# Geologic Map of Bhutan



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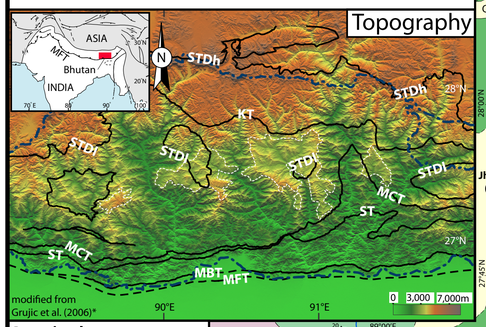



## Symbols

- stratigraphic contact
- thrust fault (teeth on upper plate)
- detachment fault (ticks on upper plate)
- normal fault (ball on down-thrown side)
- anticline
- syncline
- strike and dip of bedding and foliation
- structural data from Ganssner (1983)
- vertical bedding and foliation
- horizontal bedding
- mineral stretching lineation
- crenulation axial plane
- town
- peak
- pass (La)
- road
- river ('chu' or 'ri')
- highest occurrence of partial melt textures in structurally-lower GH section in central Bhutan**

## Structures

| | |
|---|---|
| STDh | structurally-higher South Tibetan detachment |
| KT | Kakhtang thrust |
| STDl | structurally-lower South Tibetan detachment |
| MCT | Main Central thrust |
| ST | Shumar thrust |
| MBT | Main Boundary thrust |
| MFT | Main Frontal thrust |

## Map Units

### Quaternary sediment

**Qt** **River terraces** – Uplifted remnants of older alluvial terraces in southwest and south-central parts of map area (Gansser, 1983).

**Qu** **Undifferentiated** - Unconsolidated sediment deposited in braided stream, alluvial fan, and floodplain environments across southernmost Bhutan and northernmost India. Also includes undifferentiated sediment of Tibetan Plateau (Wu et al., 1998).

### Subhimalayan Zone

**Siwalik Group (Miocene-Pliocene)**

**Tsu** **Upper member** - Medium- to coarse-grained conglomeratic sandstone and pebble-to cobble- and locally boulder- (up to 1-2 m in diameter) conglomerate, interbedded with tan siltstone. 1,500 m-thick near Samdrup Jongkhar (Long et al., 2011A). Equivalent to Diklai boulder bed of Ganssner (1983).

**Tsm** **Middle member** – Tan to gray, medium- to coarse-grained sandstone and pebble- to cobble-conglomeratic sandstone. 1,300 m-thick near Samdrup Jongkhar (Long et al., 2011A).

**Tsl** **Lower member** – Gray to green, massive-weathering siltstone and shale, interbedded with tan to gray, fine-grained, lithic-rich sandstone. 2,900 m-thick near Samdrup Jongkhar (Long et al., 2011A).

### Lesser Himalayan Zone

**Pzg** **Gondwana succession (Permian)** – Gray, medium-grained, feldspathic, lithic-rich sandstone interbedded with dark-gray to black, thin- to medium-bedded, carbonaceous siltstone, shale, slate, and argillite, and rare black coal beds (Ganssner, 1983; Lakshminarayana, 1995; Long et al., 2011A). 1.2 to 2.4 km-thick (Long et al., 2011A).

**Pzd** **Diuri Formation (Permian)** – Green-gray, pebble- to cobble-, slate-matrix diamictite (Ganssner, 1983; Tangri, 1995b; Long et al., 2011A). Conglomerate at base along Kuri. 2.3 to 3.1 km-thick (Long et al., 2011A).

**Pzj** **Jaishidanda Formation (Neoproterozoic-Ordovician[?])** – Gray, biotite-rich, locally garnet-bearing schist, interbedded with gray to tan, biotite lamination-bearing, lithic clast-rich quartzite (Bhargava, 1995; Dasgupta, 1995; Long et al., 2011A). Typically 600-900 m-thick, but 1,700 m-thick along Kuri (Long et al., 2011A). Upper greenschist to lower amphibolite facies (Ganssner, 1983).

