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LATE HOLOCENE FLUCTUATIONS OF BRENVA GLACIER (***)

ABSTRACT: OROMBELLI G. & PORTER S. C., *Late Holocene fluctuations of Brenva Glacier* (IT ISSN 0084-8948, 1982).

Fluctuations of the terminus of Brenva Glacier during the last several centuries have been reconstructed using documentary evidence in the form of maps, painting, lithographs, drawings, written accounts, photographs, and instrumental surveys, supplemented by geologic mapping and botanical dating. The glacier terminus lay close to its present position during the late 18th century and advanced to its Holocene maximum in 1818. Following this culmination the glacier retreated several hundred meters before readvancing in the 1840's to reach a new maximum about 1850 only slightly short of the earlier one. During the next three decades the terminus receded about 1 km upvalley but then readvanced sharply during the 1880's to a secondary culmination about 1890-1895. Slow persistent retreat until about 1914 was then followed by renewed advance. Massive rockfalls from M. Bianco in 1920 thickly mantled the ablation zone with granitic rubble. This debris cover inhibited ablation of ice and caused the terminus to continue its advance until a new maximum was reached in 1940-1941 only about 50 m behind the 1818 limit. From 1940-41 until the mid-1960' the glacier front receded some 400 m, but renewed advance was detected between 1965 and 1967 which has continued to the present.

The terminal fluctuations of Brenva Glacier show a consistent relationship to a meteorological record from Great St. Bernard Pass (1818 - present) and to a long temperature record from Milano (1763 - present). Glacier advances followed intervals when winter accumulation was above average and air temperature, especially during the ablation season, was below average.

Buried logs found embedded in the upper right-lateral moraine of Brenva Glacier record earlier ice advances when supramorainal forests were killed and buried by morainal debris. One log is 1170 ± 55 ^{14}C yr old (=760 - 980 A.D.), whereas a younger log has an age of 285 ± 60 yr, probably equivalent to a calendar age of 1660 A.D. or older. The dated samples lie near the crest of the 150 m - high moraine which may contain in its core a succession of still-older morainal accretions providing a record of multiple ice advances extending far back into the Holocene.

RIASSUNTO: OROMBELLI G. & PORTER S. C., *Variazioni tardo-oloceniche del Ghiacciaio della Brenva* (IT ISSN 0084-8948, 1982).

Le variazioni della fronte del Ghiacciaio della Brenva negli ultimi secoli sono state ricostruite mediante l'analisi di antiche carte, stampe, disegni, descrizioni scritte, fotografie, misure topografiche e mediante lo studio geologico e la datazione botanica delle morene terminali. La fronte del ghiacciaio era prossima alla sua attuale posizione durante l'ultima parte del secolo XVIII e avanzò sino a raggiungere la sua massima estensione in tutto l'Olocene nel 1818. Successivamente a questa culminazione il ghiacciaio si ritirò di alcune centinaia di metri, prima di tornare ad avanzare negli anni 1840 sino a raggiungere un nuovo massimo circa nel 1850, soltanto di poco più arretrato del precedente. Nel successivo trentennio la fronte retrocesse di circa 1 km, quindi riprese ad avanzare negli anni 1880 fino a raggiungere un massimo secondario nel 1890-95. Si ebbe in seguito un lento ritiro fino al 1914, quindi il ghiacciaio tornò ad avanzare. Nel novembre del 1920 ingenti frane di crollo staccatesi dal M. Bianco ricopersero l'area di ablazione di massi e detriti granitici. Questa copertura detritica sopraglaciale inibì l'ablazione e causò una prosecuzione dell'avanzata della fronte sino a raggiungere un nuovo massimo nel 1940-41, soltanto 50 m più arretrato del limite raggiunto nel 1818. Dal 1941 alla metà degli anni '60 la fronte si ritirò di circa 400 m, ma una rinnovata fase di avanzata si manifestò tra il 1965 e il 1967 ed è proseguita fino ad oggi.

Le variazioni frontali della Brenva mostrano una stretta relazione con le registrazioni meteorologiche del Gran S. Bernardo (dal 1818 ad oggi) e con la serie bisecolare di temperature di Milano (1763 ad oggi). Le fasi di avanzata della fronte seguirono periodi con precipitazioni nevose sopra alla media e temperature, specialmente durante la stagione di ablazione, inferiori alla media.

