Tethyan Fold-Thrust Belt and Indus-Yalu Suture Zone, Southwest Tibet

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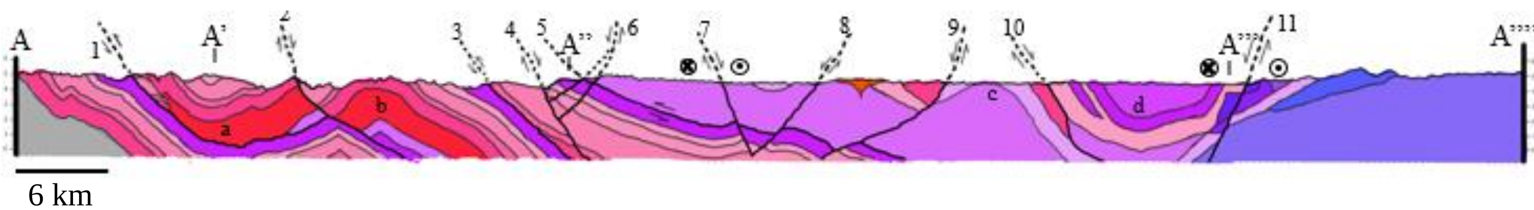


Murphy, M. A., & Yin, A. (2003). Structural evolution and sequence of thrusting in the Tethyan fold-thrust belt and Indus-Yalu suture zone, southwest Tibet. *Geological Society of America Bulletin*, *115*(1), 21-34.

System of Structures

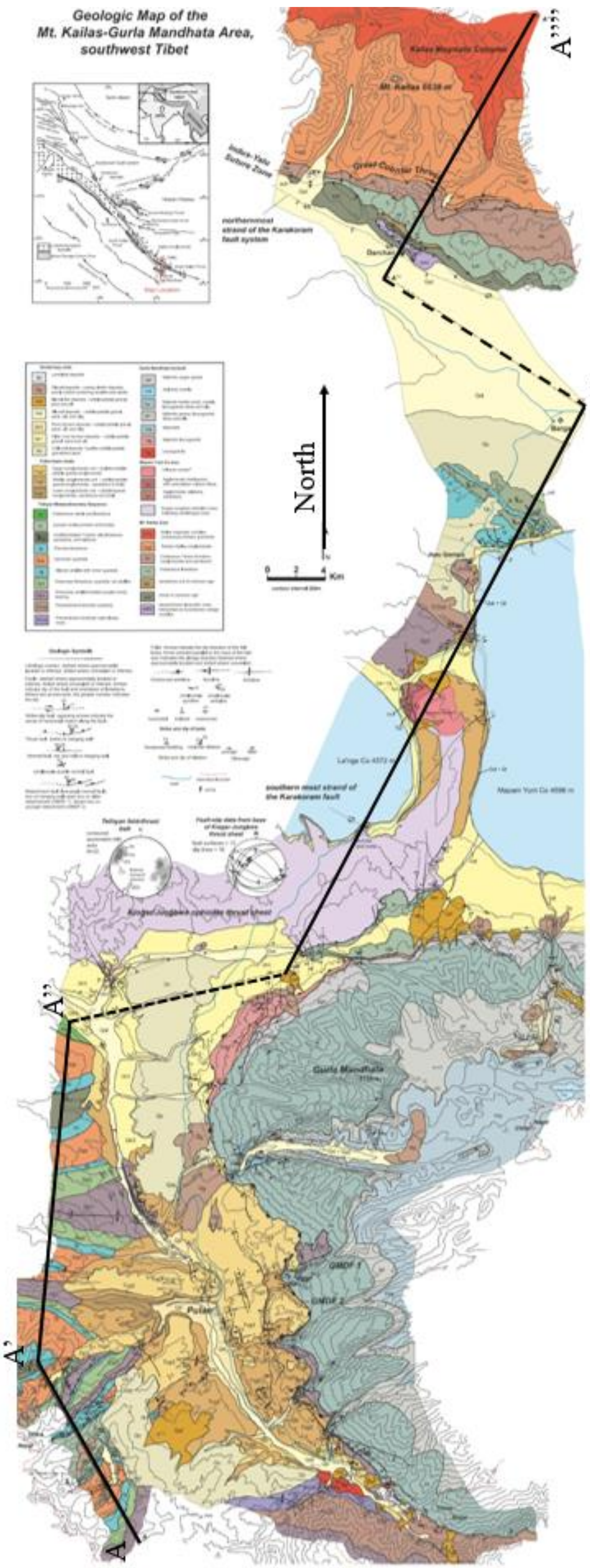
The cross-section shows 4 folds and 11 faults. The folds can be further subdivided as there are 2 synclines and 2 anticlines, with one of each at the southern end, and one of each more northward. However, the cross section makes the folds appear much more parallel then they truly are as the southern anticline and syncline are much closer to the lying directly east to west, while the northern pair are more SE to NW.

