Application of geodesy, photogrammetry, history and geography to the study of long-term mass balances of Central Asiatic glaciers

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Abstract. Some examples demonstrate seldom-used possibilities of the application of several disciplines to the study of the recent glacial history in High Asia:

(1) A geodetic triangulation of 1900-01 (Sachen Glacier, Punjab-Himalaya).
(2) The photogrammetric analysis of amateur photographs in cases where at least one photogrammetric survey has been performed.
   (a) Evaluation of a single photograph of 1902.
   (b) Mapping from two photographs of 1970 (Chogo Lungma Glacier, Karakoram).
(3) The study of the history of the use of glacier passes since the Middle Ages in relation to climate (Nushik La and other passes in the Karakoram, Himalaya, Hindu-kush).
(4) The evaluation of the work of early explorers like that of the brothers Schlagintweit in 1854-57 requires an approach from the history of science.

INTRODUCTION

The many thousands of glaciers of High Asia should be studied and judged on their own standards, not with preconceived ideas learned from the relatively small glacier areas in the European Alps. But such a study requires much more reliable reports and measurements than are available at present. With the exception of some glaciers in the USSR almost no repeated investigations have been carried out and most data consist of isolated scientific observations or sporadic, and not always reliable, reports by travellers. It is necessary to judge the reliability of all information about the recent glacial history and to collect together the reliable parts of the reports. This requires the application of various disciplines.

GEODESY

Sometimes a useful glaciological contribution is provided unintentionally by another scientific discipline. This happened in the case of the Sachen Glacier on Nanga Parbat (Punjab-Himalaya). There Captain G. A. Beazeley, an officer of the Survey of India, made a triangulation for geodetic and topographic purposes in 1900 and 1901 ("Kaghan Minor Extension Series"). When I examined the list of triangulated points
Long-term mass balances of Central Asiatic glaciers (Survey of India, 1923) and at the same time plotted the points onto Finsterwalder’s map of 1934, at first like Beazeley only for geodetic and not for glaciological purposes, I discovered the surprising fact that four intersected points which are given by their coordinates and altitudes had been positioned not on stable land but on the glacier surface and one station on the ridge of the right-hand lateral moraine.

The authorities who published the geodetic results described the intersected points as outstanding rocks with certain striking colours or shape. They did not mention their position on a glacier. Obviously at that time none of the parties concerned had thought of an application to glacier variation measurements. It was only some years later, in 1905, that the Geological Survey of India (not the Geodetic) began to mark some glacier snouts.

Now an evaluation of this certainly rare data became of particular importance because the same Sachen Glacier was mapped photogrammetrically by Finsterwalder in 1934 and was resurveyed again by photogrammetry by Loewe and myself in 1958. Besides the maps which have resulted from these surveys, a painting, a sketch map, and a description showing the state of the glacier in 1856, have been discovered in the Manuscript Department of the State Library in Munich.

Before the plotting of the five points of 1900-01 on the modern contour map it was necessary to transform their geographical coordinates into the geodetic framework which underlies the photogrammetric plotting of 1934 and 1958. Also several other points on the unchanged surroundings have been transformed in the same manner in order to check the accuracy and to interpolate the level differences of the two systems at the locations concerned. As a result a reliability in elevation of ±6 m has been ascertained.

The four intersected points are rather well distributed on the glacier surface within a region from a few hundred metres to more than 3 km from the glacier snout. The results of the calculations showed that each of the four positions had not changed in level from 1900-01 to 1934 by more than ±6 m. This is rather a surprising result compared with the behaviour of comparable height zones on European Alpine glaciers which underwent a loss by shrinkage of about 35 m in the same period.

The remarkable stability of this Sachen Glacier continued in the following period from 1934 to 1958 with very small surface height variations over the whole of the tongue. These two later surveys include the area from the glacier snout at about 3400 m altitude up to 3800 m, that is a length of more than 3 km and an area of $3 \times 10^5$ km$^2$. On an average the left-hand side of the glacier surface dropped by $4.2 \pm 1$ m within the 24 years and the right half by an amount which is even smaller than the mean error of ±1 m for the same period.