### Baxa Group

**Pzph** **Phuentsholing Formation (age range uncertain; Neoproterozoic[?] or younger)** - Dark-gray to black, finely-laminated slate and phyllite, interbedded with thin- to medium-bedded, gray to tan limestone, thin-bedded, tan to dark-brown, fine- to medium-grained quartzite, and creamy gray dolostone (Bhargava, 1995; Tangri, 1995a). Maximum exposed thickness is ca. 2,250 m near Phuentsholing.

**Pzm** **Manas Formation*** (Neoproterozoic-Cambrian[?])** - Gray to white, medium- to thick-bedded, medium- to coarse-grained, locally-conglomeratic quartzite exhibiting common trough cross-bedding, interbedded with dark-gray to dark-green, thin-bedded to thinly-laminated phyllite, and medium-gray dolostone (locally divided out) (Bhargava, 1995; Tangri, 1995a; Long et al., 2011A). Intraformational thrust faults indicate structural repetition of multiple, 1.5 to 2.8 km-thick thrust sheets (Long et al., 2011B). Lower greenschist facies (Ganssner, 1983).

dolo

**pCp** **Pangsari Formation (age range uncertain; Mesoproterozoic[?]-Cambrian[?])** - Dark-green to dark-gray, thin-bedded to laminated, locally talcose phyllite interbedded with white, pink, and green, medium- to thick-bedded dolostone and marble, and green, fine- to medium-grained, thin-bedded quartzite (Bhargava, 1995; Tangri, 1995a). Maximum exposed thickness is 2,400 m (Tangri, 1995a).

### Daling-Shumar Group (Paleoproterozoic)

**pCd** **Daling Formation** - Similar lithologies to Shumar Formation, but dominated by schist and phyllite. Quartzite is thin- to medium-bedded, and medium-gray limestone interbeds are rare. Lower contact is gradational with Shumar Formation (McQuarrie et al., 2008; Long et al., 2011A). Between 2.3 and 3.2 km-thick (Long et al., 2011A).

**pCo** **Orthogneiss** - Concordant bodies of mylonitized, granitic orthogneiss at varying stratigraphic levels; interpreted as deformed Paleoproterozoic granite plutons that intruded Daling-Shumar Group (Long et al., 2011A). Thicker in easternmost Bhutan (Gansser, 1983). Interpreted as Indian crystalline basement east of Bhutan in Arunachal Pradesh (Yin et al., 2010).

**pCs** **Shumar Formation** - Light-gray to white, tan-weathering, very fine-grained, medium- to thick-bedded, cliff-forming quartzite. Interbeds of thin- to thick-bedded, green, muscovite-biotite schist and phyllite with diagnostic sigmoidal quartz vein boudins become more common upsection. Between 1-2 km thick, except for 6 km-thick section local to Kuri valley (Long et al., 2011A). Upper greenschist facies (Gansser, 1983).

### Paro Formation

**Pzpun** **Undifferentiated (age uncertain)** – Metasedimentary rocks at west end of map area in Sikkim (Gansser, 1983).

**Pzpu** **Upper unit (Cambrian-Ordovician)** – Tan to gray, very coarse-grained, thin- to medium-bedded, cliff-forming, biotite-rich quartzite, interbedded with biotite-muscovite-garnet schist (Tobgay et al., 2010). Marble marker bed (m3; 250 m-thick) is divided out. 1,600 m-thick total (Tobgay et al., 2010).

m3

**Pzpm** **Middle unit (Cambrian-Ordovician)** – Gray to tan, thin-bedded, fine-grained, micaceous quartzite, interbedded with biotite-garnet-muscovite schist (Tobgay et al., 2010), rare calc-silicate rocks, and marble. Contact with schist of lower unit is gradational. Two white to gray, medium-crystalline marble marker beds (m1, 10 m-thick; m2, 100-200 m-thick) are divided out. 2,000 m-thick total (Tobgay et al., 2010).

m2

m1

**Pzo** **Orthogneiss (Ordovician)** - Concordant, foliated leucogranite and granitic orthogneiss bodies within middle and upper unit, interpreted as deformed Ordovician granite plutons (Tobgay et al., 2010). Kyanite- and sillimanite-bearing schist locally present in country rock adjacent to intrusions (Tobgay et al., 2010).

