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HOLOCENE VARIATIONS OF THE YANZIGOU GLACIER (GONGGA SHAN MASSIF, DA XUESHAN, CHINA) (**)

ABSTRACT: SMIRAGLIA C., *Holocene variations of the Yanzigou Glacier (Gongga Shan Massif, Da Xueshan, China).* (IT ISSN 0391-9838, 1997).

Extending from the Sichuan basin to the Tibetan Plateau in the Da Xueshan Mountains, the Gongga Shan is the highest massif (7514 m) in China east of the Himalaya and also one of the principal glaciated areas (255 km^2) controlled by a monsoon climate. Geomorphological and historical research was carried out on the Yanzigou Glacier, which is located on the eastern slope and is one of the longest ice bodies on the massif. The objective of this research was to reconstruct Holocene fluctuations. Many end and lateral moraines were identified, some of which are completely covered with vegetation, while others are only partially covered with grass. The moraines were attributed to Little Ice Age advances and to 20th-century fluctuations of the glaciers, respectively. Many layers of organic material (wood, soil, peat) were observed in the highly eroded inner wall of a right lateral moraine at about 3900 m a.s.l., consisting of a complex of superposed debris units. The radiocarbon dating of samples indicated at least six periods of glacier expansion prior to the Little Ice Age, between 4000 years BP to 700 years BP, as well as two glacier advances during the Little Ice Age. For the past 100 years, the Yanzigou Glacier has been in a phase of retreat (for a total of about 4 km), except for a short period of stability in the early 1980's. At the point of the glacier's maximum extension in the Little Ice Age, the equilibrium line altitude was situated at about 4920 m, 180 m below the current one.

KEY WORDS: Glacial variations, Holocene, Yanzigou Glacier, Gongga Shan, China.

RIASSUNTO: SMIRAGLIA C., *Le variazioni oloceniche del Ghiacciaio Yanzigou nel Massiccio del Gongga Shan (Da Xueshan, Cina).* (IT ISSN 0391-9838, 1997).

Il Gongga Shan, che si estende nei monti del Da Xueshan fra l'altopiano tibetano e il bacino del Sichuan, è il più elevato massiccio montuoso cinese (7514 m nella cima omonima) ad Est dell'Himalaya e costituisce anche una delle principali aree glacializzate (255 km^2) controllate dal clima monsonico. Sul Ghiacciaio Yanzigou, situato sul versante orientale, uno dei più lunghi apparati glaciali del massiccio, sono stati condotti studi geomorfologici e ricerche storiche per ricostruire le sue fluttuazioni oloceniche. Sono stati identificati numerosi complessi di morene frontali e laterali, completamente ricoperte di vegetazione o solo parzialmente inerbite, che sono state attribuite rispettivamente alle avanzate della Piccola Glaciazione e alle fluttuazioni del XX secolo. A circa 3900 m, sul versante interno profondamente eroso di una morena laterale di sovrapposizione, formata da numerose unità di *till*, sono stati osservati molti strati contenenti materiali organici (legni, suoli, torbe). La datazione dei campioni al radiocarbonio indica almeno sei periodi di espansione glaciale prima della Piccola Glaciazione, fra 4000 e 700 anni BP, e almeno due avanzate glaciali durante la Piccola Glaciazione. Durante gli ultimi 100 anni il Ghiacciaio Yanzigou è costantemente arretrato per un totale di circa 4 km, se si eccettua un breve periodo di stazionarietà all'inizio degli Anni Ottanta. Durante la massima estensione della Piccola Glaciazione la linea di equilibrio era situato a circa 4920 m, 180 m al di sotto del limite attuale.

TERMINI CHIAVE: Variazioni glaciali, Olocene, Ghiacciaio Yanzigou, Gongga Shan, China.

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1. INTRODUCTION

The Gongga Shan area (from the Tibetan word, *gong* = ice and the Chinese word, *shan* = mountain; also called *Minya Gongkar* in Heim, 1936; *Minya Konka* in Imhof, 1974; *Gongga Shan* on official Chinese maps, such as those found in the *Atlas of the People's Republic of China*, 1989) is certainly one of the areas most unfamiliar to the western world from the geographical point of view, but also in terms of its glaciological features. The Gongga Massif is located in the central area of the Da Xueshan mountains, between the Sichuan basin to the east and the northeastern sector of the Tibetan Plateau to the west. It extends north to south for a length of 80 km and a width ranging from 15 to 40 km, constituting one of the largest glaciated areas in a monsoon climate. The highest peak, which lends its name to the massif

(Gongga Shan), reaches an altitude of 7514 m and up until the union of Tibet, it represented China's highest peak.

The area remained virtually unknown to the West until the scientific expedition of A. Heim in 1930-1931 (Heim, 1931) and the first ascent of the Gongga Shan accomplished by Burdsall and Moore in 1932 (Burdsall & *alii*, 1980). In the nineteen fifties, after the borders were closed, Chinese researchers participating in official scientific and mountaineering expeditions began compiling observations on the geology, geomorphology and glaciation of the Gongga range (Li Chengshan, 1958; Cui, 1958).

It was only in the early 1980's that authorizations were granted to Western climbers and researchers once again. A series of expeditions followed (American, Swiss, Japanese) and completed the exploration of the massif, while surveys were conducted by Chinese researchers between 1982 and 1984, for the preparation of a large-scale map of the region, with detailed attention given to the representation of glaciers (Chen, 1986). Between 1981 and 1983, observations were collected on recent glacier history as part of the Chinese Academy of Science Expedition (Su & *alii*, 1992), whereas in 1990, two expeditions were at work in the Gongga range and particularly on the Yanzigou Glacier: an Italian mountaineering and scientific expedition, during the pre-monsoon season, and a joint Sino-Soviet expedition, during the post-monsoon season. (Some of the scientific results obtained by the Italian expedition are presented here in this report.)

2. THE GONGGA SHAN GLACIERS: FEATURES AND DISTRIBUTION

The various reports now existing which summarize the characteristics and distribution of glaciers in China usually do not devote much attention to the Gongga Shan glaciers (Lehr & Horvath, 1975; Shih & *alii*, 1980; Wang & Yang, 1992). Only the first of the references cited includes observations made by Heim (1936) and his estimates of the snowline (5200-5400 m on the western slope). A wider range of information is provided in Cui (1958) and in Li Jijun & *alii* (1986)

The later estimate the overall surface area of the Gongga Shan glaciers to reach 274 km^2, with five glaciers exceeding 10 km in length, among which the Hailuogou and Yanzigou Glaciers on the eastern slope. According to Su & *alii* (1992), there are 74 glaciers on the Gongga Massif, covering an overall surface area of 255 km^2 , with a volume of 24.6 km^3. There is a marked difference between the two flanks. The overall surface area covered by glaciers, is equal to 155 km^2 on the eastern flank, with a snowline located between 4800 and 5000 m in altitude, whereas the total glacier surface area on the western flank is slightly greater than 100 km^2 and the snowline ranges between 5000 and 5200 m. Front altitudes also indicate a marked difference in climate. In fact, the longest glacier on the eastern flank, the Hailuogou Glacier, descends to 2940 m, whereas the largest glacier on the western flank, the Da Gongba Glacier, terminates at 3930 m (fig. 1).

