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Physical Geography of the Gaoligong Shan Area of Southwest China in Relation to Biodiversity

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The Gaoligong Shan mountains (Gaoligong Shan) comprise the western-most part of the Hengduan Mountain Range. They include all of the contiguous ridges west of the Nujiang River and east of the Irrawadi-Nmai Rivers and lie at the junction of the Indo-Malaya and Palearctic zoogeographic realms. The Gaoligong Shan are one of the world's most significant biodiversity hotspots outside of the tropics.

The Hengduan Mountains, of which the Gaoligong Shan are a part, are a result of the collision of the South China Block and Eurasian Plate during the late Mesozoic. During the Cenozoic, the Gaoligong Shan have also been affected by the continuing movements of the Indo-Australasian Plate and Eurasian Plates to the west of the Hengduan Mountains.

The Gaoligong Shan are characterized by a number of unusual features. Their high, contiguous ridges extend further south than do most of those of the other Hengduan Mountains. Also, their river valleys are unusually narrow and deep because they are incised into hard rock that maintains steep slope profiles. Continuing uplift, steep gradients, and swiftly flowing rivers have eroded deep gorges. The north-south orientation of the river valleys causes the Gaoligong Shan to have an unusual face aspect relative to the sun; nearly all slopes face either east or west. The deep valleys and north-south orientation of the ridges result in the region having a more moderate climate than surrounding non-mountainous areas situated at the same latitude. Because of their antiquity, the Gaoligong Shan have accumulated a high level of biodiversity. At the same time, their high elevations and deep gorges have acted as barriers to migration for most terrestrial organisms. Moreover, because of their unusual climate and many protected environments, the Gaoligong Shan provide a refugium from global climate perturbations. It is significant that the difficult terrain has, until recently, deterred extensive human habitation, thus preserving the region's biodiversity.

Keywords: Gaoli Gongshan, Gaoligongshan, Hengduan Mountains, Biodiversity Hotspot, Climate, Refugia, Indian Plate, Australasian Plate, Eurasian Plate, Tibetan Plateau, GIS, Conservation, Biogeography.

The Gaoligong Shan mountains (GLGS) are widely acknowledged as an important center of biodiversity and as such have been recognized as a World Heritage Site (UNESCO 2003). The listing recognizes the region's unusual geological context, ecological diversity, and scenic beauty. Although many authors have written about the GLGS, there is no general agreement as to the geographical definition of the region. This paper presents such a definition.

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Ecologists recognize that the interplay of many factors is responsible for the accumulation of biodiversity. The prime factor is the environmental gradient produced by latitude and its effect on trophic production. The effect of latitude is modified by elevation and climatic variation due to local factors and ecological niche structure and complexity. The degree of isolation of the environment controls interchange of species along the trophic levels. The age of the environment and its biotic components also promote biotic heterogeneity. Competition and predation interact with the niche structure to form biotic communities with various degrees of complexity. Generally, the older and more stable the area, the greater the biodiversity. Many aspects of mountain ecology serve to exaggerate the complexity of niche structure. Although many authors have alluded to different aspects of the ecology of the GLGS, none has reviewed them comprehensively in terms related to the physical geography. In this paper, the relationship of geography to ecologyis investigated with respect to the promotion and maintenance of biodiversity.

In addition, the region's plate tectonics and geology are described. These two factors explain how the physical geography of the GLGS evolved. Tectonics causes rocks from different places to be brought together, building mountains or creating areas of subduction. The composition of the rocks dictates how they will behave as they are uplifted and eroded. Erosion of rocks contributes to soil formation, and the kind of soil formed is, in part, dependent on geology. The soils of the GLGS, therefore, are reviewed because of their bearing on biodiversity. The conformation of mountains and rivers has important biological consequences for the high levels of biodiversity in GLGS.

General Considerations

The purpose of this paper is to define the GLGS more accurately than has been done previously. This requires a starting point. Broadly speaking, the GLGS, as referred to here, are the most westerly ridges of the Hengduan Mountains that extend north to south between the Nujiang River in the east and the Irrawadi River in the west.

The name Gao–Li–Gong–Shan[1], strictly speaking, applies to a single peak at the junction of Baoshan, Lushui, and Tengchong Counties at approximately 25.133°N, 98.716°E. The exclusive

[1] In contracting Chinese names, I have used the established method of Zhao (1986) who suggested that names should not be contracted to less than two characters using the example of the Tian Shan Mountains, which he thought was preferable to Tian Mountains even though Shan means Mountains. Similarly, here I use Nujiang River rather than the Nu River despite the fact that "jiang" means river. This follows the most common usage of the name in the non-Chinese literature.

Gao–高–Li–黎–Gong–贡–Shan–山

The name Gaoligong Shan in Chinese is complicated. It, like many Chinese names, has different layers of meaning. It can mean, literally, and based on the characters alone, High Multitude Tribute Mountain. The character Li that is used, is the same as the one used for the transliteration Li in the name of the people called Lisu and who are the dominant ethnic minority group of the area. The exclusive usage in Chinese is that Gaoligong Shan implies the whole range of which Mount Gaoligong Shan is in the middle. The alternative term that could be used is Shanmai, which means mountain range in Chinese. This would give the rather cumbersome and never used term Gaoligong Shanmai or more correctly, but even worse sounding, Gaoligong Shan Shanmai. In this paper, the name used for the whole range will also be Gaoligong Shan (GLGS); I recommend that alternative names, sometimes seen in print, should be avoided, e.g. "Gaoli's," "Gaoligong," "Gaoli Gongshan," or just "Gongshan." "Mount Gaoligong Shan" should be used for the single peak if needed.

Another point: names in this region are difficult because of diverse ethnicities and dialects, e.g., the commonly referred to name Gongshan, is used sometimes for the mountains, at other times the county seat for the administrative zone, and most often, as an abbreviation for an administrative zone itself. This is the Gongshan Dulong Nuzu Zizhixian. Sometimes the Gongshan administrative zone is referred to as the Dulong area. Officially, it should be the Gongshan Drungzu Nuzu Zizhixian (Carto. Pub. Hse 1984), and in this paper it will be referred to as (Gongshan County). Drung, Dulong, and even Delung are the name for same people but spelled in different dialects. The name used can have many implications (Gros 2004). In this paper, place names are given to be as informative as possible to the general reader (see also cartography section in the main text). Lastly, GLGS is used in the plural to signify the whole range, as we do for the Rocky Mountains of the western United States.

Carto. Pub. Hse (1984). *Map of the People's Republic of China*. Cartographic Publishing House, Beijing; Esselte Map Service AB, Sweden.
Gros, S. (2004). The Politics of Names: The Identification of the Dulong (Drung) of Northwest Yunnan. China Information. *The Documentation and Research Centre for Modern China, Sinological Institute, Leiden University* **18**(2):275-302.

FIGURE 1. Regional locator map showing the Gaoligong Shan highlighted in relation to political geography.

FIGURE 2. Locator map showing the Gaoligong Shan highlighted in relation to local political geography.

usage in Chinese is that Gaoligong Shan includes the whole range of mountains of which the peak named Gaoligong Shan is in the middle. Chinese does not distinguish between plural and singular.

The GLGS are a poorly known biodiversity hotspot in Southwest China located mostly in Yunnan Province. They are the most biodiversity-rich area (Lan and Dunbar 2000; Mackinnon et al. 1996) of Yunnan, which is China's most biodiverse province (Zhang and Lin 1985) (see Figs. 1 and 2). The GLGS occupy about 10.5% of Yunnan Province.

The GLGS are a rugged mountainous border region adjoining Myanmar on the northeast. From a biogeographic perspective, the GLGS form the junction of several biogeographical realms, the Indo-Malayan, and Palearctic, and the biogeographical provinces of the Tibetan Plateau and South China subregion. The GLGS also stand at the junction of three major tectonic plates, which are discussed below, and, thus, three geological provinces. This position has given them an interesting and complex geological structure.

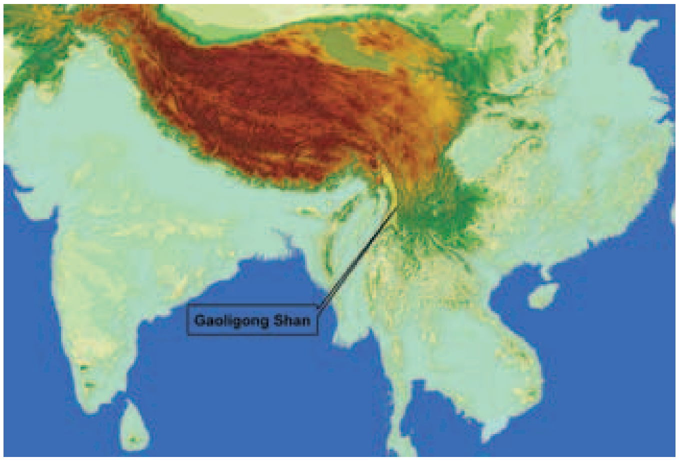


FIGURE 3. Regional locator map showing the Gaoligong Shan highlighted in yellow to the south of the Tibetan Plateau and to the west of the rest of the Hengduan Mountains.

The formation of the Hengduan Mountains, of which the GLGS are a part, preceded the uplift of the Qinghai-Xizang (Tibetan) Plateau. However, today the GLGS are, more or less, an extension of the Tibetan Plateau, which extends far to the south into Yunnan (see shaded area in Fig. 3). Subsequent to the uplift of the Plateau, the Hengduan Mountains and GLGS

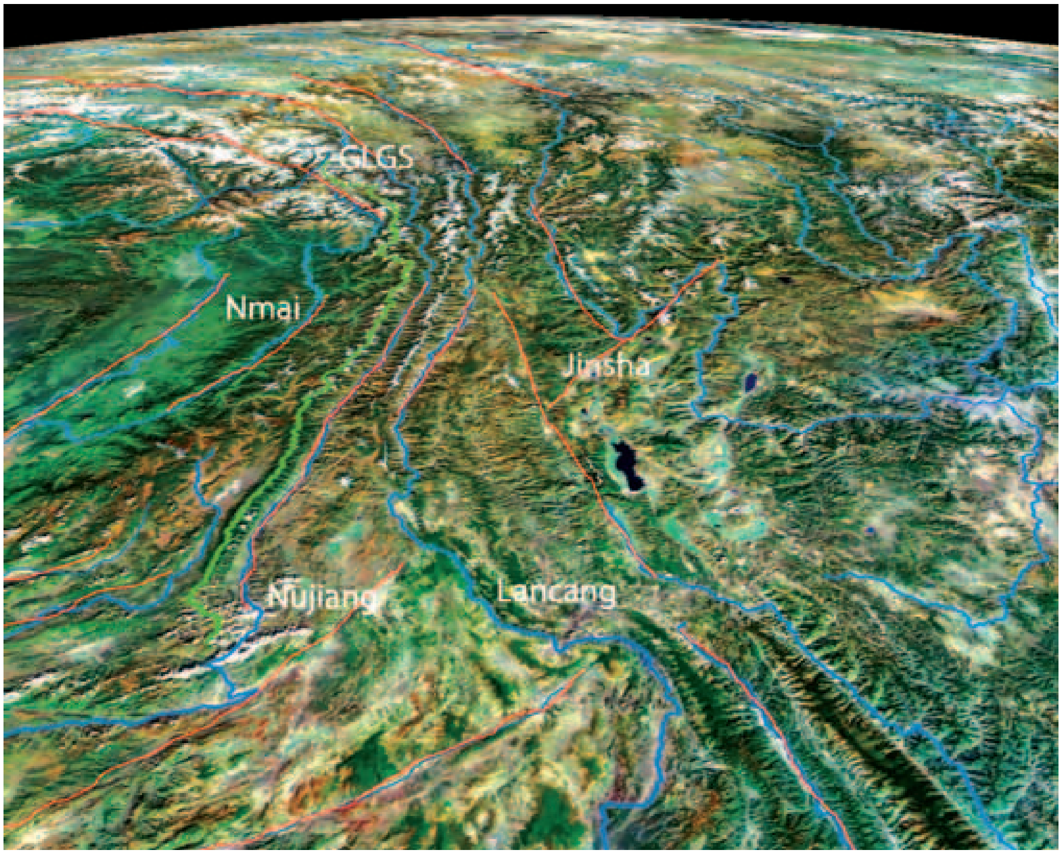


FIGURE 4. Satellite Image of Hengduan Mountains centered on Mt Gaoligong Shan, the Nujiang River can be seen entering the snow covered Tibetan Plateau at the top of the image (NASA 2004a).

experienced uplift, which has continued throughout much of the Cenozoic, and is associated with the Himalayan orogeny. The region is divided by a few large north-south flowing rivers, which are of major importance to Southeast Asia. The rivers run in extremely deep, gorges, which, having cut into the uplifting mountainous area, gave rise to a series of narrow, north-south-oriented, high mountain ridges. The rivers, which are associated with major fault zones (see Fig. 4), divide the area biogeographically.

