Space based observation of a newly found high altitude Red Colored Glacial Lake in Ladakh, Northwest Himalaya

Abstract

The present study reports the existence of one of the unique and unusual features of the Zanskar valley (Ladakh) - a proglacial 'Red/Brown Colored Lake' observed from space based remote sensing data sets. The lake has not changed in the color and size over the years. Here we report observations from the year 2004 onwards till recently. The local geology plays an important role and iron dominated lithology of the region, interacts with snow and glacial melt waters and subsequently deposit red/brown color suspended silt in this proglacial lake. The spectral analysis of the reflectance data from SENTINEL-2 images in visible- infrared (VIS) region of electromagnetic spectrum suggests the color of the lake is due to high concentration of suspended solids, having dominant reflectance at 660-700 nm, causing the red/brown color of the water.

Keywords: Red Lake, Ladakh, Zanskar Valley, Himalaya

The Zanskar valley lies between Karakoram Range in the north and the Great Himalayan Range in the south and offers surreal landscapes (such as glaciers, glacial lakes, saline lakes, permafrost features, and dunes) and fascinating geology. The region is located at the intersection of the two most important atmospheric circulation systems via. the Indian summer monsoon system and the midlatitude westerly winds and thus, has an important implication towards understanding the climate dynamics of the region[1-4]. This arid part of the Indian Himalaya is least populated due to harsh and extreme climate and scanty vegetation. A fair number of studies pertaining to the climate of the region[5], change in glaciers[6], glacial lakes[7] (Schmidt et al., 2020) and diverse landforms formed due to permafrost, glacial activity etc.[8] have been carried out from the region. However, owing to the extreme high altitude environment of the region with lower oxygen level, higher UV radiation and extreme cold weather, most of the remote locations in Ladakh remain unexplored and unknown.

The ongoing global warming has resulted in the continued glacier melting and the formation and expansion of the glacial lakes in the Himalayan region[9-11]. One such glacial lake, which is in ~30 km southwest of Lamayuru - 'moon land of Ladakh', Leh, shows a unique reddish/brownish color.

The glacial lake is located at around 34° 0.280'N and 76° 43.295'E, at an altitude of ~5060 m asl (Figure 1). The distance of the lake from the nearest road and village Photoskar (~4200 m asl) is ~11km. This lake is dominantly fed by the meltwater from its northeasterly facing mother glacier. The morphometry analysis shows that the lake covers an area of ~0.19 sq km, the perimeter of ~1.19 km, length of about 700 m and width of ~300 m. The orientation of the lake is north-east and the slope between the mother glacier and the Red Lake is about 20º. The shape index revealed a near circular shape of the lake (shape index 0.75). The analysis of the time series images of the Red/Brown Lake (Red lake henceforth) indicates that the size and the color of the lake have not changed over the years (Figure 2). The water body of the lake remains frozen tentatively from November to April.