This situation is largely attributable to the north-east monsoon, with ensuing precipitation prevalently on the eastern flank. In Hailuogou Valley, where there is a scientific and meteorological station, annual precipitation at 3000 m reaches 1872 mm, with a mean annual temperature of 3.7 °C. Precipitation levels in the accumulation area have been estimated to reach 3000 mm. At the Gongga Temple station (3700 m) on the western flank, annual precipitation amounts to 1 174 mm, with a mean annual temperature of 1.9 °C, whereas precipitation in the accumulation area has been estimated to reach 1800 mm, approximately.

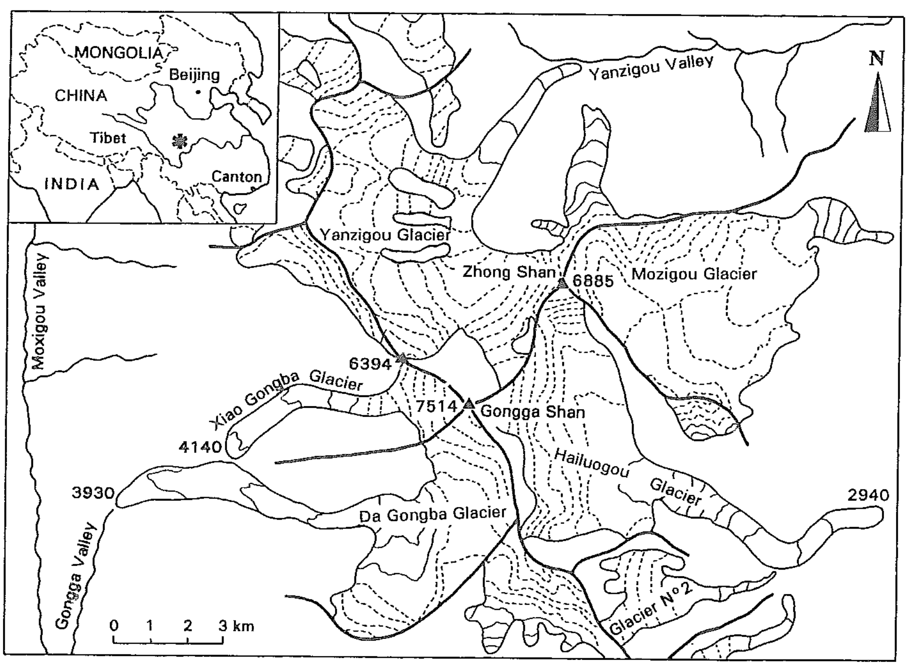


FIG. 1 - The Gongga Shan glaciers and the general location of the area.

3. THE YANZIGOU GLACIER

Although it is one of the largest glaciers on the massif, the Yanzigou Glacier is certainly one of the lesser known and least explored among the glaciers located on the eastern flank of the Gongga Shan range (certainly studied less than the nearby Hailuogou Glacier, the front of which descends to 2940 m in the spruce forest).

According to affirmations made by Heim (1936), he was the first to discover and report on this and other glaciers on the northern and eastern slopes. Arnold Heim was a professor of geology for many years at the University of Canton. He provides a brief description of the glacier, which, however, is no longer a true portrayal of the present-day situation: *The Yantsöko Glacier bends around like a snail toward west, then to north and east* (pg. 445).

The glacier, which has maintained a considerable length of about 10 km and a surface area of 32 km^2, has in fact lost a good part of the sector that bent to the east and which represented the head of the «snail» image suggested by Heim.

The Yanzigou Glacier presents a morphology typical of Himalayan glaciers. The accumulation area consists of steep ice streams and ice-fluted walls. The streams descend from the Gongga Shan summit (7514 m) for 2500 m over a distance of less than 3 km, ending in a step between 4900 and 4600 m, characterized by icefalls, which feed a long narrow tongue.

The latter is also nourished by at least three coalescing streams in the left (however, confluence with the other two streams further downglacier is now uncertain). Scattered debris cover on the tongue begins at about 4200 m, and the glacier then turns into a classic «black glacier» with a thermokarst morphology. In fact, in the lower sector of the tongue, the surface glacial debris becomes continuous cover and ends up almost completely burying the underlying ice, reaching thicknesses of over 2 m (fig. 2) in the vicinity of the terminus (3700 m in altitude).

3.1. Moraines on the Yanzigou Glacier

The study of Holocene fluctuations of the Yanzigou Glacier was conducted by identifying geomorphological evidence of the various advance phases (essentially the moraine ridges). These features were mapped, using as an aid, an enlargement of the Mount Gongga map from the scale of 1:25,000 to a scale of 10,000. The original map was prepared by the Institute of Glaciology and Geocryology of Lanzhou, China (Iggl) and published in 1985. Taking into account the distribution of the moraines, their morphology and the vegetation cover, the moraines were subdivided into separate morphological units (fig. 3).

The analysis of the maps and photographs and sketches, unfortunately none of which were prepared prior to the 20th century, together with the data available in the scientific literature, has permitted the author to propose a reconstruction of the recent variations of the glacier. The reconstruction was also partially supported by radiocarbon dating of wood and other organic material found on the inner slope of a lateral moraine.

The moraines were subdivided into two groups: moraines dating from the Little Ice Age (or even older), and indicated in fig. 3 by the solid line, and those dated after that event, all of which can be chronologically classified within the present century (indicated by the dashes).

3.2. Moraines of the Little Ice Age

The most advanced moraines attributable to the Little Ice Age are found at an altitude of about 3225 m (Y1 in

FIG. 2 - The ablation area of the Yanzigou Glacier presenting the typical debris-covered glacier landforms. The ice is visible only on the side of the steepest cones (Photograph by Smiraglia, May 1990).