TECTONICS

The north-south orientation of the Hengduan Mountains is orthogonal to the predominant east-west mountains found throughout eastern Eurasia. The Chinese name "Hengduan" translates as the "Transverse" or "Transecting" Mountains. The GLGS comprise the most westerly mountain ridge of the Hengduan Mountains.

EARLY TECTONIC MOVEMENTS.— The Hengduan Mountains were formed by several different major tectonic events. The mountains are at the margins of several plates, the Eurasian Plate to the north, the Indochina Block to the south, and the Indian Plate to the west. These plates are constrained by the Philippine-Pacific Plates to the east, and the Australasian Plate to the south (Hall 1997). These plates are all moving relative to the stable Eurasian Plate. The Hengduan Mountains region, being at the plate margins, is an active earthquake zone.

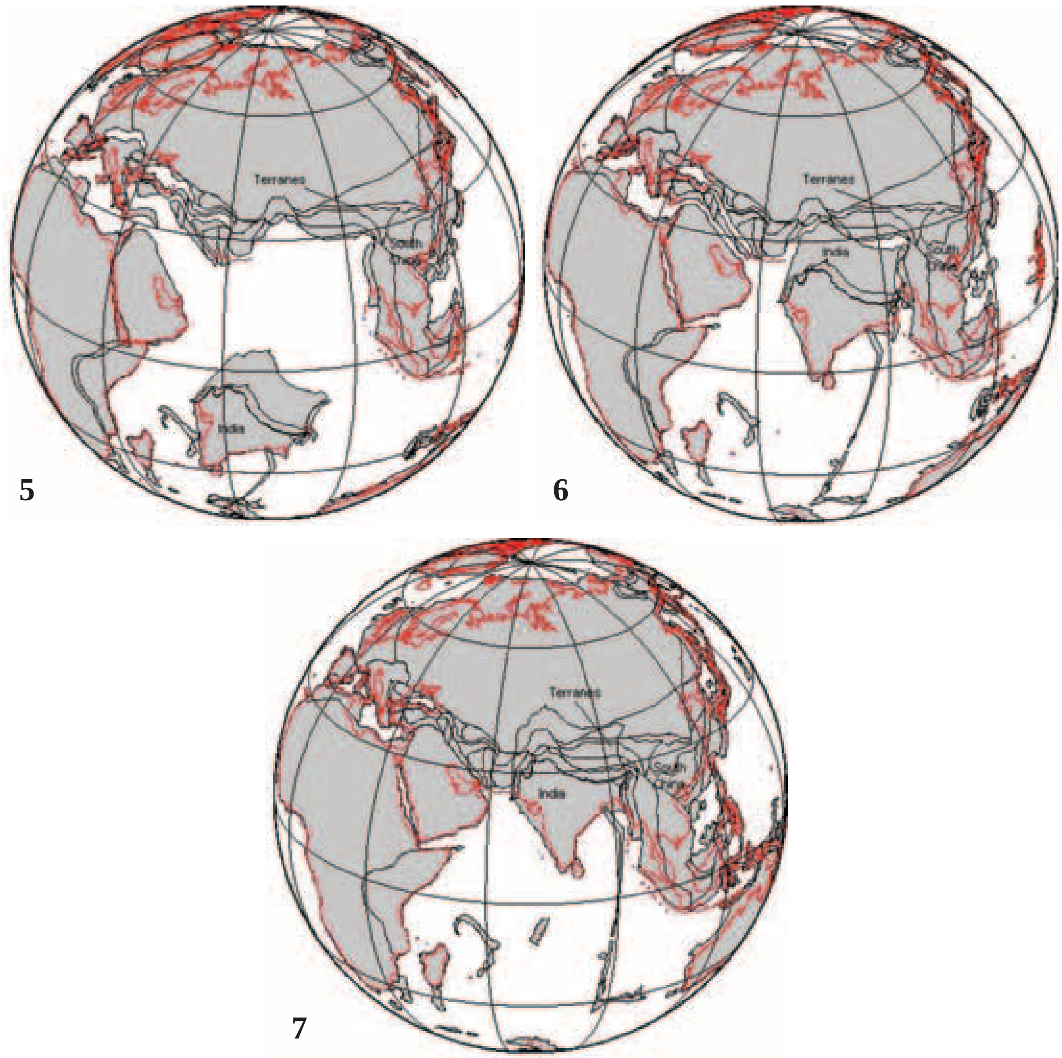
The very earliest collision involved the subduction of plate fragments (blocks or terranes), including the Southern China Block, which were driven north and eastwards by the Philippine/Pacific Plates after they broke away from Pangea and Gondwana. These older movements underlie the eastern part of the Hengduan Mountains in northern Sichuan and their extension along the Longmen Mountains. From the initial breakup of Pangea, in the early Carboniferous between 350 to 300 Mya, the South China Block was always slightly ahead of the Indochina Block as both moved northwards. Nonetheless, the two were always closely associated. The Southern China Block contacted the Eurasian Plate shortly after the Northern China Plate and before the Indochina Block; this happened as early as 200 Mya.

The Southern Terranes separated from the Northern Terranes very early, around 300 Mya. The sub-plate of the Southern Terranes broke away from Pangea much later than did the previously mentioned Plates and Blocks (South China, Indochina, and Northern Terranes). The Northern Terranes impacted the Eurasian Plate to the northwest of the South China Block. The Lhasa Terrane forms part of the GLGS and it belongs to the Northern Terrane group. The Southern Terranes managed to catch up with the Lhasa and Northern Terranes as they were slowed by collision into the Eurasian Plate. By 100 Mya, the Southern Terranes were abutting the Northern Terranes, on the south side of the Eurasian Plate and were adjoining the west side of the Hengduan Mountains. These plates can be seen in Figure 5 at 65 Mya and are already in place at that time. Figures 5–7 were produced using the web service of the Ocean Drilling Stratigraphic Network Plate Tectonic Reconstruction Service (Soeding 2004), and the general discussion follows maps produced at the History of Global Plate Motions (Dutch 1998, citing data from Scotese 1994). The Hengduan Mountains are, thus, the result of these collisions. Formerly, the upper GLGS region would have been influenced by these early tectonic movements and collisions. However, in the GLGS, any early signal has now mostly been overwritten by subsequent events.

Cenozoic Tectonic Movements.— In the early Tertiary, by 55 Mya, both Northern and Southern terrane groups were enclosed by the Indian Plate to the south, the South China Block to the east, and the Eurasian Plate to the north. The closing of the Tethyian seaway north of the GLGS was achieved by the relatively fast collision of the Indian Plate with the Eurasian Plate in the early Cenozoic. Eventually, both Northern and Southern terranes were sandwiched between the Indian Plate and the Eurasian Plate and became extruded and highly deformed (see Fig. 6 at 25 Mya). The present strains on these plates change orientation in the region of the northern GLGS from north-south to east-west (Bi 2004).

The Indian Plate moves north by as much as 50 mm per year, and the area has absorbed some 1500 km of deformation since first contact between India and Eurasia (Replumaz et al. 2004). In Myanmar, the amount of annual movement is only 35 mm (Socquet and Pubellier 2003). The crustal thickness over the Tibetan Plateau is much greater than elsewhere. Remnants of ocean crust lie now just west of the GLGS in Assam and can be seen as the white patch in Figure 7. The terranes can be seen as thin strips sandwiched in between the larger plates. The congregation of plates in the region of the Hengduan Mountains can clearly be seen in Figure 7.

As a consequence of the Indian Plate's collision into the Eurasian Plate, the eastern Himalaya syntaxis rotated clockwise, and crustal fragments of the Northern and Southern Terranes extruded southeastward. The extrusion was along the NW-trending Karakoram-Jiali, N-trending Gaoligong Shan, and Sagaing Faults (Lin et al. 2004). Ages of the faults indicate that deformation may have started from the south along the Sagaing Fault in Indochina and propagated toward the north along the Gaoligong Shan Fault. Subsequently, the deformation proceeded toward the northwest along the Jiali Fault and then the Karakoram Fault in southern Tibet. Such a deformation trend reflects continuous deformation caused by the northward indentation of the Indian Plate into the Eurasian



FIGURES 5–7. (5): Reconstruction of Plate movements for 65 Mya; (6): at 25 Mya; (7): present. Present coastline is shown in red on the grey plates. White indicates sea floor. Images courtesy of Soeding (2004).

Plate, which has continued during the whole of the Tertiary (Lin et al. 2004).

The Hengduan Mountains are bound by a series of north-and-northwest-striking Cenozoic faults: to the west by the Gaoligong Shan and Batang-Lijiang strike-slip systems, to the east by the Longmen Mountain thrust belt and the Xiaojiang Fault, and to the south by the Red River fault shear zone (Wang et al. 2001). The Cenozoic deformational history of the eastern Indo-Asian collision zone may be divided into three stages: (1) Eocene-Oligocene (40–24 Myr) transpression in eastern Tibet starting in the Red River Shear Zone just below the GLGS; (2) early-middle Miocene (24–17 Myr) transtension in eastern Tibet; and (3) late Neogene-Quaternary east-west extension, widespread in eastern Tibet and Indochina, which created small basins to the east, west and south of the GLGS (Wang et al. 2001).

QUATERNARY TECTONIC MOVEMENTS.— The newest tectonic arrival, the Australasian Plate, has driven the Indochina Block northwards, crushing and distorting the latter's northern front. The Indochina Block is highly deformed in the north but behaves approximately like a rigid block in the south (Wang et al. 2001). Secondary thrusting in the area is now active in the south of the GLGS as a result of the Australasian Plate subducting beneath Indonesia. For example, in Pupiao—a basin adjoining the GLGS along the east bank of the Nujiang River in Baoshan County—the Miocene/Pliocene soft coal beds are uplifted 70 m and tilted so that the adit entrance is at 60 degrees (pers. obs.).

The latest area to deform is south of the GLGS at the point where the Nujiang River first heads east, then south, and then southwest. The river courses of the Nanding River to the south of the study area, the Dayang, Wanding, and Longchuan Rivers run along associated en echelon faults in a newly established rupture zone. In addition, the Nujiang River is strongly diverted westwards by them. This zone of active faults dates from the Early Pleistocene. The ENE-WSW trending Longling-Lancang fault zone cuts across the earlier tectonics during the later period (Guo et al. 2000). This extensional drag possibly resulted from the orthogonal friction of the Indian Plate moving north along the middle of Myanmar (Socquet and Pubellier 2003) or from the Australasian Plate's impact along Sumatra and the Andaman Islands. The Tengchong region also exhibits a series of N-S faults, which contain the upper reaches of the Daying, Longchuan and Mingguan Rivers.

Tectonics and Mountain Building in the Gaoligong Shan.— The Paleozoic and Mesozoic Era plate movements resulted in faulting, folding, and the formation of metamorphic rocks and magmatite. These tectonic features were formed in the Paleozoic Era with the breakup of Pangea. The same trends continued with added impetus throughout the Mesozoic as the plates assembled on the south side of the Eurasian Plate. Then, in the Cenozoic, the extensive regional fault system was activated as a result of the collision of the Indian Plate with the Eurasian Plate, and a collage of terranes and other plate fragments. The complex tectonics of the GLGS region has resulted in extensive orogeny and erosion. It has also resulted in volcanism, extensive metamorphism, and local eruptions. And, in the GLGS, it has resulted in the uplift and exposure of rocks of much older periods. The movements of the tectonic plates and reentrant terranes were facilitated through a series of large strike-slip faults, as mentioned above. The courses of the Nujiang River, Lancang River, the northern part of the Jingsha River, and the Red River to the south, flow in these very large fault structures. The main branch of the Irrawadi River follows in the the course of another set of faults zones further to the west. The rivers have been entrained by the uplift, but, because of their huge watersheds, their large flows were sufficient to keep pace with the uplift through their down-cutting action. The Nujiang River Gorge Fault facilitates some 17 mm of slip per year along the Yunnan River Valley fault system (Socquet and Pubellier 2003), a fact highly relevant to the dams planned for the area. The constitution, trending, and formation period of the compressional, north-south older tectonics are totally different from those of east-west extensional tectonic active in the Longling-Lancang Rupture Zone that formed in the Pleistocene.

