

Overview of the geology of the Himalayas



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Executive Summary

The Himalaya mountain range stretches over 2500km (Le Forte 1975), and its geology directly impacts upon the people who live in the area. This report on Himalayan Geology covers its mode of formation, glaciation and quaternary geology, current tectonics and resources. It will also outline aspects specific to Ladakh as this report was commissioned by *Geology for Global Development* as part of a geo-hazards education project in the Ladakh region.

The Himalayas formed in two stages. Firstly, India collided with Eurasia at some point between 65 million years ago (Ma) and 45Ma, creating the Indus Suture. During the second stage, in which the uplift of the Himalayan Mountain Range began to occur as it was gravitationally unstable, the India plate was thrust further beneath the Eurasian plate. The pressure and temperature increase caused the rocks to recrystallize, forming minerals which reduced friction and enabled further thrusting. This occurred at about 20Ma, however the Himalayas did not reach their present height until between 2.5Ma and 1.8Ma (Powell & Conaghan 1973).

The uplift of the Himalayas had an effect on climate circulation, and the region began to experience monsoons (Zhisheng et al. 2001). The heating of the Tibetan plateau provides the required thermal gradient to drive the South Asian summer monsoons (Pant et al. 2005). In addition to this, as a result of the uplift, the region began to experience high altitude glaciation. In Ladakh, the monsoonal moisture supply has been blocked by the uplift of Himalayan ranges, such as the Karakorum, resulting in glacial retreat (Owen et al. 2006). More recently, climate change has accelerated the shrinking of Himalayan glaciers.

The majority of the convergence of India and Eurasia occurs due to slip on faults in temporally localised events, which generates Earthquakes. These can be of relatively high magnitude, as shown by the Wenchuan Earthquake in the Longman Shan region, which was of magnitude 7.9 (Hubbard & Shaw 2009). Earthquakes present a major geo-hazard in the Himalayas, but with a relatively long repeat time (Bilham et al. 2001).

The Himalayas don't have a particularly high abundance of resources. There have been some hydrocarbons found in the lower relief areas nearby, but none in areas such as Nepal (Mukhopadhyay 2008). Neither are they mineral rich, but this may be due to the fact that the mountain belt is relatively young and so hydrothermal circulation is not yet well developed.

The Ladakh region is experiencing movement at a slow pace of approximately 3.4mm/year along the Karakoram fault. Ladakh has impressive hydrothermal reserves, which are currently unharnessed. These occur due to the accumulation of magma close to the surface, which heats up the groundwater, causing it to circulate. There are 20 hot springs within the area with three sites which theoretically could produce >20MWe of energy. The most important of these is Puga, where up to 5000MWh could be harnessed. Power cuts are not uncommon in Ladakh and the surrounding area, particularly during winter. The Indus River freezes during this time, which causes their hydropower plants to fail (Craig et al. 2013). Metal deposits can also be associated with hydrothermal systems (Mitchell & Garson 1983) and the area has an abundance of Rubies due to the intense metamorphism that has occurred there (Wilson & Wilson, 2014).

Despite these possible economic benefits, the mountains surrounding Ladakh create a risk of landslides. This is due to the steep slopes: two thirds of all rock avalanches occur on the steepest 5% of the Earth's surface. The steeply dipping beds are created by the deformation that has occurred in the area, which creates arch-like folds. Other factors that aid the formation of landslides include glaciers and rivers undercutting rock, heavy rainfall, melting glaciers, layering within rock and weaknesses such as fractures and movement on faults. 14 out of 16 large landslide deposits recorded and dated within the area occurred during monsoons, suggesting that rainfall is a common trigger mechanism. The region experiences earthquakes and these could also be a significant trigger (Dortch et al. 2008).

The Himalayas are very dynamic, generating hazards such as earthquakes (Hubbard & Shaw 2009) and landslides (Dortch et al. 2008), but also economic opportunities such as hydrothermal energy and tourism (Craig et al. 2013). Glaciers provide the local people with a water store, but this needs to be carefully managed due to the accelerating retreat of the ice (Qiu 2012). It is important to understand the geology of the Himalayas in order to be able to work towards a sustainable future, mitigating the risks that hazards pose but also managing and harnessing the available resources.

1. Introduction

The Himalayan mountain range stretches from the Brahmaputra to the Indus River. It ranges over 2500km and is between 200-250km thick (Le Forte 1975). The Geology of the Himalayas is particularly important because it helps us to understand the formation of large mountain belts and how these regions vary over time. In addition, these mountains affect the daily lives of all the people living within their shadow.

