EVIDENCE OF RECENT CLIMATIC CHANGES SHOWN BY TIBETAN HIGHLAND LAKES

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IN 1905 Ellsworth Huntington[1] observed that the Pangong Tso in Ladakh shows a set of benches and beach-lines which lie lower than any of the older terraces surrounding the lake. The latter, of which Godwin Austen in 1866 said that they must be witnesses of the Ice Age, have unduly diverted the attention of explorers from a less conspicuous but equally important feature: the erosive and bathymetric evidence of recent climatic oscillations on the Tibetan highland lakes.

During the summer of 1932 we[2] had occasion to spend several weeks in the immediate neighbourhood of the lakes Pangong, Pongur, Mirpa, Morari, and Kar in eastern Ladakh along the Kashmir–Tibetan boundary. Our geological and biological work provided, amongst other results, new information regarding changes of depth, of shore features, and related phenomena which bear witness to regional climatic oscillations of Post-Quaternary age. It may encourage those who visit lake shores to gather more data.

The evidence for recent changes of lake-levels is topographic, physiographic, and hydrographic. Data gathered by former explorers most fortunately record changes in level and in local precipitation in Ladakh reaching back over one hundred years, which had made it possible to compare these oscillations and to trace their origin.

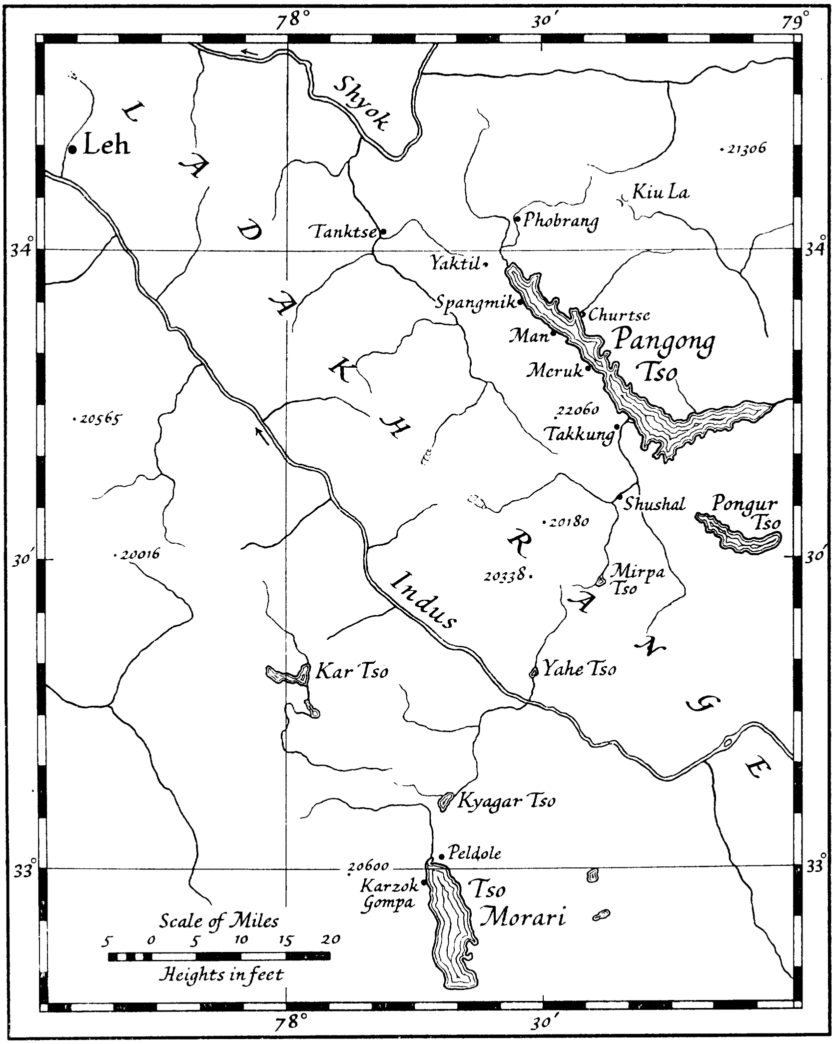
The Pangong Tso, being the largest mountain lake north of the Himalaya (13,915 feet above sea-level), gave the first evidence of recent topographic changes. When our pony caravan attempted to use an old path along the northern shore between Churtse and Lukung we found it impossible to proceed round the base of the cliffs as the path had become flooded. On the promontory which flanks the north-western part of Churtse bay the old path was found well constructed with large slabs of rock, and the road, which first follows a higher beach terrace, could be seen to lead into the lake, where the path continued 5 feet below the water and around the cliff. We noticed two drowned beaches at 3 and 5 feet which may also be recognized on Plate 1. Natives from the hamlet of Lukung corroborated the recent rise of the lake. At some previous date a path had been constructed through the rocks above the cliff, but this road had long been out of use, for we were warned that it had been impassable for years. Sven Hedin[3] however had been able to use it in 1901, from which we may conclude that the natives had since then con-