Earthquakes.— As a result of extensive and ongoing tectonic activity in the Hengduan Mountains, it is an active fault zone with many earthquakes (Meyerhoff et al. 1991). To the east of the Hengduan Mountains, along a line from the Longmen Mountains to east of the Lancang River, is an active zone of large earthquakes that have registered eight and above on the Richter Scale. The Nujiang River Fault, Lancang Fault, and the Red River Rupture Zone, are strike-slip faults that register earthquake magnitudes of typically less than eight and rarely above seven. In contrast, the Yarlung Zangbo (Brahmaputra) Fault Zone, which encompasses a system of low-angle thrust faults, experiences larger earthquakes, ones that often register over eight. Strike-slip faults rupture at lower magnitudes than do thrust faults, which are usually associated with subduction boundaries.

At first, the axis of the zone of thrust faults seems to have been in Longmen Mountains but moved west to the Nujiang River in the Permian and now is along the Yarlung Zangbo fault system (Meyerhoff et al. 1991). Currently, the main thrusting activity has moved south from the Yarlung Zangbo to the Frontal and Main Boundary Thrust systems in northern India and Nepal. Large earthquakes have the potential for tectonic damming of the rivers, that is major slides that often result from earthquakes generated by fault movement. For example, this happened on the Yi'ong Zangbo River just northwest of the GLGS. There a 33-km^{-2} lake formed behind a 2500 m by 60 m high dam in 2000. The dam subsequently failed, which resulted a catastrophic flood of over 100 km in length. Evidence of such damming, and scouring floods should be visible in the river terraces if they have occurred on the Nujiang River.

Biodiversity Implications of Tectonics.— The paleo-separation and subsequent reaggregation of plates from Gondwana and their eventual collision with the Eurasian Plate brought diverse biotas together from different paleo-continents. The area's complex uplift history has fostered greater genetic diversity in the region because of complex patterns of exchange, isolation, adaptation, extinctions, and speciation. Of particular importance has been geographic division due to the tectonically-driven incision of the landmass by massive rivers that has given rise to opportunities for vicariant events leading to further diversification. Tectonic activity has implications for the evolution of diverse host rock and soil types (see below).

Geology

Geological Province Overview.— The geologic provinces of the GLGS broadly agree with the boundaries of their tectonic elements. The GLGS contain three geological provinces: (1) the Lhasa Terrane from the Northern Terrane Group, which extends from the north along the Nujiang River valley to 70 kms south of Fugong Town; (2) the Himalaya Block of the Southern Terrane Group in the northwest near the Dulong River and south to near Gongshan Town; and (3) the Tenasserim-Shan Block of the Indochina Block, which includes all of the middle and southern GLGS. The Qintang Terrane forms the eastern border to the GLGS, but it is seen within only a tiny portion of the study area near Lishadi Village just north of Fugong Town, (see Figs. 2, 8). Each province has a set of geologic characteristics that distinguishes it from surrounding provinces. These characteristics may include the predominant lithologies, the age of the strata, and the structural style (Steinshouer et al. 1997; Wandrey and Law 1997).

Age of the Rocks of the Gaoligong Shan.— The Paleozoic Era GLGS formations are dominated by fault-, fold-, metamorphic-, and magmatite-deformed rocks. The major outcropping of Mesozoic Era rocks is more to the east of the study area along the Qintang Terrane; the rocks have been uplifted and folded, accompanied by compressional foreshortening, giving rise to the Nushan Mountains. However, smaller outcrops of Mesozoic rocks occur at both ends of the study zone (Fig. 9). To the southeast and generally along the western edge are large areas of Precambrian-age metamorphic rocks. Further to the west in the modern Burmese Basin (Myanmar), the Precambrian is overlain by Tertiary and Quaternary sediments. Many sedimentary strata in the GLGS have been lifted to being nearly vertical. The whole southern Hengduan Mountains area underwent more folding and uplift throughout the Cenozoic Era. This high degree of folding led in the southern GLGS to the exposure of older Lower Paleozoic sequences, some as early as Cambrian. Cenozoic rocks in the GLGS include further metamorphic changes to host rocks and, locally, volcanism around Tengchong Town, in the southwest and west of the GLGS in Myanmar probably reflect extensional tectonics as a result of ongoing subduction of the eastern limb of the Indian plate. Both Tertiary and Quaternary volcanics and sediments have formed in Tengchong

County. During the Cenozoic, a series of extensional basins formed and can be seen as small patches around the GLGS in Figure 9. These basins are associated with the change in thrust direction in the Plio-Pleistocene. Recent geological deposits consist of considerable scree and colluvium, alluvium, flood facies, and river terracing that can be seen in a few places in the river valleys. In the extreme north of the GLGS, there are extensive glaciers and paleoglacial features. The glaciers are shrinking at an astonishing rate, as can be seen when comparing recent satellite photographs with photos taken in the 1970s; this is probably as a result of global warming.

Generalized Geology

Starting from the north, the geology of the GLGS will be examined in more detail and briefly discussed, because geology has an impact on present landforms and implications for biodiversity. The data are taken from two USGS open-file reports for Far East Asia and South Asia, respectively (Steinshouer et al. 1997; Wandrey and Law 1997). The maps presented in this paper that were derived from these data are not accurate beyond 1 km and the discussion is of regional overview or generalized geologies only.

Lhasa Terrane.— The Lhasa Terrane comprises the north of the GLGS area, in eastern Chayu County (Zayü Xian) and the southern part of Zougong County (Zogang Xian) of the Tibetan Autonomous Region (Xizang Zizhiqu). The Lhasa Terrane also forms the northwestern part of Gongshan Dulong-Nu Autonomous County of Yunnan Province (Gongshan Drungzu-Nuzu Zizhixian) (referred to herewith as Gongshan County). The Lhasa Terrane is formed into a high mountainous area of Upper Paleozoic Rocks (PZu) (Figure 10). The Upper Paleozoic Rocks in general within the GLGS consist of intercalated beds of carbonate, argillaceous deposits, basalts, and metamorphosed rocks with the upper facies containing more volcanics. The Lhasa Terrane is flanked to the northwest (north of the Dulong

Figure 8. Map of the Geological Provinces within the Gaoligong Shan; these provinces broadly agree with the positions of tectonic plates (data from Steinshouer et al. 1997, Wandrey and Law 1997).

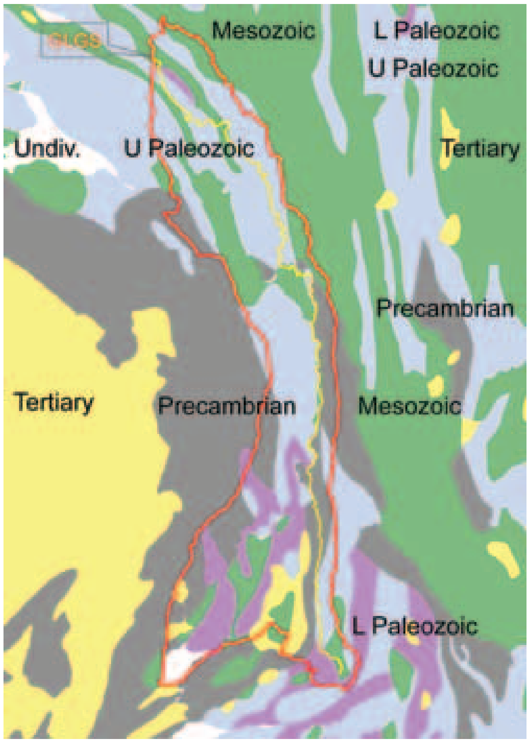


Figure 9. Geologic Map of the Gaoligong Shan showing the geologic age of the strata.

River) by Jurassic- Cretaceous (JK) age sequences. These sequences occur to the east where beds of Jurassic-Cretaceous age form the course of the Nujiang River. In the finger of the terrane extruded towards the town of Fugong, the river cuts through the Triassic (Tr) beds of the Lhasa or Qintang Terrane. Beyond, the Nujiang River reaches the Precambrian (pC) beds, which consist of some paratethys and some metamorphic and basaltic rocks. These Precambrian rocks form most of the ridge of the GLGS. The Precambrian metamorphics also form the ridges in the extreme west of Gongshan County and part of the ridge of the Patkai Range. The Patkai Range and other ridges in Myanmar are not part of the GLGS and lie outside of the study zone. Small patches of these Precambrian rocks are also exposed at the junction of the Himalaya Block, Lhasa Terrane, and the Tenasserim-Shan Block near to the town of Gongshan.

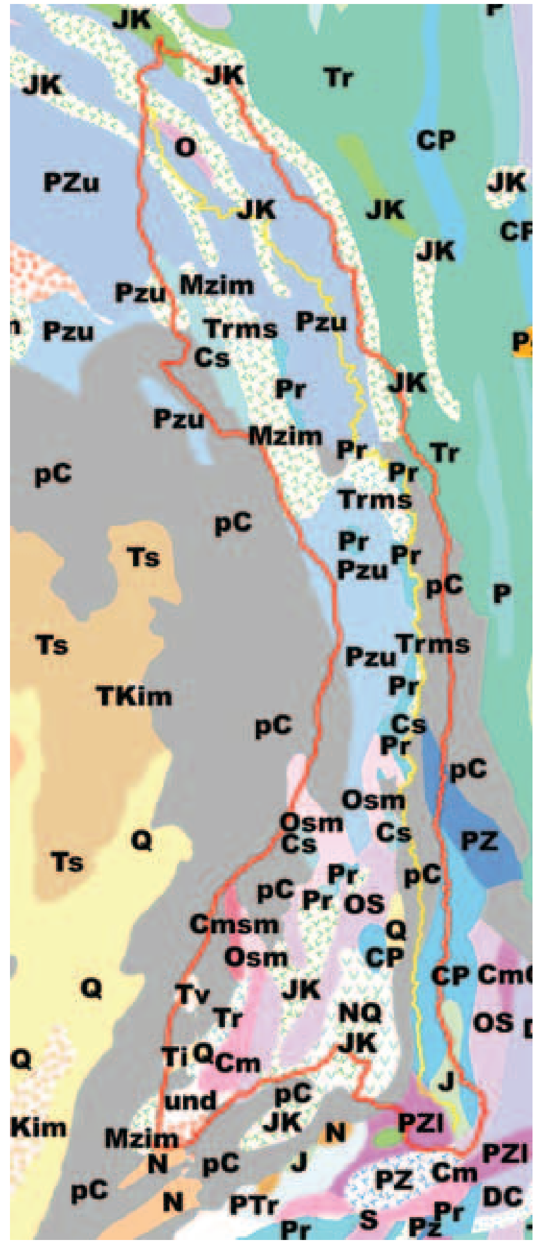


FIGURE 10. Map showing the geologic units in the Gaoligong Shan.

HIMALAYAN BLOCK.— The Himalayan Block forms the southwest of Zayü County and forms all of the eastern part of Gongshan County west of the Dulong River watershed. The mountains of the Himalaya Block are lower than those of the Lhasa Terrane. The Himalayan Block is formed mostly of Mesozoic intrusive and metamorphic rocks (Mzim). The Himalayan Block also extends across the northern end of the Tenasserim-Shan Block to form the finger that is caught between the Tenasserim-Shan Block and the Lhasa Terrane. This finger is formed of Triassic metamorphic and sedimentary rocks (Trms), possibly a shallow sea ophiolitic melange. To the west, mostly outside of the study area, in the northwest corner of Gongshan County, there are extensive areas of Precambrian (pC) rocks belonging to the Himalaya Block. Between these and the metamorphic core of the Himalaya Block in Gongshan County is a flank of Carboniferous sedimentary rocks (Cs). On the other flank, between the westerly edge of the Himalaya Block and the Lhasa Terrane, are small outcroppings of Permian sedimentary rocks, probably consisting of deep-water turbidites (Meyerhoff et al. 1991).