Education is the key to this and this literature review is provided to enable the delivery of an effective Students' Programme on the topic of Landslides and Environment by *Geology for Global Development*, by compiling information to be adapted into material suitable to be taught in Leh, the Ladakh Region of India. This will be in the form of a Schools conference to children aged 14-16. In addition to this, the information will also be presented to the nomadic Changpa Tribe.

The material explored within this summary will include the formation of the Himalaya, its glaciation and quaternary geology, its current tectonics and its natural resources. This will cover the entire Himalayas, however there will be special emphasis on the information directly relevant to the Ladakh region. It will also focus on any major faults and the occurrence of landslides, as they present a major hazard to people living in this area.

2. Formation

130 Million Years ago (Ma), India began to drift north due to the movement of tectonic plates, closing the Tethys Ocean. Fossil dating suggests this was occurring until at least 65Ma. At some point before 45Ma India collided with Asia and subduction began to occur along the Indus Suture, likely generating the Himalayan Batholiths. This subduction formed a collision zone, resulting in down buckling of material (Powell & Conaghan 1973). Subduction also resulted in the Eocene Transgression and reduced spreading rates in the Indian Ocean (Le Forte 1975).

Isostatic adjustment of the mountain belt as a result of this collision began at approximately 20Ma (Powell & Conaghan 1973). However, when the movement gradually resumed, the Indus Suture was too thickened and granitised for it to occur here, so it instead took place along a new line of weakness (Le Forte 1975). The formation of Gneisses and Schists lead to reduced resistance and under-thrusting of the India subcontinent which allowed a double layer of continental crust, requiring further isostatic adjustment of approximately 5km (Powell & Conaghan 1973). Hence the Himalayas did not reach their current height above sea level until the Late Pliocene – Early Pleistocene. This is all supported by the fact that there are no Blueschist Facies rocks, indicating that this event occurred slowly (Powell & Conaghan 1973).

There are three main thrust faults in the Himalayas that formed during isostatic adjustment: The Main Central Thrust (MCT), The Main Boundary Thrust (MBT) and The Main Frontal Thrust (MFT). The MCT is on the scale of kilometres and is a mylonitic zone separating the High Himalayan Crystalline from the lower Tertiary sediments in the Lesser Himalayas (Korup et al. 2006).

The base of the High Himalayas is unknown, with Cambrian rocks being the oldest recognised. The upper Devonian rocks may be missing from the sequence, and there is an unconformity between the Carboniferous and Permian rocks. The sequence ends with Eocene marine sediment. The Tibetan Slab lies above this sedimentary sequence. The slab consists of highly metamorphosed Palaeozoic and Mesozoic sediments. Its lower boundary can be found in the MCT. The sediments found here are very typical of that found in a platform environment, such as a continental shelf. (Le Forte 1975).

The MBT divides the Nappes of the Lesser Himalayas from the Sub-Himalayas (Korup et al. 2006), which is composed of Tertiary sediments. The sediments of The Lesser Himalayas were formed in shallow water, tidal, lagoonal and continental settings whereas the Sub-Himalayas were terrestrial dominated. Granites are found in the Higher Himalayas, adjacent to the MCT and in the Lower Himalayas adjacent to the MBT.

3. Glaciation and Quaternary Geology

The Himalayas have experienced three glacial cycles during the Pliocene and the Pleistocene (Le Forte 1975). The uplift of the Himalayas affected climate circulation, leading to the onset of monsoons. As rainfall became far more seasonal and restricted to the summer months, aridity increased in the region (Zhisheng et al. 2001).

This phased uplift continued and there was an intensification of both the summer and winter monsoons at 3.6-2.6Ma. The intensification of the winter monsoon continued, coupled with weakening of the summer monsoon. The Himalayas are large enough that they affect global climate, possibly influencing the major Northern Hemisphere glaciations. Increased aridity produces dust and strong winter winds, which may lead to global cooling (Zhisheng et al. 2001).

There is evidence for extensive regional glaciation during the early Quaternary, including U-shaped valleys, moraines and till. Maximum glacial advance occurred at 63ka, after which the ice begins to retreat. Deglaciation left a fluvio-lacustrine environment in its wake. Many lakes were created by landslides or moraines blocking the course of rivers. The area then became more humid, altering lake sedimentation patterns. Seasonal changes in discharge in varve sedimentation suggests that there was some renewal of the glaciers (Pant et al. 2005).