[1] "Pangong, a Glacial Lake in the Tibetan Plateau," *Jour. of Geol.*, vol. 14, pp. 599–617.

[2] Dr. H. de Terra was leader of the Yale University Expedition to northern India in 1932–33, to which Mr. G. E. Hutchinson had been attached as a biologist (see *Geogr. J.*, vol. 82, no. 4, 1933, p. 379; also *Himalayan Journal*, vol. v, pp. 33–45; and *Geographical Review*).

[3] 'Im Herzen von Asien,' Leipzig, 1903, vol. 2, p. 502.

structed the safer and shorter road along the base of the cliff which eventually had become flooded so that the northern shore road fell entirely into disuse. For this reason the northern trade and shepherd route from Tanktse to Rudok leads nowadays *via* Phobrang across the Kiu La. Our native guide stated also



that the outlet of the eastern Pangong near Ot had become unfordable owing to high water.

A few days later our surveyor, Khan Sahib Afraz Gul Khan, drew my attention to the fact that a rocky islet a quarter of a mile out in the lake from the shore at Yaktil which had been marked as lying 5 feet above the lake-level on the old survey sheet (27.13922′) did not now exist. Hutchinson set out for a line of soundings and found that the shallowest water was 13·1 feet at the spot where the islet had been in 1861. Thus the lake had risen since then at least 18 feet.

As we proceeded from Lukung to Man and Takkung on the southern lake side further physiographic evidence for a recent rise presented itself. The fan formation which here makes the lake front is seen to be superimposed on the pleistocene deposits and is therefore of post-glacial origin. A young talus-cone at the slope of a cliff between Yaktil and Spangmik showed two distinct beach lines 3 and 5 feet above the water, and a third could be seen in the clear water 2 to 3 feet below the level of the lake. Shortly before reaching this spot the path makes a detour around the advancing water of a shallow bay. Beyond Spangmik several river-beds must be crossed, of which some are deeply entrenched into the fan, which is underlain by glacial and interglacial deposits. In some of the shallower flood channels a more recent heavy accumulation of gravel had taken place, so that the road had been completely obliterated. Former erosion naturally had entrenched the river-bed during a progressive fall of the lake-level until this process had recently been checked, if temporarily, by a rise of the water to which the rivulets had responded by accumulation.

Twelve miles south-east of Takkung the underwater beaches were seen to follow the contours of an old shore-line (Fig. 1). A small delta had here been

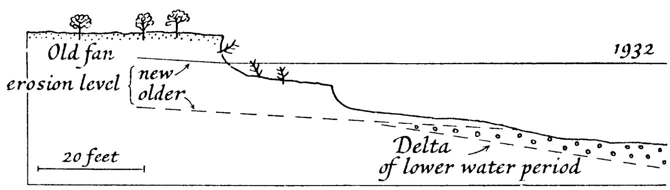


Fig. 1

built into the lake, and as the underwater beaches broke abruptly off along the drowned shallow flood-channel of the rivulet it is evident that the beach preceded the delta. Larger bushes could still be seen clinging to the upper beaches while others had already become uprooted and were tossed about by the waves. These had cut a cliff 7 feet high into the older fan deposit from which the vegetation was breaking loose. The two beaches in front of the cliff had evidently been made at lower water, and owing to a further fall of the lake a younger fan had then been formed in front of them. The rising lake water had then flooded these shore features until the lake is now cutting into the front of the older fan.