TENASSERIM-SHAN BLOCK.— MAIN RIDGE OF THE GAOLIGONG SHAN IN FUGONG, LUSHUI, AND KACHIN.— The majority of the GLGS sits on the Tenasserim-Shan Block. The middle reaches of the GLGS comprise Fugong and Lushui Counties and to the west, Kachin State of Myanmar. The middle reaches of the GLGS ridge are in the northern part of the Tenasserim-Shan Block that extends south from the border with Gongshan County and the Himalaya Block. The GLGS main ridgeline skirts around the northern edge of Triassic metamorphic and sedimentary rocks (Trms) and runs south through the middle reaches between Precambrian (pC) on the east and Permian (Pr) and more Triassic metamorphic and sedimentary rocks (Trms). The Permian beds have more Tethyian affinities. To the west, the middle reaches of the GLGS are formed of Upper Paleozoic rocks (PZU). The actual ridge and the eastern flank of the GLGS are formed of Precambrian (pC) rocks. Small Carboniferous sedimentary (Cs) bodies pop out in the southern part of the middle section together with a larger Ordovician sedimentary outcrop, mostly grapholitic shales and metamorphic rocks (Osm), probably composed of flysch and paraflysch. At the southern end of the middle section, in Lushui County, occurs the end of the highest peaks where the ridgeline is above 3500m.

Tenasserim-Shan Block: Main Ridge of the Gaoligong Shan in Baoshan Prefecture.— In the whole of the southern part of the GLGS, the main ridgeline is in Baoshan Prefecture. To the east of the main Ridgeline, the rocks are mostly Precambrian (pC). There are also outcrops of undifferentiated Paleozoic age of in northern Baoshan Prefecture; south of these are rocks of Carboniferous and Permian (CP) age. Around Daxue Mountain in Longling County in the south of Baoshan Prefecture, there are Lower Paleozoic rocks (PZl). At the eastern foot of Daxueshan at the southern extremity of the GLGS main ridgeline, in southeastern Longling County, is a Jurassic (Jr) intrusion. The Nujiang River flows east of this in a Silurian and Ordovician (SO) region between Longling and Shidian Counties. The western slope from the main GLGS ridge in Tengchong County down to the height of the Tengchong Basin is again Precambrian (pC) south to the Longchuan River. To the south of the Longchuan River in Longling County, the western and southern slopes of the main GLGS ridge are Lower Paleozoic rocks (PZl).

Tenasserim-Shan Block: "NE-SW Trending Ridges" of Myanmar, and the counties of Tengchong and Longjiang.— Because these ridges do not have a collective name, hereafter I will refer to them as the "NE-SW Trending Ridges." Between Lushui and Tengchong Counties, the border of China moves away from the GLGS main ridgeline into Myanmar along a line of high "NE-SW Trending Ridges." These ridges extend from Lushui County Line near Lushui Town towards Jiangao Mountain and continue further for 140 kms into Yingjiang County. The tectonic influences in the southern part and to the west are considerably younger, and have a tighter fold and fault structure imposed on the area. In the Myanmar part of the GLGS, there has been less uplift. Below Lushui County, the rock types become numerous, with smaller outcroppings. In the southern part of the GLGS south of Lushui County, there are similar sequence motifs between the western branch of "NE-SW Trending Ridges" and the eastern branch of the GLGS main mountain ridge, although the rock sequences are not identical.

The westernmost flank of the "NE-SW Trending Ridges" is composed of rocks of Precambrian (pC) age. North of Tengchong County in Myanmar are Ordovician sedimentary and metamorphic (Osm) rocks, and southwest of these are more Carboniferous sedimentary (Cs) rocks. The Precambrian rocks return to be replaced further southwest by a small body of Cambrian (Cmsm) sediments and metasediments. Next to these Cambrian beds are more Ordovician sedimentary and metamorphic (Osm) rocks. The Precambrian makes up the south-westernmost corner of the GLGS ridges, except for inclusions of various igneous rocks. These parts of the "NE-SW Trending Ridges" are all in the Myanmar part of the GLGS.

The eastern flank of the "NE-SW Trending Ridges" in northern Tengchong County is Ordovician/Silurian (OS) and Permian (Pr). In western Tengchong and Yingjiang Counties, the eastern slopes of the "NE-SW Trending Ridges" are composed of Jurassic, Cretaceous, Triassic and other undifferentiated Mesozoic igneous rocks. West of these are small outcroppings of Tertiary volcanics, namely basaltic flows, andesitic lavas and pyroclastics, which overlie the Precambrian (pC) rocks that form the ridges of the "NE-SW Trending Ridges" in Myanmar. Just south of this, and slightly to the east in Yingjiang County, is an outcrop of Triassic (Tr) rocks along the border between Yunnan and Myanmar and the east flank of the "NE-SW Trending Ridges."

TENASSERIM-SHAN BLOCK: CENTRAL BASIN AREA OF YINGJIANG, LONGCHUAN, AND TENGCHONG COUNTIES.— The area between the eastern flank of the "NE-SW Trending Ridges" and the western flank of the main ridgeline of the GLGS is a raised area dissected by the Daying and Longchuan Rivers and their tributaries. Running NE-SW down the middle of the area is a spine of Ordovician Silurian rocks that separates the drainage of the two rivers. There is a series of N-S to NE-SW trending faults that split the central area of Tengchong County from the "NE-SW Trending Ridges" down to the Longchuan River. These open up the Tengchong Basin into a "fan - folded" series of mountainous ridges. The upper headwaters of the Dayang and Longchuan Rivers and their tributaries like the Mingguan River run along these fault lines. These can be best seen in Figure 10.

To the east of the Triassic igneous rocks, which occur along the border with Myanmar, there are Cambrian (Cm) and Silurian and Ordovician (SO) rocks, which extend towards the Longchuan River. To the east of the Longchuan River and north to the region of Tengchong Town, the area is mostly filled with Mesozoic beds of Jurassic-Cretaceous (JK) age, although these are extensively overlain by Neogene and Quaternary volcanic deposits and some younger volcanically-derived sediments. Tengchong County is characterized by a horseshoe-shaped opening to the south composed of Neogene sediments surrounding the Jurassic-Cretaceous mountains. The central region of Tengchong and eastern Yingjiang Counties is probably a zone of extension along the *en echelon* fault system that extends from here and further south. These younger faults cut across the older tectonic imprint (Guo et al. 2000). This extension would have exposed different rocks, as well as having allowed infilling by volcanic activity and for sedimentation to have taken place. These form the Quaternary Tengchong Basin, which appears to have subsequently uplifted. The Tengchong County pyroclastic cone field is not shown on Figure 10. It covers 600 km^{-2} and has erupted in five phases since the Tertiary. The nature of the eruption has changed from andesitic lavas in the early Tertiary to olivine-rich basalt lavas during the Pliocene through to the present. Daying Mountain Crater, 2865 m at 25.32°N, 98.47°E, last erupted in 1609 in an explosive eruption (Smithsonian 2005). The many preserved cones in this area could be a source of local adaptation and vicariant speciation of smaller organisms.

SOILS

The heterogeneity of soils in the GLGS is a consequence of the region's geologic diversity. The variety of host rocks, of very different ages, has given rise to many soil types. Although the remotely sensed data for this region are rather coarse (1:4 M), some different dominant soil types are observable (F.A.O. 2005). The existence of many host rocks with different suites of predominant minerals and a multitude of microclimates ensure a much greater diversity of soils on the ground than has been actually mapped. Within the study area, there exists a variety of soils with pH that varies from limestone-derived alkali types to acidic ones.

In the north, on the Himalaya Block, are found the following lithosoils, humic cambisol, and eutric cambisol west of the Dulong. From the Lhasa Terrane in the north along the entire eastern slope and ridge of the GLGS are calcaric fluvisols. The western slope from the northern to the northwestern part of Tengchong County has lithosoil and humic cambisol. These continue south from Tengchong County along the western slope of the main GLGS ridge. In southwestern Tengchong and northern Yingjiang Counties are orthic acrisols. A tongue between them, from the central part of Tengchong County south until the Longling County border, is composed of ferric acrisol. The very southern portion of the study area in Longling County exhibits a more developed orthic acrisol (F.A.O. 2005). The predominant agricultural soil types seem to be latosols, laterite, red earths, yellow earths, purple earth, and paddy soils (F.A.O. 2005). These are mostly alluvial terraces derived from the material of calcareous sedimentary rock, although the orthic acrisols are more acidic (F.A.O. 2005).

Soils evolve according to the latitude, elevation, temperature, and rainfall regime in which they are distributed. The same host rock minerals will give rise to different soils depending on the environment. Soil diversity, in turn, gives rise to floristic diversity and, ultimately, is another source of biodiversity. The soils at the two ends of the GLGS range are quite different. The great range of host rocks, elevation, latitude, and monsoon conditions within the GLGS gives rise to considerable soil diversity, hence contributing to the region’s biodiversity.

Hypsography and Landform Analysis

The size of physical geographic structures in the Hengduan Mountains is large and the component ranges or ridges can extend hundreds of kilometers. The GLGS are the most southerly reaching of the major ranges. Each range can have many names where it crosses ethnic boundaries. These names will be given from north to south and will be abbreviated to that shown in brackets. (1) the most easterly transverse ridge being the Ninjingshan-Yunling-Qingshuilangshan (Yunling Mountains), which form the eastern bank of the Lancang River; (2) between the Lancang and the Nujiang Rivers is the Taniantawenshan-Nushan Ridge (Nushan Mountains); and (3) the most westerly ridges of the Hengduan Mountains are the GLGS, with the “NE-SW Trending Ridges” of Jiangao Mountain extending into the Kachin State of Myanmar. The Shanngwa Range west of the Nmai and Tamai Nmai Rivers is not considered part of the Hengduan Mountains. Neither is the next ridge beyond the Mali River, the Kumon Range. The transverse ridge joining these Myanmar ranges in the north (the Patkai Mun Range between upper Myanmar and Assam) is not part of the GLGS.

Northern Limit of Gaoligong Shan.— The upper GLGS are separated from the eastern Himalayas by a major tributary of the Yarlung Zangbo River (Brahmaputra), the San Qu River (Luhit River in Assam, also known as the Sang Qu and Zayü Qu River further north). This tributary extends as far as the Zayü County and Zogang County border. A few kilometers to the north of the Zayü Qu rise the Parlung River and Yi’ong Zangbo River, other tributaries of the Yarlung Zangbo River (Brahmaputra). North of this area, the Nushan Mountains loop over the northern end of the GLGS. The most southerly of the mountain ranges of the Tibetan Plateau, the Nyainqetanglashan, are just north of the Yarlung Zangbo River (Brahmaputra). These are separated from the GLGS by a river that is a tributary of the Nujiang River to the east. This tributary almost joins the drainage of the Parlung and Yi’ong Zangbo Rivers south of Bomi Town to the upper course of the Sang Qu River (Luhit). These mark the northwestern river boundary of the GLGS. Together they form a high valley between the Nyainqetanglashan and the GLGS, near Baxoi Town, well south of Qamdo. At Baxoi Town, the most southerly road from Sichuan Province and Lijiang City, Yunnan passes into eastern Zayü County towards towns of Gyigang and Zayü. This is just north of the Diphu Pass above the headwaters of the Tamai Nmai River. The Diphu Pass marks the boundary of the Patkai Range and the GLGS. All these structures combine to make a break in the GLGS that clearly separate it from its higher neighbors. Many of the peaks in the upper

Nushan Mountains and eastern Himalaya are 7000 m plus. These physical features can be seen in the elevation perspective model (see Figs. 11–13 and the satellite image, Fig. 14).

Southern Limit of Gaoligong Shan.— The southern boundary of the GLGS is clearly defined. The GLGS end where the main ridge ends in an encirclement by the Nujiang River to the east, south and west, and its tributary the Supa River. The Supa River rises off the northwest side of the main GLGS ridge on Daxue Mountain- near the village of Zhen'an. The Supa River runs northeast of the city of Longling to join the Nujiang River north of Pingda. This tributary is almost met by the Mangshi River, a tributary of the Longchuan and Irrawadi Rivers, which rises just southwest of Longling Town. To the west of this promontory are the NNE-SSW ridges of the low mountains within Luxi County that meet the GLGS ridge just north of Longling Town. These are separated from the GLGS by a saddle between the aforementioned rivers. These physical features can be seen in the elevation perspective model (Figs. 15–17) and satellite image (Fig. 18).

