The Siachen Glacier: The Second Longest Glacier Outside the Polar Regions

Mahendra R. Bhutiyani

Abstract

The Nubra Valley in Karakoram Himalaya is a highly glacierized valley with about 33 valley glaciers of different lengths and sizes. The glaciers occupy nearly 2/3rd of the total basin area. The most prominent and longest amongst them is the Siachen Glacier. This well-known glacier is a fine example of a compound and piedmont glacier. Glacier erosion has resulted in the development of a myriad of erosional and depositional features. These include numerous tributary glaciers with cirques, arêtes, horns, bergschrunds, moraines, supra-glacial streams and glacier lakes. Being a temperate glacier, the Siachen produces copious amount of runoff during ablation season in its proglacial streams. Heavy sediment load carried by the Nubra River has given rise to many glacio-fluvial depositional landforms and features such as outwash plains, braided rivers, alluvial fans, varved clays, etc. Evidence indicates three periods of glaciation in the area during the last ~145 ka. The role of tectonics in the late Quaternary period is also evident by way of at least three episodes of uplift, resulting in the formation of river terraces. There is no indication of significant recession of the Siachen Glacier snout during the last millennium.

Keywords

Siachen glacier • Karakoram Himalaya • Piedmont glacier • Valley glaciers • Moraines • Quaternary glaciations • Snout recession

1 Introduction

The Himalaya, one of the youngest folded mountain systems, is one of the most dynamic regions (seismically and geologically) on the surface of the Earth. With about 17 % of the total area occupied by approximately 15,000 glaciers, it has a large influence on the meteorological and hydrological conditions over the Indian subcontinent, particularly on the Indo-Ganga Plains where majority of the rivers derive significant portion of their runoff from either seasonal snowmelt and/or glaciermelt.

The Karakoram Range (Fig. 1) in the northern-most part of the Himalaya is highly glacierized with about 37 % of its area covered by a number of valley and piedmont glaciers of varying lengths, ranging in altitude from 2,800 to 7,600 m a.s.l. The Shyok River, with the Nubra River as a tributary, is a major river system in the area (Fig. 1). The Shyok is a tributary of the Indus River.

Closeted in a lap of an archetypal U-shaped glacier valley with the Saltoro Hills to the west and Karakoram Range to the east in the Ladakh District of the state of Jammu and Kashmir, the Siachen Glacier is the longest (76 km) glacier in Himalaya and the second longest glacier in the world outside the Polar Regions. A northwest-southeast trending glacier, it originates from a cirque

M. R. Bhutiyani (✉)
Defence Terrain Research Laboratory, Metcalfe House, New Delhi 110054, India
e-mail: mahendra_bhutiyani@yahoo.co.in

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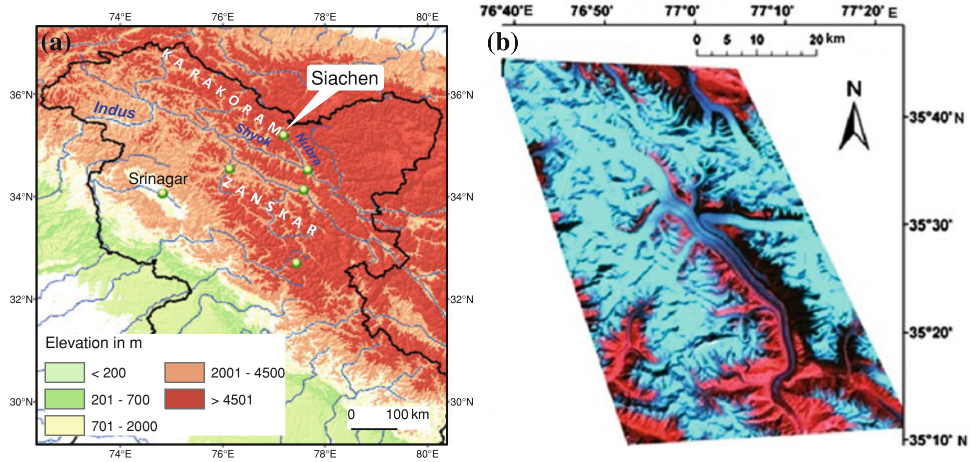