Tronchi d'albero sepolti rinvenuti nella porzione sommitale della morena destra testimoniano precedenti avanzate del ghiacciaio, quando la copertura forestale sopramorenica fu distrutta e sepolta da detrito morenico. Un tronco ha un'età di 1170 ± 55 anni ^{14}C (770-915 d. C.), mentre un tronco più recente ha un'età di 285 ± 60 anni ^{14}C, probabilmente equivalente ad un'età calendario 1660 d. C. o più antica. I Campioni datati sono stati rinvenuti presso la cresta della morena destra, alta 150 m, che deve pertanto contenere nel suo nucleo una successione di accrescimenti morenici ancora più antichi, che potrebbero fornire una testimonianza di multiple fasi di avanzata glaciale estendentesi all'intero Olocene.

TERMINI-CHIAVE: ghiacciaio, Olocene, Val d'Aosta.

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We wish to thank for aid in the research of iconographic material and for providing reproductions of etchings, paintings, and drawings Mr. NAVA P. *(Bergamo) and the following libraries and institutions: Istituto di Geologia dell'Università di Torino, Biblioteca Regionale di Aosta, Biblioteca Nazionale di Torino, Biblioteca Reale di Torino, Biblioteca CAI di Torino, Biblioteca CAI Sezione di Milano, Biblioteca dell'Università Cattolica di Milano, Tipografia Torinese Editrice, Nicola Zanichelli Editore Bologna. Lichen determinations were made by* ANDREIS C. *and wood determinations by* CASTELLETTI L.

INTRODUCTION

The variations of climate through past centuries resulted in fluctuations in the size of temperate mountain glaciers which respond primarily to change in precipitation and temperature. For this reason, the variations exhibited by glaciers provide us with a useful measure of the course of climatic change. Brenva Glacier, which flows off the southeastern flank of the Mont Blanc massif, is among the best known glaciers of the Italian Alps, and its terminal fluctuations have been observed and documented discontinuously for several centuries. Although portions of this record have been reported earlier (e.g., CAPELLO, 1941; GROVE, 1966; HEYBROCK, 1941; LE ROY LADURIE, 1971; MAURER, 1910, in DRYGALSKI & MACHATSCHEK, 1942; SACCO, 1918; SILVESTRI, 1925), no systematic attempt has heretofore been made to draw together all the diverse information and to develop a detailed picture of the history of movements of the glacier in the last several centuries.

The summary presented here constitutes part of a larger investigation concerning the recent history of glacier variations on the Italian flank of the Mont Blanc massif (PORTER S. C. and OROMBELLI G., in preparation). Brenva Glacier has been singled out for special attention because the historical record for this glacier is well documented and permits a more-detailed reconstruction of its variations than is possible for most other glaciers on this side of the Alps.

BRENVA GLACIER AND ITS MORAINES

Brenva Glacier originates near the crest of the Mont Blanc (Monte Bianco) massif on the East side of Mont Blanc (4 807 m) and descends steeply to the floor of Val Veni where it terminates at an altitude of 1 405 m (figs. 1 and 2). The glacier is some 6 km long and its lowermost 1.5 km lies within steep-walled moraines that extend beyond precipitous cliffs of the granitic massif. The terminal zone is extensively mantled with granitic debris, the remains of massive rockfalls that were deposited in November 1920 (VALBUSA, 1921; 1931; OROMBELLI & PORTER, 1981). The debris also overlies the crest and distal slope of the prominent right-lateral moraine, and a small segment of the left-lateral moraine as well (fig. 3). The lateral moraines locally consist of several crests, and obviously represent successive accumulations, or accretions, of drift during numerous historic and prehistoric advances of the glacier tongue. The outermost identified Holocene drift attributable to the glacier lies below the chapel of Notre Dame de la Guérison and opposite the entrance to the Mont Blanc tunnel, about 1 km upvalley from the community of Entrèves.

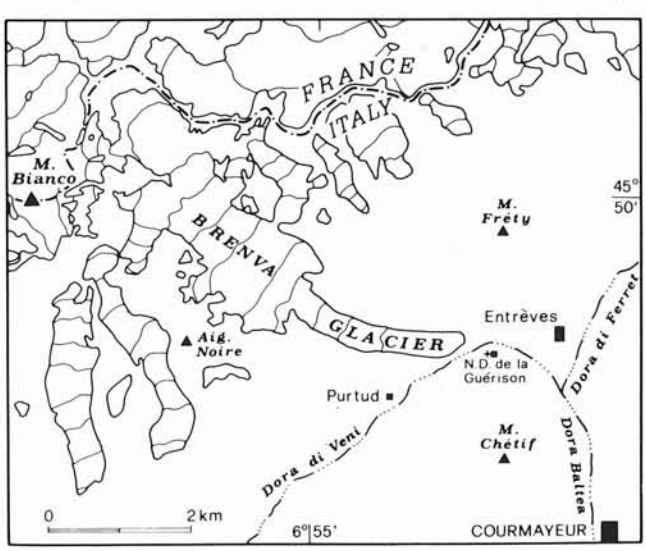

FIG. 1 - Map of Brenva Glacier and vicinity.