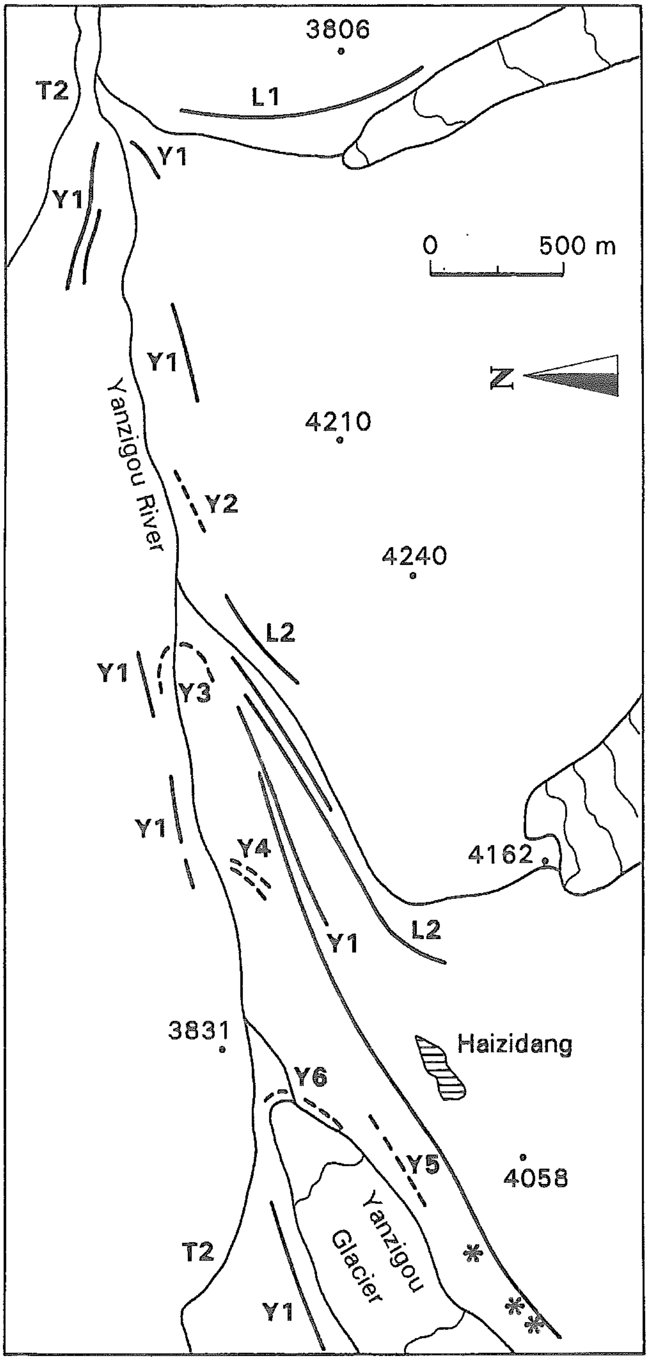


FIG. 3 - The moraine complex of the Yanzigou Glacier. Y = moraines of the Yanzigou Glacier; L = moraines of confluent glaciers; T = streams. Some spot heights are also indicated.

fig. 3). These are remnants of lateral-front ridges and they are found on both slopes (the one on the left is more evident and preserved better). They are composed prevalently of large blocks of granite and quartzose sandstone, with a diameter range of meters, almost entirely covered with lichen and moss and also colonized by conifers (prevalently by spruce). There are actually at least two ridges, as is evident on the left slope, where another ridge runs alongside the main ridge noted previously, but at a slightly lower altitude.

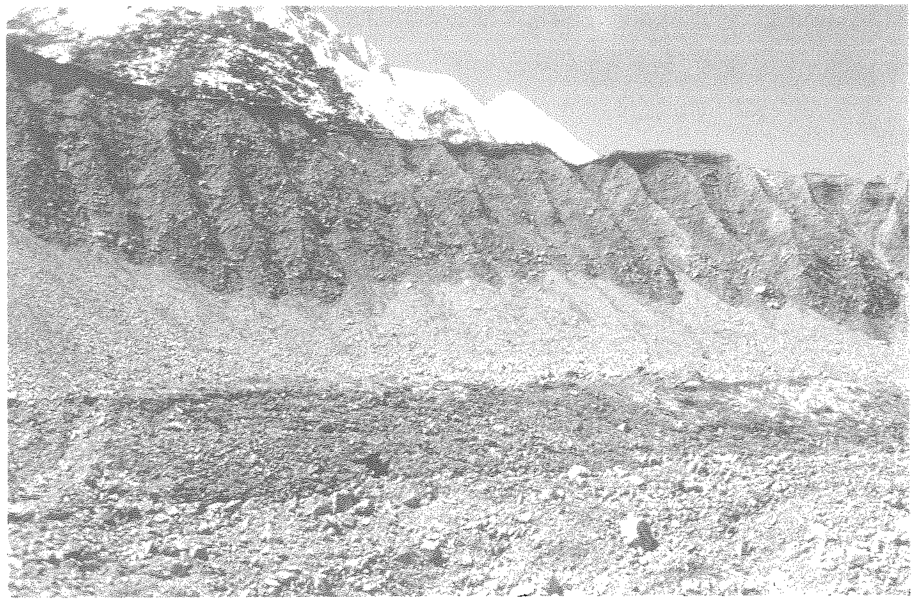
The situation on the right is very complex because of the intensive torrential erosion (this is an area of confluence between two rivers), and because of the presence of additional ridges deposited by the steep, narrow glacier flow that originates from the nameless peak at an altitude of 5772 m. This stream's coalescence with the main glacier flow is rather uncertain. Distinct traces of this ice stream are found in a long moraine ridge (L1) which on the right, extends from 3300 m up to about 3600 m, bordering the present glacier tongue for a short tract. The ridge in the lower sector which dominates the valley floor for about thirty m, shows a cross-profile that is clearly asymmetrical. From the point of view of its sedimentological composition, it shows the structure characteristic of large lateral moraines of the Little Ice Age. In fact, it consists of a matrix-support massive diamict, with clasts with a large range of sizes, among which blocks exceeding a diameter of 1 m stand out. The ridge is deeply incised on the inner slope by subvertical and parallel gullies.

Along the main valley, on both slopes, there are remnants of lateral moraine ridges that are still colonized by conifers which become increasingly sparser and by shrub vegetation, and which appear to be correlatable with those cited above (Y1). Only a few patches are visible on the left and they are interrupted by large debris flow .

On the right slope, a confluence (it is the glacier originating from the Zhongshan, 6,888 m, which presently terminates in a steep ice wall at approximately 4150 m in altitude), interrupts the uniformity of the Y1 ridge for a lengthy tract. The confluence is well marked by lateral moraines which highlight the sinuosity of the flow, which from a south-north direction (at one time) curved almost at a right angle in a nearly parallel alignment with the main tongue (L2). It is very well preserved in the left , where it extends for over one km (in some places with at least one parallel ridge being very distinct), whereas it appears more discontinuous on the right. The height of the left ridge ranges between 25 and 30 m, displays a sharp profile with a steep inner slope undergoing accelerated erosion, and an outer slope that is not as steep and densely covered with shrubs (particularly with rhododendron).

A small valley, also colonized by shrubs, separates this ridge from the greatest geomorphological feature of the Yanzigou Glacier attributable to the Little Ice Age: the large lateral moraine on the right. Though there are a few interruptions, it can be followed for 5 km from the L2 confluence area at about 3700 m to as far as 4100 m (again indicated as Y1 in fig. 3). Heim's brief description (1936, pg. 445) is as follows, *The side moraines are well-defined crests with sharp scarps towards the glacier, 10 to 20 metres in height* (fig. 4). The description does not render justice to the full magnitude of the glacier environment, perhaps also owing to the changes that have occurred in the period of over 60 years since his expedition. The right lateral moraine of the Yanzigou Glacier, just as the left lateral moraine (the latter, however, is not as well preserved), constitutes an enormous ridge towering above the present glacier with

FIG. 4 - The inner wall of the large superposition lateral right moraine of the Yanzigou Glacier. The deep gullies and traces of bedding are observable. (Photograph by Smiraglia, May 1990).



a 60-80 meter difference in height. This is a superposition moraine (an accretion moraine along several tracts in the lower sector), consisting of a matrix-support massive diamict with blocks within a diameter range of meters. The inner wall is very steep and furrowed by gullies which terminate in large debris cones and which lend the moraine a «bad land» appearance. The slope is undergoing intensive, accelerated erosion. The intensity of the phenomenon is highlighted by steps in the upper part of the slope and by open fractures with gaps ranging between 5 and 10 cm and lengths ranging between 50 and 70 m and which can be observed on the outer slope. The latter is covered with grassy vegetation and with sparse willows and it is distinct up to 3900 m, at which point the moraine has created a barrier lake (the locality is called Haizidang). The ridge then becomes only slightly distinguishable and is often buried by debris flow deposits (at least three generations are distinguishable). Several of these deposits have clearly broken through the ridge, creating large gaps.