One should examine other geodetic work done by Captain Beazeley or his colleagues of the Survey of India. Perhaps they have also made similar glaciological measurements at other places in the north of India.

PHOTOGRAMMETRY – THE ANALYSIS OF AMATEUR PHOTOGRAPHS

For several reasons the topographical survey of glaciers in High Asia has been done almost exclusively by terrestrial and not by aerial photogrammetry. But owing to their remote location the surveys have not normally been repeated and many more amateur photographs of Asiatic glaciers are available than photographs taken with special survey cameras.

With amateur photographs a reliable plotting with sufficient and determinable accuracy can be achieved only if one photogrammetric survey exists. For this purpose a terrestrial survey is better than an aerial one. We have several single photogrammetric surveys of Asiatic glaciers but almost no re-surveys. The following examples show how in these cases amateur photographs taken before or after the photogrammetric survey...
may provide valuable data about the glacier variations both in length and in volume, and the method may also be applied, of course, to glaciers outside Asia.

The evaluation which at present takes a lot of time will be considerably reduced in future when not only a computer will help but also automatic pattern recognition for pass-point selection and for automatic evaluation will be possible. But let us see what can be achieved now.

From the huge Chogo Lungma Glacier in the Karakorum range a single photograph of the glacier snout was taken in 1902. A survey by terrestrial photogrammetry was made in 1954. A single photograph can only provide angles measured from the standpoint of the photographer. Therefore a trick had to be used to get the necessary information. First a lot of points in the stable ground behind the glacier were identified on both the 1902 photograph and the 1954 survey-photographs (unfortunately only very few such control points in the foreground could be identified). Then the orientation parameters of the old photograph were computed by a somewhat tedious iterative solution of several equations of projection. By means of these parameters several points on the ice edge and on the glacier surface of 1954 were projected into the old photograph of 1902. By using intersections of the ice edge line of 1954 with that of 1902 and neglecting the level variation of the foreground some numerical values of the glacier variations were obtained, see Figs. 1 and 2 (Kick, 1962, 1964).

Much more information has been provided not by a single photograph but by two taken from standpoints sufficiently distant from one another.

In 1970 a group of mountaineers, Peter von Gizycki and three companions from Munich, visited the Chogo Lungma Glacier. They took several photographs with a Rollei camera, 6 x 6 cm, from certain standpoints which I had asked them to use. Thanks to the photogrammetric survey of 1954 a lot of control points on the unchanged ground behind and also in front of the glacier could be identified in the photographs of both 1970 and 1954. The three ground coordinates of each of these control points were calculated from the image coordinates of 1954 by the known orientation parameters of these photographs. The corresponding image coordinates in the photographs of 1970 were measured by a coordinatograph.

For the determination of the nine orientation parameters of each 1970 photograph, namely the three ground station coordinates, three orientation angles (aversion, inclination, swing), and three interior orientation parameters (two image coordinates of the principal point and the focal length), E. Dorrer of Fredericton has developed a FORTRAN IV programme for an IBM computer, system 360/50, of the University of New Brunswick, Canada. The nine parameters are calculated by means of linearized observation equations of at least five control points, each point providing two equations. Since much more than five, namely 13 to 19 control points have been used, a least squares adjustment has been performed. After that the corrected image coordinates of each glacier surface point provided a determination ray for the calculation of intersections from the stations of these photographs. The three space coordinates of 23 surface points on the glacier in 1970, see Fig. 3, were calculated and the points plotted on the 1954 contour map (scale 1:10,000). The result is shown in Figs. 4 and 5.

The glacier snout at the portal of the Basha river has receded by 210 m within the last 16 years. The surface within a distance of 600 m from the glacier end of 1954 has dropped by 30 to 40 m. At the place above the 1954 efflux of the Basha river the loss of ice thickness down to the now ice-free ground was 60 to more than 70 m. The mean error of the height variations provided by the mensuration of amateur photographs is calculated to be ±2 to ±3 m, this corresponds to a mean error of 3 to 10% of the changes in ice thickness.