Another interesting physiographic change connected with the rise of the Pangong is the formation of small lagoons. They appear in parallel rows along the shore and in one place two could be seen at distances of 3 and 10 feet from the shore. Fig. 2 may illustrate how their peculiar arrangement can be explained by a progressive rise of the lake-level. Their formation is greatly assisted by preceding shore-ice action. The accumulation of gravel and sand in the form of ridges is a common feature along Tibetan lakes (Plate 2). Owing to the severity of the frost, which keeps the lakes solidly icebound during four or five months of the year, shore-ice is a much greater factor of accumulation than around lowland lakes in middle latitudes. On Tso Morari I measured the beach gravel walls which were piled up by shore-ice to 4 feet high. Huntington[1] and Hedin[2] have pictured the same process. Such walls are found on many of the lagoons, but it is evident that they can survive a temporary inundation only if they consist of coarser gravel or of sand which has become somewhat cemented. During stage 2 of Fig. 2 Terrace A will become slightly hollow as the result of weathering, especially by deflation, whereby the height of the new beach wall is accentuated. Most lagoons on Pangong can be traced back to the same process; particularly where low terraced fans have become inundated, this indicates a recent rise of the lake-level.

There are also new data on soundings which lead to comparison with previous bathymetric work done by H. v. Schlagintweit in 1856[3] and Sven Hedin in 1901.[4] During our expedition soundings were made in the extreme northwestern end of the lake, in the vicinity of trig. station 27 of the survey of 1863, an islet now covered with water. One of these soundings, over the station, can be placed with confidence; the position of the others is very close;

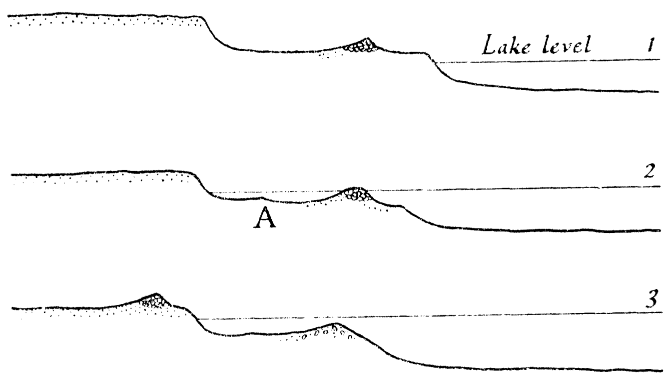


Fig. 2

the soundings near Man can be placed with fair accuracy, but several soundings to the east of Takkung can be located only roughly.

Hedin sounded the lake in 1901. He obtained one long line in the most southern part of the basin and another from Man across the lake to Churtse. The latter may be on nearly the same profile as ours, from which a rise of 15 feet between 1901 and 1932 can be deduced. H. v. Schlagintweit had obtained a maximum depth of 170 feet (51·4 m.) in the centre of the lake opposite Takkung. He also made two lines across the lake, one from Meruk, the other from Man. In the latter a maximum depth of 148·4 feet (45·1 m.) was encountered. When Schlagintweit's profile across the lake at Man is drawn, and the portion of the profile represented by our soundings then drawn below the older profile, the deeper of our soundings is found to lie just north of the central sounding of Schlagintweit's series. By comparing Schlagintweit's

[1] *Op. cit.*, Fig. 4.
[2] 'Scientific Results of a Journey in Central Asia, 1899–1902,' vol. iv, Stockholm, 1907.
[3] 'Reisen in Indien und Hochasien,' Jena, 1872, vol. 3, p. 172.
[4] *Op. cit.*, pp. 333 ff.