Slightly above the lake, fragments of tree trunks, buried soils and other organic matter were found on the inner wall of the large moraine. Dating analyses revealed several glacier expansion phases, from about 4400 years BP to about 140 years years BP, although correlation of these events with the frontal moraines located further down-glacier, was not possible. Therefore, it was not possible to obtain the corresponding area variations for the glacier.

The slope examined (* in fig. 3) descends for about sixty m (from 3910 m to 3850 m) from the top of the moraine to the base and it is furrowed by a deep gully at the foot of which irregular debris cones have built up. The debris consists of blocks with a diameter range of meters, which have rolled down, and by fine material which has flowed down from above. At least eight main levels with organic matter have been identified from the top of the cones at the base to a few m just below the moraine crest.

These are prevalently shallow soil layers, A horizon with a depth of 1-3 cm and sometimes B horizon with a depth of 3-5 cm. In these soils, there are outcropping willow trunks and roots (1-5 cm in diameter), which were sampled. In some cases, (at the base of the moraine and 10-12 m below the moraine crest), dense sequences of layers of thicknesses ranging in centimeters, were found; they contain dark brown to tobacco-colored felty organic matter (locally including wood fragments) and other layers of the same depth composed of overconsolidated fine sands and silty sands of a light gray color (at times with a bed of a thickness in the millimeter range, consisting of coarse sands with rare appearance of pebbles with a diameter range of centimeters). The overall thickness of these deposits was about 20 cm.

The first situation (the soil layers) was interpreted as a pre-existing topographical surface (the outer slope of the lateral moraine, covered by grass and shrubs), buried by the debris during an advance of the glacier. The ^{14}C date should therefore represent the soil and shrub burial date and thus mark the time of the advance. The second situation (the thin organic and inorganic layers complex) was attributed to lacustrine deposits from small lakes, where peat formed and was later covered by till. While quite rare in the Alps, the presence of lacustrine deposits outcropping on the inner slopes of lateral moraines, has also been observed by the author of this paper in the Karakorum Range, particularly in Braldo Valley, however, without the formation of hydromorphic soils.

In terms of its morphology, the origin of the depression containing the fine deposits could be attributed to various phenomena such as: 1) the settling of the loose material composing the moraine on the top of the moraine itself (also due to the melting of patches of buried ice); 2) the formation of an accretion moraine resting on a pre-existing moraine (in which case the glacier advance reached a slightly less advanced position than the preceding advance); 3) the formation of a moraine blocking the flow of a small lateral stream. In all three cases, the next glacier advance will have to reach a slightly more advanced lateral position in order to bury the lacustrine deposits, creating a superposition moraine. Taking into account the marked lateral development of the fine deposits and the hydromorphic soils of the Yanzigou, as well as the surrounding morphology (presence of numerous small lateral valleys that furrow the right side of the main valley), the basins where sedimentation of the fine matter occurred may be considered as having been created by a series of events of the third type. The above-mentioned Haizidang lake, slightly lower in altitude from the sampling area, presents the same characteristics. A considerable glacier advance in the future, which would create a superposition moraine, could bury the small lake, along with the lacustrine and any peaty deposits.

Soil samples, peat fragments and trunks were collected on the inner wall of the moraine, for a total collection of about twenty samples. Of the latter, eight were sent to Krueger Enterprises Inc., Geochron Laboratories Division, in Cambridge, Massachusetts, USA, where they were dated by the ^{14}C dating method.

The results of these analyses are presented in fig. 5 and in tab. 1, in which the conventional and calibrated dates are indicated, in accordance with Stuiver & Pearson, 1986 and Pearson & Stuiver, 1986.

Over and beyond the uncertainty involved in the dates and the problems involved in the ^{14}C dating method applied to the organic matter buried in the moraines (see, for example, Gey & *alii*, 1985 and Mortara & *alii*, 1992), the vertical chronosequence revealed some interesting findings.

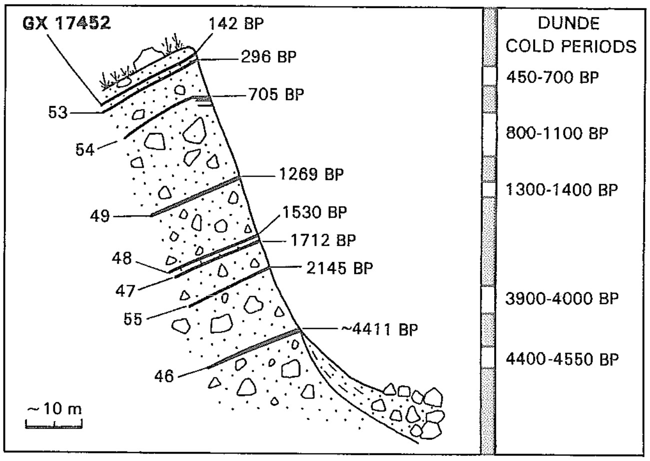


FIG. 5 - Lateral right moraine of the Yanzigou Glacier. Profile and calibrated radiocarbon dates, with assigned laboratory numbers. The cold phases recorded in the Dunde ice core are also shown.

Such findings include the following:

1) The large lateral Yanzigou ridge was built up through accumulations overlying previous accumulations at increasingly higher altitudes. The moraine can therefore be defined as a superposition moraine, in accordance with the terminology coined by Röthlisberger & Schneebeli (1979).

2) There were at least seven deposition phases, which correspond to glacier expansion phases, and which occurred over a time interval slightly exceeding 4000 years. Therefore, the building-up of the moraine lasted much longer than the Little Ice Age.

TABLE 1 - Conventional and calibrated ^{14}C dates for the organic samples collected (location shown in fig. 3)

Lab. n.	^{14}C data (years BP)	sample type		calibrated age (*)	δ 13CPDB (‰)
GX-17452	145 +/-100	wood	BP AD	300 (264, 142, 0) 0 1650 (1686, 1808, 1955) 1955	– 26.3
GX-17453	235 +/–110	wood	BP AD	460 (296) 0 1490 (1654) 1955	– 24.2
GX-17454	795 +/–60	peat	BP AD	903 (705) 670 1047 (1245) 1280	– 24.4
GX-17449	1305 +/–110	wood	BP AD	1310 (1269) 1070 640 (681) 880	– 20.3
GX-17448	1610 +/–65	wood	BP AD	571 (1530) 1420 379 (420) 530	– 21.3
GX-17447	1785 +/–65	wood	BP AD	810 (1712) 1628 140 (238) 334	– 25.0
GX-17455	2150 +/–120	soil	BP BC	2 340 (2145) 2000 390 (196) 50	– 23.5
GX-17446	3920 +/–75	peat	BP BC	>4439 (4411) 4236 > 2490 (2462) 2314	– 23.6

(*) The central value (or values) of the calibrated age compatible with the corrisponding ^{14}C age, is indicated in parentheses; this value is inserted between the two extreme ages computed, taking into account the root-mean-square deviation (tab. 3 in Stuiver & Pearson, 1986 and tab. 2 in Pearson & Stuiver, 1986).

