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ADVANCE AND RETREAT PHASES OF THE KARAKORUM GLACIERS DURING THE 20TH CENTURY: CASE STUDIES IN BRALDO VALLEY (PAKISTAN)

ABSTRACT: PECCI M. & SMIRAGLIA C., *Advance and retreat phases of the Karakorum glaciers during the 20th century: case studies in Braldo Valley (Pakistan).* (IT ISSN 0391-9838, 2000).

Variations that took place at the terminus of some Karakorum glaciers (particularly the Baltoro Glacier and the Liligo Glacier) during the 20th century have been reconstructed using several methodologies. The two glaciers studied have shown different behaviours at the termini, at least regarding the rate of variations. The Baltoro is one of the longest glaciers on the Earth, excluding the Arctic and Antarctic regions, with a length of about 60 kilometres. Though characterised by phases of expansion (1913-1929, 1954-1987, 1990-1997) and of contraction (1929-1954, 1987-1990), the position of the terminus has moved over time with reduced variations compared to the dimensions of the overall glacier. The Liligo is a small and transversal glacier, already flowing into the Baltoro glacier, and it is characterised by phases of great advance (+1650 m between 1985 and 1997) and retreat (–1750 m between 1909 and 1953). Some morphologic features of the advance phases, particularly the frontal ice wall and the lower sector that is completely shattered into crevasses and seracs, lead to the suspicion of a surging glacier. The frontal variations of another small, nameless transversal glacier (the name «Mazzoleni Glacier» has been proposed) seem to be in keeping with the behaviour of the Liligo Glacier.

KEY WORDS: Glacial variations, Surging glaciers, Baltoro Glacier, Karakorum (Pakistan).

RIASSUNTO: PECCI M. & SMIRAGLIA C., *Fasi di espansione e di regresso dei ghiacciai del Karakorum durante il XX secolo. Alcuni esempi nella Valle del Braldo (Pakistan).* (IT ISSN 0391-9838, 2000).

Sono state ricostruite con metodologie diverse (analisi di relazioni storiche, cartografia a media e grande scala, foto da terra e da satellite, rilievi diretti sul terreno) le variazioni frontali di alcuni ghiacciai del Karakorum, in particolare il Baltoro e il Liligo, durante il XX secolo; i due apparati hanno evidenziato un comportamento molto diversificato delle fronti, almeno per quanto riguarda l'entità delle variazioni. Il Baltoro, che con una lunghezza di quasi 60 km è uno dei maggiori ghiacciai della Terra se si eccettuano le regioni polari, ha fatto registrare un andamento pulsante con alternanze di fasi di espansione (1913-1929; 1954-1987; 1990-1997) e di ritiro (1929-1954;1987-1990), che tuttavia hanno comportato variazioni della posizione della fronte ridottissime rispetto alla dimensione del ghiacciaio. Il Liligo è un piccolo apparato trasversale (lunghezza 12 km), già confluente nel Baltoro, anch'esso caratterizzato da diverse fasi di avanzata e di ritiro, di dimensioni molto cospicue (–1750 m fra il 1909 e il 1953; +1650 m fra il 1985 e il 1997). Alcune caratteristiche morfologiche delle fasi di espansione, in particolare la fronte a falesia e la frammentazione completa del settore inferiore in crepacci e seracchi, fanno pensare a un fenomeno tipo *surging*. Le variazioni frontali di un altro piccolo ghiacciaio trasversale senza nome (è stato proposto il toponimo «Ghiacciaio Mazzoleni») risultano abbastanza in fase con quelle del Liligo.

TERMINI CHIAVE: Variazioni glaciali, Surging glaciers, Ghiacciaio Baltoro, Karakorum (Pakistan).

FOREWORD

Thousands of glaciers fill the Karakorum Range for an estimated surface area of about 15.000 km^2 (Mercer, 1975). Excluding the polar regions, many of the longest glaciers are found there: the Siacen Glacier (75 km), the Hispar

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1985 (C. Smiraglia) and 1997 (M. Pecci) field data collected, respectively, during the «Quota 8000» Expedition and the «Ev-K2-CNR» Expedition, both organised by A. Da Polenza. We sincerely thank P. Maragnoli and L. Rampini for their observations and data on the Baltoro Glacier. We also thank the participants in the 1997 Expeditions: M.A. Lenotti, G. Ciresa, E. Colombo and the local guide Ghulam Nabi Shigari for their help, which was essential in carrying out the scientific program. Finally, special thanks are due to Professor A. Desio for his interest and participation concerning the research and for the reference, cartographic and photographic material (often unpublished) kindly provided.

The processing of the data that led to the preparation of this study was part of the research program entitled «Risposta dei processi geomorfologici alle variazioni ambientali» (MURST 1997, National chairperson Professor A. Biancotti, Local chairperson Professor S. Belloni).

Glacier (61 km) and the Baltoro glacier (58 km). Their classification and recent variations still represent an unresolved problem. In fact, they can be subdivided into transversal and longitudinal glaciers, taking into account their positions with reference to the general axis of the mountain range (Mayewski & Jeschke, 1979), or into debris-covered glaciers and clean glaciers, if the presence of a superficial cover of moraine and glacial debris in the ablation zone is considered (Moribayashi & Higuchi, 1977). The debris cover is what makes all these glaciers especially interesting. It in fact modifies energetic exchanges between glaciers and the atmosphere, creating different responses (compared to alpine environments) to climatic changes and, in this way, originating particular superficial morphologies (Benn & Evans, 1998; Smiraglia, 1998). Furthermore, in the Karakorum range several surging glaciers have been surveyed, some of which showing exceptional advances like the Kutiah Glacier (12 km in two months' time, in Desio, 1954).

Various hypotheses have been proposed by researchers concerning the recent variations of this kind of glacier, particularly variations occurring after the end of the Little Ice Age. Among some researchers, the opinion (Mayewski & Jeschke, 1979) is that a general retreat phase characterised the Karakorum glaciers starting from the second half of the last century. Others hold that the regression phase started at various times in different sectors of the Range and only in some cases, at the beginning of the present century.

Lastly, it is important to remember that the Italian scientific community (Duca degli Abruzzi, F. De Filippi, G. Dainelli, O. Marinelli and above all, A. Desio) has offered a frequent presence in the area, greatly contributing to our knowledge of glacial processes in the Karakorum.

The present paper is aimed at proposing a synthesis of the variations registered during the present century by different glaciers, particularly the Baltoro and the Liligo, using both field data collected during two scientific expeditions in the Karakorum (1985 and 1997) and historical data from various sources.