**Pzpl** **Lower unit (Neoproterozoic[?]-Ordovician)** - Muscovite-biotite-garnet-staurolite schist, with kyanite present within quartz veins (Tobgay et al., 2010). Quartzite interbeds become more common upsection. 600 m-thick (Tobgay et al., 2010).

### Greater Himalayan Zone

**Structurally-lower Greater Himalayan section**

**GHlmu** **Upper metasedimentary unit (Neoproterozoic-Ordovician[?])** - Variable metamorphic grade; dominantly amphibolite facies (Gansser, 1983), partial melt- and often kyanite-, sillimanite-, or staurolite-bearing paragneiss, schist, and quartzite in east (Grujic et al., 2002) and near base in west-central Bhutan, and melt-free, dominantly upper greenschist-facies (Gansser, 1983) quartzite and biotite-muscovite-garnet schist in central Bhutan (Long and McQuarrie, 2010). Upper limit of partial melt textures** in central Bhutan is shown. 0.5-6.7 km-thick (Long et al., 2011B).

**GHlo** **Orthogneiss unit (Cambrian-Ordovician)** – Cliff-forming, massive-weathering, granite-composition orthogneiss; generally exhibits leuco-somes** and abundant feldspar augen (Long and McQuarrie, 2010; Long et al., 2011B). Paragneiss, schist, and quartzite intervals locally split out. Interpreted as deformed Cambrian-Ordovician granite plutons that intruded Greater Himalayan sedimentary protoliths (Long and McQuarrie, 2010). 1.5-8.0 km-thick; thickens toward eastern Bhutan (Long et al., 2011B).

**GHlml** **Lower metasedimentary unit (Neoproterozoic-Cambrian[?])** – Dominantly amphibolite-facies (Gansser, 1983; Grujic et al., 2002; Daniel et al., 2003) metasedimentary rocks, including quartzite, and biotite-muscovite-garnet schist and paragneiss often exhibiting kyanite, sillimanite, or staurolite, and partial melt textures** (Long and McQuarrie, 2010). Orthogneiss intervals locally split out. Up to ~5.0 km-thick; thickens toward western Bhutan.

**Structurally-higher Greater Himalayan section**

**Tgr** **Leucogranite (Miocene)** – Massive to foliated, syn-Himalayan leucogranite plutons. Leucogranite intrudes the structurally-higher and structurally-lower Greater Himalayan sections, as well as Tethyan Himalayan rocks near the STDl in the Lingshi region (Gansser, 1983).

**GHhu** **Undifferentiated (age uncertain)** - Upper amphibolite-, granulite- (Gansser, 1983; Swapp and Hollister, 1991; Davidson et al., 1997; Warren et al., 2011), and locally eclogite-facies (Chakungal et al., 2010) migmatitic orthogneiss and metasedimentary rocks, including schist, paragneiss, quartzite, and marble. At least 13 km-thick (Long et al., 2011B).

**GHhm** **Metasedimentary rocks (age uncertain)** – Migmatitic schist and paragneiss, and lesser quartzite and marble, locally divided out, based primarily on the mapping of Gansser (1983).

### Tethyan Himalayan Zone

**THu** **Undifferentiated (Paleozoic-Eocene)** – Limestone, sandstone, shale, and locally marble, quartzite, slate, and phyllite above STDh in Tibet and parts of northernmost Bhutan (Wu et al., 1998; Edwards et al., 1999).