middle sounding of 140·0 feet (42·6 m.) with the point on our profile immediately below it, a rise of water-level of 19·4 feet (5·9 m.) can be deduced, and approximately the same rise is given when our deeper sounding is compared with Schlagintweit's profile. Our shallower sounding lies under a part of Schlagintweit's profile at which the depth is changing too rapidly to give any data of value. From a consideration of the present depth of the islet which was covered with water before 1859, it is clear that this figure of a net rise of 19·4 feet (5·9 m.) since 1856 is too great. In all probability the lines of Schlagintweit's soundings and ours do not exactly coincide. From the rate at which the island rose after 1859 we are probably justified in supposing that the lake was 10 feet (3 m.) shallower in 1856 than in 1932. Comparison of the areas of the profiles of 1856 and 1932 shows an increase of 18 per cent. corresponding to a rise of 19·4 feet (5·9 m.); since this is about the total rise between the minimum and to-day, we may assume an increase of volume of about 18 per cent. since the sixties of the last century.

The general correctness of the information obtained is however confirmed by a multitude of earlier observations all indicative of changes of the Pangong level. These historic data have been condensed in diagrammatic form on Fig. 6. For reference this list of historic data can briefly be summarized as follows:

1. W. Moorcroft and G. Trebeck ('Travels in the Himalayan Provinces of Hindustan and the Punjab,' London, 1831, pp. 401, 435) gave the first account of Tso Pangong and mention the lack of a road along the northern shore in 1821.

2. H. Strachey ("Physical Geography of Western Tibet," *Jour. Royal Geographic Soc.*, vol. 23, 1853), who visited the lake in 1848, remarks on the outflow of the eastern Pangong at Ot. His native guide, who had been with Moorcroft, said that the lake had perceptibly receded in the last twenty-seven years.

3. H. von Schlagintweit (*op. cit.*, vol. 3, pp. 168 ff.) relates native information according to which higher lake-levels in connection with good harvests were frequent before 1841. In 1856 soundings were made but no rock islet is mentioned.

4. H. H. Godwin Austen ("Notes on the Pangong Lake District of Ladakh," *Jour. Asiatic Soc. Bengal*, vol. 37, pt. 2, pp. 84–117, 1866) surveyed the rock islet in 1863 which appeared in 1859 above the lake-level. Shore roads were passable. He observed five to six beach-lines, 1 foot distant from each other, and also a submerged lake terrace, 10 feet below the 1863 level. From these phenomena he infers climatic oscillations.

5. In 1869 F. Drew ('The Jummoo and Kashmir Territories,' London, 1875) pictures the islet and mentions a total seasonal rise and fall of the lake by 3 feet.

6. M. S. Wellby ('Through Unknown Tibet,' London, 1898) had the choice to use either the shore route or the longer but safer one across the Poranda La.

7. Sven Hedin (*op. cit.*) gives soundings of 1901 and comments on the condition of the northern shore route which was inundated, but the river at Ot was fordable. The existence of an older road, 10 m. above the path which he followed, makes him believe that his road of 1901 was once flooded.

8. E. Huntington (*op. cit.*) observed in 1905 three to four small drowned beaches 10 to 12 feet below the level, and gives native information according to which the lake was 10 to 12 feet lower during 1875–85. Although he recognized that oscillations were recent he attempted to couple them with the formation of clay and gravel deposits near Man which Godwin Austen in 1866 had rightly interpreted to be of glacial and interglacial origin.

To this historic record must be added a chemical analysis of the lake water made for Henderson and Hume in 1871.[1] A comparison of the chloride content of the lake as given by him with that found in 1932 indicates that the lake has been diluted by fresh water by 16 per cent. of its former volume since that date. This increase in volume is comparable to the increase of 18 per cent. in area of the cross-section at Man indicated above.

The whole clearly indicates that within 112 years Tso Pangong has experienced one low and two high levels.