METHODOLOGIES AND TOOLS

The analysis of the variations of the Baltoro Glacier and the Liligo Glacier was carried out on the basis of several different sources and tools , particularly:

- historic documents and previous works;
- large-scale historic and dedicated cartography;
- medium-scale official cartography;
- historical and recent photographs;
- satellite photographs;
- data collected directly from field surveys.

Such sources clearly present problems deriving from their different uses and they are particularly characterised by the imprecision directly linked to the age of the sources themselves. The reports drawn up by explorers and scientists in the last two centuries are often subjective and do not always permit data and quantitative observations to be obtained. The oldest cartography often involves a low level of precision and comparability and sometimes, also interpretative difficulties. Furthermore, the official small-scale cartography has usually been prepared on the basis of the oldest large-scale maps, thereby amplifying the previous inaccuracies, due to the reduced scale, and thus limiting their use in past-glaciological reconstructions. As is well known, ground-photographs are a considerable qualitative support, but their generalised use is often limited, due to the difference in the points of view or to different objectives. Correctly used, satellite images could permit accurate quantitative reconstructions, at least for the largest glaciers, but obviously and unfortunately, they cannot provide data for periods preceding the nineteen seventies. Ground data are often difficult to interpret and are collected with tools that are not comparable. The reconstruction of the dynamics of the glaciers studied must include all of the pointed out sources, not only in order to increase the input data, but mostly to permit crosschecks to be performed. Table 1 reports the types and features of the documents collected, starting from the 2nd half of the 19th century, to evaluate the variations at the terminus of the Baltoro and the Liligo Gla-

TABLE 1 - Data sources and typology

Authors (Year of publication)	Year	Type of information used	Glaciers	Type of photo	Map scale
Godwin Austen (1864)	1861	D	B		
Conway (1893, 1894)	1892	C, D	B, L, M		1:126,720
De Filippi (1912)	1909	C, F, D	L	B/W	1:100,000
Dainelli & Marinelli (1928)	1913	C, F, D	B, L, M	B/W	1:150,000
Desio (1936)	1929	C, F	L	B/W	1:75,000
Anonymous (unpublished)	1936	D			
Desio (1961)	1953	D, F	B, L	B/W	
Desio (1991)	1954	C, F, D	B, L, M	B/W	1:100,000
Smiraglia (1987)	1985	F, D	B, L	C	
Anonymous (unpublished)	1986	D, F	B	C	
Maragnoli (unpublished)	1987	D, F	B, L	C	
Rampini (unpublished)	1990	D, F	B, L	C	
Pecci (unpublished)	1997	D, F	B, L, M	C	

ciers and of the nameless glacier, which we propose to call the «Mazzoleni Glacier» (C = cartography, P = photograph, D = description; B = Baltoro, L = Liligo, M = Mazzoleni; b/w = black and white photo, c = colour photo).

THE BALTORO GLACIER

The Baltoro represents one of the longest glaciers in the world with a length of about 60 km and a total surface area of about 800 km^2. The Baltoro Glacier is located in northeastern Pakistan (fig. 1), occupying the upper sector of a longitudinal valley as a «model glacier» of the Karakorum Range.

The regular body of the glacier can be divided into three zones: 1) one long, relatively thin and gently dipping tongue, almost completely covered by debris; 2) an upper basin composed of two almost perfectly symmetric streams (Godwin Austen Glacier and Abruzzi Glacier) and closed by an edging of ice and rock developing along some of the highest peaks of the world like K2 (8611 m asl), Broad Peak (8051 m asl) and the Gasherbrum (8068 m asl);

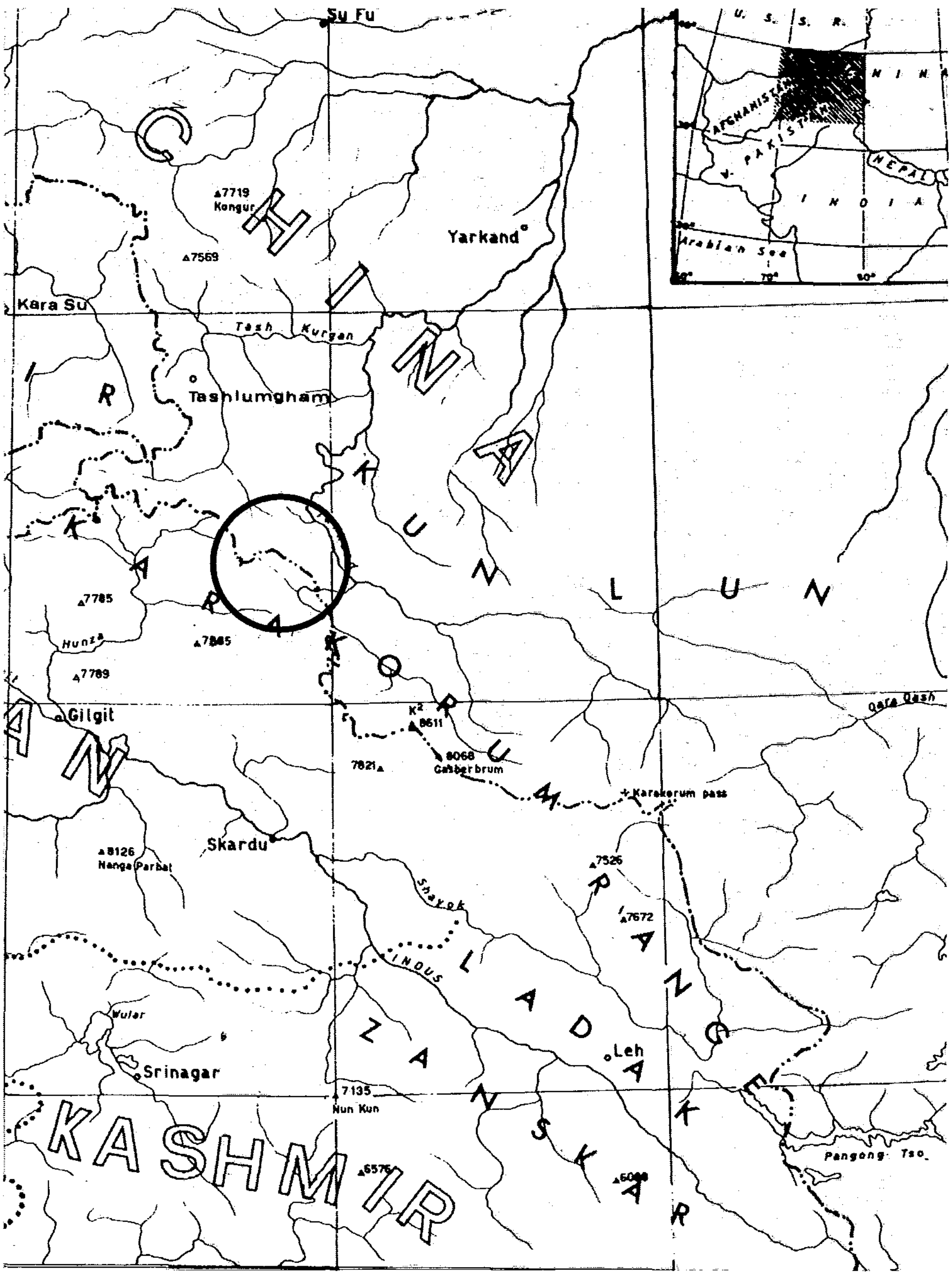

FIG. 1 - Location of the study area.