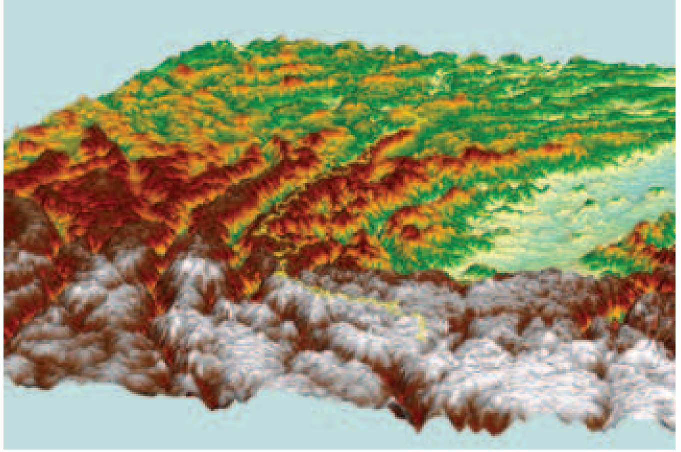


Figure 11. Perspective view of the Gaoligong Shan from the north looking towards the southeast. Main ridgeline shown as a yellow line.

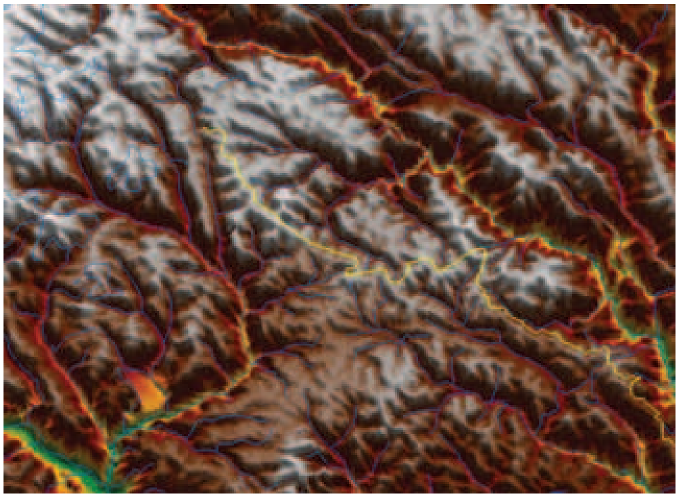


Figure 12. Close-up perspective view of the northernmost Gaoligong Shan (GLGS) looking from the west looking northeast, note the valley of the Luhit-Sang Qu incising into the GLGS and forming a near connection of the Luhit-Sang Qu-Parlung Zangbo and Nujiang drainages. Main ridgeline shown as a yellow line.

Land Form of Gaoligong Shan.— The elevational nature of physical features is the result of the interplay between tectonic, geologic, and natural erosional forces. High mountains are formed by tectonics and are maintained either by hard rocks and slow erosion, ongoing tectonic actions, or both. Harder rocks make for steeper slopes and more bare outcrops. Rain, wind, and ice work together with gravity to reverse tectonic uplift. The steep mountains in this area result from ongoing uplift, and the hard nature of their rock. Despite the fact that rainfall in the area is considerable and biotic productivity high, soil formation and rock decomposition are unable to wear down the mountains fast enough.

As noted above, the majority of high ground is formed from the Precambrian rocks, mostly metamorphics. The main ridge of the GLGS runs due N-S and is composed primarily of these rocks. To the east of the ridge is the Gaoligong Shan Fault, which forms the bed of the Nujiang River (see Fig. 4). The action of the fault causes enough brecciation and mylenation of the country rock to enable the river to carve a gorge that is thousands of meters deep and form a non-glacial "U-Shaped" valley. The easterly side of the Nujiang River is the Qintang Terrane composed of primarily younger rock. It also has a large fault structure river complex along the course of the Lancang River (see Figs. 3–4).

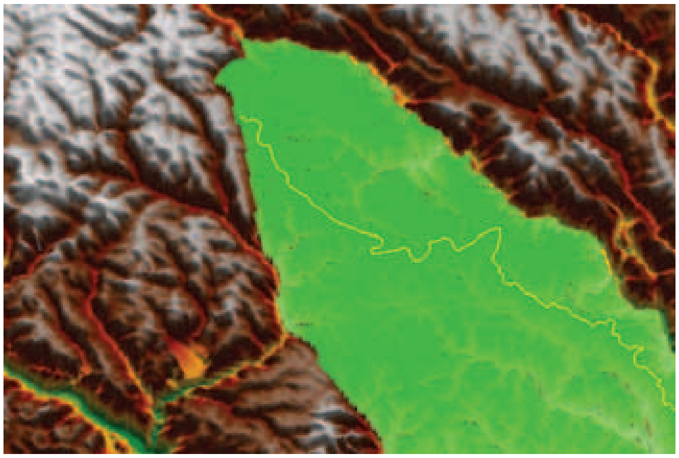


FIGURE 13. Close-up perspective view of the northernmost Gaoligong Shan, showing the area included in the GLGS in green. Main ridgeline shown as a yellow line.

The non-glacial "U-Shaped" valley of the Nujiang River is formed by uplift. The land is currently being uplifted more in the west. This forces the river towards its east bank and hence undercuts it, thus, widening the valley floor. On the western bank in many places can be seen a bench that forms about halfway down from the ridge (personal observation, but it also can be seen on the elevation models; this bench is just visible in Fig. 15.). Most of the roads and towns of the Nujiang River valley are located on this bench and on the western bank in general.

FIGURE 14. Space Imagery, taken looking ENE along the Luhit-Zayü and Sang Qu Rivers towards the Nujiang. Note the treeline at the headwaters of the Dulong in the south (right). Image courtesy of the Image Analysis Laboratory, NASA Johnson Space Center (NASA 2004c).

SHAPE OF THE MAIN GAOLIGONG SHAN RIDGE.— The mountains of the GLGS and southern Hengduan Mountains in general rise from the south to reach impressive heights in the north. Just north of the GLGS across the Luhit-Zayü Qu-Sang-Qu drainage, is a large glacier field with peaks rising above 5000 m. This glacier is shrinking. The main GLGS ridge changes height from the 3001 m peak of Daxue Mountain Longling County at the southern terminus, down through a small saddle at 1930 m the lowest point of the ridgeline, to rise steadily upwards to 4500 m proceeding north as shown in Figures 19 and 20. The maximum height of any peak in the study area is 6318 m southeast of Zayü County. The course of the Nujiang River by comparison rises only 1500 m from 600 m in the south to around 2100 m towards the north of the study area. Therefore, the depth of the channel is much greater in the north than it is in the south. The valley is more than 3000 m deep at most points in the north and almost always more than 2000 m deep throughout the GLGS.

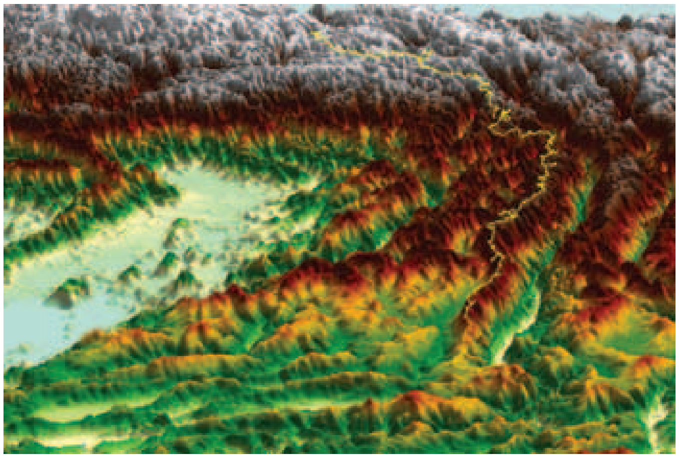


FIGURE 15. Perspective view from the southeast looking along the drainage of the Nujiang. Main ridgeline shown as a yellow line.

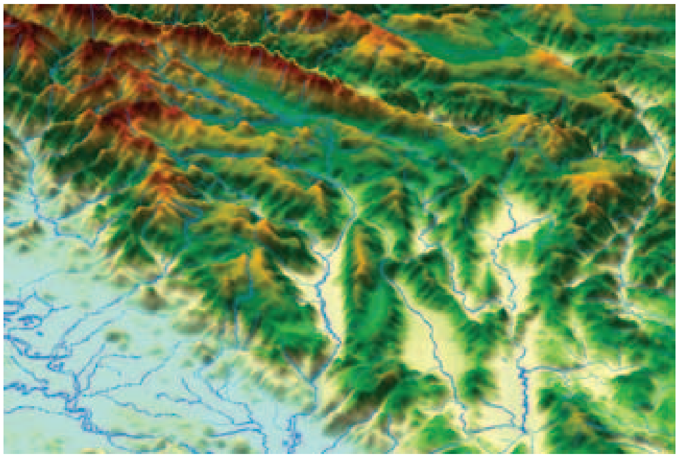


FIGURE 16. Close-up perspective view of the southernmost Gaoligong Shan, GLGS main ridgeline shown as a yellow line.

The GLGS ridge is traversed by only a few passes. In the south is the pass to Longling County that is the main route to the Myanmar border. Luoshuidong Pass, between Bawan and Tengchong Towns, provides another vehicle route to Myanmar. Pianma Pass is near Lushui Town. Other passes include the E'ga Path just north of Lukiu Town, the Yaping Path north of Fugong Town, and the Dazhu Path a little south of Gongshan town. A full vehicle road has been built through the high Dulong Pass in the north. Lastly, the Zayü County and Zogang County border road from Sichuan to Lhasa forms the northern limit of the GLGS.

CROSS-SECTIONS THROUGH THE GAOLIGONG SHAN.— The cross-sectional profiles of the GLGS area were taken from the low point at the easternmost edge of the study area in the west to the Nujiang River in the east. These profiles are remarkable for showing the steep walls of the peaks and deeply incised river valleys. The northernmost profile (Fig. 21) from the Zayü River to the Nujiang River shows uniformly high ground. The cross-section of Bingzhoulou Town, Gongshan County (Fig. 22) has some interesting features. To the east is the land that is lower in the upper Nmai-Irrawadi Rivers and generally lower across the eastern extreme of the Himalaya Block. The harder rocks of the tectonically deformed Lhasa Terrane stand very high. The Dulong River cuts a swathe through them almost as deep as that of the Nujiang River 's valley on the other side of the main GLGS ridge. To cut this deep, there may be another fault active, although it is not shown on small-scale maps available. The Nujiang River runs in a very deep and steep valley at this point.

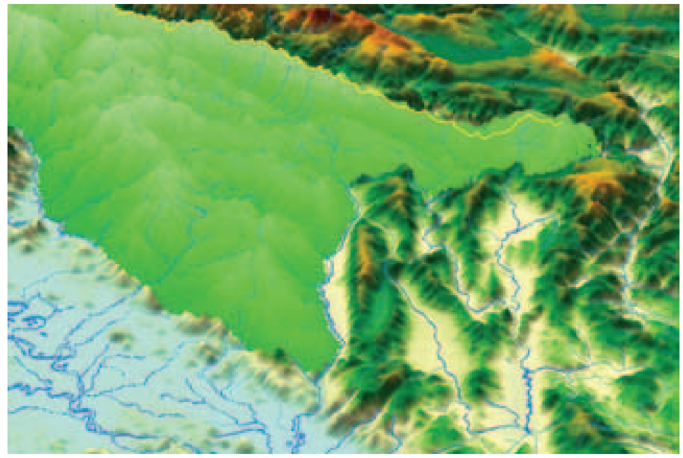


FIGURE 17. Close-up perspective view of the southernmost Gaoligong Shan, showing the study area included in the GLGS in green.

