8 kbar, than were the schists found in Huai Sak and Huai Phi Rong.
7. Conclusions
The blueschists - greenschists of Huai Sak, the barroisite - greenschists of Hua Phi Rong and greenschists from other stream sections all share an apparently identical deformation history. We suggest that they were all derived from a similar structural position in the subducting slab and thus share a similar geological history. It is likely that all of these various schist units were metamorphosed under very similar PT conditions and that the appearance of different Na and Na-Ca amphiboles is a function of whole rock composition and/or their oxidation state. In this regard it is notable that some of these schists contain significant amounts of large, euhedral haematite, indicating a high degree of oxidation.

Most of the float ‘exotic’ samples have mineral assemblages involving garnet and Ca-amphiboles (figure 4), which is consistent with their initial metamorphism being in the upper greenschist to lower amphibolite facies. In many of these samples the Ca-amphiboles display bright blue to lavender / violet rims (figure 3). Of the 3 such specimens which have been analysed to date by EPMA, one (2019-1 figure 3G) has very dark blue rims proved to be riebeckite, in the other two specimens their lighter blue coloured rims proved to be the Na-Ca amphiboles winchite and barroisite. A further 14 similar specimens await analysis, some with distinct blue – violet pleochroic fringes that are may well prove to be Na amphiboles.

Our working hypothesis is that many of these float ‘exotic’ rocks were initially metamorphosed under upper greenschist to amphibolite facies PT conditions. Subsequently they were torn off from a position higher in the subduction zone, possibly in some cases from the underside of the overlying continental plate, often becoming highly sheared in the process, and carried to greater depth, losing heat to their new surroundings. Thus, following an anticlockwise PT path, they entered a transition zone to the blueschist facies, with Ca-amphiboles changing to more stable Na-Ca and Na amphiboles.

The discovery of a wide variety of rocks containing Na-Ca and Na amphiboles in this one small study areas suggests that similar localities may be found throughout the Nan river mafic-ultramafic belt. On this note, thin sections of two cobbles collected from a point bar on recent scouting trip to the Wa River, near the Mae Charim National Park, proved to contain large blue to violet pleochroic amphiboles, optically identified as glaucophane.

8. References
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