Fig. 1 **a** Location of the Siachen Glacier and **b** LISS-III satellite image of the WNW-ESE trending Siachen Glacier showing its snout and tributary glaciers

at the base of the ridge called "Indira Col" at an altitude of 6,115 m a.s.l, follows a well defined WNW-ESW trending valley and culminates in a snout located at an altitude of 3,570 m a.s.l (Fig. 1). Two proglacial melt-water streams emerge out of two ice caves in the snout region and merge into a single stream one km down-stream. The Nubra River thus formed, traverses its own outwash plain for a distance of about 90 km in a braided channel pattern up to its confluence with the Shyok River near Deshkit.

High relief, sub-zero temperatures, scanty precipitation in the lower reaches and moderate to heavy snowfall in the upper reaches and presence of numerous valley glaciers have made the terrain extremely rugged and difficult to traverse. The lower altitudes are marked by arid climate and high climatic gradient, resulting in the formation of typical dry desertic landscape features such as sand dunes and sand bars within the river-bed.

The Siachen Glacier has fascinated many explorers in the past two centuries who had organized a number of expeditions to this region and generated significant amount of information in the form of their travelogues and technical reports. First-ever recorded report on the Siachen Glacier was authored by Henry Strachey in October 1848. In 1909, Dr. Tom Longstaff, Dr. Arthur Neve and Lt. A M Slingby crossed over Bila Fond La Pass and later over to the Siachen Glacier snout in a pioneering effort to establish the length and exact locations of various passes. Dr Tom Longstaff was the explorer who named this glacier as Siachen. "*Sia*" in the Balti language refers to the rose family plant widely dispersed in the region. "*Chun*" refers to any object found in abundance. Thus, the name Siachen refers to a land with an abundance of roses.

2 Geology and Climate

Geologically, the Nubra Valley can be sub-divided into three sub-divisions: (1) The Northern Sedimentary Zone (2) The Central Crystalline Zone, and (3) The Southern Volcanic Schist Zone.

The northern portion of the valley is almost entirely covered by ice and has very few rock outcrops. However, the moraines originating from this part of the valley have abundance of sedimentary rocks like dolomitic limestones, carbonaceous shales and slates. These moraines, which form the middle three rows on the glacier body have a whitish grey tone on the satellite imagery. This northern sedimentary zone has a thrusted contact with the central crystalline zone to its south (Ganser 1964) which has pink granites with phenocrysts of pink feldspars and quartz at its centre and granodiorites and granite-gneisses towards the periphery. The granodiorites and granite-gneisses can be demarcated from granites by their dark greyish tone (Fig. 2). This zone is traversed by number of pegmatitic and quartz veins and lit-par-lit injections of the calcitic material. It has a thrusted contact with volcanic schist zone in the southern part of the valley consisting mainly of volcanic ultrabasics with serpentinite lenses, ferruginous shales and quartzites.

A major portion of the precipitation in this part of the north-western Himalaya occurs under the influence of extra-tropical low pressure systems called 'western disturbances' (WDs). The lower elevations in the Karakoram Himalaya receive an annual snowfall of about 75–150 cm (snow depth) whereas higher elevations receive more than 1000 cm (snow depth). Higher and lower portions of the area remain in sub-zero temperatures for 63–90 % and

Fig. 2 An aerial view of the Siachen Glacier and the Nubra Valley. The central crystalline zone with *pink* granites and granite-gneisses (*light grayish* tone) at centre and granodiorites towards the *top* portion (*dark greyish* tone)

35–40 % of the days respectively in a year. Minimum temperatures in the range of −20 to −40 °C have been recorded in the months from December to February. The area receives comparatively very low precipitation during the monsoon months from July to September.