Tso Morari, in the district of Rupshu on the Himalayan side of Ladakh, presents indisputable evidence of a recent rise. The prayer or mani walls on the western shore between Karzok Gompa and Peldole were half washed into the lake when we passed there in August 1932 (Plates 3 and 4). The path

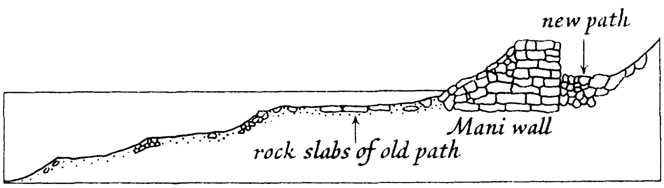


Fig. 3

did not bifurcate at the end of the prayer wall as it should, and the natives had started building a smaller mani 4 feet farther inland on the other side of the road. Plate 3 and Fig. 3 show the ruined state of this monument, and the drowned terrace across which one branch of the path led round the other side of the mani, as is required by lamaistic rite. The destruction of an older shore road became visible all the way. The people had in some places carried it across young talus 10 feet higher up. Three drowned beach-lines could clearly be seen under water as Fig. 3 illustrates, and from a higher location above the shore one could readily follow three or four of the drowned beaches all along the shore. Some lagoons occur in a beach, their spits lying 5 inches above the level. Strewn with coarse gravel and boulder they indicate a formation similar to the one formerly described. On the eastern shore also there is a drowned path 5 to 6 feet beneath the water which leads around a rocky promontory south of the plain called Titta.

Our soundings on Tso Morari showed that the lake was 160–165 feet (49 m.) deep, midway between Karzok and Peldole about 500 feet (150 m.) in from this shore. One of Drew's lines of soundings lies a little to the south, running

[1] Frankland, in Appendix B of Henderson, G., and Hume, O. A., 'Lahore to Yarkand,' London, 1873.

Plate 1. Pangong Tso: drowned beaches

Plate 2. Pangong Tso: accumulated gravel and sand

Plate 3. Tso Morari: prayer wall partly washed away

Plate 4. Tso Morari: remains of submerged prayer wall

due east from Karzok. Unfortunately it is not possible to make any comparison owing to the probable variation in the slope of the lake bottom in this region.

On *Kyagar Tso* a well-defined beach with a gravel wall made by ice-push was noticed 3 feet below the present level; within this are two less well-marked beaches. Drew found the deepest point to be in the south-west corner of the lake, where he ascertained a depth of 67 feet (20·4 m.). In the same part of the lake we obtained a depth of 69·6 feet (21·2 m.). It is probable that the water-level has risen about 3 feet in the last fifty years.

The small glacial lake, *Yahe Tso*, which is drained by a northern tributary of the Indus, showed one drowned beach at 6 feet and two others at a depth of 3 feet and 1 foot along the south-west corner. A sharp drop from the 3-foot contour at the north end of the lake may represent the second of these beaches. At the present the lake has an outlet, so large changes in water-level could not be expected.

Mirpa Tso is a glacial lake without outlet in a *kar* basin of the Ladakh Range south of Shushul. It presents drowned shore-lines at 1, 2, 3, and perhaps 4 feet. The former three are very conspicuous and can be clearly seen along the southern shore where there is also a larger set of higher and older shore-lines. The drowned beaches give here clearly the impression of being the youngest features resulting from continuous post-glacial desiccation which had been checked by the recent rise of the lake-level.

On *Pongur Tso* remains of a drowned beach, about 1 foot below the present level, were observed in several places along the western end of the southern shore.

During Dr. Trinkler's expedition in 1927 de Terra noticed a drowned river terrace at the eastern end of the Aksai-chin lake where a small river flows into it. The terrace is cut into clay deposits and was overstrewn with gravel, lying 1½ feet under water. The lake shore showed a sandy gravel beach wall 1 foot high which lay on top of a drowned terrace 2 feet below the level.

Outside the region which is known to either of the authors the lake system of Manasarowar and Rakas Tal in Tibet gives a remarkable record of oscillations which have become known through various descriptions.[1] Until the middle of the eighteenth century Lake Manasarowar regularly flowed into Rakas Tal and the latter apparently into the Sutlej. Since 1804 the flow from Manasarowar into Rakas Tal has been recorded as intermittent and no certain records exist of water leaving Rakas Tal. The channel from Manasarowar is but a few feet above the lower level of the lake, and thus a small rise will suffice to convert the dry bed of the effluent into a river. Fig. 5 gives the record of observations available since 1804.