SOURCES OF DATA

The recent history of Brenva Glacier has been reconstructed from historical documents supplemented by geologic field work and radiometric dating.

Historical sources. The glacier has been observed repeatedly during recent centuries and its former size and terminal position have been documented in written accounts and depicted in a variety of artistic renditions including etchings, sketches, watercolors, and oil paintings. The quality of such source material from the period prior to land-based photography varies considerably in

FIG. 2 - View of Brenva Glacier from Monte della Saxe (July 16, 1979).

quality, but some of the works are carefully rendered, and provide reasonably accurate and important information about the glacier. Early maps of the glacier and of the Mont Blanc massif provide additional information, but they are reliable for our purposes only starting from the middle of the 19th century. Direct observations constitute the most reliable basis for assessing the magnitude of terminal fluctuations, but they decrease in frequency and quality before the early part of the present century.

Two major sources of error exist in using artistic material and early maps. First, because drawings, paintings, and maps often were published one or more years after they were constructed, care must be taken to determine the exact year depicted. Second, in some cases artists copied previously published works, embelishing them with new foreground or background detail. Such works are of limited value and could generate major errors in interpretation if unrecognized. The artwork is most useful where foreground detail is accurately depicted, for then the site can be revisited or the work compared directly with recent photographs or topographic maps to which information about the glacier can be transferred.

Photographic records dating to the last decades of the 19th century and the early part of the present century are also extremely useful. Among the best examples are the photographs of SACCO (1918) who published many views of glaciers in the Mont Blanc region and indicated the exact year each was taken.

Beginning in 1910 a nearly continuous record of terminal variations of Brenva Glacier has been kept which continues at the present time. This record, together with contemporary maps and photographs of the terminal zone, provide an accurate record for most of the last 70 years.

Geologic field studies and dating methods. A partial record of recent variations of the glacier is preserved as end moraines that flank its margins. However, the morainal record of Brenva Glacier is less complete than that of many nearby glaciers because large rockfalls in 1920, which distributed bouldery debris over much of the ablation zone and the right-lateral moraine system, caused an anomalous readvance that brought the glacier in 1940-41 close to its maximum postglacial extent and resulted in the destruction of some older moraine elements. Only at the downvalley limit of Holocene drift and along the upper part of the compound lateral moraines are multiple moraine ridges locally preserved that predate the 1940-41 maximum.

Moraines of unknown age were dated using dendrochronology and lichenometry. A minimum age for stabilization of a moraine is provided by the age of the oldest tree found growing on it. Counts of annual rings were made using cores obtained with a Swedish increment borer. In the two cases where moraines were dated by this method, the tree-ring ages proved to be 16 and 45 years younger, respectively, than ages for these same moraines derived by lichenometry. For this reason, the tree-ring dates were judged to be of limited value in this area.

Lichens also provide minimum ages for moraines and date a time when moraines became sufficiently stable for lichens to colonize the surface boulders. Lichenometric ages were determined by measuring the minimum diameter of the largest lichen thalli found on a moraine. We utilized two species of crustose lichen, *Rhizocarpon geographicum* and *Aspicilia cinerea*, for which independent growth curves have been derived (PORTER & OROMBELLI, 1980; 1981). Two control points for the *Rhizocarpon* growth curve were provided by specimens growing on a rockfall deposited across and beyond Brenva Glacier in 1920 and on the moraine formed in 1940-41 at the culmination of its recent advance. Ages derived by this method are believed to be close approximations to the date of moraine formation and to be more reliable than those obtained from tree-ring counts (PORTER, 1981).

