Structural development of the Mid-Tertiary Doi Suthep Metamorphic Complex and Western Chiang Mai Basin, Northern Thailand

Abstract

The northern Western Ranges of Thailand contain mylonitic gneisses of the Doi Suthep Metamorphic Complex (DSMC). Near Chiang Mai, mylonitic foliations outline a southeast-trending dome, and stretching lineations trend N80°W. Low-grade metasedimentary rocks and Tertiary fanglomerates flank the dome on the east, and widespread chloritic breccia marks the intervening Doi Suthep detachment fault.

We interpret that the metamorphic complex developed between Triassic and early Miocene, with detachment faulting, mylonitization, and uplift during Oligocene to Miocene. Within the DSMC, dikes of mutually cross-cutting, hence coeval, granitic pegmatite and aplite cut mylonitic orthogneiss. Although the contacts of the dikes are sharp, the dikes contain a mylonitic fabric that parallels the fabric in the surrounding mylonitic orthogneiss; thus, we infer that intrusion occurred during mylonitization.

East of Doi Suthep, Tertiary fanglomerates of the Mae Rim Formation overlie the Doi Suthep detachment fault. Variable strikes, with dips of 10°–50°, and several outcrop-scale fold hinges suggest that the Mae Rim Formation is deformed into a set of non-cylindrical folds. Numerous, variably-striking, high-angle normal faults suggest either multiple deformations or deformation in a three-dimensional strain field. The discovery of an intraformational angular unconformity confirms that the Mae Rim Formation accumulated during folding.

1. Introduction

Extension, marked by the development of several continental basins, characterizes the Cenozoic tectonic history of northern Thailand (Polachan and Saattayarak, 1989). The north–south trend of many of these basins suggests an east–west orientation for this extension, but lack of well-exposed high-angle normal faults has precluded estimates of the magnitude of strain. Elsewhere, major low-angle normal faults and accompanying zones of ductile, normal-sense shear typically form in response to large extensional strains within continental crust. Barr et al. (1991), first recognized such structures within the gneissic complex near Doi Inthanon, within Thailand’s Western Ranges, and compared them to the mylonitic zones and detachment faults of the Cordilleran metamorphic core complexes of western North America. These high-grade ortho- and paragneisses, previously considered to be Precambrian (e.g., Baum et al., 1981), may hold the key to a better understanding of the magnitude and direction of this extension.

We describe new structural data from the Doi Suthep area of the northeastern Western Ranges (Fig. 1), that: (1) provide confirmation of the existence a detachment fault along the eastern flank of the Western Ranges; (2) reveal that mylonitic rocks within the northern part of the Western Ranges likely formed during top-to-the-east ductile shearing; and (3) delineate the structure of folded and faulted syn-extensional fluvial conglomerate and sandstone that lie along the western side of the Chiang Mai Basin.
2. Geologic setting
The crystalline complex of the north–south trending Western Ranges extends for over 400 km from near the Thai-Burmese border in the north to west-central Thailand where they flank the western side of the Chao Phraya-Sukhothai lowlands, and form a major part of the Shan Thai terrane (Bunopas and Bunopas). West of the Chiang Mai Basin, various gneissic rocks, originally mapped as Precambrian basement (Baum et al., 1981), underlie the high peaks of the Western Ranges (Fig. 2). Voluminous S-type granitic rocks, many of Triassic age, intruded the gneisses (Beckinsale and Hutchison, 1983). Paleozoic sedimentary and low-grade metasedimentary rocks, mainly continental shelf limestone and phyllitic shale, structurally overlie the crystalline complex. These rocks were likely metamorphosed, deformed, and intruded by granitoids during the Permo-Triassic collision of the Shan Thai terrane with the Indosinian Craton (Bunopas, 1992).
The contact between the crystalline core of the Western Ranges and the supracrustal Paleozoic sedimentary rocks to the east is extremely sinuous. Originally mapped as a thrust fault (Baum et al., 1981), we re-interpreted this contact as a regional low-angle normal fault that dips gently eastward. A similarly sinuous contact to the west of the crystalline complex (Dunning et al., 1995) apparently dips gently to the west (Fig. 2), and suggests that this same detachment fault may reappear to the west as a consequence of regional, post-detachment doming.
The Chiang Mai Basin lies directly to the east of the Western Ranges. The basin trends generally north–south, but with a distinct sigmoidal bend where the central and widest part of the basin trends northeast–southwest. Sedimentary rocks of unknown age underlie the rolling lowlands along the edges of the basin (Fig. 2). The central, very flat portion of the basin contains Quaternary alluvial sediments, including Holocene floodplain sediments. The stratigraphy of the interior of the basin is poorly established due to the lack of any deeply penetrating wells (Polachan and Saatayarak, 1989).