Of the faults there are two right-lateral normal faults. These two are part of the Karakoram Fault system which rums along the Western half of the Himalayas and ends near the Mt. Kailas region,. Though they are part of the larger orogeny offset of these faults had little effect on the deformation of this region

The remaining faults can be categorized further as there are 2 thrust faults, 1 reverse fault, and 6 normal faults. Fault 1 (a thrust fault) also has a clear listric shape, showing how the degree of faulting tapers from a higher to a much shallower angle. The thrust, reverse, and folds accommodate the immense shortening of the region., and the expansion brought about by the normal faults was not enough to counteract it.

Thoughts

I found the most interesting part to be the amount of deformation in what I think of as a short amount of time, geologically speaking, as the folds and faults are on the scale of kilometers. Regarding the work I did, the most satisfying part was seeing the cross-section come together, especially after it was colored and getting to see the Precambrian rock on top of Mesozoic rock.



Geometric Analysis

Faults: As shown by figure 1 there are 11 main faults shown in the cross-section, with an average vertical offset of 3075 meters, though the offset of fault 5 is unknown. Faults 7 and 11 (the Karakoram faults) have horizontal offset as well. The exact value of this is still debated, with estimates ranging from 120 kilometer to roughly 1000 kilometers [Murphey, 2005]. As shown by figures 1 and 2, the faults in general are oriented towards the northwest.

Folds: Though there are likely smaller folds which are not visible due to the scale of the cross-section, the region's main folds are two pairs of synclines and anticlines. The details of these can be seen in figure 3, which shows that the southern pair (ab) each have a height of 6500 m, and the northern pair (cd) each have a height of 9000 meters. These are generally very open folds, the exception being anticline b, with a tighter fold of 40°.

Figure 1

Faults

Name	Type	Orientation	Slip Direction	Offset
1	Thrust	240,45		6000 m
2	Normal	275,68		3500 m
3	Reverse	275,50		6000 m
4	Normal	275,65		1000 m
5	Thrust	298,40		?
6	Normal	118,62		250 m
7 Southern Karakoram Fault	Right-Lateral Normal	298,60	N70°W, 30°	250 m
8	Normal	118,52		7500 m
9	Normal	118,58		2000 m
10	Normal	298,60		2250 m
11 Northern Karakoram Fault	Right-Lateral Normal	120,70	N80°W, 20°	2000 m

Figure 3

Folds

Name	Type	Tightness	Height	Orientation
a	Syncline	85°	6500 m	55° NE
b	Anticline	40°	6500 m	95°SE
c	Anticline	75°	9000 m	119°SE
d	Syncline	87°	9000 m	125°SE

Bedding: The thickness of bedding varies greatly for some strata, such as in the Kiogar Jungbwa Ophiolitic rocks, which goes from about 1 kilometer to around 6 kilometers as one heads farther north. As the 6 km could not have been the height of initial deposition (though layering from multiple eruptions is possible, 6 km of layering is highly unlikely) the greater height of strata may be the result of multiple thrust faults layering the ophiolite on top of itself. Additionally, the Precambrian-Cambrian quartzite ranges from 0.5 km to 1.3 km, this time decreasing in height as one travels north.

Figure 2

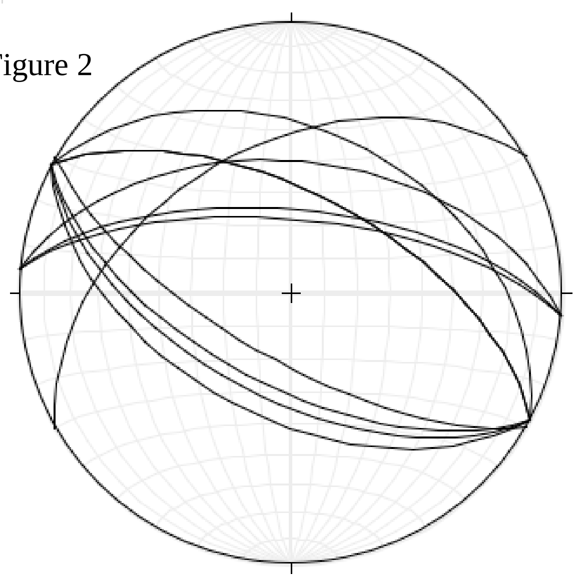


Figure 1: Table of information pertaining to faults
Figure 2: Orientations of faults 1-11 plotted on Richard Allmendinger's Stereonet program version 10
Figure 3: Table of information pertaining to folds

Kinematic Analysis

In total there are six normal faults, three thrust/reverse faults, and two dextral normal faults. Despite the cross section containing mostly normal faults, the overall change in the region was that of shortening, as between the folding and the faulting the length of the region decreased by at least 176 kilometers. Due to the faults having a mostly northwestern orientation, this allowed for offset perpendicular to the faults, thereby shortening the land in a northeastern direction.