3) It is likely that even during the Little Ice Age, there were climatic variation cycles which led to the an equal number of growth and reduction phases for the Yanzigou Glacier. According to Su & *alii* (1992), during the Little Ice Age, three advance phases occurred in the cases of the Hailougou Glacier, the largest glacier on the eastern flank of the Gongga Shan, and the Da Gongba and Xiao Gonba Glaciers on the western flank. It is possible to attribute to these phases the moraine ridges located between a few hundred meters and 3 km from the present fronts (the ^{14}C dates for the buried wood fragments range from 620 ± 40 years BP to 440±50 years BP).

The Little Ice Age is thought to have led to advances that were diversified on the basis of glacier size and exposure. The largest valley glaciers on the eastern slope are thought to have increased in length by 2-3 km, whereas the smaller ones, only by about 1 km. The extensions on the opposite side are considered to have increased between 0.2 and 1.5 km.

4) Starting from 4400 years BP to the height of the Little Ice Age, the width of the glacier probably did not change to a considerable extent. As regards thickness, the series of dates seems to indicate that the various fluctuations may have led to quite steady, increasing thicknesses up until the Little Ice Age, when the level of the glacier was at least 60 m above the level resulting for 4400 years BP. However, it should also be noted that part of this difference in thickness, a part that is not precisely quantifiable, could be attributed to the ground and surficial moraine.

3.3. Moraines dated after the Little Ice Age

Compared to the structures described above, the other moraines observed seem much smaller in size. Most of these moraines are remnants of frontal moraines situated on the valley floor or near the large ridge cited above. They are small and consist of large blocks with little matrix, but thickly covered with lichens and mosses. Five moraines of this type were identified (actually six, if one uncertain case is included).

The first moraine (Y2 in fig. 3) consists of a barely observable alignment of large subrounded blocks that are almost completely covered with mosses and lichens and some infrequent shrubs. On the right, it is positioned obliquely with respect to river from about 3400 to 3450 m in altitude. It is located slightly up-glacier from the approximate position where the glacier front must have been found when Heim had explored it. In fact, in his discussion of the Yanzigou Glacier (*Yantsöko* in the original text), Heim writes that *a tributary stream of 3-4 cubic metres per second coming from the valley in the north-west falls into a cave of ice and comes out again at the glacier foot 3-4 kilometres farther down, together with the melt-water of the Yantsöko Glacier* (Heim, 1936, pg. 445).

The only valley from the northwest, is the valley that unfolds almost exactly at the present front of the Yanzigou Glacier (on the 25,000 map, Iggl, only the lower section with the locality of Yangliuping, is indicated). If a distance of 3 km is measured on the map, the front indicated by Heim should be located at about 3400 m, slightly further down from moraine Y2. There is a frontal moraine located at 3600 m, slightly less than one km further up from Y2; it is very distinct, although the middle sector is interrupted by the glacier-fed river. At any rate, the two remaining sections are very distinct, particularly the section on the right. Two to three m high, the two ridges are mainly composed of large, subrounded blocks, with little matrix and almost completely covered with mosses, lichens and willows (the trunks of which exceed a diameter of 1 cm). Further up-glacier, on the right, other moraines are observable. There are two small parallel ridges (Y4 in fig. 3), positioned obliquely with respect to the river, and which rest at the foot of the large ridge Y1. They are slightly arched, about 30 m long and rise to about 1 m in height. The ridges are essentially composed of blocks with little matrix and patches of moss. The diameter of the willow branches is less than 1 cm. The ridges are probably correlatable to a lateral ridge that is barely visible (Y5 in fig. 3), somewhat removed from the present glacier margin and that extends at the base of the large ridge Y1, which towers above it by at least 60 m. It is composed of large blocks with little matrix and infrequent patches of grass. Its actual height (the apparent height being less than 1 m) cannot be measured as the ridges is partially buried by debris on the right from the large moraine Y1 and on the left, from the debris left by the glacier. One last small moraine ridge is observable in contact with the present frontal margin (Y6 in fig. 3). It is a typical newly formed ridge, which is only slightly distinct and composed of sharp clasts prevalently within the decimeter diameter range. The ridge extends for about ten meters over the right slope of the front, nourished mainly by clasts sliding down the steepest section of the front. All of the moraines described above (Y2 to Y6) are attributable to the brief stationary phases or brief advance phases of the glacier occurring after the start of the nineteen thirties.

4. RECENT FLUCTUATIONS OF THE YANZIGOU GLACIER

Following the end of the Little Ice Age, which, according to Su & *alii* (1992), probably occurred in the second half of the last century, the Gonga Shan glaciers, according to these same authors, showed a generalized retreat, interrupted, however, by expansion phases. More specifically, there was probably a retreat phase starting from the end of the 19th century on through to the beginning of the 20th century. The latter was followed by a stationary period or even an advance phase lasting through to the early 1930's. On the basis of the map prepared by Heim (1936), an examination of aerial photographs and measurements made in the field, Su & *alii* (1992) have proposed the fluctuations reported in tab. 2 for some of the glaciers in the Gonga Shan Massif.

As shown by the table, some of the main Gongga Shan glaciers were probably stationary during the early decades of the present century, then the fronts retreated for a period lasting up to the 1990s, with some stationary phases

TABLE 2- Frontal variations (expressed in m) of some glaciers of the Gongga Shan

Glacier name	Hailuogou	No.2	Da Gongba	Xiao Gongba
Beginning 20th cent.-1930	stationary or advancing	confluent in the Hailuogou	stationary	stationary
1930-1966	– 1150	– 800	– 175	da – 80 a – 200
1966-1981	– 178	stationary	stationary	stationary
1981-1989	– 170	—	—	—
1981-1990	—	from – 250 to – 300	– 25	from – 10 to – 15
1989-1990	– 23	—	—	—

interspersed during that time. The longest glacier on the eastern slope, the Hailuogou Glacier, is thought to have been in a retreat phase starting from 1930, resulting in an overall retreat of 1520 m.

As regards the Yanzigou Glacier, there are very few sources that could be used for a reconstruction of its recent evolution. The rare publications preceding the Heim expedition (and the Rock expedition, 1930), mainly report data on altitude measurements of Gongga Shan, whereas any maps available (for example, Davies, 1908 or Survey of India, 1922) adopt scales that are too small to be of any use for our purposes.

The basic map used to draw information on Gongga Shan glaciation in the early decades of the present century thus consists of Heim's map once again. Slightly different versions of the map appear in at least three publications. In the volume containing the official report of the expedition (Heim, 1933), a map is presented of the Gongga Shan Group at a scale of 1:275,000. The same map is included in Heim (1936) (fig. 6), with slight modifications and with a bar scale in miles. Numerous maps are found in a volume published more than forty years after the expedition. The volume was published by Imhof (1974), a topographer who participated in the expedition. One of the maps focuses on the central sector of the Gonga Shan chain, with a scale of 1:200,000, and it was compiled on the basis of surveys conducted by Imhof and Paul Nabholz in 1930, by Arnold Heim in 1930-31 and by Richard Burdsall, Arthur Emmons III and Terris Moore in 1932.