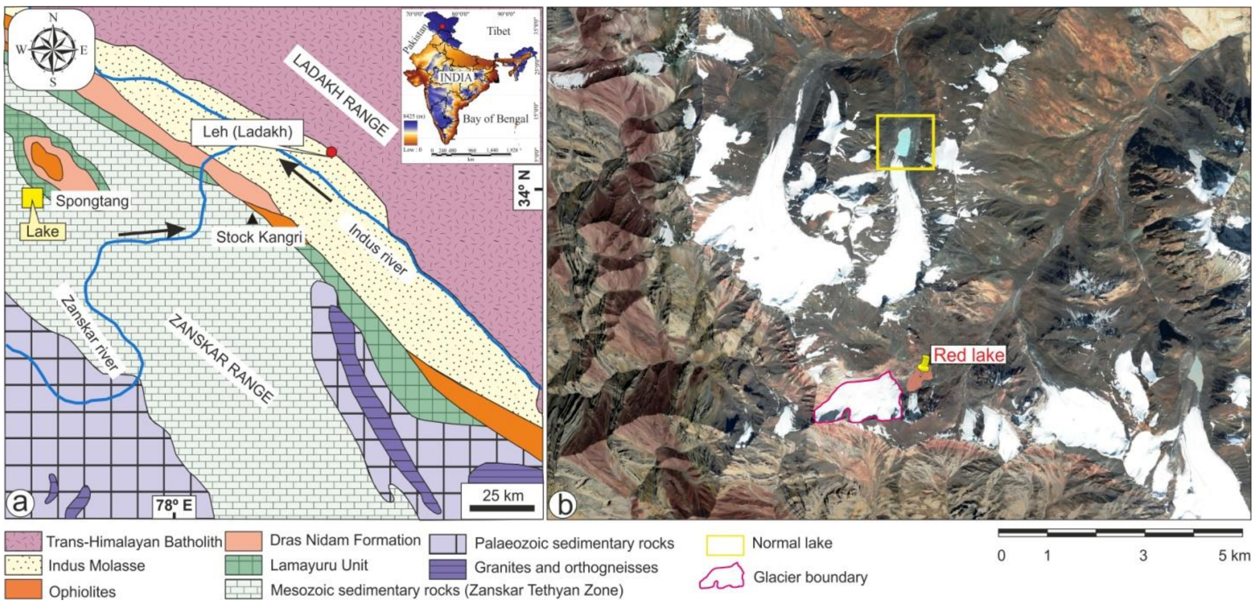

Figure 1: (a) Geological map of the Red Lake area and surrounding (modified after Thakur 1981 and Schlup and others 2003) [12-13]. The location of the Red Lake is shown as Yellow Square. (b) Google Earth image dated 10-17-2017, showing the Red Lake and adjoining normal blue colored proglacial lake.

According to various reports available in the public domain, there are only 29 pink lakes in the world[14]. Lake Hillier of Western Australia is one of the famous pink lake and the coloration is thought to be due to a red algae known as Dunaliella salina, which grows well in a salty environment only[15]. Recently the water of the Lonar Lake in Maharashtra, India has turned pink due to a large presence of the salt-loving 'Haloarchaea' microbes[16]. However, the pink color of

Dusty Rose Lake of British Columbia, Canada which is a glacial lake is due to its surrounding rocks and not due to algae[17]. Similarly the 'Blood Falls' of Taylor Glacier, Antarctica contains a diverse microbial community that is metabolically active and influences weathering and gives a reddish color to the meltwater[18-20]. Owing to the discovery of such unique environments, the subglacial environments have become important to scientific interest[21-23], however, such research is largely lacking in the Himalayan region.

The Red Lake identified in the Ladakh, Himalaya is a high altitude lake located at ~5060 m asl, average surface temperature of which varies from ~-16°C during the winter to ~6°C during the summer. The study area is located on the transition of Zanskar Tethyan Zone that formed during the progress of India–Asia collision that has resulted in the closure of the Neo-Tethys Ocean at ~55 Ma[13, 24-27] and Spontang ophiolite complex (SOC) which is an ophiolite klippe that overlies the volcano-sedimentary mélange[28-29]. The meta-sedimentary rocks of Zanskar Range contain 'Ferruginous Formation' rich in ironstone[24]. The NE facing glacier and the catchment area feeding the Red Lake is located on these rock formations of Zanskar. Therefore, we propose that the persistent red and brown color of the meltwater likely be due to the soluble iron complexes derived from weathering of the iron-rich bedrocks. Besides this, the SOC comprises of mantle-peridotites (lherzolites, harzburgites), dunites, gabbro, diorites, plagiogranites in form of numerous boulders (peridotites), dykes (Gabbroic), lenses (dunites) interbedded with volcanoclastic deposits[30]. The characteristic mineralogy of these mafic and ultramafic rocks being dominated by olivine and pyroxenes makes them metastable at surficial conditions especially, in the presence of aqueous fluid. Dissolution of primary olivine and pyroxene is accompanied by precipitation of secondary phases in form of clay minerals, carbonates and iron oxide and hydroxides. Therefore, the red-coloration of the lake may be imparted by formation of hematite and goethite as a result of near-surface aqueous weathering of iron bearing mafic and ultramafic rocks. It has been reported that the glacier melt water in the Himalayan regions are rich in chloride (Cl^-), bicarbonate (HCO_3^-) and sulphate (SO_4^{2-}) ions[31] which can form stable soluble complexes with the Fe^{2+} at pH ranging between ~7.0 - 8.0[32]. The release of Fe^{2+} in the meltwater could have been enhanced by interaction of Cl^- rich meltwater with frozen iron oxide rich fluids in the sub-aerial sections of the catchment area. Besides, microbially induced weathering of sub-glacial bedrock minerals could be another viable source of Fe^{2+}. However, differences in water residence times, water-rock ratios, refreezing at the water-ice interface, basal geologic conditions, and biological processes can produce different water chemistries[33], hence needs a proper investigation.

Due to the above described geochemistry, the lake is expected to have high concentration of suspended solids. A spectral analysis of the Red Glacial Lake water as compared to a typical blue glacial lake water (Figure 2h) using Sentinel -2 images of dates 15th August 2020, 25th August 2020 and 30th August 2020 revealed remarkable difference in the spectral response of the water of the Red Lake. The peak reflectance of the spectrum of Red Lake occur at 660-700 nm (0.66-0.7μm) wavelength range, compared to peak of the blue water lake at 0.49-0.55 μm. This marked difference gives this lake a unique red/brown color over the years.

