LECTURE-4

Tectonic Control in the Evolution of the Lakes in the Himalayas

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INTRODUCTION

Natural lakes are fairly large bodies of water occupying inland basins that are extremely varied in terms of size, shape, depth, water chemistry, and other features. Surface area of lakes varies from only a few hectares (< 1 km^2) to several thousands of square kilometres. Average depth can range from a few meters to more than a thousand meters. Lakes can be nearly uniformly round, or they can be irregularly shaped. Natural lakes are an important part of ecosystems that support a large variety of fauna and flora. They also assumed significance in the human history, as they could be important sources of water supply in certain regions. However, their origin and existence on the surface of the earth are extremely varied and conditioned by the geological processes of the region.

Lakes cover about 1 percent of the continents and contain about 0.02 percent of the world's water. Lakes may be fresh-water, brackish or saline. Most of the world's large lakes are fresh-water that contain less than one gram per litre of salt. Some lakes are saline such as Caspian Sea and Aral Sea. Some are hypersaline lakes, such as the Great Salt Lake of Utah (USA) that contains more than 250 gram per litre of salt. This value of salinity is much higher than that of the sea water (35 gram per litre). The water of caldera lakes of volcanic origin can be highly acidic, where as the water in other lakes can be nearly neutral, or highly alkaline (as in soda lakes). Lakes can be low in nutrients (oligotrophic), moderately enriched (mesotrophic), or highly enriched (eutrophic).

ORIGIN OF LAKES

Natural lakes are extremely varied in origin. A great variety of lakes owe their origin to tectonic deformation of the earth's crust that lead to uplift and subsidence of different blocks of the earth. Lakes of non-tectonic origin include those formed by the geological processes of exogenic origin that are largely fashioned by the climatic variations in different parts of the continents. Lakes of volcanic origin and those formed by the impact of meteoric bodies also fall in the group of lakes of non-tectonic origin.

Lakes have continued to form and get destroyed since the geological past. The existence of lakes on the surface of the earth is limited by the processes of deposition and infilling of lakes by sediments. In many cases, the processes of infilling of sediments are slow depending upon the rates of erosion and deposition in the region. In some regions that are characterised by rapid uplift and faster rates of erosion, creation and disappearance of lakes take place at a faster pace. Some can be catastrophic on account of some events. For example, volcanic eruption, in May 1980, lead to the pouring of rock debris and mud into the Spirit Lake at the foot of Mount Saint Helens, Washington (USA) that greatly reduced its size.

Tectonic Lakes

Most of the inland basins are formed by the tectonic processes. Formation and disappearance of active orogenic belts, such as the Himalayas, continue even today on account of active tectonics and faster rates of erosion and deposition. Uplift of downstream block across a river valley can lead to the damming and reversal of the drainage basins. Landslides can block a river or stream that can be often short-lived. Landslides can be caused by several climatic and tectonic factors that control the stability of critical slopes in the mountainous region. For example, an earthquake triggered massive landslide in 1911 in the Pamir Mountains of Tajikistan that created a natural dam and 61 km long Lake Sarez (Fig. 1). Similar damming of the rivers caused by massive landslides in Higher Himalayas has repeatedly lead to the formation of huge reservoir of water in the upstream tracts of the rivers. Preventive measures, such as reducing the lake level by artificial means and evacuation of the people, are required to in order to prevent catastrophic floods downstream that may be caused due to the breach of such natural dams.

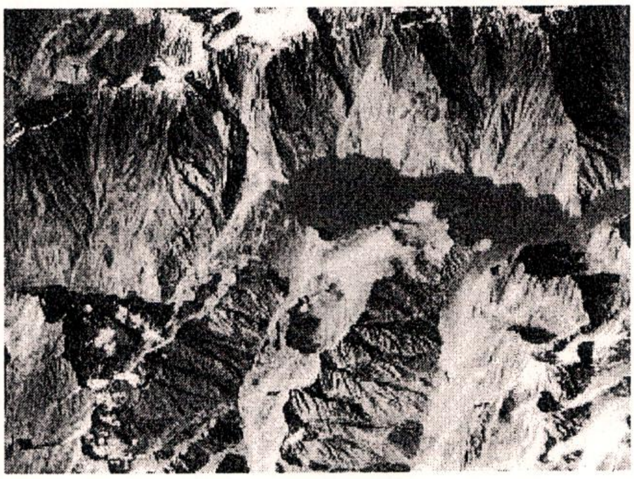

Fig. 1. Lake Sarez (61 km long) formed by natural damming caused by earthquake triggered landslide in 1911 in the Pamir mountains of Tajikistan (NASA).