The Yanzigou Glacier is well delineated on the maps cited above, but there are no altitudes or contours to supply useful information and facilitate a comparison with the excellent map recently prepared by the Institute of Glaciology and Geocryology of Lanzhou (1985). The only reference points consist in the valley and the related stream which from the northwest, flows into the main valley at an angle slightly greater than 45°, and an altitude of about 3700 m (T1 in fig. 3) and another river from the same northwest direction, flowing at a sharper angle from a minor valley in the Yanzigou Valley, at about 3300 m in altitude (T2 in fig. 3).

The Heim and Imhof maps show the first river directly joined to the glacier, which from that point descends for another 3.4 km. This is confirmed by the words of Heim (1936, pag. 445) already cited above. He estimates the distance of 3-4 km between the confluence with the tributary stream, which enters a cave on the side of the glacier, and the mouth from which the Yanzigou meltwater exits, at

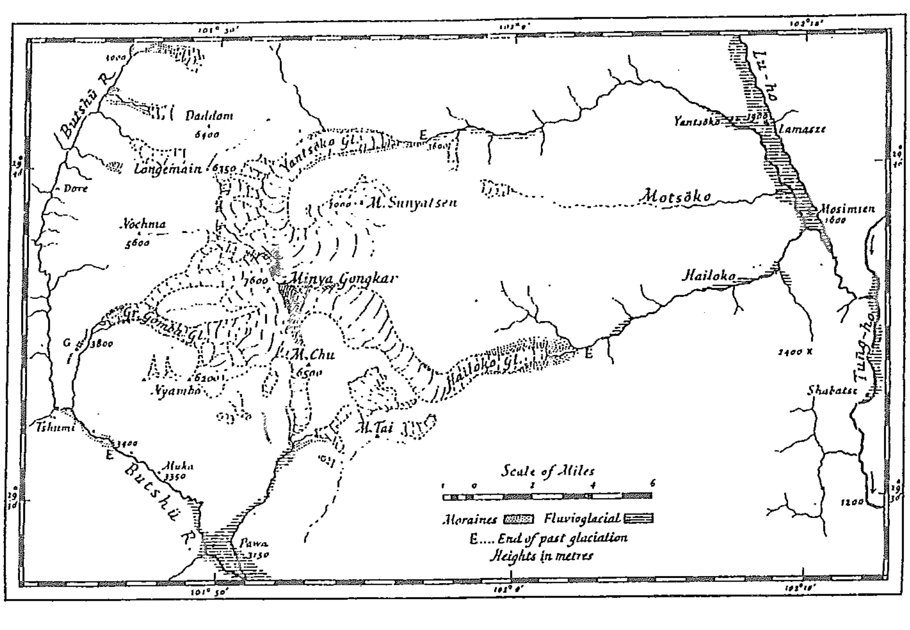


FIG. 6 - The Gongga Shan glaciers according to Heim (1936).

about 1 km up-glacier from the confluence with the second stream. A distance of slightly less than 1 km can be considered a valid estimate of the distance between the most advanced moraine attributed to the Little Ice Age (Y1 in fig. 3) and the front limit indicated by Heim in 1930, even though the reduced map scale and generic evaluations of the author, render this a very rough approximation. On his maps, Heim generically indicates the presence of till at the sides and the front of the glacier as far as point E (*End of past glaciation*), situated before the confluence with T2. There are no traces of surficial debris on the maps, however, this must have been a black glacier, given that Heim himself (1936, pag. 448) defines it as *block-covered ice*. The photograph of the glacier included by Heim (1936, no. 7) and by Imhof (1974, no. 32) (see fig. 7 here), also shows a tongue sector that is completely covered with debris.

Through the use of aerial photographs taken in December of 1966, Su & *alii* (1992), have identified the Yanzigou Glacier front location at 3662 m, about 650 m further down-glacier from the confluence with the first tributary stream (T1) (the position is also indicated on the Igcl map of 1985). Taking into account the maps and Heim's description, the tongue must have retreated by at least 2350 m between 1930 and 1966. Ding & Haeberli (1966), who evidently use the glacier maximum indicated by HEIM (4 km), tend towards a more extensive retreat (3350 m).

On the Iggl map (1985), it is also possible to check for a continuation of the retreat of the glacier between 1966 and 1982. In fact, the front limit appears to have shifted further up by at least another 300 m. Another note of interest may be found in the observation that the stream coming from the valley, which joins the main stream from the northwest (T1 in fig. 3), directly joins the Yanzigou River, whereas in 1966, it broke through further below the glacier.

The terminal sector of the Yanzigou Glacier tongue shows numerous transformations for the period between 1966 and 1982, in addition to the retreat mentioned above. More specifically, the two side swellings on the left (corresponding to the confluence with the lateral valley) and on the right (at the height of Haizidang Lake) show reductions. The map clearly indicates debris cover in the glacier's lower sector and which is denser and more uniform in the low part, becoming more sporadic at higher altitudes, until disappearing completely at about 4200 m.

On the basis of measurements made on permanent measurement sites, Su & *alii* (1992) also indicate that the glacier remained stationary between 1981 and 1983, whereas between 1983 and 1990, there was a retreat amounting to a total distance of 200 m. These findings have been confirmed by Haeberli & Hoelzle (1993). The Italian *Sichuan '90* expedition, which operated during the pre-monsoon period, measured an approximate 150-m retreat of the front with respect to the 1985 map, using simple topographical instruments. Two newly-formed, very small lakes were observable in the proglacial area which is characterized by chaotic deposits of boulders and pebbles with evident features resulting from the melting of buried ice. The front terminated at about 3700 m and appeared to be bilobate. On the right, the glacier surface was slightly undulated; in the proglacial plain there were traces of clean ice patches. The most advanced sector of the right lobe consisted of a wall of black ice with constant falls of blocks of the debris cover, which formed a barely visible frontal moraine at the foot of the ice wall. The two lobes were separated by a small saddle with subvertical, exposed ice walls, with the left lobe constituting a stocky spur of black ice with a small moraine at the base.

Recent variations of the Yanzigou Glacier have been summarized in tab. 3 and in fig. 8.