3) and a full set of secondary and transversal ice streams (about twenty).

Data, sources and results regarding a summary of previous observations concerning the variations at the terminus of the Baltoro glacier from the 1850s to the beginning of the last century can be found in Dainelli & Marinelli (1928) and in Savoia-Aosta & Desio (1936). In fact, in 1929 Desio performed the first true measurement of the distance of the terminus limit from a fixed reference boulder. The boulder was (and is still) well identified by particular features: grey gneissic composition, trapezoidal shape, well recognisable oblique quarzitic dike, position in the right frontal sector of the Baltoro fluvial-glacial deposit (fig. 2). The boulder was called «Masso Desio» and has been used for further measurements on through to present times (for example during the Desio 1954 expedition) (fig. 3).

FIG. 2 - General view of the *terminus* of the Baltoro Glacier in 1929 (from Desio Archives); in the black circle the «Desio boulder»

FIG. 3 - General view of the *terminus* of the Baltoro Glacier in 1954; in the black circle, the «Desio boulder» (from the Desio Archives).

During the 1997 Expedition, the measurement from the «Masso Desio» was performed again (fig. 4). New reference boulders (Topographic stations) were chosen for the terminus of the Liligo Glacier and the Mazzoleni Glacier and the respective distances from the lower limit of the glacier were measured.

Taking into account the objective difficulties involved in operating in Karakorum with electronic devices, due to the war between India and Pakistan for the northern areas of Jammu, traditional methodologies were adopted, using rapid topographic field tools that are simple to handle. Therefore, professional compasses and altimeters were used, coupled with a telemeter and a rolled meter for distance measurements. Table 2 summarises the features of the «Masso Desio» and the new reference stations for topographic measurements.

The other signals used in the left sector of the terminus in 1985 (Smiraglia, 1987) were not found in 1997, probably due to the strong activity of the glacial and fluvial-glacial processes in that area. The following measurements for the «Masso Desio» were performed:

- location: 3487 m asl, with a «Thomrnen 9000» altimeter, previously checked at Paju;
- distance from the ice terminus: on the azimuth of 70° N (originally used by Desio, 1954), 131.6 m with a rolled meter and 130.5 m with a telemeter. The average of 131 m was used and then, through an elemental trigonometry formula, transformed on the azimuth of 57° N, used by the expedition following Desio's (Smiraglia, 1987). The final result was 134.4 m.

Table 3 reports the measurements recorded over time, starting from Dainelli in 1913 (an estimated distance, as confirmed by Dainelli & Marinelli, 1928) and in figure 5, the relative time-distance line is illustrated.

The graph clearly shows the non-linear dynamics of the Baltoro front, which fluctuates between advance phases (1913-1929, 1954-1987, 1990-1997) and retreat phases (1929-1954, 1987-1990). The reduced number of measure-

TABLE 2 - Features of the signal boulders (reference topographic stations) identified and used for measurement of the frontal variations of the three glaciers studied

Name	Previous name	Height (m asl)	Co-ordinates	Glacer	Tool/Azimuth (°)
EV-K2-CNR MP 1 6/97		3,507	395025N-600845E	(Nameless) Mazzoleni	Telemeter/N 140
EV-K2-CNR MP 2 6/97	QUOTA 8000 CS 85-10	3,487	3940500N-600865E	Baltoro	Telemeter-tape/N 57
EV-K2-CNR MP I 6/97		4,035	3950290N-610560E	Liligo	Telemeter/N 273
EV-K2-CNR MP II 6/97		4,000	3950340N-610575E	Liligo	Telemeter/N 232-235
EV-K2-CNR MP III 6/97		4,030	3950285N-61045 SE	Liligo	Telemeter/N 282

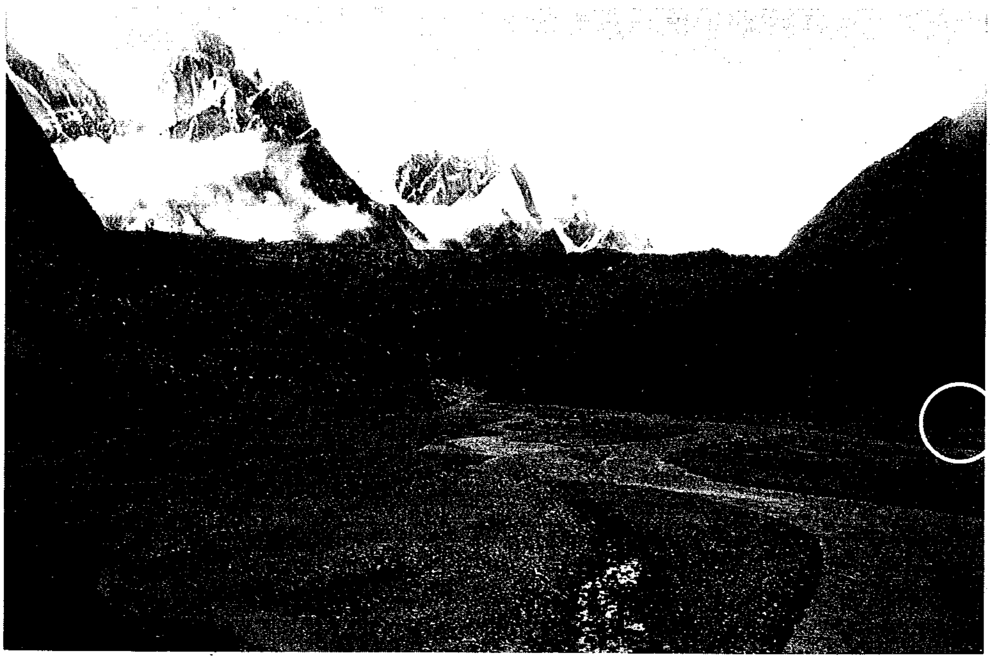

FIG. 4 - General view of the *terminus* of the Baltoro Glacier in 1997 (from Pecci Archives); in the white circle the «Desio boulder».