The next profile at Lukiu Town (Fig. 23) is across the area where the rocks are more uniform Paleozoic and form the "NE-SW Trending Ridges" that extend towards Jiangao Mountain from the main ridgeline. The main GLGS ridge stands higher and there is little penetration of the rivers that here tend to run either north or south from the "NE-SW Trending Ridges". There is little in the way of river erosion in the mountains here because of their smaller catchment basins. Although the Nujiang River flows in a steeper valley than at its outlet, it is at an elevation little changed from its exit from the GLGS. The most southerly profile, through the top of Tengchong (Fig. 24), is from where the GLGS has been opened by N-S trenches along which flow the Longchuan River to the east and the Dayang River in the West. The southern profile is longer and lower than the rest and shows a series of peaks and

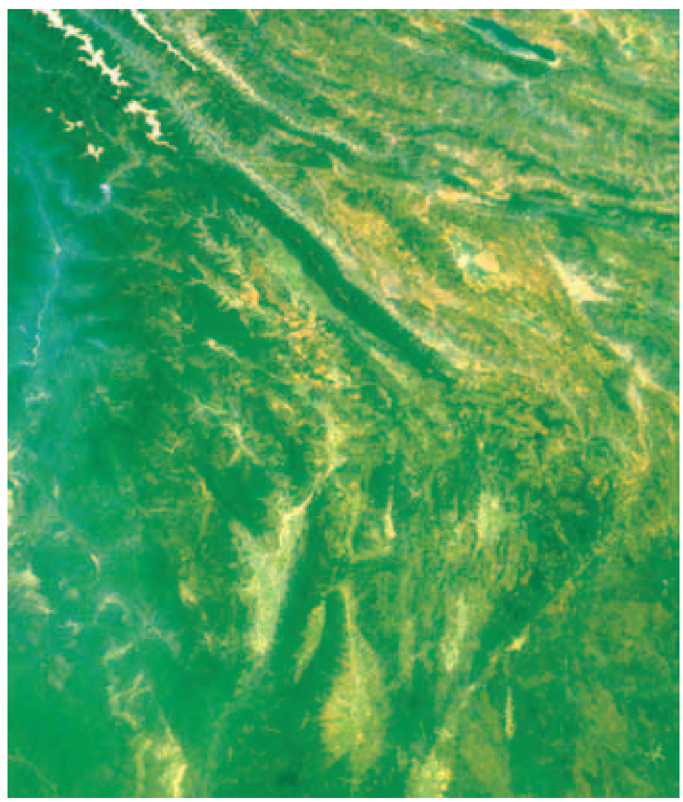


FIGURE 18. Space Imagery, taken looking east along the Longchuan River towards the Gaoligong Shan Ridge. Image courtesy of the Image Analysis Laboratory, NASA Johnson Space Center (NASA 2004b).

valleys where the tributaries of the Irrawadi River have cut into the Tengchong County region. These rivers also arise within the GLGS so have less volume or down-cutting potential. Uplift in this area is mostly lower than it is further north or it has been reduced by extension. The Nujiang River in the south is at about the same elevation as the Burmese Plain.

Slope and Slope Direction or Aspect.— What is unusual about the GLGS area profiles is that the deep valleys are cut into rocks able to support steep slopes. The average slope angle for the whole study area is high and is much higher in the north (see Fig. 25). There are very few flat areas of large size in the GLGS.

The N-S trending mountains of the main ridge of the GLGS together with the "NE-SW Trending Ridges" in the lower part both have unusual face aspects (see Table 1). Aspect is determined from the average direction that a slope faces relative to the sun. Throughout the study area, there is a paucity of north or south-facing slopes. The east-facing slopes are smaller than those to the west because they are steeper. There are many facing to the west and northwest and then again to the northeast and then east.

This fact, combined with the angle of the slope, means that many of the surfaces in the GLGS receive lower intensities of insolation relative to an ideal "suntrap." Maximum insolation is received on a slope that is facing south and that is raised to the same azimuth as the sun; in the GLGS this is about 25 degrees. The low energy capture seen in the GLGS is because not much of the energy of the sun is trapped by the slopes that face away from the sun. When the sun shines on a surface that is steeply inclined and angled away from the sun, its energy is dissipated over a much larger area. The steep terrain will also affect the local sunrise, or sunset, or both, especially in a "U-shaped" valley. Therefore, the day length of direct sun, and hence the biotic productivity, will be much curtailed in the steep, "U-Shaped" valley bottoms. These factors produce temperate conditions, which prevail further south in the GLGS than in most places in the world. The magni-

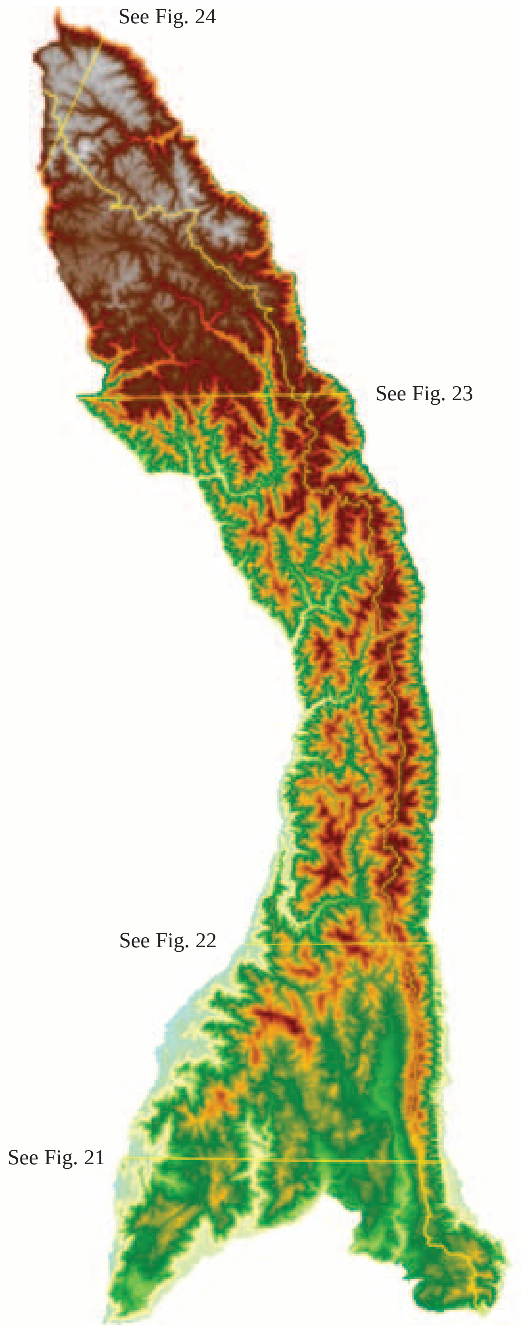
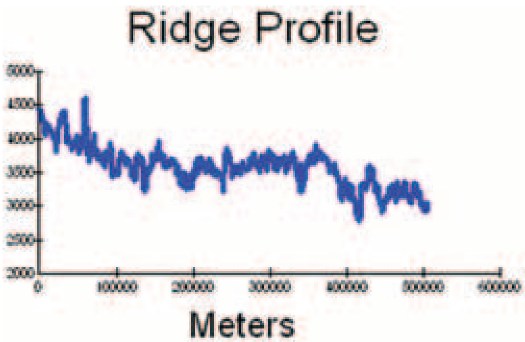
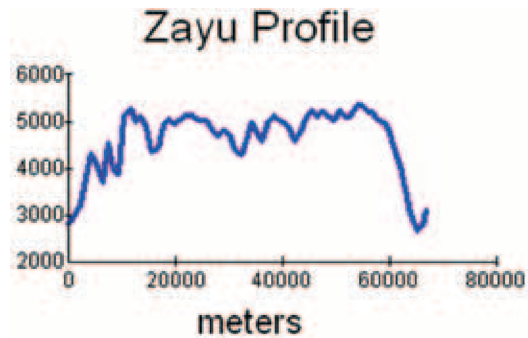
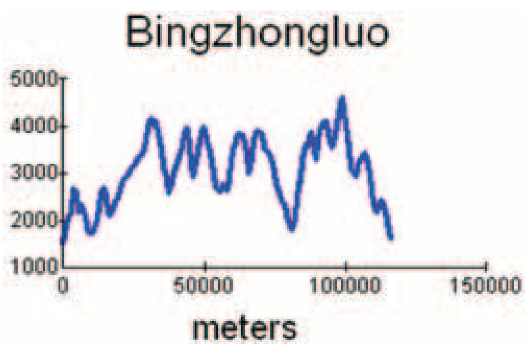
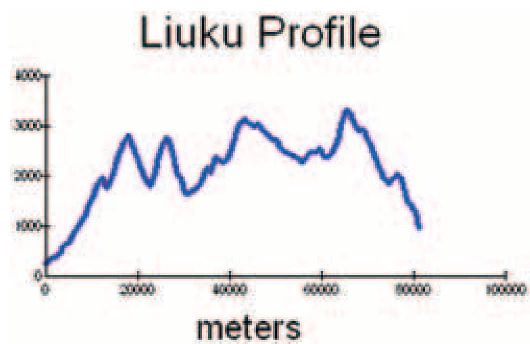


FIGURE 19. Plan of cross sections. See also accompanying figures 21ough 24









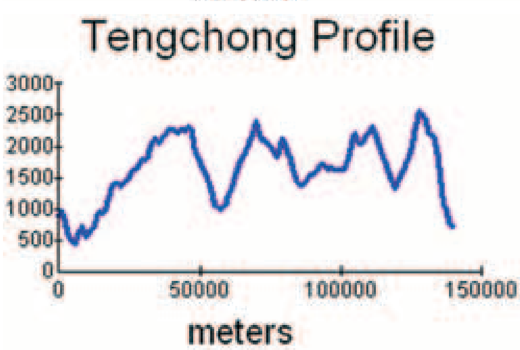


FIGURE 20. Profile of the main Ridgeline.

FIGURE 21. Cross section at Zayü.

FIGURE 22. Cross section at Bingzhongluo.

FIGURE 23. Cross section at Liuku.

FIGURE 24. Cross section at Tengchong.

tude of this effect can be calculated using advanced GIS analysis but this is too detailed to be carried out here.

LANDFORMS AND BIODIVERSITY.— The unusual physical features of the GLGS and their great latitudinal and elevational range provide for the easy maintenance of biodiversity. The north-south conduit enables exchange with the high mountains and plateau to the north. This provides a corridor for temperate animals to migrate southward during harsher conditions. The high elevation equally acts as a barrier for warm-adapted organisms seeking to migrate from west to east or vice versa. The deep, large rivers also act as barriers. The lack of south-facing slopes and the deep valleys combine to make the area relatively more temperate than land at similar latitudes. Cold

TABLE 1. Aspect faces of the GLCS.

Aspect Direction	*Plan Area %*
North	5.5
Northeast	13.0
East	15.5
Southeast	12.7
South	11.2
Southwest	13.5
West	16.8
Northwest	11.8

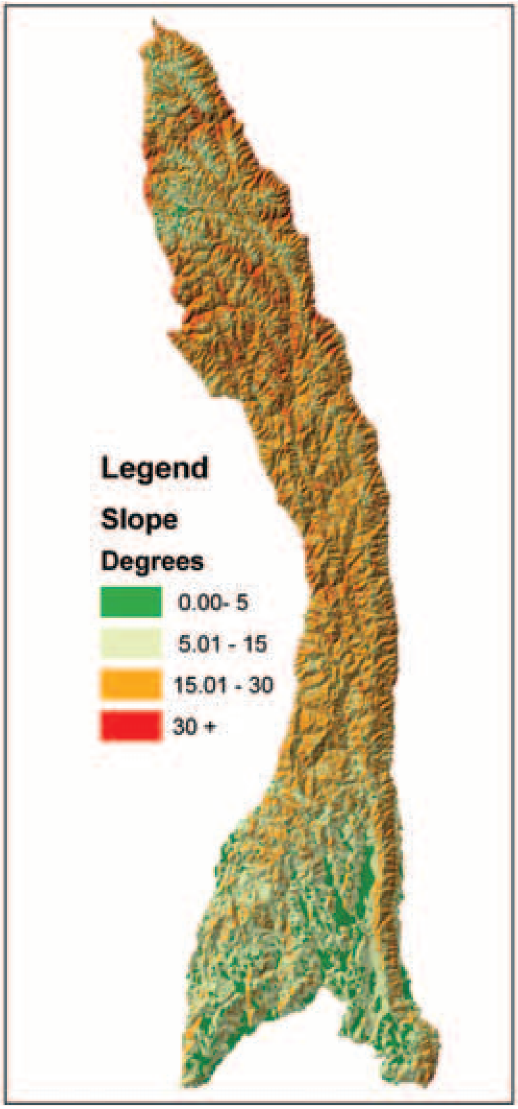


FIGURE 25. The plan view showing the Average Slope of the Gaoligong Shan.