The next most common type of lakes formed by tectonic processes includes grabens or half grabens produced by normal faulting and block faulting. Lake Baikal, located in eastern Russia, formed in the Baikal Rift of the Siberian Platform. A large number of lakes, such as Lakes Tanganyika, Lake Malawi and Lake Mobutu lay along the East African Rift Valley. Lake Tahoe at the California-Nevada border in the Basin and Range of Western USA owe their origin to block faulting. Many lakes of the Basin and Range Province of the western United States are remnants of larger lakes that existed during Ice Age of Late Pleistocene Epoch (10 to 30 Ka ago BP). These lakes were formed due to tectonic subsidence due to block faulting.

Other tectonic processes of formation of lakes by tectonic processes are related to upwarping and uplifting of land around entire basin. Subsidence caused by earthquakes can often lead to local depression and formation of lakes. Uplift of a part of the ocean floor can often lead to the formation of often large and shallow lakes (Caspian Sea and Aral Sea). Other crustal movements influencing lake formation include uplift around a central basin (Lake Victoria).

Lakes of Non-tectonic Origin

Formation of some lakes is associated with volcanic activity. Volcanic crater in cinder cone is often filled up with water body when the volcanic activity is dormant. Calderas are depression formed by the collapse of the exploded volcanoes. Lakes can also be formed by depressions surrounded by rim of lava. Damming caused by infilling of the valley floor by lava or ash can lead to formation of lakes upstream. Lakes that are formed by wind action include deflation basins, playas and sand dune lakes. Lakes formed by rivers include plunge pools and oxbow lakes. Lakes are also formed by the action of glaciers. Fjords are glacially deepened valleys adjoining the sea. They are often dammed and isolated from the sea. Glacial carved basins include cirque lakes and moraine lakes.

Solution lakes are formed by dissolution of soluble rock (often limestone) by percolating water in areas of 'Karst topography'. Sink holes are the most common water bodies in such areas that may form quickly and be short-lived. Lakes associated with shorelines include deltaic lakes and coastal lakes formed by the movement of sand in spits and bars. Coral reef built up can also lead to formation of water bodies. Some lakes are formed by meteor impact that can be very large and perfectly rounded.

TECTONIC LAKES OF THE HIMALAYAS

The Himalayas that happens to be one of the most active regions of the world extends in the form of an arc for a total length of about 2400 km from Nanga Parbat in the North-western Kashmir to Namcha Barua in Arunachal Pradesh. At its western end, the orographic trend of the Himalaya takes a sharp turn to the south and south-west to join with Sulaiman and Baluchistan mountain ranges of Pakistan. A similar arcuate bend in the orographic trend is also observed at the eastern end of the Himalaya where the NE-SW trend of the Himalaya appears to have been truncated by the NNE-SSW trending Arkan-Yoma ranges.

Structures of the Himalayas

The Himalaya that has an average width of 240 km has been sub-divided in to three longitudinal zones; from north to south Tethyan Himalayan Zone, Central Crystalline Zone of the Higher Himalaya and Lesser Himalayan Zone. The northern limit of the Himalaya is marked a tectonic zone known as Indus-Tsangpo Suture Zone (ITSZ) that extends in an east-west direction along the westerly flowing Indus River in Ladakh and easterly flowing Tsangpo River in Tibet.

ITSZ consists of a strongly deformed belt of ophiolites intermixed with Upper Cretaceous and Lower Tertiary marine sediments. It represents the zone of subduction of the northward moving Indian Plate beneath the Eurasian Plate. The line of high peaks, some of them reaching up to more than 6000 m above mean sea level, passes through the central part of the Higher Himalaya, which acts as a barrier for the south-west monsoons of the Indian sub-continent. The northern parts of the Higher Himalaya that include the Lahaul and Spiti Valleys in Himachal Pradesh are characterised by cold and arid climate.

Excellent sections of Palaeozoic and Mesozoic rock formations of the Tethyan Himalayan Zone can be seen on bare mountain slopes of this region, which is devoid of vegetation. The Tethyan rocks rest over the Precambrian formations that grade in to high-grade metamorphic rocks and granitic gneisses of the Central Crystalline Zone. The boundary between the Tethyan and Central Crystalline zones is rather fused. The Central Crystalline Zone is, however, demarcated from the Lesser Himalayan Zone by an important thrust known as Main Central Thrust (MCT).