TABLE 3 - Measurements of the frontal variations of the Baltoro Glacier from 1913 to 1997

Researcher	Expedition	Year	Measure (m)	Measure direction (degrees)	Correct measure (m)	Frontal variations (m)	Cumulative frontal variations (m)
Dainelli	De Filippi	1913	80	?	—	—	0
Desio	Duca di Spoleto	1929	18	70 N	18.5	+61.5	+61.5
Anonymous	French expedition	1936	64	?	—	–45.5	+16
Desio	Italian K2 expedition	1954	296	70 N?	303	–239	–223
Smiraglia	Quota 8000	1985	172	57 N	172	+131	–92
Anonymous	Quota 8000	1986	170	57 N	170	+2	–90
Maragnoli	Private	1987	160	57N	160	+10	–80
Rampini	Private	1990	171.4	57 N	171.4	–11.4	–91.4
Pecci	EV-K2-CNR	1997	131	70 N	134.4	+37	–54.4

ments naturally does not allow for identification of the beginning and the exact duration of the alternate phases. In any case, starting from the 1850s (and from the availability of descriptions, maps and photographs), the terminus sector of the Baltoro Glacier can be considered to have been in a stationary phase. In fact, the frontal variations measured (globally negative for a retreat of about 50 m in the present century) can be considered as virtually insignificant. The two observations that follow were obtained starting from the historical descriptions, the available cartography, the ground photographs, the satellite images (for instance, Erts 1972 and Spot 1986), the field surveys and mountaineering expeditions:

1. In the 1864-1997 period, the Baltoro terminus never advanced as far as the Paju terrace and never retreated behind the first confluent glacier (Uli Biaho), for a total distance of about 3.5 km;
2. The terminus fluctuated in the period considered only within the area of a few hundred metres up or down around the mouth of the steep and clearly recognisable valley in the hydrographic left, including the small, nameless glacier (proposed to be called the «Mazzoleni Glacier»).

In any case, the variations in length are actually insignificant for an ice flow developing down for about 60 km.

THE LILIGO GLACIER

The Liligo is a small glacier located in a transversal valley and flows in the left side of the Baltoro Glacier. The terminus has often been described by explorers and mountaineers, due to its short distance from a camp that is always used for expeditions to the upper Baltoro. The mid-

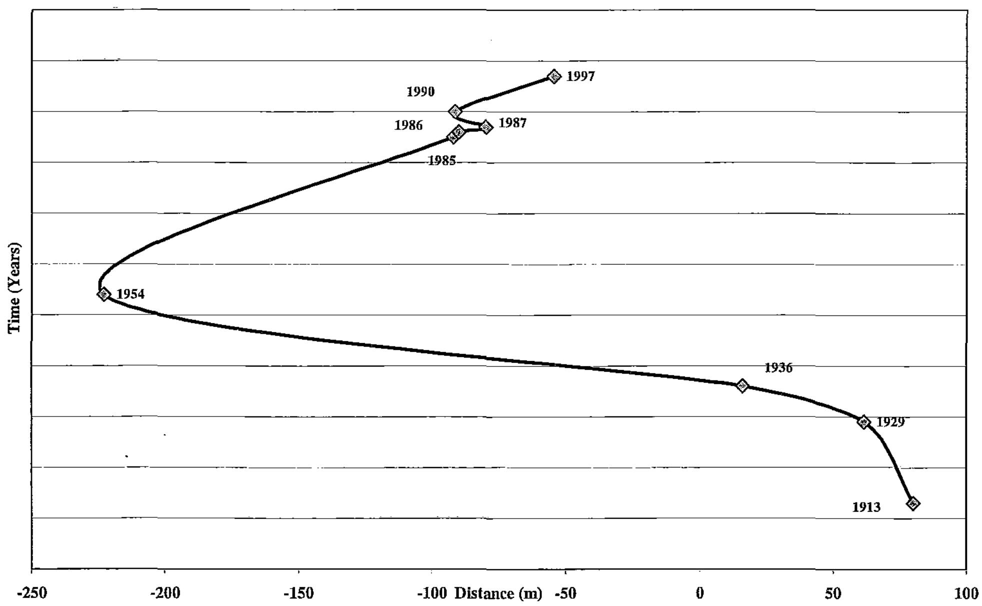

FIG. 5 - Cumulative frontal variations of the Baltoro Glacier from 1913 to 1997.

dle and the upper sector is practically unknown and only in recent times has it been mapped, owing to the use of satellite images. Already in Conway's map (1892), the separation between the terminus of Liligo and the left side of the Baltoro is clearly evident. De Filippi (1912) passed through in 1909 and described the terminus of the Liligo Glacier and the contact zone with the Baltoro with these words: *«The Liligo glacier is very broken up with no moraines, occupying at least the centre of its valley, with the terminus at a distance of about half a kilometre from the side of the Baltoro, with a steep front, a hundred metres high and with no debris cone at the toe... The space between the Liligo terminus and the side of the Baltoro is partly filled by a little lake, with a second one upward»* (page 229).

De Filippi's description is confirmed and well illustrated by the wonderful photograph by V. Sella (fig. 6). It is important to observe the characteristic and distinct structure (may be a landslide scar) on the rock wall in the hydrographic left just slightly upward from the terminus. It is useful as reference element for evaluation of frontal dynamics, at least in qualitative terms.