3 Landforms

Majority of the glaciers are aligned in WNW-ESE direction followed by a few in NNW-SSE and ENE-WSW direction. Three major sets of fractures appear to have shaped the morphology of the valleys hosting these glaciers. WNW-ESE trending fractures, which are generally parallel to NW-SW strike/trend of the Himalaya, appear to have given rise to strike valleys which now house some of the longest glaciers in the world (e.g. Siachen, Baltoro, Batura, etc.). The morphology of transverse glaciers, such as Lag-ongma and Layongma indicates that WNW-ESE and ENE-WSW trending fractures have given rise to these valleys. The glaciers occupying strike valleys tend to have longer lengths than the glaciers in transverse valleys because the lineaments are also longer in WNW-ESE direction as compared to other two directions.

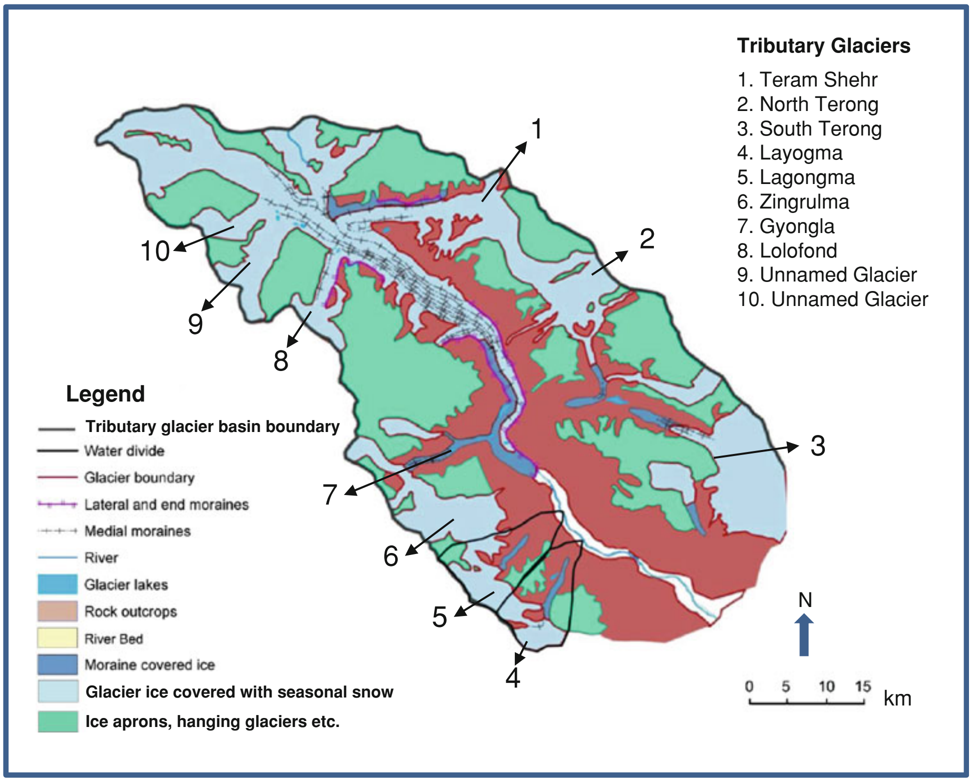

Fig. 3 Map showing different geomorphological features of the Siachen Glacier and Nubra Valley

The geological work done by the Siachen Glacier during the last glaciations has given rise to the development of a myriad of erosional and depositional glacial landforms, resulting in a truly unique and spectacular landscape (Fig. 3).