The Climatic Cause of the Changes in Lake-levels

As most of the lakes mentioned receive their water supply from glaciers or snow-fed rivers, it seems at first obvious to couple the recent rise of lake-level

[1] The last observations were recorded by Messrs. F. Williamson and F. Ludlow in 1932 (*Him. Jour.*, vol. 5, p. 103). See also Kashyap, *Jour. Asiatic Soc. Bengal*, N.S., vol. 25, 1929, and Sven Hedin, 'Southern Tibet,' vol. ii, Stockholm, 1917, pp. 171–188.

with an increase in the amount of melting water. In such a case we would expect to find widespread evidence of glacier retreat and possibly a rise in the snow-line. In the case of the Pangong lake basin however no trace of general glacier retreat could be detected. The numerous glaciers on the Pangong range south of the lake have irregular movements, and on the whole they seem at the present to be stationary so far as one can judge from topographic evidence. Mirpa and Yahe Tso have no glaciers in their immediate neighbourhood, and yet they also show drowned beach-lines. Another argument against an increased ablation is the fact that numerous patches of valley névé in eastern Ladakh have hardly changed their size in the last eighty-three years. Strachey[1] noticed one cake of valley névé in southern Rupshu 4–5 inches thick and several acres in extent, and another one in 1848 in the Mirpa Gongma which lies in the Pangong catchment area. The latter had, according to our observation, hardly lost in size and not at all in thickness. H. v. Schlagintweit[2]

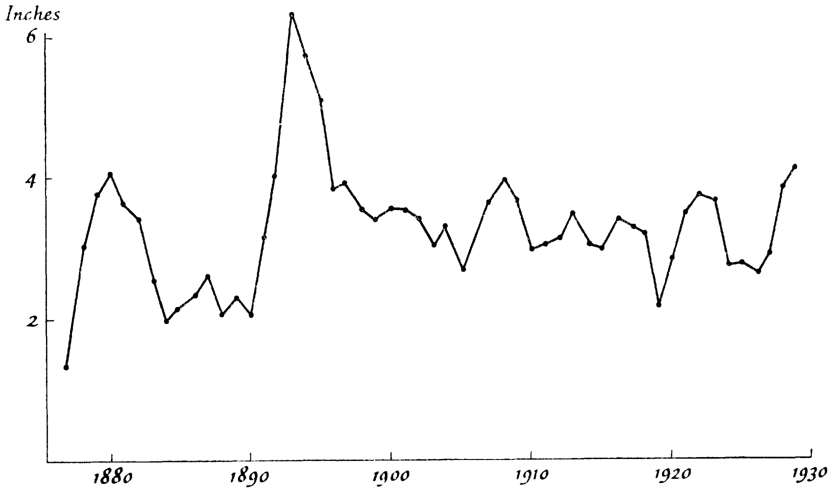


Fig. 4

reported similar névé from the Aksai-chin in 1857 which Drew[3] rediscovered in 1870, and the 4 inches of firn, 1 mile long and a quarter of a mile wide, still seemed to exist unchanged. One would think that a slight increase in temperature or solar radiation would suffice to melt such isolated and unprotected névé. The recent rise and the previous changes of lake-level cannot be traced to an increased supply of melting water, and as the phenomenon as such is one of regional extent, it must be due to changes in precipitation.

The meteorological station at Leh, which is about 50 miles north-west from Pangong as the crow flies, has registered the rainfall since 1876. A comparison between Fig. 4, which gives the changes of rainfall and the curve, and Fig. 6, which illustrates the changes of lake-level at Pangong, shows that an increase in precipitation between 1890 and 1900 corresponds with a rise in

[1] R. Strachey, "Physical Geography of Western Tibet," *Jour. Royal Geogr. Soc.*, vol. 23, 1853.

[2] *Op. cit.*, vol. iv, p. 82.

[3] *Op. cit.*, p. 353.