Desio studied the terminus of Liligo in 1929 and esti-

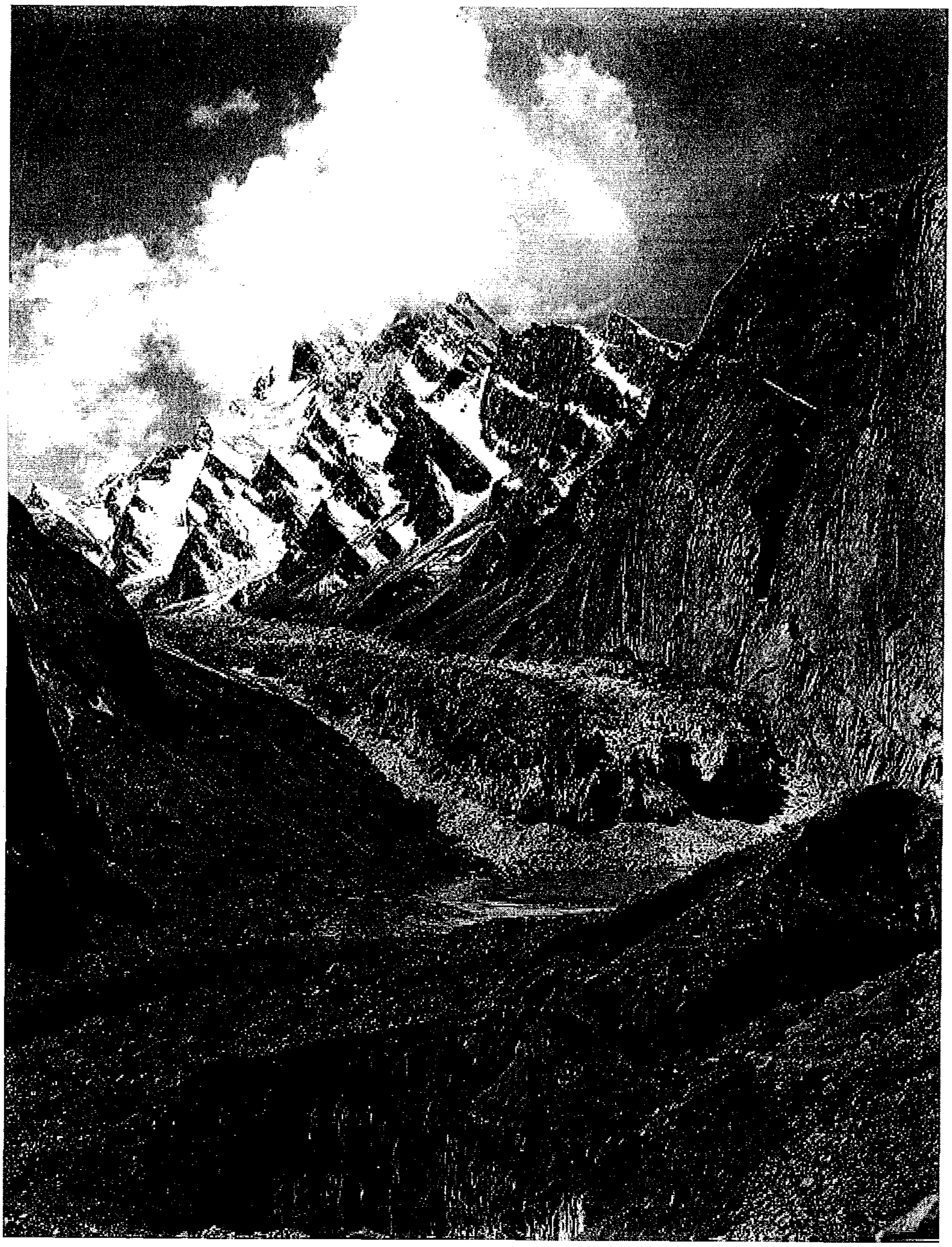

FIG. 6 - General view of the lower sector of the Liligo Glacier in 1909 (from the Sella Archives).

mated a total length of the glacier of about 12 km and a total surface area of about 17 km^2. Located at about 3900 m asl, the terminus presented a morphology differing completely from the one described by De Filippi. Desio described it as follows: «*It was possible to observe the lower sector of an ice flow so slight, little and thin, greatly covered by floating moraines, hidden downward below the glacial debris filling up the valley mostly on the right side*» (Savoia-Aosta & Desio, 1936, pp. 388-389). The photograph taken by Desio in 1953 (fig. 7) during the explorer mission preceding the Italian Expedition to K2 shows a general condition similar to the one of 1929 with a terminus inside the valley, the body completely covered by debris and far from the reference surface on the rock wall described previously.

The situation had not changed greatly in 1985 either. Smiraglia (1987) described a wide alluvial plane between the two glaciers, with a small lake and many little holes on fine material.

Starting from 1990 descriptions, distance estimations and photographs show a very different situation, comparable from several points of view to the situation at the beginning of the century. The terminus of the Liligo glacier

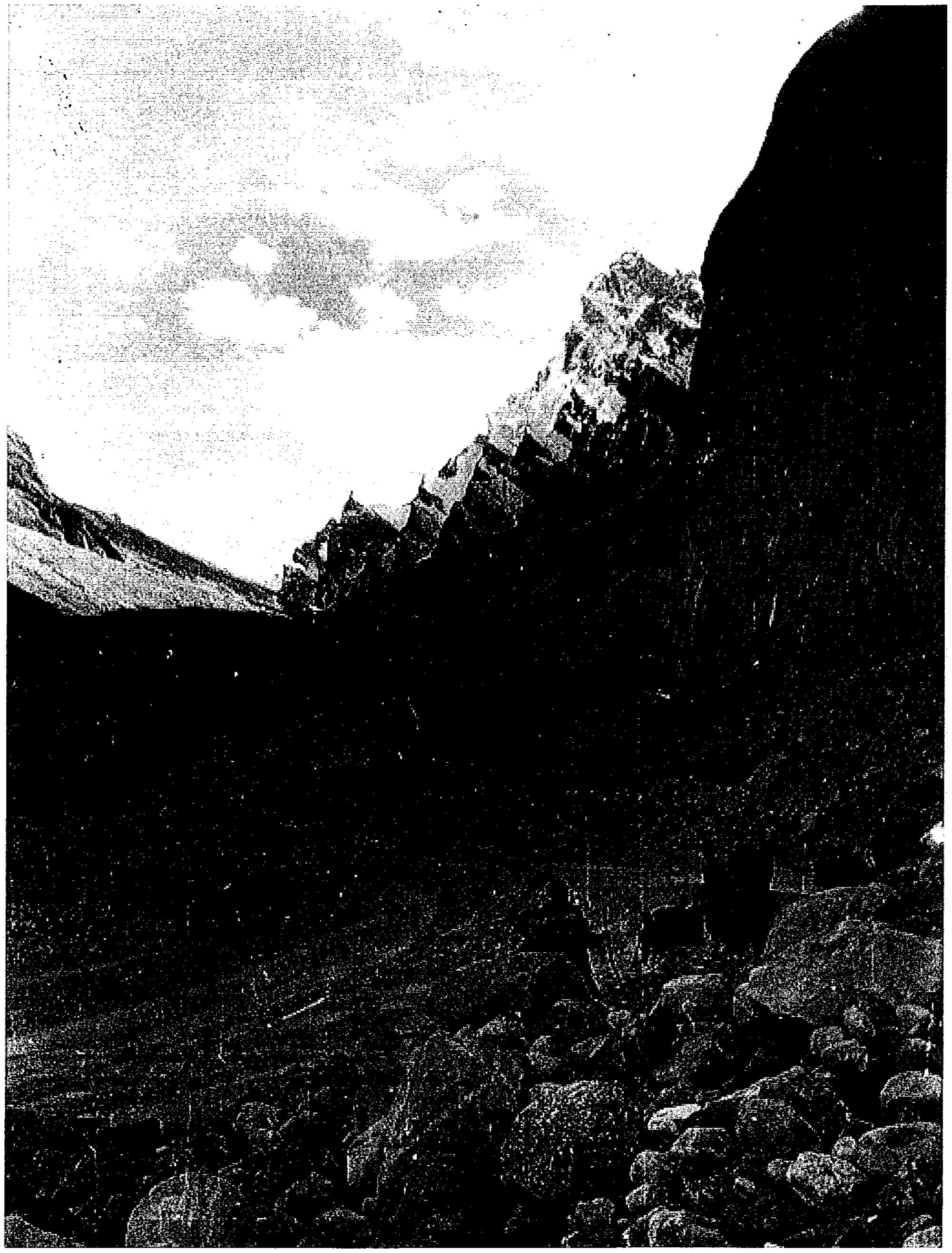

FIG. 7 - General view of the lower sector of the Liligo Glacier in 1953 (from the Desio Archives).

has been built up again, sliding down the valley lower than the reference surface on the rock wall. A small lake fills all the space between the two glaciers. Pecci's 1997 measurements reveal a distance of about 50 m between the two glaciers (fig. 8).