3. The Doi Suthep Metamorphic Complex
Orthogneiss and metasedimentary rocks underlie the mountainous area around Doi Suthep, west of the city of Chiang Mai, defining the Doi Suthep Metamorphic Complex (Fig. 3) (Rhodes and Rhodes et al., 1997). Medium grained, generally homogeneous granodioritic to tonalitic orthogneiss is the dominate lithology in the complex. The orthogneiss typically contains approximately 50–60% sodium-rich plagioclase, 20–30% quartz, approximately 0–10% each of orthoclase and biotite, and trace amounts of zircon and apatite.
Metasedimentary rocks occurs locally as concordant layers within the orthogneiss. The most common metasedimentary lithology is biotite-quartz-feldspar paragneiss and schist, with lesser amounts of quartzite and calc-silicate schist. Rare occurrence of sillimanite in the paragneiss, and of diopside and forsterite in the calc-silicate schist, suggest peak metamorphic grades in the amphibolite facies. The generally medium- to coarse-grained textures also suggest a high metamorphic grade. This interpretation is consistent with relations farther south, in the Doi Inthanon area. There, metasedimentary rocks form a thick mantle over a core of orthogneiss and the widespread occurrence of sillimanite and altered cordierite suggest low-pressure upper amphibolite facies (Dunning et al., 1995).

The thorough intermingling of the orthogneiss and metasedimentary rocks, combined with generally poor exposure over large areas, precludes the separate mapping of these lithologies. Although outcrop-scale contacts are generally concordant, the discontinuous nature of the metasedimentary layers suggest an originally intrusive relationship. Widespread discordant to semi-concordant dikes and masses of pegmatite and aplite commonly intruded the other lithologies at virtually all scales. Dikes of pegmatite and aplite mutually cross cut each other, suggesting multiple injections of nearly the same age. The aplite contain 45–70% plagioclase, 20–30% quartz, and 5–25% orthoclase, with less than 10% biotite and/or muscovite. Although much more heterogeneous in texture, the pegmatite is similar in mineral content to the aplite.

Both the orthogneiss and metasedimentary rocks contain a mylonitic foliation. Although the development of this foliation is variable at an outcrop-scale, it generally increases in intensity structurally upward in the complex, with the most strongly mylonitized rocks occurring along the eastern edge of the complex, adjacent to the Chiang Mai Basin. The orientation of the mylonitic foliation outlines a gently southeast-plunging dome, with dips on the limbs of the dome rarely steeper than 30° (Fig. 3). A nearly unidirectional lineation, defined by rod-like quartz/biotite segregations, slickenside-like striae, and/or the axes of intrafolial isoclinal folds, lies in the mylonitic foliation. The orientation of the lineation is strongly unidirectional on both limbs of the dome, indicating a stretching direction of N80°W/S80°E prior to doming (Fig. 4).
Embedding in the Mae Rim Formation dips up to 50°, with variable strikes. Poles to bedding plotted on a stereonet show no preferred strike direction (Fig. 4b). The Mae Rim Formation is clearly folded, as demonstrated by visible outcrop-scale fold hinges in at least three of the larger quarries (Fig. 6b). Fig. 3 shows no clear pattern of folding, thus the wavelength of individual folds must be smaller than the average spacing of exposures. The simplest interpretation is that the Mae Rim Formation is folded into gentle domes and basins, and this is consistent with the observed, outcrop-scale fold hinges. Interestingly, the pattern of poles to bedding for the Mae Rim Formation is nearly identical to that obtained by plotting poles to mylonitic foliation in the Doi Suthep complex. Perhaps both were effected by the same deformation.