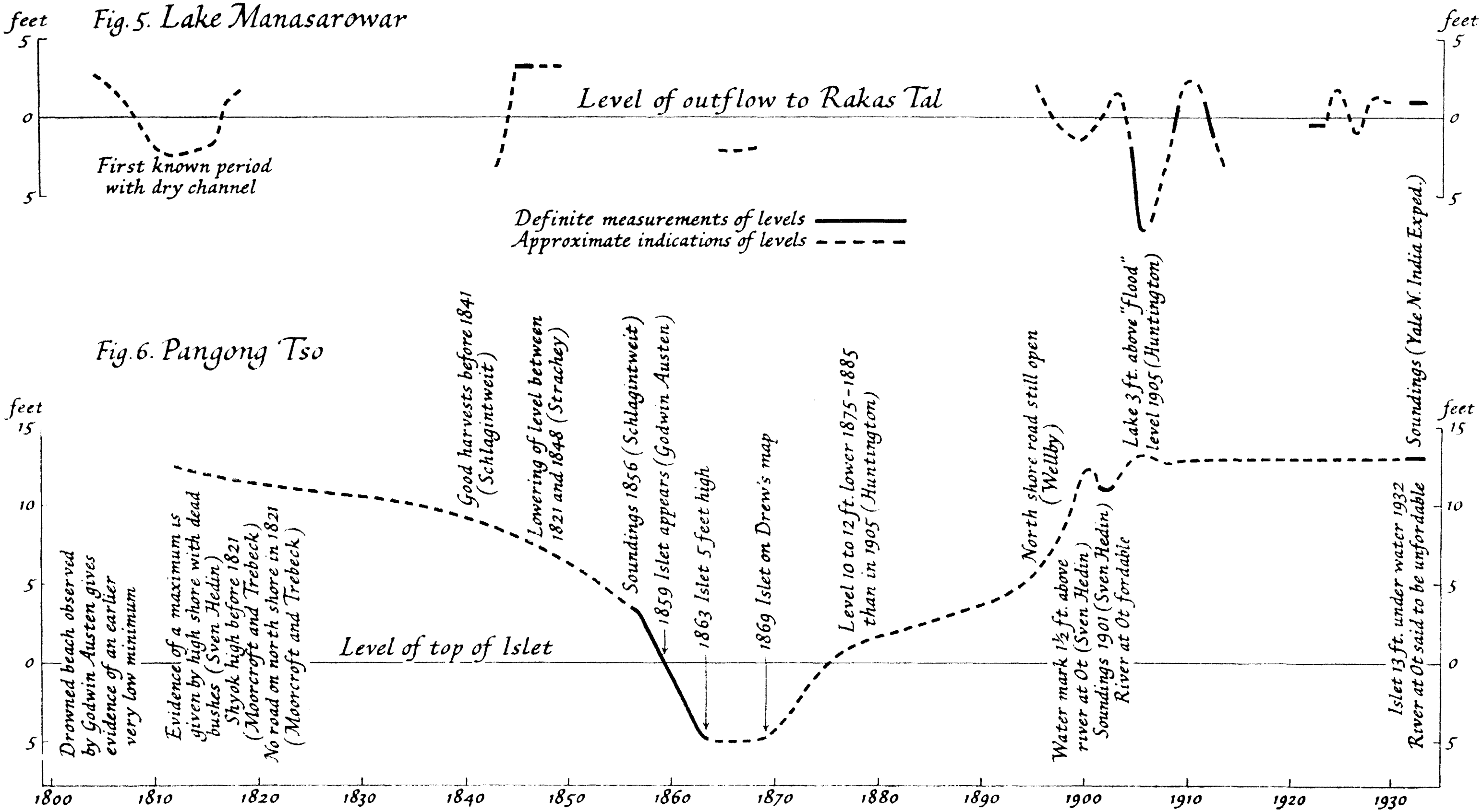


Fig. 5. Lake Manasarowar
feet
5
0
5
Level of outflow to Rakas Tal
First known period with dry channel
Definite measurements of levels
Approximate indications of levels
Fig. 6. Pangong Tso
feet
15
10
5
0
5
Drowned beach observed by Godwin Austen gives evidence of an earlier very low minimum
Evidence of a maximum is given by high shore with dead bushes (Sven Hedin)
Shyok high before 1821 (Moorcroft and Trebeck)
No road on north shore in 1821 (Moorcroft and Trebeck)
Good harvests before 1841 (Schlagintweit)
Lowering of level between 1821 and 1848 (Strachey)
Soundings 1856 (Schlagintweit)
1859 Islet appears (Godwin Austen)
1863 Islet 5 feet high
1869 Islet on Drew's map
Level of top of Islet
Level 10 to 12 ft. lower 1875-1885 than in 1905 (Huntington)
North shore road still open (Wellby)
Water mark 1½ ft. above river at Ot (Sven Hedin)
Soundings 1901 (Sven Hedin)
River at Ot fordable
Lake 3 ft. above "flood" level 1905 (Huntington)
Islet 13 ft. under water 1932
River at Ot said to be unfordable
Soundings (Yale N. India Exped.)
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930

the lake-levels.[1] Since all the lakes of western Tibet appear to behave in a similar manner inasmuch as all seem to have risen recently, it is tempting, though perhaps fruitless, to speculate whether the pronounced lowering of the Pangong Tso during the middle of the last century may not be a manifestation of the same influence that has cut off Rakas Tal from its drainage to the Sutlej.

In the case of Lake Manasarowar Hedin has pointed out that a high level leading to a filling of the channel follows, at least in some years, a heavy snowfall. It is obvious that this lake must react more sensitively to such changes in precipitation than does Pangong Tso, for only a slight rise in its level suffices to produce a refilling of the river at its outlet, an event which is more striking and more frequently noticed by travellers than the temporary formation of beach-lines. Examination of the relatively complete data for the present century indicates that a very small fluctuation in climatic conditions is responsible for the flooding and drying of the channel.