The glaciological importance of the above example lies in the provision of measured
FIGURE 1. Chogo Lungma Glacier snout. One of the images of the photogrammetric survey: 8 October 1954 (48; 3041 m); with numbered edge points to be projected on to the photograph of 1902.

FIGURE 2. Projection of the edge points of 1954 on to the photograph of 1902.
FIGURE 3. Two photographs of 10 June 1970, taken from two standpoints. The image coordinates of the numbered points provided intersecting rays.
data for the behaviour of an almost completely debris-covered glacier tongue in a subtropical climate, typical of High Asia.

In certain cases amateur photographs can be evaluated with an even higher accuracy than shown by the above example. This can be done by the introduction of further parameters besides the nine mentioned above, for example, parameters describing an affine or central-symmetric distortion of the images. But in most cases the treatment shown above will offer enough accuracy.

OLD GLACIER PASSES

Many reports are known from the European Alps, the Himalayas, the Karakorams, and the Hindukush which refer to quite a number of pass routes glacierized at the present time to a large extent and not having been used for a long time, but which were in regular use in former times. In most cases the inhabitants of the regions in question have maintained that the cause of the abandonment was an increase in the extent of the glaciers. At a first glance it looks as if traffic routes used for centuries had to be given up some time after the beginning of the last Little Ice Age.

In the European Alps Kinzl (1932) examined many such reports and came to the following conclusion: 'The abandonment of various glacierized Alpine passes cannot be correlated with the increase of the glaciers. The phenomenon is caused rather by the opening of good and easy roads for driving ... When better means of communication had come into use traffic concentrated on a few, particularly favourable passes ...'

In the Karakorum mountains O. Eckenstein wrote (1896, p. 163): 'It is curious to note how, in this country, just as in Switzerland formerly, one hears of passes which were often crossed, and were much easier formerly, but are so no more.' For several centuries many glacierized mountain passes of High Asia had been crossed regularly by trading caravans or also by raiding tribes or 'regular' military forces and in our time have not been used since about the middle of the nineteenth century (Wood, 1922; Dainelli, 1924), see Table 1.

The very few historical records of glacier variations suggest climatic deterioration as a cause of the abandonments. All the records relating to the Chogo Lungma, the Chong and Kichik Kumdo, the Aktash, and the Minapin Glaciers, agree that these glaciers increased during the first half of the nineteenth century (Visser, 1938; Mercer, 1963).

In this context the most important glacier passes (see Table 1) are the Mustag and the Nushik La. For example, the Nushik La in the Rakaposhi Range can be used to demonstrate the nature of these historical records.

The Rakaposhi Range in the Karakorum separates two completely different ethnic and language regions, namely Baltistan in the south with the Baltis speaking a Tibetan
TABLE 1. List of secondary* glacier passes abandoned in the nineteenth century