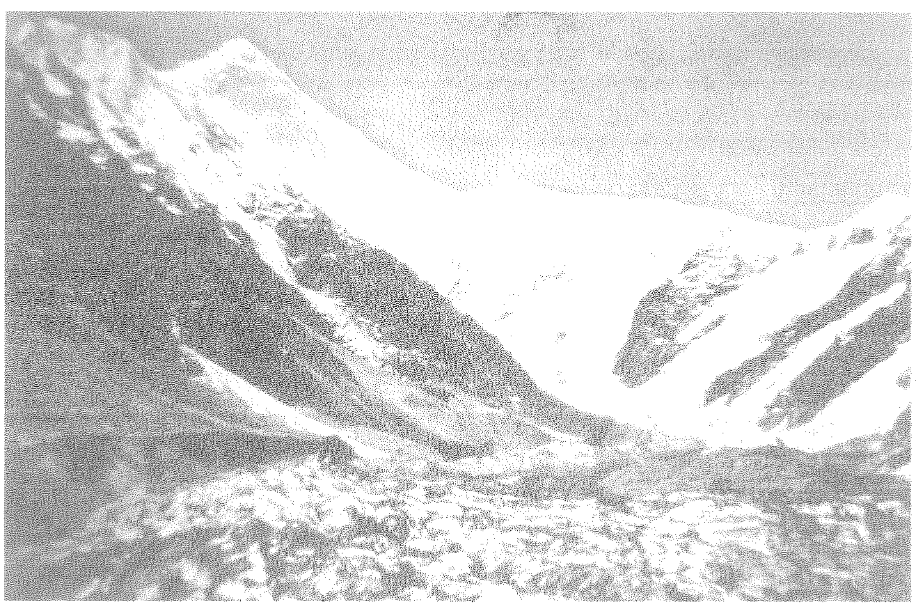


FIG. 7 - The Yanzigou Glacier (photograph by Heim, 1936). The summit (7514 m) of the Gongga Shan appears on the left. Note the same moraine appearing in Figure 5, in the lower left part of the photograph.

TABLE 3 - Frontal variations of the Ghiacciaio Yanzigou

Period	Variation in m	Mean annual variation	Source
LIA end – 1930	~ – 1000	> – 33	Heim, 1936; Imhof, 1974
1930-1966	> – 2350	> – 65	Su & *alii*, 1992
1966-1982	> – 300	> – 19	Iggl Map, 1985
1981-1983	stationary	0	Su & *alii*, 1992
1982-1990	~ – 200	– 25	Su & *alii*, 1992; Haeberli & Hoelzle, 1993

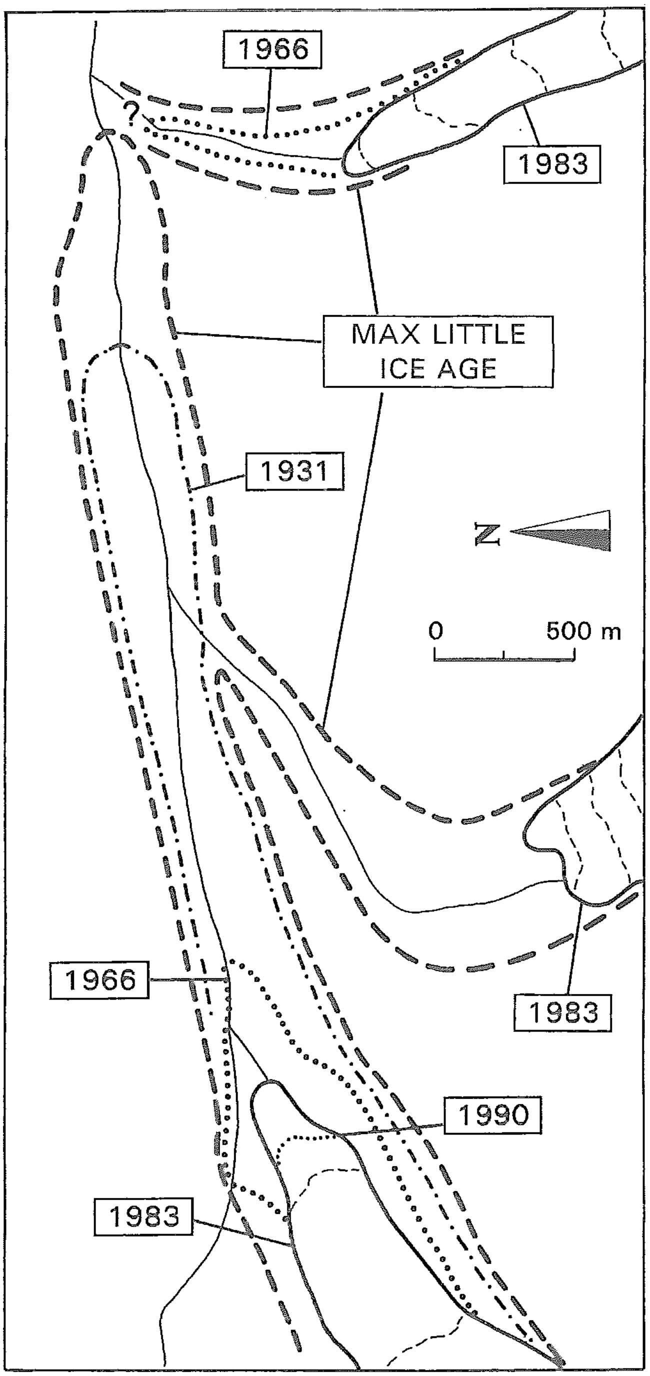


FIG. 8 - Yanzigou Glacier: a reconstruction of maximum extension in the LIA and later phases.

Therefore, from the Little Ice Age to the early 1990s, the Yanzigou Glacier is estimated to have retreated by at least 3850 m, with a brief stationary phase in the early 1980s . This estimate is comparable to that proposed by Li Jijun & *alii* (1986), who sustain that the glacier retreated by about 4000 m in the 20th century. It should also be mentioned that Su & *alii* (1992) uphold that the glacier has been either stationary or advancing, from the turn of the century to 1930.

5. CONCLUSIONS

The results of the research conducted in the Gongga Shan region and mainly in Yanzigou Valley confirm that in these areas as well, the large lateral moraines generally attributed to the Little Ice Age, actually originate from deposits attributable to a series of events which lasted for more than 4000 years. Therefore, in the Gongga Shan region, the Little Ice Age proves to have been only one of many cold periods of the Holocene. Prior to that time, there had been numerous episodes of glacier expansion and thus episodes of climatic deterioration (at least five episodes are recorded in the lateral moraine on the Yanzigou Glacier, starting from slightly more than 4000 years BP to about 700 years BP).

These findings are confirmed by the findings of other authors concerning glacier and climatic variations in China over the last 5000 years. Grove (1988) sustains that there must have been at least two glacier fluctuations in China in the last 3000 years. In his reconstruction of paleotemperatures in China in the last 5000 years, Zhu (1973) indicates a cold phase between 1500 and 1900 years BP, which may be correlated with the Yanzigou Glacier expansion phases that began approximately in 2145 BP and in 1715 BP.

The paleotemperature series obtained from the core from the Dunde ice cap on the northeastern margin of the Tibetan Plateau is more detailed and covers the past 5000 years. Taking into account the variations in $\delta^{18}O$, the coldest periods would seem to have occurred between 4400 and 4550 years BP, 3900 and 4000 years BP, 1300 and 1400 years BP, 800 and 1100 years BP, 450 and 700 years BP (Yao & Thompson, 1992; Lin & *alii*, 1995). In this case as well, the correlations with the Yanzigou Glacier advance phases that began around 4400 years BP, 1269 years BP and 705 years BP are very clear.

As concerns the Little Ice Age, the marked deviations found for the ^{14}C dates, do not permit a determination of precise periods. However, at least two glacial episodes can be postulated, starting from the 16th century, followed by a marked reduction in glaciation during the present century. As already mentioned, Su & *alii* (1992) have also indicated three advance phases during the Little Ice Age for the other Gongga Shan glaciers and which are evident in the field by three moraine systems.