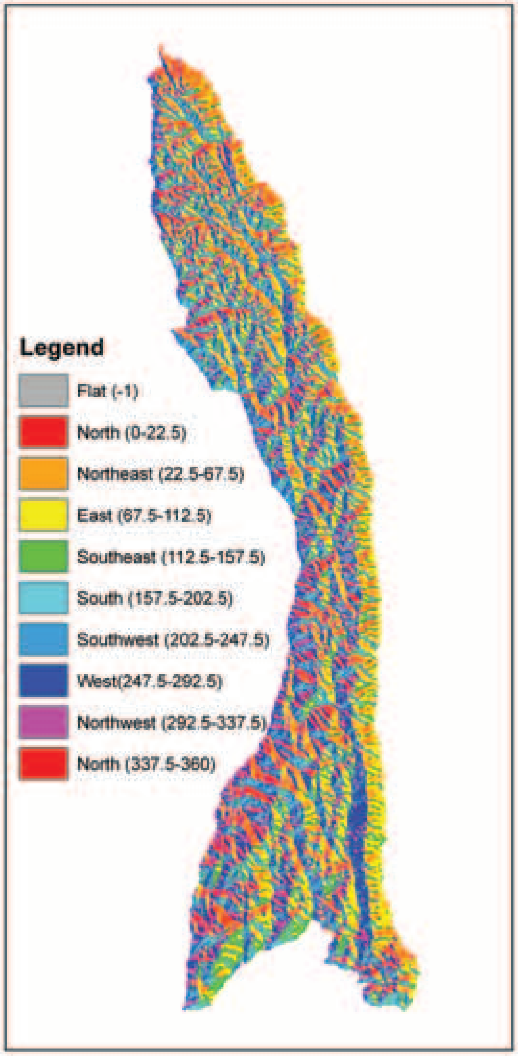


FIGURE 26. The plan view showing the Aspect of the Gaoligong Shan

air can flow into the valleys from high ground surrounding them. These "frost traps" lead to frequent fogs and temperature inversions. The high hills with damp air coming from the west have significant amounts of rainfall on their western slope. These conditions can lead to Foehn heating as damp air is forced over the ridge by the prevailing southwesterly winds. The unusual physical features combine to multiply the number of opportunities for microclimates. Furthermore, these physical features are not fixed in time but are dynamic due to the nature of the underlying geological processes. This dynamism provides ample opportunity for adaptation and vicariant events to further promote biological diversification.

Hydrology

The large N-S flowing rivers of the Hengduan Mountains are of major importance to East and Southeast Asia. The rivers are long, stretching from the Tibetan Plateau to three different seas, the Yellow Sea, the South China Sea, and the Andaman Sea in the Bay of Bengal. Because of their length, each one of the rivers can have many names where they cross ethnic boundaries. These names will be given from north to south and in this paper they will be abbreviated to those shown in brackets, which are their names as used in the GLGS region. These are not necessarily the rivers' more widely used common English names. When using the abbreviated name the intention is for the reader to think of the whole drainage not just that portion in western Yunnan.

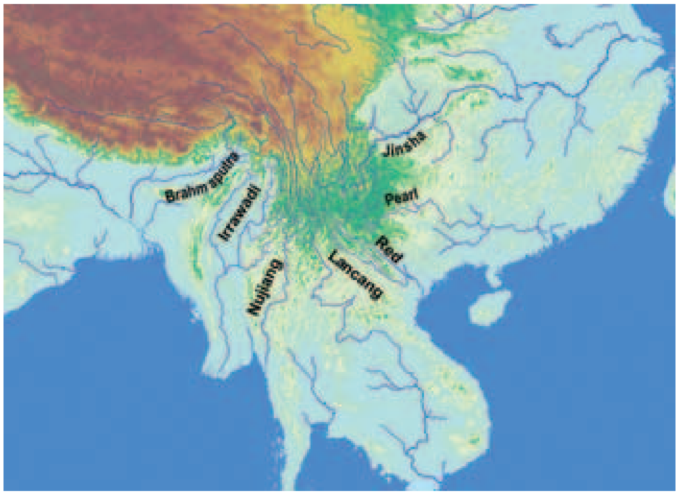


FIGURE 27. Drainage pattern of major rivers through the Hengduan Mountains emphasizing the interdigitated nature of the drainages. Data from Hydro1K (USGS 2000).

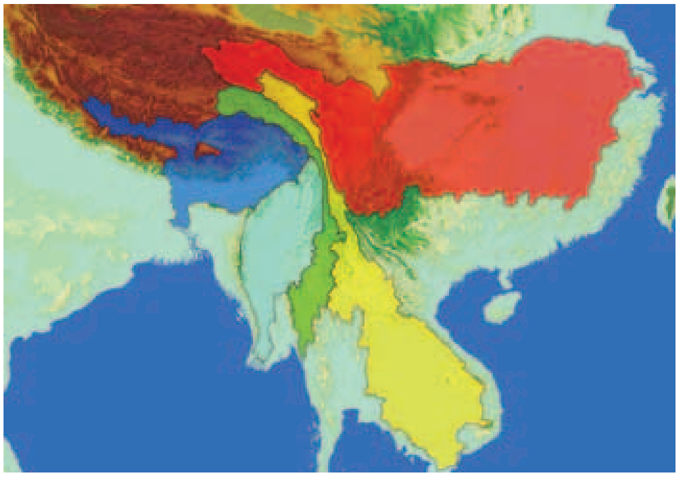


FIGURE 28. The modern drainage catchment basins data from Hydro 1K (USGS 2000).

From east to west the main rivers are the Wulanmulunhe-Muluwusuhe-Tongtianhe-Jinsha-Cang Jiang-Yangtse River (Jinsha River), the Lancang-Mekong River (Lancang River) and the dNgul-chu-Naquehe-Nujiang-Thanlwin-Salween River (Nujiang River). An important tributary of the Nujiang River is the Nanding River, flowing just below the southern end of the GLGS. Starting in China and flowing into Myanmar are the south-southwesterly flowing tributaries of the Irrawadi. They are, from north to south, the Dulong-Taron River joins the Nmai Hka River (Dulong River), Dayang River, Wanding River and Longchuan-Shweli Rivers (Longchuan River). In the southern part of western Yunnan, just to the west of the GLGS, is the source of the Lishehe-Yuanjiang-Hong River (Red River) rising between the Lancang and Jinsha Rivers and its large tributary is the Black River. In the north are the Yarlung Zangbo-Brahmaputra River (Yarlung Zangbo River) and its two easternmost tributaries the Luhit-Zayü Qu-Sang Qu River (Sang Qu River) and the Yi'ong Zangbo River and Parlung Zangbo River. These form the northwest border of the GLGS. They flow to the Bay of Bengal in the west.

It must be strongly stressed that the drainage pattern around the Hengduan Mountains is complexly interleaved. This complicated pattern interdigitates to cause formidable barriers (see Fig. 27). To the north the Yarlung Zangbo River (Brahmaputra)and its easternmost tributaries form a natural barrier. The Yarlung Zangbo River (Brahmaputra) loops in a big bend from flowing east for hundreds of kilometers to turn south, then west, and on to flow southwest to the sea. This loop forms a major obstacle to migration or dispersal. Any migration from the west would be caught in this big bend and would have to back track or go north to get around it. From about the 10 Mya, the climate and ecology to the north would have been very different than that in the big bend area (Jablonski 1998). Today the barrier is complete as the ecology changes from humid tropical to temperate to alpine tundra within a few kilometers along the hills of Arunchal Pradesh. The Jinsha River makes a similar big bend in the opposite direction flowing to the south then east, and then north to turn eventually east again to the Pacific. Between these two, the Yarlung Zangbo (Brahmaputra) and Jinsha Rivers, the following Rivers, Lancang, Nujiang, the Dulong Nmai, and Irrawadi proper, all flow north-south. To the east, starting near the big bend of the Jinsha River is the source of the Red River and to the west of the Red River is its tributary the Black River that runs parallel to it. The Black River rises near to the Lancang River just east of the GLGS. Further east of the source of the Red River is the source of the Pearl River. These form NW-SE river drainages that cut off the approach to the Hengduan Mountains from southern China. The approach from due south to the GLGS (but not the Nushan Mountains) is cut off by the Lancang River and Nanding River and by the eastward flowing section of the Nujiang River. The approach to the Hengduan Mountains from the southwest is blocked by the Nujiang River and the Shweli-Longchuan River, Dayang River and other tributaries of the Irrawadi River. The approach from the west is blocked by the Yarlung Zangbo River (Brahmaputra), Irrawadi River, Tamai Nmai River, and the Dulong Nmai Rivers. West to east migration would be the most difficult because of the need to cross rivers and change elevation across the ridges of western Myanmar. The most isolated of the Hengduan Mountains ranges is the GLGS. The GLGS is highly isolated by its almost contiguous surrounding rivers.

The rivers of the Hengduan Mountains make them exceedingly good biological barriers to terrestrial organisms (Mackinnon et al. 1996). For many terrestrial organisms, migration into the GLGS or dispersion from them is very difficult. Fording the rivers is not easy because they run in very deep, precipitous valleys cut into the mountains. The ridges of the Yunling Mountains, Nushan Mountains, and the GLGS are steep, and traversing them requires agility and considerable environmental adaptability. The steepness of the riverbeds makes the current strong; some of the rivers have dangerous category five rapids. The rivers also carry high volumes of water and experience occasional catastrophic floods.

Biodiversity Implications of the Hydrology Network.— It can be seen from Figure 28 that within the GLGS very little of the area belongs to the Nujiang River watershed. Most of the land area falls within the Irrawadi system. This can be inferred from the ridge profile as well. The Irrawadi is a much newer system than the Nujiang River because it does not drain north of the contact zone with India. A number of factors influence aquatic diversity, including age, temperature, and current.

In the past, these rivers would have been even more of a barrier than are today. The evidence strongly suggest that the larger rivers predate the closing of the Tethys Sea. The present rivers and the paleo-rivers drained regions as far north as the Kunlung Mountains an area north of the paleo-shore of the Tethys Sea.. Before the formation of mountains, there was no rain shadow. The mountains rose in sequential thrust belts developing in the west of the GLGS as the Indian Plate impacted the Eurasian Plate. Therefore, the paleo-rivers would have had to drain the area that is now behind the Himalaya. The area to the north is now in the Himalayan rain shadow. The rain shadow was absent throughout most of the history of these rivers. Therefore, they would have captured larger volumes of water than the impressive amounts they do today (see Fig. 28). The final uplift of the Himalaya to their current elevations has been in the last 7-3 million years of the 55 million years since India first contacted Eurasia. It was not until after this time that the rain shadow was extensive enough to cause aeolian erosion and loess started to be blown from the rising Tibetan Plateau. The main north-south flowing rivers divide the area biogeographically and socially. The antiquity of the rivers has insured that the areas divided by them accumulated considerable pre-Neogene diversity. Their large size and long length provide opportunity for aquatic diversity to evolve in multiple habitats. The changing levels in the rivers gave rise to fast currents and rough water, which have limited aquatic diversity and prevented migration and dispersal of endemics, while opening the possibility of local adaptation. Their encirclement of the GLGS has created one of the most isolated regions in the world, with a high number of endemic species. Another, biologically significant aspect of the large rivers is that they have provided unusually deep and secluded valleys, which have acted as refugia. Species can move up and down elevational gradients to maintain thermal equilibrium during periods of rapid temperature fluctuation. The unusual climates of the river valleys have promoted the successful survival of species extirpated elsewhere. The depth of the valleys effectively limits biotic productivity through reduced insolation relative to latitude and high humidity reduces light levels further. The rivers buffer extremes of temperature due to cloud and fog formation from high humidity. The river valleys allow warmer wind from the south to penetrate far to the north during the winter monsoon.

Definition of Gaoligong Shan

Previous Definitions and Biogeography

The GLGS have been previously defined by several workers and environmental organization. Some definitions use the physical features to define the area. The best previous definition of the GLGS is that of Li: “The Gaoligong Shan is: the mountain range between Nujiang River and Irrawadi River, it is located in N 24°40′–28°30′, covering totally 111,000 square kilometers, which includes the whole territory of Tengchong County, part but most of Longling, Baoshan, Lushui, Gongshan County area, besides N Burma area (Kachin State)” (Li 2000:vii). Although, this definition has a straight-line, latitudinal cutoff in the north and omits the SW ridge in Yingjiang County it covers most of the GLGS as it is defined in this paper. Lan and Dunbar define the Gaoligong Shan Region differently: “The region referred to as Gaoligong Shan here includes all lands west of the Salween (Nujiang) River in Yunnan. The entire region is situated at the southern edge of the eastern Himalayas, the westernmost region of Yunnan Province, and in the western part of the Trans-Himalayan Mountains” (Lan and Dunbar 2000:275–276). In practice, however, they used an essentially political definition; therefore, all of the land in Myanmar including the interconnected “NE-SW Trending Ridges” and the territory on the western side of the main GLGS main ridgeline in Lushui and Fugong Counties were excluded. Although politically this was not unreasonable, natural phenomena do not follow political constructions. The World Heritage listing definition of the Three Parallel River Region of Yunnan includes only the northern part of the GLGS ending at Lushui County at the end of the very highest ridgeline. It emphasizes the role of the gorges more than that of the mountains (UNESCO 2003). The GLGS are included in the recently revised and corrected definition of “Mountains of Southwest China, Biodiversity Hotspot” used by Conservation International (Conservation International 2005). However, it includes the whole Hengduan Mountains and Longmen Mountains and so is of little use in discussing just the GLGS.