The Lesser Himalaya is characterised by a very complex structure made up of superimposed thrust sheets (Kumar and Pande, 1972). Average altitude of the Lesser Himalaya ranges between 2000 m to 3000 m above mean sea level. It consists of three main branches of mountain ranges that emerge obliquely westward from the Higher Himalayan ranges. The Nag-Tibba Range splays off from the vicinity of Dhaulagiri Mountains in Western Nepal. The Dhauladhar Range originates from the vicinity of Badrinath in northern Uttaranchal. The Pir-Panjal Range takes off from the vicinity of Kilar. Besides these, there are three major independent ranges with in the Lesser Himalaya: Mahabharat Range in Central Nepal, Mussorie Range between Ganga and Sutlej Rivers, and Ratanpir Range of Jammu and Kashmir.

Collision of the Indian and Tibetan plates along the ITSZ as inferred from the stratigraphic records took place between 53 Ma to 47 Ma BP. It is believed that movement along this suture was blocked around 45 Ma BP that may have led to the transfer of the plate motion to the MCT in the Higher Himalayas and subsequently to the Main Boundary Fault (MBF) that marks the southern boundary of the Lesser Himalaya. Post-collision deformation in the Himalayas appears to have given rise to several new sets of structures that are related to convergence tectonics.

The Outer Himalaya includes the Shiwalik Hills that lies to the south of the MBF. These low-lying foot-hills have a maximum width of about 50 km in its western extremity in Jammu region. These hills merge westward with the Potwar Plateau of Pakistan. The width of the Outer Himalaya gradually decreases eastward to its complete elimination for a stretch of about 80 Km in Eastern Nepal. The hills again reappear further east and extend as a narrow strip of low lying hills in front of the Lesser Himalaya of Arunachal Pradesh. The Outer Himalaya has been the site of deposition of continental sediments in the foredeep in front of the rising Himalaya.

Neotectonics and Origin of Tectonic Lakes

MBF that has been active since Neogene has controlled the growth and evolution of foothill basins. Reactivation of the MBF during Holocene has given rise to intrabasinal thrusts and faults, ponding of rivers and consequent major landslides

(Valdiya, 1992). The southern parts of the Shiwalik Hills are affected by neotectonic movements, which are related to yet another active fault named as Himalayan Frontal Fault, HFF (Nakata, 1972). HFF is as yet a blind structure, which has been inferred primarily on indirect geomorphic expressions.

The morpho-tectonic evolution of the foothills is seen as a response to the compressive forces in the frontal parts of the convergent zones. The critical wedge models (Beaumont et al., 2000), which are applicable for the convergent zones such as the Himalaya, emphasises the importance of near horizontal detachments within the crust. Crustal deformations in the Himalayas had progressed at various levels in dissimilar ways. Convergence resulted in the formation of crustal wedge in front of the advancing deformed zones. The surface slopes steepen until it reaches the minimum angle at which gravitational stresses balance the basal traction. Foothill basins were formed in the south of the accretionary wedge of the material scrapped off the subducting Indian Plate. The accretionary wedge deformed at higher rates that are reflected in the stratigraphic patterns of the Shiwalik basins. South vergent thrust structures were formed in succession as the deformation propagated southward.

The GPS measurements in the northern parts of the Himalayan foothills around Nahan indicate that crustal shortening is taking place at the rate of nearly 15-20 mm/yr in a zone of 100-150 km north of HFF (Banerjee and Burgmann, 2001). Consequently, strain is getting accumulated across the HFF and other detachment surfaces. From time to time, the accumulated strain gets released to give rise to neotectonic structures.

Origin of Tectonic Lakes in the Himalayas

The Himalayas happens to be one of the youngest and most dynamic mountain systems in the world that has emerged as a result of the collision of two crustal plates. The region also happens to be one of the most active regions in terms of the rate of erosion on account of intense precipitation during the Indian Summer Monsoon. The ongoing Himalayan mountain building process has reactivated fault systems during the Quaternary, causing dislocation of many landforms such as river terraces, alluvial fans, streams and ridges in addition to the formation and shrinking of lakes and creation of numerous other morphotectonic features.

As a result of the convergence of the Indian and Asian plates, a number of lakes have also formed on either side of the ITSZ. These lakes are either brackish or freshwater. Many of them sustained by glacial melt water are shrinking today because of the reduction in discharge, faulting, and/or closing of basins due to the ongoing Himalayan uplift. Origin of these lakes can be linked with the active systems of faults that run along, oblique and across the suture zone. The Kyun Tso is an ancient twin lake system that lies to the south of the Indus Suture Zone in NW Himalaya. Remote sensing techniques have been used to understand the palaeohydrological conditions for the development of these water bodies (Phillips and Mathew, 2005). It has been shown that the dimensions of these lakes fluctuated over time that is attributed to the ongoing compression in the collisional zone.

