On late Quaternary glaciation of the foothill area of the East Kunlun Mountains, West China

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ABSTRACT Kame terraces recognized at the northern foot of East Kunlun Mountains as well as results of recent international field research allowed the reconstruction of the direction and type of glaciation and deglaciation in this area during the Late Pleistocene and Holocene. The Late Pleistocene glaciers that developed there as piedmont glaciers debouching into the high-glacial Qaidam Lake, underwent a large-scale stagnation brought about by a rapid decrease of moist air flux. This event took place late in the early Holocene, probably around 8000 years B.P.

INTRODUCTION

A number of papers have recently been published concerning the former Quaternary glaciations of the Qinghai-Xizang (Tibet) Plateau. Particularly worthy of note are papers presenting results of the joint Sino-German expeditions edited by Hövermann & Wang (1987) and by Kuhle & Wang (1988). However, our knowledge about the nature and evolution of glaciation and deglaciation processes in these areas is still incomplete and in some points inadequate. In recent investigations, glaciologists and glacial geomorphologists deal mainly with active ice masses, concentrating their field works on modern glaciers and high-mountain portions of the former ice covers. They describe only such types of forms or sediments which are clearly connected with flowing ice, i.e. glacial cirques and troughs, terminal moraines, polished and striated rocks or ground moraine. As far as glaciation of the Tibet Plateau and surrounding mountains is concerned (Sobolevsky, 1919; Hedin, 1922; Trinkler, 1930; Von Wissman, 1959; Shi & Xie, 1964; Kuhle, 1987, 1988; Drozdowski, 1989; Zhang et al., 1989), these forms and sediments have long been searched. However, in these Central-Asian areas with severe continental conditions of the Late Quaternary, as yet insufficiently known, there
were also features of ice-contact morphology associated with melting of stagnant ice. Such a type of landforms, represented by kame terraces, was encountered by the author at the foot of East Kunlun Mountains in 1989. Inasmuch as kame terraces are indicative of stagnating ice and to date no such features have been reported from Tibet or its surroundings, it seems worthwhile presenting them in more detail and discussing the implications for the course of glacial events in the studied region.

LOCATION AND PHYSIOGRAPHY OF THE STUDY AREA

The study area is located at the foot of the Burhan Budai Mountains, being the outermost north-eastern range of the East Kunlun mountain system which has in its main ridges elevations exceeding 5400 m a.s.l. (the highest summit reaching 6224 m a.s.l.). A characteristic feature of these mountains, like that of the West Kunlun Mountains (Sobolevsky, 1919; Zhang et al., 1989), is the steepness of their northern side, contrary to the relatively flat and wide southern side facing the vast Tibet Plateau. Therefore, on the northern side, characteristic are valley and dendritic glaciers, whereas on the southern side, glaciers tend to develop as ice caps and outlet valley glaciers spreading out on the adjacent plateau.

According to Shi et al. (1988), the present equilibrium line on the northern slope of the mountains is situated at 5200 m a.s.l., and the modern glaciers descend here as far down as 4300 m a.s.l. (Kuhle, 1987). The lower limit of the permafrost zone is situated at elevations ranging from 3300 to 3500 m a.s.l. (Shi et al., 1988). The Golmud River, being the main stream draining this area northwards, flows to the relic Dabsan Lake in the center of the closed Qaidam Basin. The Golmud-Lhasa highway runs through the study area in the southwest direction, along the Golmud River (Fig. 1).

The main geomorphological feature of the investigated terrain is a broad depositional piedmont plain that resulted from coalescing alluvial fans and opens northwards between lateral branches of the Kunlun mountain system. It is traversed here by the prominent South Qaidam Border Fault which runs across this line and spreads out before the front of the mountains, debouching finally into the former high-glacial Qaidam Lake. The latter developed at an elevation of approximately 2900 m a.s.l. and is marked today by a belt of dunes along its southern shore.

The investigated fragment of the piedmont plain, named here the Golmud Valley, is bordered from the east by a mountain ridge with steep slopes frequently inclined at an angle of 35-40°, whereas the summits to the ridge, rising 350-400 m above the plain, have mostly rounded shapes cut down by denudation. The rocks exposed in this area consist of batholic granite of Permian-Triassic and Devonian age as well as of limestones and arenite interspersed with
shale beds of Devonian age (Geological Map..., 1987). Most land surface (piedmont plain and lower parts of the hillslopes) consists of clastics, chiefly of alluvial fan sand and gravel.