However, the glaciation this time was restricted to higher latitudes, due to the lack of moisture. The subsequent decrease in ice mass in the main Himalaya region can be attributed to the blocking of moisture usually brought into the area via the summer monsoon, as a result of the continual rise of the Himalayas. It may also be related to a global trend towards decreased ice cover in mountainous regions in the Pleistocene (Owen et al. 2006).

More recently, climate change has accelerated the shrinking of Himalayan glaciers. Currently there is 100,000 square kilometres of ice providing water to the people living within the area and beyond. Glaciers in this region are not only affected by the continually rising global temperature, but also by wind circulation. Glaciers in regions dominated by westerly winds accumulate mass as a result of winter snow and so are less susceptible to changes in temperature. These areas give misleading results in terms of the effects of climate change on the Himalayan glaciers. However, in areas such as the central and western Himalayas, snow occurs as a result of monsoons and so slight temperature variations have larger repercussions. In the last 40 years alone, glacial lakes have increased in volume by 26% (Qiu 2012).

4. Current tectonics

The current convergence between India and Asia amounts to approximately 58mm per year, mainly occurring through seismic events. Approximately one-third of the present-day convergence-rate between India and Asia is responsible for the shortening, uplift and moderate seismicity of the Himalaya (Bilham et al. 1997). Ruptures along thrust faults are caused by crustal shortening, and they in turn generate earthquakes (Hubbard & Shaw 2009). Shortening and topography are very strongly correlated within the Himalayas and this is clear in the Longman Shan Range on the eastern side of the region.

Between 1991 and 2001, India experienced five major earthquakes. It is likely that there is still enough strain built up within the Himalayan zone to generate a major earthquake, with a slip exceeding 6m in some locations (Bilham et al. 2001). One example of a large rupture within the Himalayas is the Wenchuan Earthquake, which occurred in 2008 within the Longman Shan Range. It was of magnitude 7.9 and, coupled with its aftershocks, caused slip on two major faults. The location of the epicentre and aftershocks greater than magnitude 3.4 are shown in Figure 1. The Wenchuan Earthquake caused tens of thousands of deaths to those dwelling nearby (Hubbard & Shaw 2009).

The contraction experienced in the Himalayas is occurring at a rate of approximately 17mm per year on average (Bilham et al. 1997) and this occurs mainly along the MFT (Korup et al. 2006).

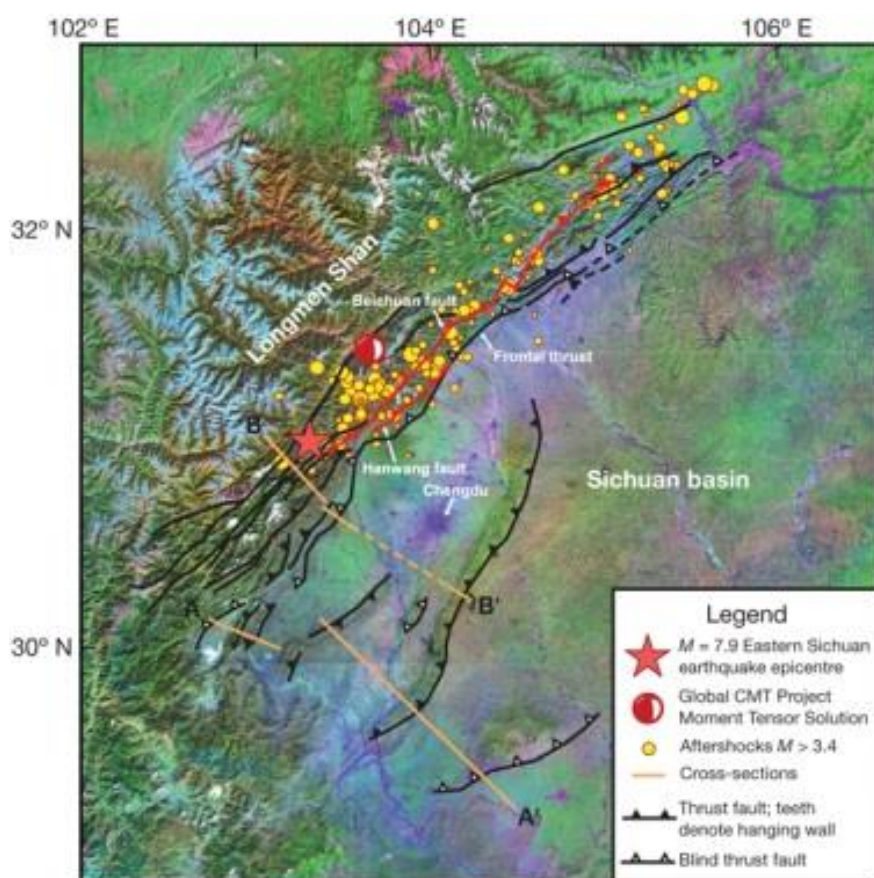


Figure 1: Longman Shan Range with Location of the epicentre of The Wenchuan Earthquake and aftershocks (Hubbard & Shaw 2009). Used with permission.