During the 1997 Expedition, three reference topographic stations were identified on solid rock for use in further checks (tab. 2). Table 4 lists the frontal variations of the Liligo glacier with respect to the left lateral Baltoro moraine. The distance evaluations were performed starting from various sources (descriptions, photographs, maps at variuos scales, qualitative estimations, quantitative field measurements) and the data presented should considered solely as indicative.

Using the data presented in Table 4, the time-distance curve shown in figure 9 was prepared for the Liligo Glacier for a period starting from the end of the 19th century to the end of the present century, in addition to a curve for the Mazzoleni Glacier.

Even when the imprecision of much of the data is taken into account, looking at the diagram, the Liligo Glacier appears to have advanced until the first decade of the present century, followed by a marked retreat (about 1.5 km) until mid-century and finally another considerable advance

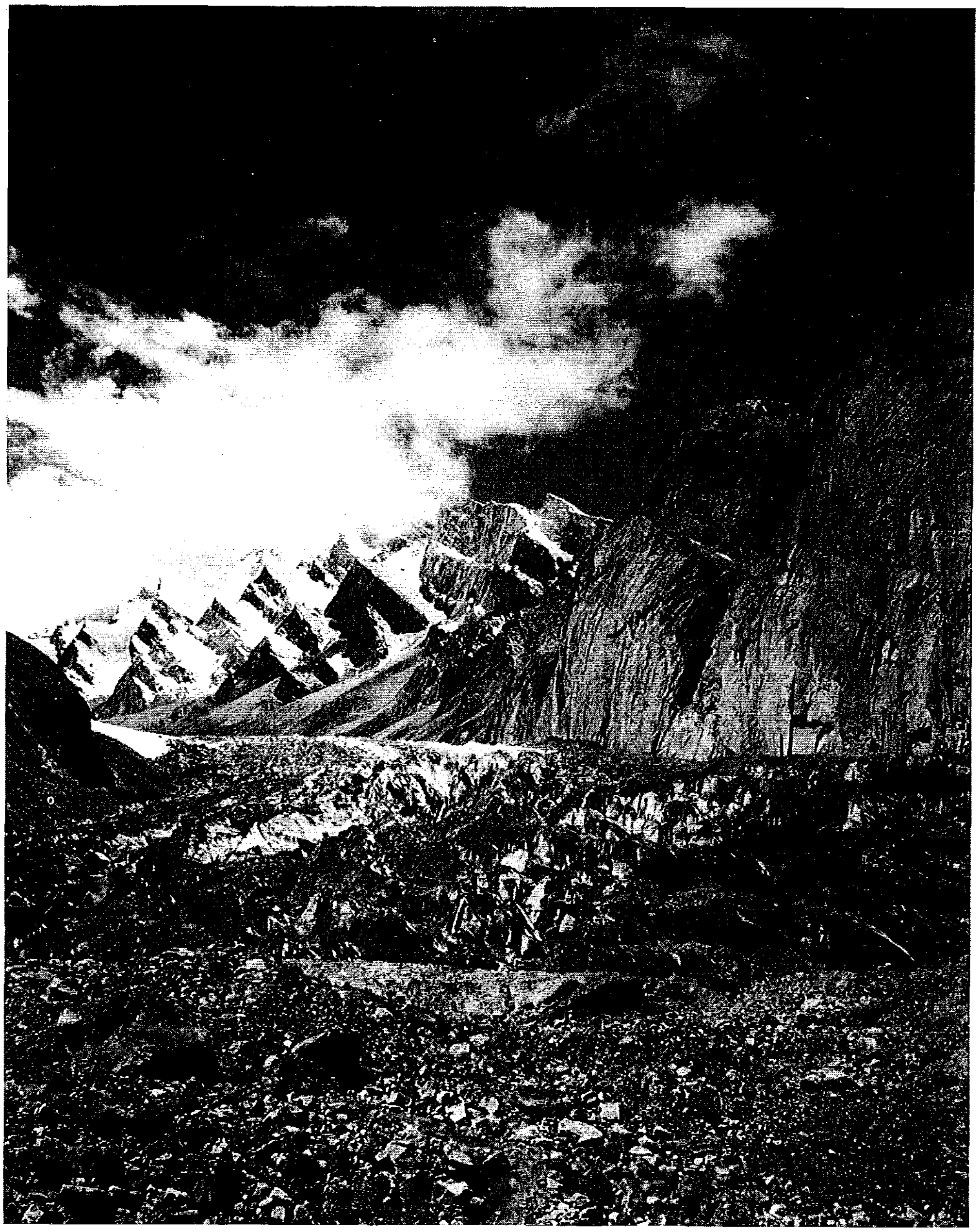

FIG. 8 - General view of the lower sector of the Liligo Glacier in 1997, behind the debris-covered Baltoro Glacier (from the Pecci Archives).

TABLE 4 - Variations of the Liligo terminus with respect to left lateral moraine on the Baltoro Glacier

Year	Distance from Baltoro (m)	Frontal variations (m)	Cumulative frontal variations (m)	Method of calculation	Source
1892	760	—	—	cartographic	Conway, 1894
1909	about 500	+260	+260	field evaluation	De Filippi, 1912
1913	900	–400	–140	cartographic	Dainelli & Marinelli, 1928
1953	about 1750	–850	–990	field evaluation	Desio, 1961
1954	1700	+50	–940	cartographic	Desio, 1991
1985	about 1700	about 0	–940	field evaluation	Smiraglia, 1987
1990	about 500	+1200	+260	field evaluation	Rampini
1996	about 400	+100	+360	evaluation from photos	Da Polenza-Scoppola
1997	50	+350	+710	direct (telemeter)	Pecci

(about 1.5 km again). Even when only the most reliable data are used (the 1892 map by Conway, De Filippi's evaluation in 1909, the 1954 map by Desio and Pecci's 1997 measurements), a retreat phase during the first half of the century and an advance phase during the second half are clearly detectable. Taking into account the geometric features of the glacier, the dimensions of these variations in terms of length are marked and comparable in degree to those of Alpine glaciers of the same dimensions (several dozens of metres per year).