3.1 Erosional Features

Siachen, a compound glacier housed in a U-shaped glacial valley with steep valley walls on either side, is fed by a number of tributary glaciers with their own U–shaped valleys on both sides. On the left flank, it has three prominent tributary glaciers, namely Teram Shehr, North Terong and South Terong (Fig. 3). Teram Shehr is the longest tributary of Siachen having a length of ~32 km. North Terong and South Terong glaciers, which are now independent glaciers, occupy NNW-SSE trending valleys. On the right flank, there are five tributary glaciers namely Zingrulma (length ~6 km), Gyongla (~22 km), Lolofond (~11 km) and two unnamed glaciers in the north having lengths of ~12 km. There are numerous hanging glaciers with their individually carved glacial valleys. Because of such large number of tributary glaciers, there are many cirques, arêtes and glacier horns (Fig. 4). The highest of such horns in the Nubra Basin is a peak called "Sia Kangri" with an altitude of about 7,600 m a.s.l.

Generally, two types of crevasses, transverse and longitudinal, have been observed. The average gradient of the Siachen Glacier being low (~3°), not many transverse crevasses are noticed on the main glacier body. They are mostly confined to the areas of higher gradients and bends. They are also found at the confluences of various tributary glaciers and in the snout region. The longitudinal crevasses have been observed only in the snout region and are about 1 to 2 m in width. The tributary glaciers, such as Gyongla, Zingrulma, Lolofond and Teram Shehr, are highly crevassed because of relatively high gradient (~11°).

3.2 Depositional Features

The Siachen Glacier is characterized by the presence of extensive supraglacial lateral, medial and terminal or end moraines covering almost half of its total surface area. Although accumulation zone is relatively free of moraines, the ablation zone is largely covered with moraines, making Siachen a predominantly a debris-covered glacier.

The end or terminal moraines of Siachen have a length of ~4 km and a width of ~1.5 km (see Fig. 2). They mainly consist of unsorted, heterogeneous mixture of boulders of granite, granodiorite, granite gneisses, limestones, carbonaceous shales, slates and conglomerates. They are also characterized by a highly undulating and

Fig. 4 A typical cirque showing bergschrund. Multiple horns and arêtes are visible in the background

hummocky topography with a number of glacial lakes and supraglacial channels. The end moraines of Siachen coalesce with the end moraines of its tributary, the Gyongla, which has almost an E–W orientation.

The lateral moraines of the Siachen are seen on both the sides of the steep-sided valley. They consist of unsorted loose boulders of granites, granodiorites and granite gneisses with abundant rock waste.

Eight rows of medial moraines have been observed on the main glacier body. The western rows of medial moraines are entirely made up of pink granites and granite gneisses. The middle rows consist of sedimentary rocks, mainly limestones, dolomites and carbonaceous shales. The eastern rows of medial moraines consist mainly of granodiorites and granite gneisses. The differential melting of the glacier ice covered with medial moraines over a period of time has made the topography of the glacier-body highly undulating with the formation of number of morainic ridges (Fig. 5) and ice pinnacles.

Many active supraglacial streams and lakes are observed on the glacier body. The glacial lakes at some places have been formed as a result of whirling action of the supraglacial meltwater channels. A few of them have also been formed due to subsidence of the upper crust and caving in of the englacial cavities. The lakes thus formed vary in size from few meters to 30–40 m in diameter and are round to oblong in shape. The glacier lakes found in the snout region are shallow and smaller in size. They are interconnected by supraglacial channels/streams and at some places by englacial channels. Due to shrinkage of Teram Shehr and North Terong since their maxima, a few inactive glacier lakes, such as the one near the confluence of Teram Shehr Glacier with the main trunk glacier have also been formed.

Fig. 5 Numerous rows of medial moraines making topography of the glacier body highly undulating

The outwash plains of the proglacial stream of the Siachen Glacier are marked by extensive proglacial deposits of varved clays alternating with sand beds. These fluvio-glacial deposits are traversed by braided rivers. Tectonic activity during the late Quaternary period is evident by way of at least three episodes of uplift and formation of river terraces (Fig. 6). At places, wherever there are tributaries joining the main valley on both sides, these terraces are overlain by alluvial fans consisting of loose boulders near the valley slope and sandy to loamy soil in the middle portion and clayey soil on the periphery. Because of high fertility, some of these alluvial fans are cultivated and have human inhabitation on them (Fig. 7).