Exposures on the steep proximal slopes of lateral moraines provide opportunities for finding and dating buried soils and (or) remains of vegetation that were buried during historic or prehistoric ice advances (e.g., RÖTHLISBERGER & SCHNEEBELI, 1979). The outer rings of tree trunks or branches can provide close maximum limiting ^{14}C ages for overlying drift. Only immature

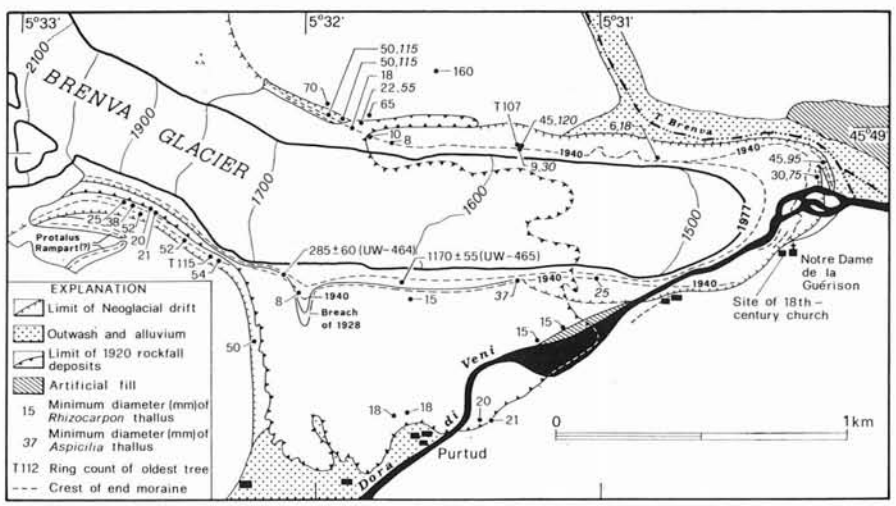

FIG. 3 - Geologic map of Brenva Glacier moraines and associated deposits. Lichen measurements were made in July 1977.

soils representing brief intervals of profile development are likely to give close limiting ages (MATTHEWS, 1980). Both wood and soil was found in exposed section of the right-lateral moraine of Brenva Glacier and provide information on the earliest recognized Holocene advances of the glacier.

EARLY ADVANCES

The massive lateral moraines of Brenva Glacier are capped by young deposits representing ice advances that culminated within the last two hundred years, but they are cored by older glacial deposits which may date back many thousands of years. This inference is based on the occurrence of a buried soil and fossil tree stumps that were exposed in 1977 on the proximal slope of the upper right-lateral moraine near a breach that formed in 1928 (fig. 3). About 10 m West of the breach at 1700 m altitude, a buried soil with associated wood was found 4 m below the crest of the moraine. The yellowish-brown soil, some 3 cm thick, was traceable for about a meter. Wood lying at the level of the soil has an age of 285 ± 60 yr (UW-464). When the date is corrected for atmospheric variation in radiocarbon using STUIVER'S (1978) curve, its age at one standard deviation (67 % probability) is at least 290 years, equivalent to a calendar age of 1660 A.D. However, the radiocarbon date could also be equivalent to an age of as much as 460 yr or even greater (1490 A.D. or earlier). At two standard deviations (95 % probability), the range of possible ages expands to include 150-220 yr (1730-1800 A.D.) and 280 yr or greater (1700 A.D. or earlier). Therefore, at best one can say that the wood was killed prior to the beginning of the 19th century, and very likely during or prior to the middle 17th century. Although it could record an advance during the historic period at a time when Brenva Glacier was known to have been in a reasonably advanced position (see below), it also might reflect an older advance during the early part of the Little Ice Age (16th century or before).

Two additional pieces of wood were found on the proximal face of the same moraine at an altitude of 1 635 m. One log protruded 6 m below the crest of the moraine, which at this locality is mantled with rockfall debris emplaced in 1920. A second nearby log lay 8 m below the crest of the moraine, with its trunk dipping into the face at an angle of 35° and with its roots exposed. The log was encased in till and has a radiocarbon age of 1170 ± 55 yr (UW-465). When corrected for atmospheric radiocarbon variations using the correction table of STUIVER (1982), the date is equivalent to an age of 970-1190 yr at one standard deviation, or a calendar age of 760-980 A.D. The geologic relationships and age of the sample therefore point to an advance of the glacier sometime during the late-8th to late-10th century. Although this is the oldest date pertaining to the Holocene history of Brenva Glacier, it seems likely that the entire record of fluctuations must be far older and complex, for the dated sample lies only 8 m below the crest of a lateral moraine which is at least 150 m high and which may contain in its core a succession of sedimentary accretions of drift that reflects multiple advances extending well back beyond 1000 A.D., possibly to late-glacial times.