The Dunde core indicates a rise in temperature starting from about 1250 AD, with a maximum around 1360 AD. There was also a reduction with a first minimum around 1650 AD and another around 1840 AD. A significant increase in temperature then followed in the 20th century (Yao & Thompson, 1992; Lin & *alii*, 1995). The analyses conducted on the Guliya core (western sector of the Tibetan Plateau) reveal instead a warm phase between 1300 and 1800 AD (Thompson & *alii*, 1995). According to the dendrochronological analyses conducted by Wang & *alii*, 1983, on juniper tree rings in the Chilan Shan region, there were probably cold periods lasting 70 years with peaks in 1480, 1690 and in 1810 AD. The winter temperature data series for Shangai, based on historical documents collected by Zhang (1978) and covering the past 500 years, also show two cold peaks towards the mid 1600s and mid 1800s, along with a drop of about 0.5 °C, with respect to the warmest periods.

Advances of the glaciers in the Himalaya and in the Karakorum Range between 1550 and 1850 AD, are also reported by Röthlisberger & Geyh, 1985. The history of the Yanzigou Glacier in the Holocene has thus revealed a series of advances, among which the most recent may be found in the Little Ice Age, followed by a retreat phase that is still ongoing.

As is well known, one of the parameters held to be most representative of climatic conditions determining glacier variations, is the Equilibrium Line Altitude (ELA), which roughly corresponds with the snowline, in the case of temperate glaciers. Along with the well known difficulties and uncertainties involved in the indirect computation of the ELA, in the case of the Gongga Shan Massif, we must add those caused by the particular characteristics of the glaciers in this region, which are of the Himalayan type, such as the morainal cover of the tongue, the nourishment mainly derived from avalanches, the marked difference in height between the accumulation area and the surrounding walls and the numerous confluences.

Among the various methods available, we used the now classic method according to which the ELA for a glacier undergoing steady conditions, is computed taking into account a relation between total area and accumulation area (AAR). According to Muller (1980), for the Everest glaciers, which are of the same type as those on the Gongga Shan Massif, the most correct AAR value would be 0.50. Therefore, the ELA would be found along the contour line separating the upper 50% of the glacier surface (accumulation area) from the lower 50% (ablation area).

On the basis of the Iggl map (1985), the hypsometric curve was constructed for the Yanzigou Glacier. The equilibrium line, corresponding to an AAR of 0.50 would be found at 5400 m. Considering observations made by Cui (1958), Shih & *alii* (1980), and Su & *alii* (1992), who indicate a snow limit altitude no higher than 5000 m on the eastern slope of the Gongga Shan Massif (as observed also by the author of this paper), the resulting value appeared to be too high. Therefore, we preferred to apply the AAR value, that is, 0.67, traditionally utilized for Alpine glaciers (Porter, 1975, Gross & *alii*, 1976; Braithwaite & Müller, 1980). The equilibrium line, corresponding to the contour line that separates 67% of the glacier surface, considered

FIG. 9 - The top of Gongga Shan with a part of the Yanzigou Glacier accumulation area. Note the large right lateral moraine in the center and the change in glacier thickness compared to figure 7 (Photograph by Smiraglia, May 1990).

to be the accumulation area, from the remaining 33%, considered to be the ablation area, is found at 5100 m (fig. 10). On the basis of the surveys conducted (particularly the positions of the moraines indicated in fig. 3 and their heights), the topography of the glacier was reconstructed, with relative contour lines, for the phase of its maximum expansion, attributed to the Little Ice Age. It was thus possible to construct the hypsometric curve for this period, as shown in fig. 10. The resulting ELA was thus found to be located at 4920 m, approximately. Therefore, there was probably a rise in the altitude of the equilibrium line by about 180 m, taking place between the Little Ice Age and the present. This represents a markedly greater variation than that reported for glaciers in the Alps (averaging 100 m, in Gross & *alii*, 1977; 102 m in the central sector of the Italian Alps, in Pelfini, 1995), but nonetheless, it is lower than that found for several other glaciers in the Himalayas (300 m for the Dudh Khunda Glacier, according to Williams, 1983).

If this increase in altitude were to be attributed solely to a rise in temperature, taking place from the Little Ice Age to the Present, applying a thermal gradient of 0.6 °C/100 m, as suggested by Müller (1980) for the Everest region, there would have been an increase in temperature of about 1 °C in the Gongga Shan area.

It is clear that for a correct understanding of the climatic events that have determined the variations in the mass balance of the glacier, and as a result, the variations in length, it would be necessary to consider the «accumulation» parameter as well. As is well known, in monsoon climates, accumulation is largely (about 70%) due to summer precipitation. The stationary phases or slight advance phases reported in the case of the Gongga Shan glaciers for the early decades of the 20th century and in the 1980s (however, such phases in the early decades remain uncertain in the case of the Yanzigou Glacier), could thus be attributed to variations in summer monsoon precipitation levels and in the amounts of snowfall, as reported by Mayewski & *alii* (1980) for the Trans-Himalaya glaciers, which showed an advance phase for the period from 1890 to 1910.

In conclusion, it should also be mentioned that the geographical location of the Gonga Shan massif east of the Himalaya and the Tibetan Plateau, as well as the topography of its valleys, oriented in a north-south direction, make the eastern slopes more exposed to the monsoon precipitation coming from the low Bengala Gulf, and which converge east of Burma. This could be the cause underlying the greater activity and shorter response times for the glaciers located on the eastern flank of the massif, such as the Yanzigou and Hailuogou glaciers, as suggested by Su & *alii*, 1992.

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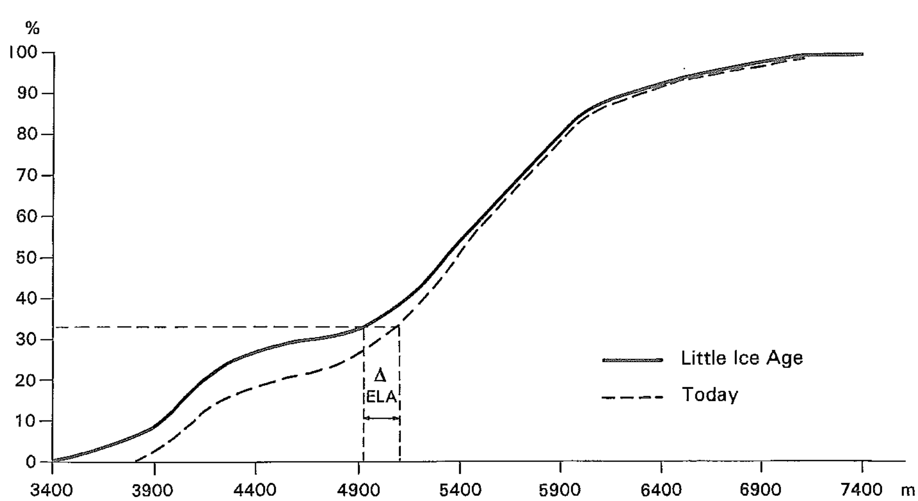

Fig. 10 - Hypsometric curves for the Yanzigou Glacier at present and during the maximum extension in the Little Ice Age. The ELA variation is also indicated.

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