4 Retreat of the Siachen Glacier

Mountain glaciers located at higher elevations in the mid-latitudes and tropics like Himalaya are sensitive indicators of the changes in climatic conditions. The fluctuations in the climate are reflected in variations in the mass balance, glacier lengths, advance and retreat of the glaciers.

Majority of the glaciers in the Himalaya have had negative specific mass balance during the period from 1974–1975 to 1990–1991, coinciding with general rise in air temperature. Highly negative values of mass balance of the Siachen Glacier from 1986–1987 to 1990–1991 imply significant ice loss during this period (Bhutiyani 1999). Although no mass balance data are available for this glacier after this period, it is estimated that the glacier must have lost about 1.3 km^2 of its area since 1989 (Chander et al. 2012). The glacier has undergone retreat at a much lower rate, about 0.6 to 2.0 m/year between 1962 and 1998, as compared to other glaciers, which are comparatively shorter in length. This may be attributed to the fact that Siachen is a very long, compound and piedmont glacier with a low average gradient and its response time appears to be much longer than the other smaller glaciers (Bhutiyani 1999; Ganjoo and Kaul 2010).

Fig. 6 The braided channel pattern of the Nubra River on its outwash plain. A prominent river terrace is seen on the *left*

Fig. 7 View of an alluvial fan/talus cone with cultivated fields and human inhabitation on the periphery

5 Late Quaternary Glaciations

The understanding of past climatic changes serves as a benchmark against which predictive models of future climate can be evaluated. In recent years, many studies have been carried out to reconstruct the chronology of glaciations in the Himalaya and the Karakoram. Field evidence of remnant lateral moraines and striations on either side of the Nubra Valley up to its confluence with the Shyok River near village Deshkit (∼90 km downstream of current position of snout) suggests that the Siachen Glacier might have extended up to the confluence and also fluctuated considerably during the late Quaternary. Studies based on field mapping, remote sensing and ^{10}Be terrestrial nuclide surface exposure techniques have indicated three glacial stages, namely, Deshkit 1, 2 and 3 (∼45, ∼85 and ∼144 ka, respectively) which are synchronous with Milankovitch time-scales (Owen et al. 1998, 2008; Seong et al. 2007; Dortch et al. 2010). The Nubra Valley was extensively glaciated around 24 and 18 ka, a period corresponding with the Last Glacial Maximum (LGM) (Nagar et al. 2013). In addition, a number of north and south draining tributary glaciers may have contributed to the Siachen Glacier during the LGM. During the Little Ice Age (∼1600 to 1850 AD) when Himalayan glaciers advanced marginally, the present position of the Siachen Glacier snout was insignificantly affected (Nagar et al. 2013). Recent warming trend has had a negligible effect on it and the glacier snout has remained, by and large, unchanged in the last millennium (Upadhyaya 2009; Ganjoo and Kaul 2010; Nagar et al. 2013).

6 Conclusions

Siachen, meaning a land with an abundance of roses, is the name of a long, compound and piedmont glacier in Karakoram Himalaya. The glacier is exclusive because it is the longest glacier in the Himalaya and the second longest glacier in the world outside the Polar Regions. Three major sets of fractures trending in WNW-ESE, NNW-SSE and ENE-WSW have dominantly shaped the glacial geomorphology of this part of Karakoram Himalaya. The Siachen Glacier is characterized by extensive supraglacial lateral, medial and end moraines, supraglacial streams and lakes and pro-glacial deposits. The area has witnessed three episodes of glaciations during the last ~145 ka, when the glacier may have extended up to the confluence of the Nubra with the Shyok River. If correct, this would indicate that the total length of the Siachen was nearly 165 km. The present position of the Siachen Glacier snout has not shown any detectable effect of twentieth century warming trend and it has remained largely unchanged in the last thousand years.

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