HISTORIC RECORD

PRE-17TH CENTURY

Documents dating from the 7th century A.D. mention the martyr St. Jean who was killed by the Gauls in « Pertu » during the reign of Emperor Maximian at the end of the 3rd or 4th century (DUC, 1915). The locality of his death probably lay near the site of modern Purtud (fig. 3). According to VIRGILIO (1883) the small village of St. Jean de Pertuis (Purtud) lay on a low plain approximately in the position of the right lateral moraine of Brenva Glacier in the 14th and 15th centuries. Local tradition states that the community was destroyed and overrun by the glacier as punishment to its inhabitants for cutting hay on St. Margaret's Day (FORBES, 1843). SACCO (1918) suggested that the village was destroyed in the 16th century, whereas MATTHES (1942, p. 206) gave 1600 as the approximate data when the village was overwhelmed by the glacier, "church and all". However, LE ROY LADURIE (1971, pp. 221, 327) thought that the event cannot be definitely dated. He suggested that the destruction may have occurred in the 12th or 13th century because although St. Jean de Pertuis is said to be the oldest parish in the Brenva district, its name does not appear on any parish list of the Val d'Aosta in the late Middle Ages. There is no definite proof that the village was, in fact, destroyed by the glacier. DOLLFUS-AUSSET (1867; cited by VIVIAN, 1975, p. 209) mentioned a manuscript dating from 1300 that documents the existence of the village of St. Jean de Pertuis on the South side of Mont Blanc in front of the chapel of Notre Dame de la Guérison. According to DOLLFUS-AUSSET the village was destroyed by a landslide or rockfall (éboulement) and was subsequently overridden by Brenva Glacier; it is said that at several times wood from the houses was brought down by the glacier (VIRGILIO, 1883). This interpretation appears to be most consistent with the currently known history of Brenva Glacier and of rockfall activity in the area (PORTER & OROMBELLI, 1980; 1981) and implies that the glacier may have advanced some time after about 1300 A.D. in the early part of the Little Ice Age.

17TH CENTURY

On April 6, 1600, a notary named Blanc from the town of Aosta was visited by Jacques Cochet, a Frenchman from Les Bois (near Chamonix) who asked him if the glaciers on the Italian side of Mont Blanc, and in particular the Brenva Glacier, had recently retreated. His reply was no, that the glaciers were as threatening as ever, thereby implying that by 1600 the glacier was in an advanced state and probably lay near one or more small communities in the vicinity of Courmayeur (LE ROY LADURIE, 1971, pp. 151-152).

A description of the Val Veni glaciers in 1691 by

FIG. 4 - « Vue du Glacier de la Brenva ». Engraving by TÖPFFER A., from a drawing of JALLABERT J. (1767), published by DE SAUSSURE (1786, v. 4, pl. 3). Biblioteca Università Cattolica, Milano.

Philbert Amédée ARNOD, a judge of the Val d'Aosta, indicates that the Brenva Glacier was in an advanced state, for there was "a very narrow pass" between it and the adjacent wooded hillside (the so-called "Cross of Beriex", later the site of the chapel of Notre Dame de la Guérison). At that time, the Brenva Glacier apparently barred Val Veni much as it does at present (ARNOD, manuscript dated 1691 with notes added in 1694; LE ROY LADURIE, 1971, pp. 187-188).

According to DRYGALSKI & MACHATSCHEK (1942, p. 214) the glacier covered the floor of Val Veni between 1691 and 1694. These are the two dates of the manuscript of Arnod, from which this reference is indirectly (through VACCARONE, 1881) and erroneously derived.

18TH CENTURY

A drawing by JALLABERT in 1767, published as an engraving by DE SAUSSURE (1786, v. 4, pl. 3) and figured by LE ROY LADURIE (1971, pl. 25), shows Brenva Glacier spilling into the main valley and terminating close to "the huts of the farmers who cultivate the fields near the glaciers" (DE SAUSSURE, 1786, p. 286). In this figure (fig. 4), the glacier appears to have breached its right-lateral moraine in two places, and forms a lateral but confluent tongue outside the main ridge. The Dora di Veni is depicted as emerging from a subglacial channel, indicating that the ice apparently stood against the rock buttress of the southeast valley wall, and may have terminated slightly beyond the position of the present (1980) terminus. The surface of the glacier was shown