THE MAZZOLENI GLACIER (1)

In a small space below the terminus of the Baltoro Glacier, a short, narrow valley opens up in the hydrographic left, containing a small glacier (fig. 10).

The valley is easily recognisable on the topographic map of the Baltoro area at the scale of 1:100,000, surveyed and published by Desio (1991), owing to the left hydrographic edge, containing spot heights (4208, 5016, 6093). With a total length of few kilometres, the nameless glacier is easily identifiable on large-scale maps, particularly on Conway's and on Desio's.

Taking into account its position respect with to the Baltoro Glacier and the Liligo Glacier, and its dimensions, a reference topographic station was established for further measurements (big boulder in the path on the right lateral moraine on the Baltoro Glacier - table 2).

(1) The authors propose naming the glacier «Ghiacciaio Mazzoleni» in memory of the mountaineer from Lecco, Lorenzo Mazzoleni, who tragically fell from K2 during the scientific and mountaineering Expedition of 1996. One of the objectives reoched by the expedition was the remensuring of the exact height of the top of K2. Negotiations between the Italian Embassy in Pakistan and the Pakistani Administration are now in progress with the aim of mating the proposed toponym official.

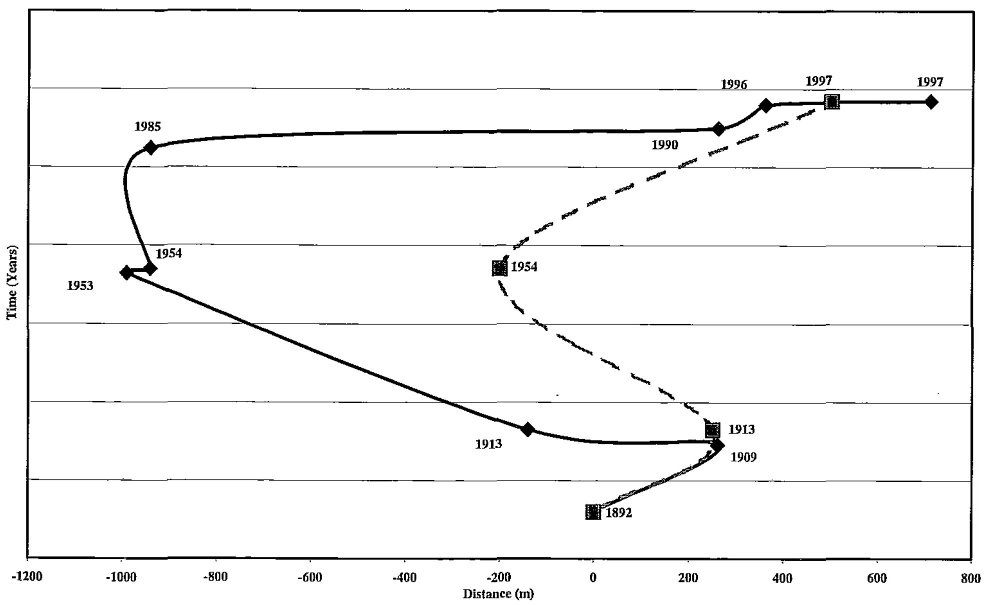

FIG. 9 - Time-distance curves for the Liligo Glacier and the Mazzoleni Glacier during the last century with respect to the left lateral moraine on the Baltoro Glacier.

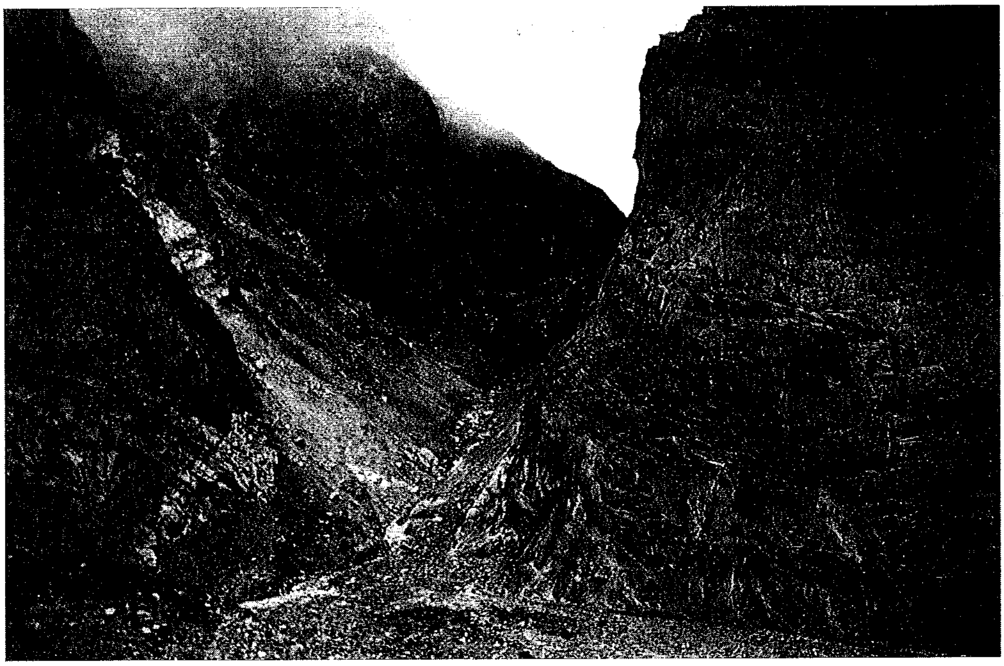

FIG. 10 - General view of the lower sector of the «Mazzoleni Glacier», about two hundred metres suspended above the left sector of the terminus of the Baltoro Glacier (photo by M. Pecci taken from the signal: EV-K2-CNR - MP1).

A system of signals is now available in this region for monitoring the frontal dynamics of three glaciers differing in dimensions and morphology: a large longitudinal debris-covered glacier (Baltoro), a transversal glacier of medium dimensions (Liligo) and a transversal, but small glacier, characterised by a well-confined basin and a lack of lateral alimentation (Mazzoleni).

In any case, the examination of the cartographic documents available made it possible to obtain information, even if semi-quantitative, on the frontal variations of this glacier during the present century. This information is reported in table 5 and was used in the preparation of the time-distance curve found in Figure 10 (together with the Liligo glacier curve).