5. Resources

In the Himalayas, two sedimentary regions with hydrocarbon source and reservoir rocks have been found adjacent to the Central Crystallines. Despite the fact that oil seeps in other areas have been recorded, none have been found in any Himalayan region within either India or Nepal. Exploration of these areas did occur during the 20th century, but yielded very little. This may simply be because of the lack of knowledge of the complex structural geology of the region at that time. It is possible that the recent renewed interest may lead to more lucrative discoveries (Mukhopadhyay 2008).

There is a lack of peer-reviewed literature on mineral resources specific to the Himalayas, so the following information is deduced from general information found on mineral deposits within collisional settings and more specific information compiled from grey literature. There is evidence suggesting that the Himalayas are not well mineralised, but it is still possible that metals are present in economically viable amounts within this mountain range (Wilson & Wilson, 2014). Hydrothermal systems often allow metals to precipitate into the crust and therefore the lack of substantial mineralisation may be due to the fact that such a system has not had time to develop in the relatively youthful Himalayas (Mitchell & Garson 1983). In ophiolites, it is often possible to find chromite and copper sulphide and the Himalayas has an abundance of these obducted slabs (Wilson & Wilson, 2014).

6. Ladakh Geology

The Ladakh region is mainly comprised of Palaeozoic to Cretaceous sediments, meta-sediments, granitic intrusions and the Ladakh Batholith. The latter is an intermediate rock which is located to the north of the Indus River (Dortch et al. 2008).

There are five recorded glacial cycles in Ladakh. Within this there are five identified glacial advances: The Indus Valley (older than 430ka), Leh (3rd cycle), Kar (start of 5th), Bazgo (middle of the 5th cycle) and Khalling (early Eocene) (Owen et al. 2006). Over this time the glaciers have been increasingly restricted to smaller areas, thought to be due to the reduction in moisture, referred to earlier

Soft fluvio-lacustrine sediments in this area, which were deposited as a result of the formation of the glaciers and are approximately 150m thick, often contain deformational structures. These particular features likely formed at 5Ma, due to liquefaction induced by earthquakes generated at the Karakoram fault. However, unlike in the general Himalaya region, the records of historic earthquakes are sparse (Upadhyay 2001).

Ladakh specifically is experiencing shear at a slow pace along the Karakoram fault. The slip along this fault is dextral and is occurring at approximately 3.4mm/year. The convergence between this area and India is approximately 18.8mm/year at a bearing of 224 degrees. If the slip along boundaries such as the Karakoram fault were rapid, then this would be used as evidence to prove the Tibetan Plateau behaves like a rigid plate. However, this is not the case, slip rates are instead independent of fault length and location, which suggests that it is deforming more continuously, like a fluid (Jade et al. 2004).

In this particular region of the Himalayas, there is evidence for increased geothermal activity in the form of 20 hot springs. These could be harnessed for energy and thus potentially could be an important resource to those living in the area. This energy is produced by granitic intrusions within the crust; the melt is hotter and less dense and therefore rises and heats the water table, causing the circulation of hot water. There are three sites of special interest with the potential to produce >20MWe of energy in this region, with the most important being Puga (Craig et al 2013).

This however, is not being harnessed as of yet. In Ladakh, power shortages are not uncommon, particularly in the winter months when the Indus River freezes over and hydropower fails. At Puga, there is a 90% chance that a 20MWe power plant could be sustained and it is estimated that 5000MWh could be harnessed, providing energy for heating, greenhouses and electricity (Craig et al. 2013).

Batholiths are associated with porphyry copper, tin-tungsten and gold deposits, and so these minerals could potentially be found in the Ladakh batholiths (Mitchel & Garson 1983). Jammu and Kashmir State also has an abundance of rubies due to the very high grade metamorphism (Wilson & Wilson).