FIG. 1 Location map and schematic geomorphological map of the study area. (A) location map; (B) geomorphological map: 1 - rockslope, 2 - main mountain ridges, 3 - principal fault lines (Geological Map..., 1987), 4 - kame terraces, 5 - shoreline of the high-glacial Qaidam Lake.
KAME TERRACES

The kame terraces, identified by the author during a scientific journey in 1989, are already seen from far due to the light colour of their sandy material, abutting on the lateral ridge of the Burhan Budai Mountains approximately 30 km south of the Golmud City (see Fig. 1). They occur in a series of four steps sloping downstream and overlying still another one in a stairway fashion roughly at the following elevations: 10-15, 30-35, 50-55 and 70-80 m above the adjacent piedmont (Fig. 2). The descending, actual ice-contact slopes of the terraces vary in their inclination. The higher and lower terraces have slope angles between 8 and $28^\circ$, whereas the middle terrace is inclined between 25 and $30^\circ$.

FIG. 2 General view on the kame terraces as seen from southwest. The distinct face of the middle terrace 50-55 m above the piedmont plain is visible.

The largest and, simultaneously, the best-developed kame terrace, the middle one, is bound by a spectacular
descending slope with sharply expressed straight edge. It extends over a distance of over 800 m, its width almost 400 m and it possesses a flat-topped surface with a relatively gently inclined longitudinal profile contrary to higher and lower terraces whose outer parts are more denuded and somewhat undulated due to wind erosion.

Terraces seem to be well preserved because the geological structure is rather intact and there is angular debris of a supraglacial origin. The debris has been produced by rock fracturing above the glacier and fallen from flanking rock-slopes onto the glacier surface. Subsequently, being transported in high position in the glacier or on the surface of the glacier, it was dumped and slid down onto the sides of the kame terraces. The loose angular rocky material is composed chiefly of granite particles of silt and clay size to heavy fragments larger than 20 cm in diameter with glaciofluvial sediments, thereby constructing a strong, "armoured" slope resistant to any post depositional erosion.

The amount of supraglacial material incorporated into the kame terraces was controlled by the volume of debris transported over the glacier and inside it and by its distribution within the glacier. Where concentration of debris occurred as, for example, along former ice gullies or in ice crevasses, there was a tendency for thick localized debris accumulations at the lateral glacier margin (Boulton & Eyles, 1979). It is likely that such an enhanced debris supply has accompanied the formation of the kame terraces, particularly at the end of formation of the middle terrace producing an exceptionally thick "armoured" slope. Also, for this reason and for the lack of dead ice blocks buried by kame sediments, the kame terraces did not experience deformations by collapsing of the sediments after the disappearance of ice that had supported them. Therefore, despite the destructive high erosional energy characterizing the desert and tectonically active environment, in which they occur, the terraces preserved their original constructional forms up to the present.

The stairstep pattern of the kame terraces is believed to denote successive stages in the process of thinning and shrinkage of the last glacier, as illustrated in Fig. 3. This explanation implies successive lowering of water level in the ice-lateral stream or temporary lake and concurrent increases of the terrace width as the supporting glacier is melting. These processes also took place in the neighboring foothill area of the Burhan Budai Mountains, occupied by a glacier abutting on the opposite side of the mountain ridge and divided further downstream by a low col from the Golmud piedmont glacier. Between these glaciers, probably in a later stage of deglaciation, there existed an interrelated meltwater system which affected the rate of ice melting and, in consequence, the distribution and formation of ice-contact features.
However, no comparable kame terraces developed on the opposite side. Instead, irregular more or less discrete patches of sandy sediments can be seen, which might have originally been deposited in ice-lateral stream as kame sediments and, later on, redepósited by wind. The reason for the lack of well-formed kame terraces may be the insufficiency or the lack of coarse heavy debris of supraglacial origin, unfavourable slope inclination for the deposition of sediments mainly of the ice that led to collapse of the sediments after the ice melted away. Determination of the true mode of formation of these features and their classification need special detailed research.