<table>
<thead>
<tr>
<th>Name of Pass</th>
<th>Valley on the one and the other side</th>
<th>Altitude (m)</th>
<th>Height of the pass above Snow limit (m)</th>
<th>Length of way beside or on glaciers (km)</th>
<th>Used until about</th>
<th>Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Karakorum mountains</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Baltistan-Turkestan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Old Mustag</td>
<td>Baltus-Baltoro</td>
<td>5420</td>
<td>150</td>
<td>1920</td>
<td>50</td>
<td>1840</td>
</tr>
<tr>
<td>New Mustag</td>
<td>Baltus-Panmah</td>
<td>5640</td>
<td>350</td>
<td>2150</td>
<td>55</td>
<td>1880</td>
</tr>
<tr>
<td>Nushik La</td>
<td>Basha-Kero Lungma</td>
<td>4990</td>
<td>300</td>
<td>2000</td>
<td>36</td>
<td>1850</td>
</tr>
<tr>
<td>Hispar La</td>
<td>Baltus-Biapo</td>
<td>5150</td>
<td>300</td>
<td>2000</td>
<td>110</td>
<td>1837</td>
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<td></td>
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<tr>
<td>Hoh Lungma</td>
<td>Basha</td>
<td></td>
<td></td>
<td></td>
<td>12</td>
<td>before 1860</td>
</tr>
<tr>
<td>Raskam route</td>
<td>Braltus-Pamir-Shingshal</td>
<td>unknown</td>
<td></td>
<td></td>
<td>19th century</td>
<td>Mason (1914)</td>
</tr>
<tr>
<td></td>
<td>Biapo or Panmah</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Schomberg (1936)</td>
</tr>
<tr>
<td>Bialpand La</td>
<td>Saltoro-Yarkand-Stiechen</td>
<td>5550</td>
<td>350</td>
<td>1800</td>
<td>60</td>
<td>19th century</td>
</tr>
<tr>
<td>(b) Ladakh-Turkestan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changchenmo or Changlang</td>
<td>Nubra or upper Shayok</td>
<td>5950</td>
<td>700</td>
<td>?</td>
<td>?</td>
<td>before 1850</td>
</tr>
<tr>
<td>2. Punjab-Himalaya (Nanga Parbat massif)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mazeno P.</td>
<td>Astor-Rupal</td>
<td>5358</td>
<td>650</td>
<td>1700</td>
<td>17</td>
<td>still 1856</td>
</tr>
<tr>
<td></td>
<td>Chilas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Collie (1902)</td>
</tr>
<tr>
<td>3. Hindukush</td>
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<td></td>
</tr>
<tr>
<td>Kotgaz An</td>
<td>Chitrai Wakhan</td>
<td>5441</td>
<td>550</td>
<td>1850</td>
<td>19th century</td>
<td>Schomberg (1936)</td>
</tr>
</tbody>
</table>

* 'Secondary' compared with the Karakorum Pass which connects Kashmir with Turkestan via Ladakh.

language, from the Hunza and Nagar principalities in the north with the Burushaski speaking 'Burushos'. Reports from earlier centuries are in striking contrast with the present complete separation of the two regions, see Fig. 6.

In the chronicles of the Shigar Rajahs of Baltistan (Hashmat, 1939) the following three passages are of interest:

1. Some of the ancient inhabitants (of northern Baltistan) came here through the Karakorum via Baraldowla (Braldu La = Mustag Pass) and others through Gilgit, Hunza
and Nagar via Basha.’ The only way from Hunza-Nagar via the Basha valley goes across the Nushik La.

(2) Cha Tam, the founder of the present dynasty of the Shigar Rajahs, is said to have come from Nagar ‘via the Basha’ in about the fourteenth century. Later he let more people come from Nagar and founded several villages in the Basha valley. The settling of the Basha valley partially by people from Nagar is confined by present place-names right in the upper part of the valley near the Nushik La (Kick, 1957). An example is the name Bisil (Bihitsil) for a village with a hot spring. The word ‘tsil’ for water exists only in the Burushaski language.

(3) Watch towers were built at the southern outlets of the pass routes via the Nushik and the Hispar La, near Arandu and Askole, in the sixteenth century. They were occupied by observers who gave warnings of raiding Burushos when they crossed these passes. The existence of these watch towers, whose erection the chronicle reports, was confirmed by European travellers up to the middle of the nineteenth century (Vigne, 1842, Schlagintweit, 1856). Moreover, the tower below the Nushik La is shown on the Map of the Punjab, Kashmir etc., by J. Arrowsmith of 1840 (or 1847) and is still marked on the present official edition of the Quater Inch Map, sheet 43 M, which is based upon the plane table survey of Godwin Austen in 1861. A similar fortification (‘darband’) in the Rosh Gol, Hindukush, confirms the reports of the natives about an old route over the glacier pass Kotgaz An (Schomberg, 1936).

According to the report of Vigne on his stay in Arandu in 1835 and according to what was told to A. Schlagintweit on his stay in the Basha valley in 1856, the Nushik La was still regularly crossed in those times. But the people had to use ropes. Godwin Austen in 1861 and M. Conway in 1892 were still told by old people that the last raid by Nagar men via the Hispar La to Askole happened in 1837. On their way back over the pass, which takes nine days on or beside the glaciers, several hundred people died in the snow and cold (Conway, 1894).