The color of this newly found high altitude glacial lake might be affected due to snow/ice melt water interaction with local lithology. It will be worthwhile to investigate this phenomenon and geo-chemical processes by conducting extensive field campaigns during the next summer season in this region. Therefore, we propose a systematic study of this lake that will provide important insights in understanding the ecology of such sub-glacial environments along with the geochemistry and glacier dynamics in the Himalayas.

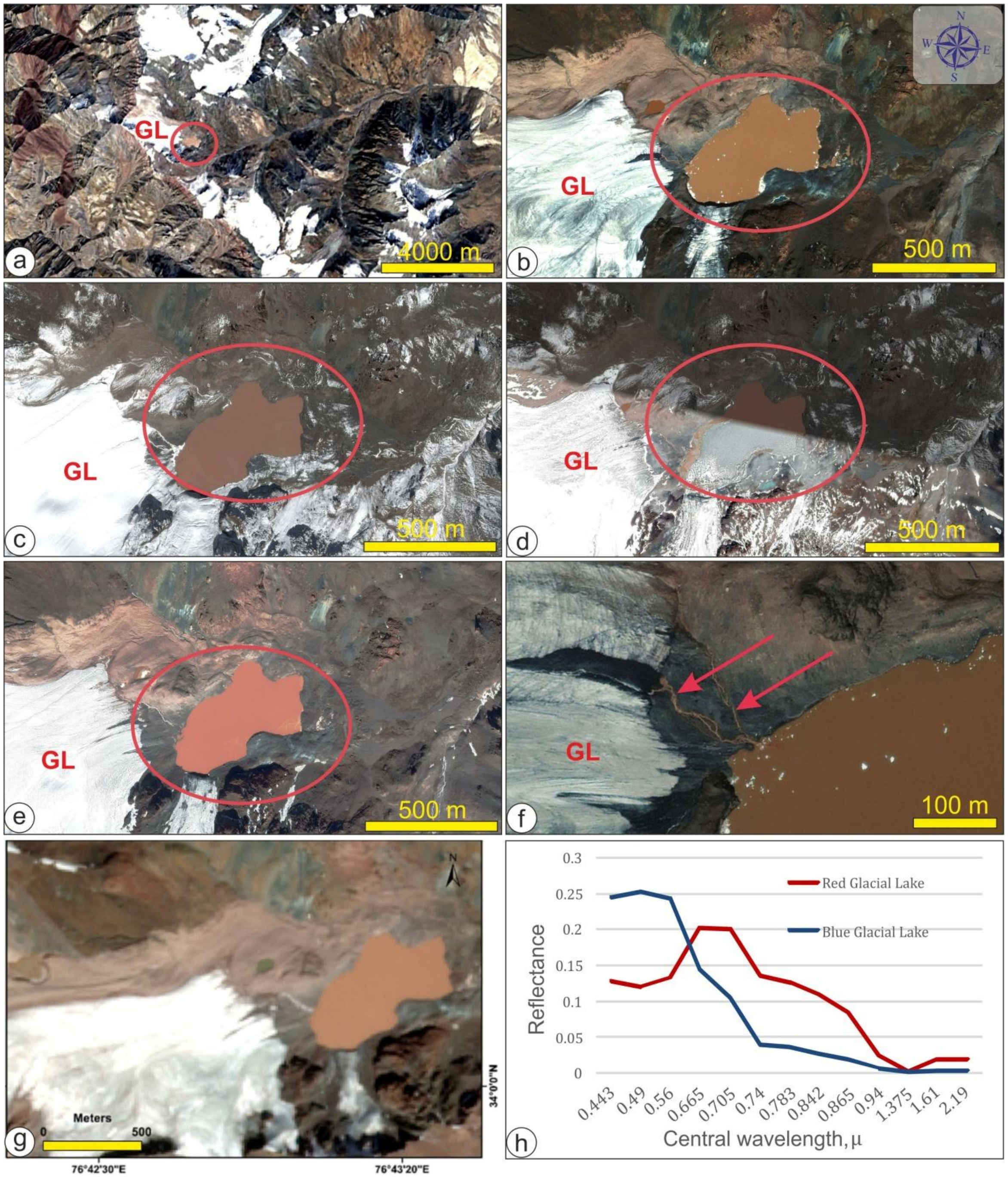

Figure 2: Time series images obtained from Google Earth Pro showing the mother glacier (GL) and the coloration of the Red Lake in (a) in 2000 ; (b) 2004 (c) 2013; (d) 2014 ; (e) 2017; (f) close-up of 2004 shows the color (red arrow) of the melt water; (g) Natural color composite (bands 432) of Sentinel 2A dated 4th October 2020 showing the Red Lake and; (h) spectral response curves of the Red Glacial Lake and the nearby blue glacial lake (Lake shown in Figure 1b) obtained from Sentinel 2A dated 30th August 2020.

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