This extreme 176 km of shortening would therefore explain the immense height of the Himalaya region, because as shown by figure 5, there was a large amount of horizontal shortening accommodated by an increase in height of the land.

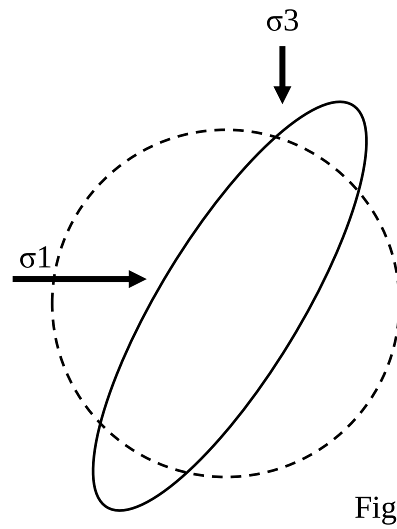


Figure 5

Not visible in the cross-section, due to later deformation, is the décollement between the sedimentary rocks and the Precambrian-Cambrian quartzite (which is part of the Greater Himalayan crystalline sequence).

Additionally, the cross-section does not show the extent of offset for the Karakoram faults. This is due to their mostly strike-slip motion. Therefore, they sheared the land along the northwest to southeast line, and on a side note this fault system is still active. This fault system had little effect on changing the length of the region (less than 5 km).

The folds are perpendicular to the thrust faults, which further demonstrates their role of shortening to the northeast, and these folds are asymmetric. They appear to be flexural slip, however that could be caused by regions being sheared off by faults as seen by the listric thrust fault 1 at fold a.