![Diagram](image)

FIG. 3 Diagram presenting successive stages in the formation of the kame terraces.
1 - rockslope, 2 - angular supraglacial debris, 3 - glaciofluvial and glaciolacustrine sediments, 4 - successive stages in the formation of the kame terraces.

A sample of sediments from the middle kame terrace was submitted for thermoluminescence (TL) dating in the TL Laboratory at the Gdansk University. The result obtained is: \(6700 \pm 1200\) years B.P. Even if the rather broad 17% measurement error is taken into account, the age of the sample seems to be much younger than local deglaciation when compared to the dating of final deglaciation of the northeastern part of the Qinghai-Xizang Plateau which - as interpreted from a series of radiocarbon dates (Kuhle, 1988) - occurred between 9400 and 8600 years B.P.

CONCLUSIONS

The general conclusion should be that in the investigated area there is an assemblage of sediments and landforms,
defined by Boulton & Eyles (1979) as a glaciated valley sediment and landform system. The principal feature, intimately associated with this system and making it different from those produced by non-valley depositional systems, is the supraglacially-derived debris (resulted from rock fracturing on the sides of nunatack valleys) that did not undergo a phase of tractional transport at the glacier bed. Fortunately, this significant element of the glaciated valley system seems to have occurred here producing supraglacial material preserved in the described kame terraces. Other constituent elements of the system, such as terminal or lateral moraines, have been erased by subsequent Holocene erosion.

The next important conclusion, which might be inferred from the fact of occurrence of the kame terraces themselves, concerns the transformation of the former active valley glacier into stagnant ice mass. Most probably, this phenomenon occurred within a relatively short time span as a consequence of a rapid decrease of moist air flux. Leaving aside the atmospheric circulation changes demanding special studies, here considered are questions pertaining to the general conditions of the glacier before reconstruction of its morphology and dynamics. It is likely that the valley glaciers which debouched from steep mountain valleys into the Qaidam Basin later on broadened out and formed large piedmont glaciers. In the Golmud valley, such glacier at maximum could reach 45-50 km in length and at least 20 km in width, counting from the mountain front to the shoreline of the former Qaidam Lake. This glacier as well as a number of similar piedmont glaciers at the foot of Kunlun Mountains presumably coalesced with one another. They were drained by large subglacial and englacial streams which carried great volumes of bed loads and suspended loads, finally depositing them north of the South-Qaidam Border Fault, in the area of relative subsidence, corresponding to the Qaidam Lake. Stratigraphically this is demonstrated in a deep borehole at Nomhon (see Fig. 1) by thick glaciofluvial sequences covered and interlocked with lacustrine sediments (Hövermann, 1987; Kuhle, 1987).

In the light of available radiocarbon dates the Qaidam Lake and the glacio-hydrological system connected with it existed approximately between 35 and 23 kyr B.P. The described kame terraces should be referred to the end of the last glacial period in the foothill area at the East Kunlun Mountains. The buried dead ice supporting the kame terraces remained here since the depth of freezing in winter exceeded the depth of thawing in summer. Under suitable climatic and ground conditions, the dead ice masses might have persisted for a considerable span of time, may be for hundreds of years. The TL date obtained for the sediments in the kame terraces suggests that they were deposited late in the early Holocene, that is 7900 years B.P. (if the date is corrected in accordance with the maximum measurement error). Hence, the estimation of
the age for the local deglaciation, which could have occurred a little earlier, is around 8000 years B.P. However, this dating figure for the deglaciation chronology should be treated with caution, not only because it is younger than the related radiocarbon dates, as mentioned earlier, but also because it is based on a single, stratigraphically isolated sediment. Further corroborating dating is needed to substantiate this interpretation.

Information on the glaciation pattern of the mountains at the close of the Central-Asian Ice Age is still vague. Based on the presented and discussed evidence, it is more likely that the glaciers were then largely controlled by the underlying topography. In other words, they drained several icefields situated higher in the heavily dissected mountains similar, for example, to the present-day glaciation of the St. Elias Mountains. Nevertheless, the preceding piedmont glaciers might have had the form of outflow glaciers radiating from more extensive areas of ice and snow in the form of ice caps or an ice sheet less controlled by the underlying topography, as suggested by Kuhle (1988).

REFERENCES


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