Other workers defined the area according to biogeographical or ecological considerations. The Hengduan Mountains subalpine conifer forests zone (PA0509) used by the World Wide Fund for Nature (WWF) does not extend so far south or west as does the GLGS (Carpenter 2001a). The part of the GLGS region is included in Nujiang River Lancang Gorge Alpine Conifer and Mixed Forests (PA0516). "The Nujiang River Lancang Gorge ecoregion includes the valley system through which rivers flow down from the Tibetan Plateau into the tropical hills of northern Indochina" (Carpenter 2001b). This definition missed the western slopes of Myanmar that are in Northern Triangle subtropical forests (IM0140) (Than et al. 2001). The GLGS are spread between three different ecozones according to the WWF. Similarly, the GLGS are split by many other biogeographers and ecologists. Because of its elevation and latitude, the northern part of the GLGS is often classed as part of the Tibetan Plateau; the middle reaches with Yunnan Plateau; and the southern parts as subtropical forest continuous with that of Myanmar or Thailand (Mackinnon et al. 1996; Zhao 1986). The area of western Gongshan County and Fugong County is included in the Himalayan Southern Slope Region by Zhao (1986). Mackinnon (1996) includes most of the GLGS in the Paleartic Realm, Southwest China Province but makes a new subunit for the Nujiang River Lancang Gorges Area 39f, the middle of the GLGS is within sub-unit Yunnan Plateau 39a, whereas, the south is in the Indo-Malayan Realm, Tropical South China Province, sub-unit 10 the Thailand Subtropical Monsoon Forest (Mackinnon et al. 1996).

The Definition of the GLGS as Used in this Paper

The name GLGS refers to mountain features, so it is best that it is defined by its physical geography. Therefore, the GLGS comprise the contiguous mountain ridges between the drainages of the Nujiang River (Salween River) and the Irrawadi River systems. In the north beyond the Irrawadi River headwaters the GLGS are between the Sang Qu River (Luhit), a tributary of the Yarlung Zangbo River (Brahmaputra) and the Nujiang River (Figs. 12–14).

The contiguous ridges were defined as land over 1800 m. The areas above 1800 m form interconnected ridges that join the Hengduan Mountains. This elevation was chosen as it is the cutoff of the "Monsoon Evergreen Broad-Leaves Forest" belonging to the *Castanopsis hystrix* and *Castanopsis echidoncarpa* forest type. This forest is distributed in moist ravines, on the east-facing slope in the southern part of the region, at elevations rising to but not above 1800 m (Li 2000). Using "Monsoon Evergreen Broad-Leaves Forest" for choosing the elevation for the ridges was helpful for two reasons. First, there are no barriers between "Monsoon Evergreen Broad-Leaves Forest" within the Gaoligong Shan and the same zone that spreads throughout a large area to the south and east covering broadly most of Myanmar and much of Southeast Asia. Second, above 1800 m the ridges are complete and continuous within the GLGS (Fig. 29).

In areas where there is neither a river barrier nor an extending ridge, the study area was curtailed at the 1000 m mark. This was necessary for only two small areas to the southwest of the "NE-SW Trending Ridges." Here the essentially flat area north of the Dayang River and south of the next tributary of the Irrawadi extend far into Myanmar before joining the Irrawadi. This area is also extensively farmed.

The Dayang River was followed as the boundary in the south until it turned to the north near Nansong Town. Then the boundary was cut across the top of Lianghe County from Nansong to Pingshan and the Longchuan River. The Longchuan River provides the boundary of the GLGS until it reaches the western slope of the GLGS ridge. Here the Longchuan River turns north along the border of Tengchong and Longling Counties. The final section of the GLGS southern border is encompassed by a line following the lowest contours round the end of the Mangshi River until it reaches the first tributary of the Nujiang River the Supa River. The Supa River rises north of Zhen'an Village and runs from the northwest slope of Daxue Mountain on the GLGS ridge to travel west, before traveling south, southeast, and then eventually east to encircle the southern point of the GLGS main ridge. This definition provides the shortest route between the Nujiang River and Irrawadi drainages that encompasses the entire ridge complex.

As per the discussion of the GLGS above, the low ridges to the southwest of the GLGS, low ridges in Yingjiang Lianghe Counties and those in western Longling that extend into Luxi County could be argued to be also a part of the Gaoligong Shan. However, the decision not to include them was based on hypsographic arguments alone. The ridges are not contiguous but are separated by low points or watershed boundaries. These lower ridges all belong to the Irrawadi system not the Nujiang River drainage system. Therefore, they lie outside of the watershed between the Nujiang River and Irrawadi. The Nujaing-Irrawadi drainage boundary is at the Longchuan River, which forms the border between Longchuan, Lianghe, and Luxi Counties and this boundary is north of those County's southernmost ranges.

The Nujiang River and Irrawadi River Valleys provide the cutoff points to the Gaoligong Shan as these are the lowest points. The GLGS are defined as a hypsographic feature. On the opposite bank of these river drainages the slope must, by definition, rise again. Therefore, the contiguous slope runs only between the rivers.

FIGURE 29. Map indicating all contiguous land over 1800 m in brown.

The main observations about the physical features of the GLGS are presented in Table 2.

CONCLUSIONS AND IMPLICATIONS FOR BIODIVERSITY

The Hengduan Mountains are a haven of biodiversity. The GLGS are the most isolated of the ranges of the Hengduan Mountains, due in large part to the drainage pattern. The potential of the GLGS for preserving biodiversity, as well as causing it, may be unique in Eurasia. The position of the GLGS in Eurasia enables them to be a reservoir of biodiversity for all of East Asia.

The GLGS straddle the Indo-Malayan and the Paleartic biogeographic realms and have been split into different biogeographic provinces by different workers. The descriptions of these provinces have not caught up with modern understanding of tectonics, leading to considerable confusion. The physical geography of the GLGS is the result of tectonic activity. All of the plates form-

TABLE 2. General Facts about the Gaoligong Shan

1. Maximum Linear Length along Main Ridge 585 km.
2. Minimum Linear Length along NE-SW Ridge 565 km.
3. Maximum Width 150 km in the south near Tengchong.
4. Maximum Width 100 km in the north near Gongshan Town.
5. Minimum Width 48 km near Fugong Town.
6. Bounding Box 97.47°E, 29.51°N and 99.03°E, 24.37°N decimal degrees.
7. Maximum Elevation 6318 m southeast of Zayü County.
8. Minimum Elevation 183 m Drainage of the Nmai River in Myanmar.
9. Minimum Elevation 620 m Drainage of the Nujiang River.
10. Mean Elevation 2638 m.
11. 62% of the land lies between 1500–3500 m.
12. 11% of the land is above the approximate tree-line of 4500 m.
13. Only 7.8% of the surface area is essentially flat (slope < 3%).
14. Mean slope for the whole area including the drainages is 13.4%.

Elevation Band	*Surface Area In Plan View km^{-2}*	*3d Surface Area Along Slope km^{-2}*	*Area in Band 3d Surface km^{-2}*	*% of Total 3d Area in Band*
0–499	41937	44147	279	0.63
500–999	41661	43867	1642	3.72
1000–1499	40056	42226	4078	9.24
1500–1999	36114	38147	8395	19.02
2000–2499	28007	29753	8453	19.15
2500–2999	19951	21300	6040	13.68
3000–3499	14309	15260	4520	10.24
3500–3999	10133	10740	3491	7.91
4000–4499	6891	7249	3334	7.55
4500–4999	3763	3915	3112	7.05
5000–5499	778	803	798	1.81
5500–5999	4	5	5	0.01
Total Area	41937 km^{-2}	44147 km^{-2}		

ing the GLGS are from Gondwanaland, but some of them have been in contact with the Eurasian Plate (Paleartic Biogeographic Realm) for upwards of 200 million years. The Indo-Malayan region is physically an assembled unit composed of units of vastly different ages. For a review of current usage of China's zoogeographical zonation refer to Mackinnon et al. (1996).

Tectonic forces themselves create a genetic "melting pot" for biodiversity. The paleo-separation and subsequent re-aggregation of plates from Gondwana and the collision of plates from different paleo-continents laid a foundation of high genetic diversity. This was accentuated by the region's long and complex uplift history. Slowly rising landmasses provided opportunities for adaptive changes in resident organisms. Geographic isolation due to the tectonically driven incision of the landmass by massive rivers has further enhanced biodiversity through vicariance.

Tectonic forces give rise to a diversity of host rock and soil types. This diversity has further enhanced the potential for increased biodiversity. The great range of host rocks, elevations latitudes, and monsoon conditions within the GLGS has given rise to considerable soil diversity. This, in turn, gives rise to floristic diversity and heightened biodiversity at all higher trophic levels. Adaptive forces related to tectonics operate at both the macro as well as the micro landscape scale. The many preserved volcanic cones in the area of Tengchong resulting from tectonic melting, could be a source of local adaptation and vicariant speciation of smaller organisms as is known from other volcanic fields, e.g., *Drosophila* on Hawaii.

SUMMARY

摘要

高黎贡山是由不寻常的地质连锁成形运动构成的一个独特地区。同其它相近纬度的地区比较，由于缺少南向坡面和具有较深的山谷，它的气候更为温和。冷空气从周围的高地注入，导致了多雾和气温倒位现象。从西面来的潮湿空气，在高海拨山体的西面形成大量降雨。季风气候的形成改变了降雨模式，以致大量降雨在短期之内于该地区倾降下来。沿山脊被挤压的樊风进一步改变了气候。透过减少和纬度相关的隔离，山谷的深度限制了生物的生产能力。这一地区的河流的存在，缓冲了由于潮湿而成的多云多雾导致的极端气温。上述所有不寻常的物理现象，它们共同作用的结果增加了小气候形成的机会。

怒江和伊洛瓦底江的古老性，河流规模和长度是形成淡水生生物多样性进化的可观因素。河流自身同时也是有机体不可逾越的迁移和散布屏障，它将高黎贡山内部与周边区域隔离开来。河流从生物地理上分割了这个区域（Jablonski and Pan 1988）。从而导致了高水平的特有性（Mackinnon et al. 1996）。河流的屏障作用在于阻止散布，并保护该地区不受外来物种的侵入而失去完整的特有性。高深河谷的另一作用是提供难得的深而隐蔽的气候避难所。物种能沿海拔高度倾斜而维持气温急剧波动期间的热量平衡。不寻常的河谷气候促成了那些在其它地区灭绝的物种能在该地成功存活。用当地居民的话来说就是：“这里一天之内四季分明”。

结论

高黎贡山的地貌来源于地球物理运动，是多次发生于该地的气候变化结果。古地中海时代，该地的气候既炎热又潮湿。季风形成后，变为较为干躁和凉爽。自季风气候在早于七百万年前形成后，许多发生于该地区的物种已经跨越了这个间隔，适应了季节性的季风气候。孤立的高黎贡山自然环境可能提供了相对较低的捕食动物负荷。自然动力和地球物理作用本身为形成生物多样性替代物种的适应提供了广阔的空间。加深了诸如古气候变化、季风和冰区避难所形成，而导致全球性的影响。这类全球性影响的方式已在横断山得到表达，而在高黎贡山所不同的是，它对低地与周围东西走向山地的影响。这个对地球作用的独特性增加了该地的生物多样性。高黎贡山以其数量繁多的孓遗、特有和替代种闻名。高黎贡山的独特性保证了其生物多样性的繁盛，艰险的地形制约了当地的农业发展并进一步限制了高度的人类活动，从而对其生物多样性具有保护作用。

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Cartography and data.— Care was taken to ensure that political borders were depicted representatively; however, they are provided only for indicative purposes and do not represent any territorial claim or agreements. Representation of borders will depend on the dataset used and differs slightly between maps. The reader should note that the borders are disputed in a number of areas within the Hengduan Mountains region. No opinion is expressed or implied in the cartography or text. Place names are given to be as informative as possible to the general reader; they do not mean to imply any special meaning to the names used in this paper. Place names are taken from the Map of the People's Republic of China (Carto. Pub. Hse., 1984) and from common usage.

The data used in this paper came from a variety of sources. The following datasets were used either alone or in combination to produce the maps (ESRI 1996; F.A.O. 2005; Steinshouer et al. 1997; USGS 1993, 2000, 2004; Wandrey and Law 1997). All maps are original maps produced from the data using ArcGIS© and ArcView© (ESRI 1999, 2004).

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