However, there are also disadvantages to living in regions such as Ladakh. Two thirds of all rock avalanches occur on the steepest 5% of the earth and so, despite a region such as this having energy advantages, Ladakh also has to deal with geo-hazards such as landslides. These are aided by the steeply dipping, highly folded beds coupled with the discordance of some of the granitic intrusions which occur in the area, making the slopes more susceptible to failure (Dortch et al. 2008). Landslides are discussed in more detail in the accompanying *Geology for Global Development* report, 'Mass movement events in the Himalaya: The impact of landslides on Ladakh, India'.

5. References

- Bilham, R., Gaur, V.K & Molnar, P. 2001. *Himalayan Seismic Hazard*. Science, **293**, 1442-1444.
- Bilham, R., Larson, K. & Freymueller, J. 1997. *GPS Measurements of Present-Day Convergence across the Nepal Himalaya*. Nature, **386**, 61-64.
- Craig, J., Absar, A., Bhat, G., Cadel, G., Hafiz, M., Hakhoo, N., Kashkari, R., Moore, J., Ricchiuto, T.E., Thurow, J. & Thusu, B. 2013. *Hot Springs and the Geothermal Energy Potential of Jammu & Kashmir State, N.W. Himalaya, India*. Earth-Science Reviews, **126**, 156-177.
- Dortch, J.M., Owen, L.A., Haneburg, W.C., Caffee, M.W., Dietsch, C. & Kamp, U. 2009. *Nature and Timing of Large Landslides in the Himalaya and Transhimalaya in Northern India*. Quaternary Science Reviews, **28**, 1037-1054.
- Hubbard, J. & Shaw, J.H. 2009. *Uplift of the Longmen Shan and Tibetan Plateau, and The 2008 Wenchuan (M=7.9) Earthquake*. Nature, **458**, 194-197.
- Jade, S., Bhatt, B.C., Yang, Z., Bendick, R., Gaur, V.K., Molnar, P., Anand, M.B. & Kumar, D. 2004. *GPS Measurements from the Ladakh Himalaya, India: Preliminary Tests of Plate-like or Continuous Deformation in Tibet*. Geological Society of America Bulletin, 1386-1391.
- Korup, O., Strom, A.L. & Weidinger, J.T. 2006. *Fluvial Response to Large Rock-Slope Failures: Examples from The Himalayas, The Tien Shan and The Southern Alps in New Zealand*. Geomorphology, **78**, 3-21.
- Le Forte, P. 1975. *Himalayas: The Collided Range. Present Knowledge of the Continental Arc*. American Journal of Science, **275-A**, 1-44.
- Mitchell, A.H.G., & Garson, M.S. 1983. *Mineral Deposits and Global Tectonic Settings*. Academic Press: London, 405p.
- Mukhopadhyay, D.K. 2008. *Hydrocarbon Exploration in the NW Himalayas: A Perspective from Structural Geology*. AAPG Search and Discovery:
http://www.searchanddiscovery.com/abstracts/html/2008/geo_india/abstracts/mukhopadhyay.htm
- Owen, L.A., Caffee, M.W., Bovard, K.R., Finkel, R.C. & Sharma, M.C. 2006. *Terrestrial Cosmogenic Nuclide Surface Exposure Dating of the Oldest Glacial Successions in the Himalaya Orogen: Ladakh Range, Northern India*. Geological Society of America Bulletin, **118**, 383-392.
- Pant, R.K., Phadtare, N.R., Chamyal, L.S. & Juyal, N. 2005. *Quaternary Deposits in Ladakh and Karakoram Himalaya: A Treasure Trove of the Palaeoclimate Records*. Current Science, **88**, 1789-1798.
- Powell, C. & Conaghan, P.J. 1973. *Plate Tectonics and the Himalayas*. Earth and Planetary Science Letters, **20**, 1-12.
- Qui, J. 2012. *Tibetan Glaciers Shrinking Rapidly*. Nature News. doi:10.1038/nature.2012.11010
- Upadhyay, R. 2001. *Seismically-induced Soft-sediment Deformational Structures around Khalsar in the Shyok Valley, Northern Ladakh and Eastern Karakoram, India*. Current Science, **81**, 600-603.

Wilson, L. & Wilson B. 2014. *Ore Deposits*. Welcome to the Himalayan Orogeny:

<http://www.geo.arizona.edu/geo5xx/geo527/Himalayas/ores.htm>

Zhisheng, A., Kutzbach, J.E., Prell, W.L. & Porter, S.C. 2001. *Evolution of Asian Monsoons and Phased Uplift of the Himalaya-Tibetan Plateau since Late Miocene Times*. *Nature*, **411**, 62-66