**Ku** **Cretaceous, undifferentiated** – Dark-gray to black, brown-weathering, carbonaceous shale, and brown sandstone (Gansser, 1983). Equivalent to upper part of Lingshi Formation of Tangri and Pande (1995). Ca. 600 m-thick.

**Tr-Jru** **Triassic-Jurassic, undifferentiated** – Dark-gray, tan weathering shale, and fine-grained sandstone (Gansser, 1983). Forms diagnostic tan slopes. Equivalent to lower part of Lingshi Formation of Tangri and Pande (1995). Ca. 2,000 m-thick.

**Pzu** **Paleozoic, undifferentiated** – In Lingshi region: medium-gray, cliff-forming, thin-bedded, silt lamination-rich, fossiliferous limestone (Gansser, 1983) equivalent to Barshong Formation (Early-Middle Cambrian) of Tangri and Pande (1995), and brown, pebble-clast diamictite (Gansser, 1983) equivalent to Shodug Formation (Permian-Carboniferous) of Tangri and Pande (1995). Ca. 4 km-thick total. In Dang Chu klippe: Gray to brown, fine-grained quartz sandstone of Deschilling Formation (Late Cambrian), dark-gray shale of Maneting Formation (Late Cambrian), and gray, fine-grained sandstone of Quartzite Formation (Late Cambrian) of Pele La Group (Hughes et al., 2010), and Late Devonian-Early Carboniferous Wachi La and Ripakha Formations of overlying Tang Chu Group (Tangri and Pande, 1995). Ca. 2 km-thick total.

**Pzm** **Maneting Formation (Ordovician or younger)** - Dark-gray, graphitic, crenulated, finely-laminated, biotite-garnet phyllite (Tangri and Pande, 1995; Long and McQuarrie, 2010). At least 1,000 m-thick (Long and McQuarrie, 2010).

**Pzc** **Chekha Formation (Ordovician or younger)** – Tan to gray, thick-bedded, fine- to medium-grained, cliff-forming, micaceous quartzite, interbedded with biotite-muscovite-garnet schist in eastern and central Bhutan (Tangri and Pande, 1995; Long and McQuarrie, 2010). Interbedded with green to white, thin-bedded marble in Dang Chu klippe. Dominated by tan, cliff-forming marble, with lesser gray phyllite and dark-gray phyllitic quartzite in Lingshi region (Gansser, 1983). Dominantly upper greenschist facies (Gansser, 1983). 2.2-4.0 km-thick (Long et al., 2011B).

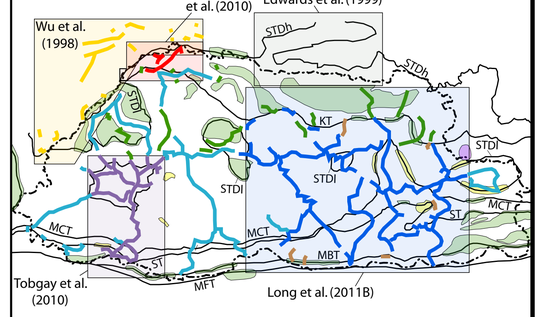
**Footnotes:**

*White dashed lines on topography inset bound patches of a low-relief relict landscape (from Grujic et al., 2006).

**Partial melt textures defined by presence of cm-scale, granite-composition leucosomes. Partial melt textures are observed through entire structurally-lower GH section in eastern and western Bhutan. Lower limit of partial melt textures is the MCT.

***Rocks referred to as undifferentiated Baxa Group in McQuarrie et al. (2008), Long et al. (2011A; 2011B), and Tobgay et al. (2010) are referred to as Manas Formation in this study.

## Data sources




Area of compiled geologic map

Mapping compiled from areas of:
- Yin et al. (2010)
- Bhargava (1995)
- Gansser (1983)

Strike and dip data compiled from:
- **this study**
- Tobgay et al. (2010)
- Long et al. (2011B)
- Chakungal et al. (2010)
- Wu et al. (1998)
- Gansser (1983)
- Gokul (1983)