The route from Nagar to Shigar over the Nushik La is already mapped on J. Arrowsmith’s Map of Moorcroft’s and Trebeck’s journey of 1819/20 (1841). There the pass has the name Yakh-kut-Pass.

Also on the Burusho side of the Nushik La reports and relics confirm a regular
traffic in former times. The two existing fortresses of Altit and Baltit (the capital of Hunza) are said to have been built by Balti people; even the place-name of Baltit is said to originate from the fact that the Baltis had built the village in the fourteenth century (Conway, 1894). The Burushos believe that their technique of building was once influenced by the Baltis. They know a sort of door which they call Baloski (= Balti) hing and a sort of hedge which they call Baloski chash (Lorimer, 1935). The inhabitants of the three villages Samaiyar, near Nagar at the entrance of the glacier route over the Nushik La, are said to descend from Balti immigrants who had come over the mountains a long time ago (Conway, 1894).

In 1852 a messenger from Shigar went to Hunza no longer over the Nushik La, but by the very long and devious route over the easier New Mustag Pass and following down the Shimshal valley (Schlagintweit, 1856). In 1896 and in 1908 Western travellers tried in vain to cross the Nushik La. They had to turn back because of the state of a bergschrund on the northern side of the pass (Neve, 1913; Workman, 1910). Only once was the pass crossed by foreign travellers. This was in 1892 by some mountaineers of Conway’s expedition. They found the route rather difficult. Nobody else is known to have crossed the Nushik La since the middle of the nineteenth century.

The reason for the abandonment of these glacier passes in High Asia cannot be the same as Kinzl assigned for the Alpine passes and as Dainelli had done earlier for the Karakorum passes (1924), namely the development of a better means of communication. This was only applicable to a few passes on which, therefore, all traffic has become concentrated. In High Asia the means of communication remained unchanged until the middle of the twentieth century, i.e., long after the abandonment of all those glacier passes. Political reasons such as the annexation of first Ladakh and then Baltistan by Jammu-Kashmir in 1841 may perhaps be responsible for the end of all immediate traffic between Baltistan and Yarkand-Turkestan via the Mustag La. But this event could have affected only the Baltistan frontier passes and not those elsewhere. The phenomenon is also known outside Baltistan, for example, in Chitral, and in the Astor and Chilas districts.

The increase in the extent of the glaciers was probably not a direct reason for abandoning old pass routes. The primary reason was perhaps a general deterioration of the climate accompanied by increased snowfall, depression of the snowline, more avalanche disasters, more severe snowstorms, depression of the tree limit and consequently a gradual lack of firewood at the traditional resting places.

Some of the numerous reports about the old glacier passes in Asia may be a mixture of history and legend as in some cases with Alpine passes. Human imagination likes such stories. But enough reports are confirmed and are truthful. It is still a task for oriental historians to clear up the facts and their causes which may involve glaciology.

ANALYSIS OF EARLY EXPLORATION WORK

At the beginning of glaciological exploration in High Asia the three brothers Schlagintweit did important work. They did not know the term ‘interdisciplinary’ but they knew the sense of it. They practised a universal way of thinking in the field of science in an almost unlimited realm of exploration, like their master Alexander von Humboldt had done before them. Their glaciological work from 1854 to 1857 in several parts of the Himalayas, the Karakorums, and the Kuenlun, is of both historical and real value.

To obtain a good reconstruction of the state of the Himalayan glaciers at that time from their detailed manuscripts and to judge the reliability and accuracy of their observations, it is necessary to understand their scientific aims, methods and instruments. This requires an approach from the discipline of the history of science.
So far the Schlagintweits' work has been evaluated only for the Nanga Parbat glaciers (Kick, 1967). It revealed valuable information on the condition of the glaciers at the time of the last glacial maximum in Europe. More of their work needs to be evaluated.

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