Altogether it may be stated that the recent rise of the water-level in the lakes of Ladakh is due to increased rainfall. Such an increase of rainfall is, as has been shown by Brooks[2] for the thirty years prior to 1910, apparent throughout almost the whole of the temperate part of the Eurasiatic continent. This has a definite bearing on the question of the water supply in high Asia which is always quoted as if undergoing a process of continuous desiccation. That this is not the case may be inferred from the foregoing evidence. It is not improbable that in the long run desiccation might go on or that it might become definitely checked by a general increase in rainfall, but in either case it is a discontinuous process.

In view of the fact that this region borders on one of the most glaciated mountain regions on earth, namely, the high Karakoram, it is inviting to compare our figures with those given by Mason[3] for the movements of the Karakoram glaciers. The Chong Kumdun glacier, famous for its tendency to block both the Central Asian trade route and the upper Shyok river and therefore the most accurately observed glacier, has experienced two principal advances within ninety years, one before 1842 and another from 1925 until to-day. Both long-lasting advances appear to correspond roughly with our Pangong rises. Visser[4] states that the glaciers of the Saser group had recently advanced, which would also correspond to the recent rise in lake-level.

It appears therefore as if definite relationships exist within this region between oscillations of precipitation, of lake-levels, and larger glacial movements. The geological significance of this lies in the fact that these slight oscillations of climate in Indian Tibet, occurring as they do in a much elevated region, seem to be of a similar, though much smaller, order to those which determined glacial and interglacial periods during the Ice Age.

[1] The authors considered that such changes of lake-level might be correlated to sunspot cycles such as the Brückner or Wolf cycle. In view of the uncompleted range of observations from this local area, it was thought advisable not to stress this point until a wider study of such phenomena can be made.

[2] "The Secular Variation of Rainfall," *Quart. Jour. of the Royal Meteor. Soc.*, vol. 45, 1919, p. 240.

[3] Kenneth L. Mason, "The Glaciers of the Karakoram and Neighbourhood," *Rec. Geol. Surv. India*, vol. 63, pt. 2, 1930, pp. 214–277.

[4] Ph. C. Visser, *Zeitschr. f. Gletscherkunde*, vol. 16, 1928.