Thakhola graben in northern Nepal represents a sediment filled lake that existed during the Neogene – Quaternary periods. The graben structure is transverse to the Himalayan trend representing a phase of extension tectonics along the northern edge of the Indian Plate. A number of similar transverse graben structures are noted in the NW Himalaya. The Kathmandu Basin in the central part of the Lesser Himalayas in Nepal is also a sediment-filled palaeo-lake that existed for most part of the Quaternary Period. The Kashmir Basin that is dotted with lacustrine sediments (Karewa Formations) and existing water bodies owe their origin to the warping and faulting of crustal blocks. Other Lesser Himalayan Lakes, such as Nainital in Uttaranchal and Renuka Lake in Himachal Pradesh have developed due to morphotectonic evolution of the Lesser Himalaya.

Tectonic Models

Studies on the origin of tectonic lakes of the Himalayas have shown a qualitative relationship between the formation of lakes and morphotectonic evolution of the mountains. Quantitative model has been proposed for the long-term evolution of lakes and internally drained basins resulting from tectonic vertical motions, sediment infill, outlet erosion, and climatic regime. The model accounts for the formation of a water body in the topographic basin that is created by tectonic uplift across a river. The model also addresses the notion that, after cessation of tectonic forcing, lakes are transitory phenomena over geo-logical time scales. High uplift rates across an antecedent river, in combination with low upstream precipitation, result in river defeat and lake formation. Post-tectonic lake extinction is caused by sediment overfill. Erosion of downstream regions can also lead to incision of the dam that reopens the drainage. Thus, the lakes at high altitudes undergo a reintegration into the drainage network and extinction.

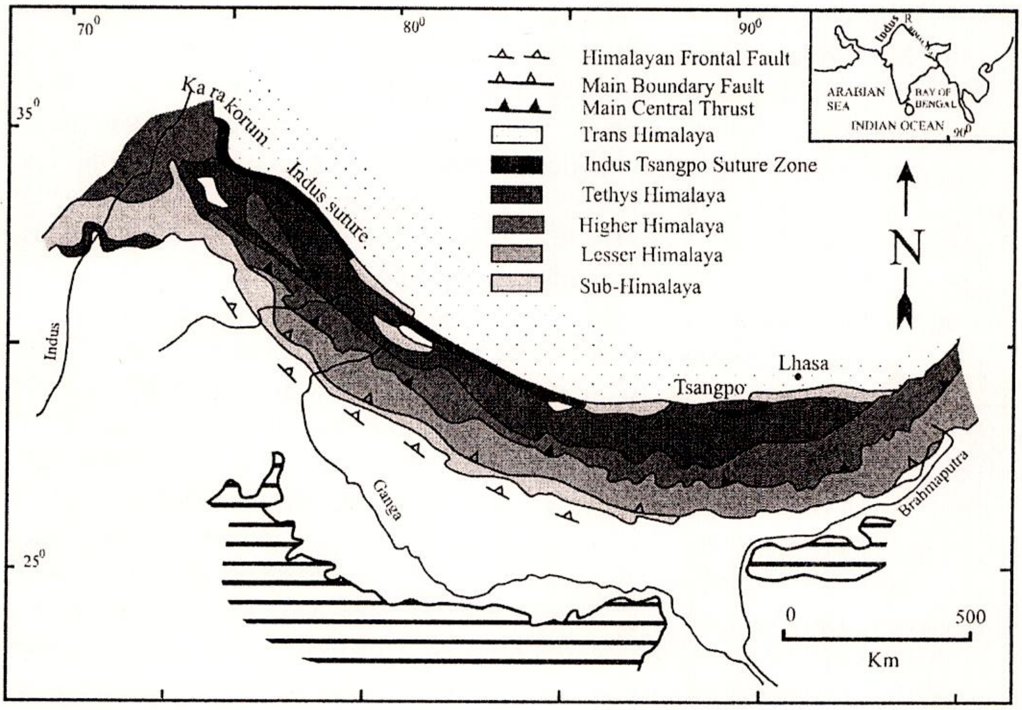

Fig. 2: Geological divisions of the Himalaya (Based on Valdiya, 1993)

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