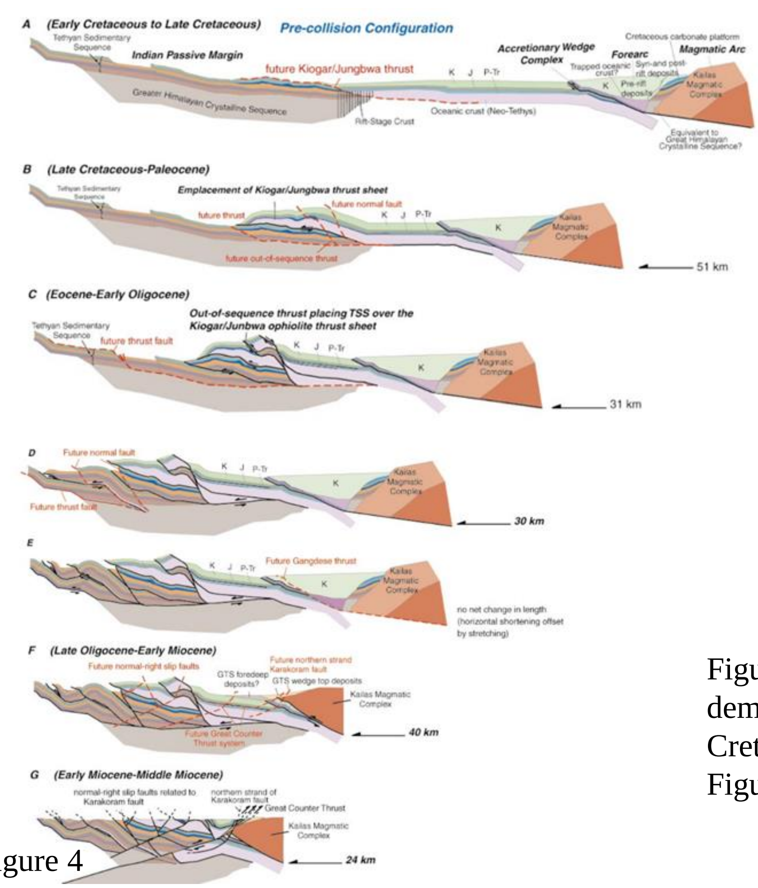


Figure 4

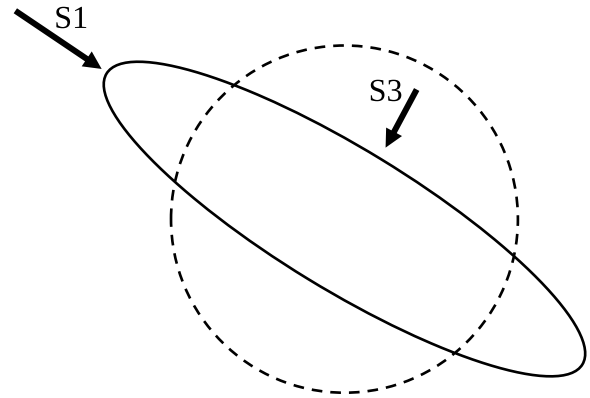
Figure 4: [*Murphey 2003*] Cross-section of the region demonstrating the shortening that took place between the Early Cretaceous to the Mid-Miocene
Figure 5: Generalized strain ellipse for the region

Dynamic Analysis

The deformation of this region is a result of the Himalayan-Tibetan Orogeny, which began during the Early Cretaceous. However, in this relatively short time, with the movement of India beginning about 90 million years ago, and the actually collision between continents happening about 40 million years later, there has been immense deformation, partially due to the nature of continental-continental collisions, but mainly because of great speed at which the Indian Plate collided with Eurasia, at 150 mm/year.

This collision put a lot of horizontal stress on the region as show by figure 6, resulted in the thrust faulting and folding. As stated earlier, there are likely more folds at a smaller scale, however, I believe that the level of faulting demonstrates brittle deformation.

It makes sense then that there would be numerous thrust faults and folds, however the normal faults seem out of place. There are two theories regarding their origin



1. They are the related to the development of thrust belts in a simple shear zone
2. They are part of the South Tibetan Detachment System (Figure 7)

If option 1 is correct, then then they would have formed throughout the Oligocene as shown in figure 4. However, if option 2 is correct, then their activity would have come later.

There are two major types of bedding shown in this region, the Greater Himalayan Crystalline Complex and the Tethyan Sedimentary Sequence. The former has its origins as very old metamorphic rock on the Eurasian plate, while latter comes from deposition in the Tethys Ocean, which closed when the two plates collided.

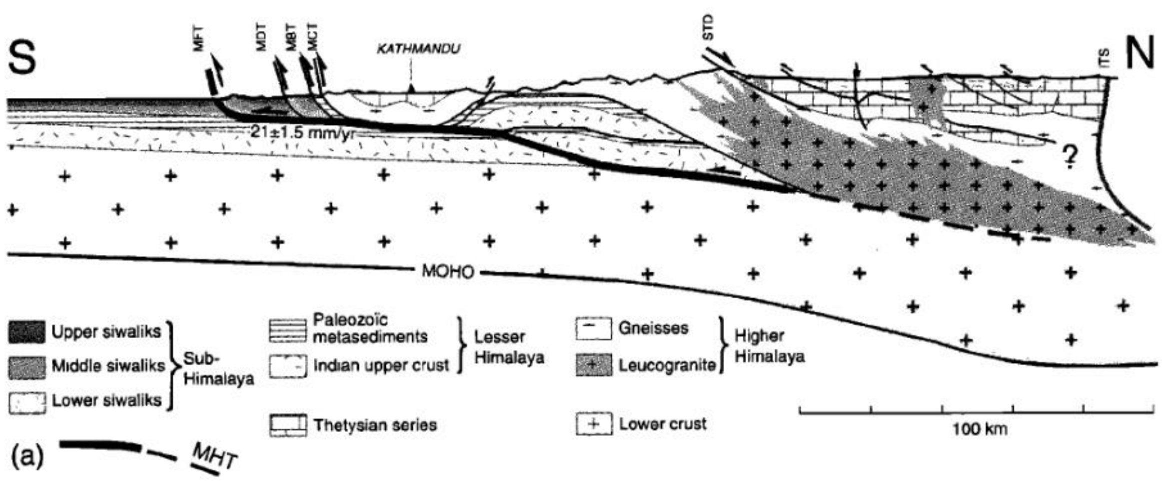


Figure 6: Generalized Stress Ellipse for the region
Figure 7: [*Lavé 2001*] Cross section with South Tibetan Detatchment visible (labeled STD).

References

Lavé, J., & Avouac, J.P. (2001). “Fluvial incision and tectonic uplift across the Himalayas of central Nepal” Journal of Geophysical Research, 106 (B11), 26561 26591. https://doi.org/10.1029/2001JB000359

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