Even when the limited data set is taken into account, for this glacier it was possible to identify the following: an expansion phase at the beginning of the 20th century, followed by an intensive regression phase with the maximum corresponding to mid-century and finally, another expansion phase. As is detectable from a comparison of the time-distance curves, the terminus of the Liligo Glacier and the terminus of «Mazzoleni Glacier» seem to fluctuate with fair level of synchronicity.

CONCLUSIONS

Though with differing degrees of precision, the sources and the direct measurements made it possible to determine the variations of the terminus during the 20th century for three glaciers in Braldo Valley, in the K2 region. Several advance and retreat phases were determined to have developed synchronously, although differing in degree. All three glaciers studied are characterised by a common advance phase taking place during the early decades of the 20th century, followed by a retreat phase with a maximum during the «fifties» and, then another advance phase, which is still in progress. While the fluctuations of the three glaciers are comparable from a chronological point of view, the scope of these fluctuations varies markedly. In fact, the terminus

TABLE 5 - Variations of the terminus of the «Mazzoleni Glacier» with respect to the left lateral moraine on the Baltoro Glacier

Year	Measured distance from the Baltoro (m)	Frontal variations (m)	Cumulative frontal variations (m)	Method of calculation	Source
1892	1000			Cartographic	Conway, 1894
1913	750	+250	+250	Cartographic	Dainelli & Marinelli, 1928
1954	1200	−450	−200	Cartographic	Desio, 1991
1997	500	+700	+500	Direct (telemeter)	Pecci (1997)

of the Baltoro Glacier, a large, classic debris-covered glacier, registered extremely limited fluctuations (almost a few dozen metres) compared to the dimensions of the whole glacier, and the whole terminus sector of the Baltoro Glacier could be considered as stable throughout the century or in any case, characterised by a low level of activity. As a sole comparison (but obviously, in a completely different climatic, morphologic and dynamic context), the terminus of the Aletsch glacier, the largest in the Alpine chain, but half the length of the Baltoro glacier, has shown a frontal retreat excceding 3 km starting from the middle of the 19th century (Bachmann, 1980).

The termini of the two smaller glaciers, and mainly the Liligo Glacier (due to the greater availability of data), are definitely more active and show fluctuations comparable in dimensions with the those of Alpine glaciers.

At least for the study area, the results obtained provide for completion of the work of previous authors, particularly Mayewski & Jeschke, 1979 and Kick, 1989. The first two authors had already identified an expansion phase on the southern side of the Karakorum Range taking place during the early decades of the 20th century, followed by a phase characterised by an intensive retreat. After Mason, 1930, Kick affirmed that, starting from the second half of the 20th century to at least 1909, the terminus of the Baltoro Glacier had been stationary and started to retreat thereafter.

The fluctuations of the two smaller glaciers and above all, the Liligo Glacier, permit us to introduce a very interesting topic concerning our knowledge of glacial dynamics. Even though it has not been possible to establish the beginning of the expansion phase of the Liligo Glacier in the second half of the 20th century, evidence is provided that the position of the terminus in 1954 and in 1985 was similar (as well as the morphology of the entire frontal sector). In the same manner, it is certain that the glacier started to advance markedly immediately thereafter and that the terminus has developed a completely different and characteristic morphology. Quantifying the advance in about 1700 metres up to 1997, the annual average rate of advance can be estimated at more than 140 metres, with an almost double rate of 240 m of advance with the supposition that the expansion phase began in the early nineteen nineties.

This rate of advance is remarkably different from the rate resulting for the Kutiah Glacier (a total advance of 12 km in 1953, with a velocity of 113 m/day - Desio, 1954). Nevertheless, the hypothesis that the Liligo Glacier is of the type characterised by rapid, sudden and exceptional advance (popularly known as «galloping glaciers» and scientifically termed «surging glaciers») cannot be rejected until further studies are carried out.

This is not the proper occasion to approach the complex theme of surging glaciers, but we can make mention of the plentiful literature on the subject (e.g. Meier & Post, 1969; Mac Meeking & Johnson, 1986; Paterson, 1994). It should be emphasised that a sole exact definition of surging glaciers has not yet been formulated and that there probably do exist transitions between surging glaciers and «normal» glaciers. The Liligo Glacier may be a type III surging glacier, according to the classification system by Meier & Post, 1969 (glaciers of small dimensions, 2-10 km in length, with a frontal advance in 1-10 years reaching 10-30% of the total length). Nevertheless, it is necessary to check whether other evidence (adding the fluctuations described, and including a quantitative measure of the morphologic features of the entire glacier) can be found to substantiate the hypothesis formulated.

A basic document regarding this discussion consists in the photograph taken by Sella in 1909 (fig. 6). The Liligo Glacier shows a terminus that is unusual for the Karakorum and Himalayan glaciers. In fact, a vertical falaise of ice that is a hundred metres high (as described in De Filippi, 1912) is observable. It extends downward on the lower sector of the glacier, surrounded by a crown of ice debris. The surface area, opposite to the stagnant debris-covered glacier, is only partly covered by debris where the lateral moraines are found. However, the most interesting element is the fragmentation in crevasses, which involves the entire glacier that is visible in the photograph and which transforms the surface into a structure that is chaotically broken up into pinnacles of ice. Overall, and particularly regarding the presence and distribution of the crevasses, the morphology of the Liligo Glacier seems similar to the Kutiah Glacier, as is visible in some unpublished photographs taken by Desio.

To sum up, the following elements appear to favour inclusion of the Liligo Glacier in the surging glacier type classification:

1. the fluctuations previously registered;
2. the morphology of the terminus;
3. the features of the crevasses;
4. the terminus sector resembling well-known surging glaciers;
5. the presence of phenomena of the same type in the same mountain chain.

On the other hand, the following elements appear to discourage inclusion of the Liligo Glacier in the surging glacier type classification:

1. the synchronicity of the pulsing between the Liligo Glacier, «Mazzoleni glacier» and Baltoro glacier could be justified by a climatic control over the frontal variations;
2. the concentrated rate of the positive pulsing and the excessive temporal extension;
3. the lack of other morphologic evidence typical of surging glaciers, particularly the presence of looping or folding moraines created by the smaller confluent ice flows, which are not visible on the Liligo Glacier even in the detailed satellite images covering the middle--upper sector of the glacier.

In conclusion and with this state-of-the-art information and data, the inclusion of the Liligo Glacier among the surging glaciers of the Karakorum Range (retreat phases 1-2 decades long, alternated with a dormant phase many decades long) can be a reliable hypothesis. Only improved precision and a more in-depth examination of the historical sources and the satellite images, in addition to field surveys (mostly velocity measurements), will confirm it or invalidate it.

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