In one spectacular exposure, a distinct angular unconformity is visible within the Mae Rim Formation (Fig. 7). Here, a gentle anticline is clearly breached by a gently folded unconformity, which in turn is offset by a high-angle, probably normal fault. Gravel beds overlying the unconformity are also gently folded. Interestingly, dips within the Mae Rim Formation generally lessen toward the east with horizontal bedding most common along the eastern edge of Fig. 3. We can not rule out the possibility that the more gently dipping exposures overlie one or more angular unconformities. These observations make it clear that deformation and deposition of the Mae Rim must have been synchronous.

Table 2. Summary of the tectonic history of the Doi Suthep area

<table>
<thead>
<tr>
<th>Age</th>
<th>Events</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proterozoic (?)</td>
<td>Deposition of the protoliths of paragneiss in the Western Ranges</td>
<td>Poor compositional match between paragneiss and Paleozoic and Mesozoic rocks in the area perhaps indicates a younger age for the protoliths</td>
</tr>
<tr>
<td>Ordovician</td>
<td>Deposition of slate and limestone in a continental shelf environment</td>
<td>Piylite and marble represent the metamorphosed equivalents of these rocks in the hanging wall of the Doi Suthep detachment fault</td>
</tr>
<tr>
<td>Triassic</td>
<td>Intrusion of voluminous granitoids, deformation, and low-grade metamorphism likely accompanied the collision of the Shan-Thai Terrane with the Indochina Craton</td>
<td>Triassic granitoids are likely the protoliths for orthogneisses in the Doi Suthep Metamorphic Complex</td>
</tr>
<tr>
<td>Triassic to Late Cretaceous</td>
<td>Peak of metamorphism at high temperatures and low pressure (Donning et al., 1995)</td>
<td>This event may have been accompanied by localized partial melting, generating magma for pegmatite and aplite dikes in the Doi Suthep Metamorphic Complex</td>
</tr>
<tr>
<td>Oligocene – Miocene</td>
<td>Mylonitization</td>
<td>Goethite and chlorite represent the earliest and shallowest expression of this extension</td>
</tr>
<tr>
<td>Oligocene – Miocene</td>
<td>Detachment faulting, deposition of the Mae Rim Formation, and regional doming</td>
<td>Age of these events is poorly constrained. Uplift (i.e., doming), detachment faulting, and folding and faulting within the Mae Rim Formation must have been synchronous with deposition of Mae Rim conglomerates</td>
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8. Conclusions

Future models explaining the Cenozoic tectonic development of the Western Ranges must take into account the following conclusions:

- East–west extension persisted in northern Thailand during the time of deposition of the Mae Rim Formation.
- Erosion and/or tectonic denudation must have exposed the core of the Western Ranges during the deposition of the Mae Rim Formation.
- A regional mid-Tertiary or younger detachment fault extends along the entire eastern flank of the Western Ranges. This fault was subsequently domed, and the metamorphic complex of the Western Ranges represents the footwall core of this dome.
- Kinematic indicators in the mylonitic rocks of the footwall of the detachment fault indicate uniform top-to-the-east simple shear consistent with eastward detachment faulting.
- Latest movement on the Doi Suthep detachment fault came after the deposition of the Mae Rim Formation.
- Any estimates of the magnitude of extension in northern Thailand must take into account extension accommodated by detachment faulting and ductile flow of the mid- to lower-crust.
Fig. 7. (a) Photograph of an angular unconformity within the Mae Rim Formation. (b) Sketch of the same photograph. Bubble pattern indicates conglomerate, dashed pattern indicates sandy siltstone, and lined pattern indicates shale. The thick line indicates the trace of a high-angle normal fault.

7. Structural history
The tectonic history of the Doi Suthep area is outlined in Table 2. The timing of these events is based on geochronology by Dunning and Upton et al., 1997; however, many of these ages are still poorly constrained. Of
particular importance is the age of the Mae Rim Formation; its age is critical to the timing of the latest movement on
the Doi Suthep detachment fault, and unroofing of the metamorphic core of the Western Ranges. Further study is
also needed of other Cenozoic sedimentary rocks that crop out at the southern and northern ends of the Chiang Mai
Basin (Fig. 2), as they may be correlative with the Mae Rim Formation. Finally, more detailed geochronologic work
on the metamorphic core is needed, utilizing a variety of isotopic systems, before we will fully understand the timing
of metamorphic and ductile-shearing events in the Western Ranges.