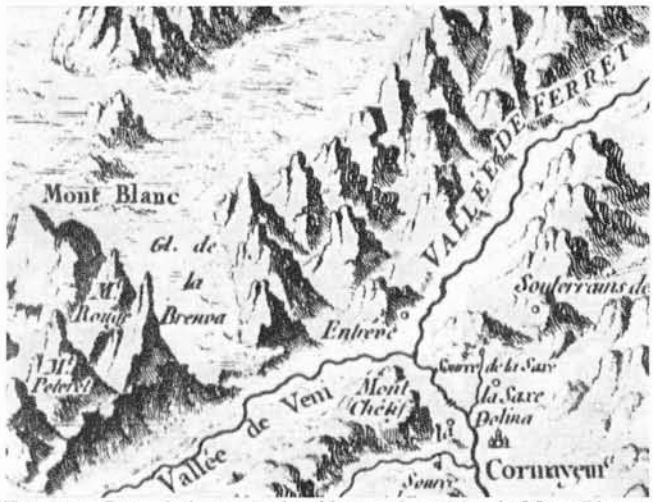

FIG. 5 - « Carte de la partie des Alpes qui avoisine le Mont Blanc » (detail), by PICTET M. A., in DE SAUSSURE (1786, v. 3). Biblioteca Università Cattolica, Milano.

as having a pronounced slope to the North through its lowermost 2 km.

BOURRIT (1776), in a letter written from Courmayeur on August 18, 1776, described the Brenva Glacier as having blue and violet crevasses. The Dora di Veni flowed beneath the glacier and emerged under a "beautiful arch of ice" suggesting that the glacier extended to the south wall of the valley, a position achieved subsequently during the culminating advances of 1818, 1849 and 1940.

PICTET'S (1778?), map of the Mont Blanc region which was included in DE SAUSSURE'S 1786 treatise

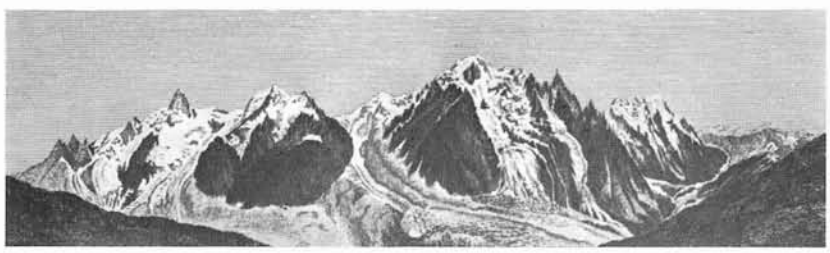

FIG. 6 - « Le Mont-Blanc vu en face du coté de l'Allée-Blanche ». Engraving by TÖPFFER A., after a drawing of BARTOLOZZI M. (1781), published in DE SAUSSURE (1786, v. 4, pl. 5). Biblioteca Università Cattolica, Milano.

FIG. 7 - The Brenva Glacier in a drawing by LINCK J. A. (ca. 1795), from PEYROT (1972), by kind permission of Tipografia Torinese Editrice.

FIG. 8 - The Brenva Glacier in the map of RAYMOND (1797-1799). From VALLOT (1922). Collection P. NAVA, Bergamo.

(v. 3) and was reprinted by ALIPRANDI & *alii* (1974, pl. 44) shows the glacier terminus extending beyond the steep mountain front onto the floor of the Val Veni, but separated from the Dora di Veni (fig. 5). Like JALLABERT's drawing, this map implies that the glacier was somewhat less extensive than it was during the subsequent early 19th century maximum. However, one must be careful in assessing this map, for FORBES (1865) spoke disparingly of the DE SAUSSURE maps, stating that "they are filled with material absolutely fictitious".

An engraving from a drawing by BARTOLOZZI in 1781 (DE SAUSSURE, 1786, v. 4, pl. 5) shows a distant view of the glacier rising above the crest of the right-lateral moraine and spilling across the upper part to reach the adjacent valley floor (fig. 6). It apparently lay close to or had retreated somewhat from the position depicted in JALLABERT's 1767 etching.

In a drawing of Brenva Glacier in 1795 (?) by Jean-Antoine LINCK, an artist from Geneva, the extremely broken surface of the lower glacier extends onto the main valley floor, but lies well below the original chapel of Notre Dame de la Guérison (PEYROT, 1972, p. 109; VIVIAN, 1975, pl. 19) (fig. 7). The glacier apparently terminated close to the present limit of its terminus, but was much thicker than now in the vicinity of the icefall (ca. 2 000-2 400 m), for only two small outcrops of bedrock are shown in the middle of the icefall. This suggests that the glacier was in a healthy state and was advancing downvalley. The map of RAYMOND (1797-1799; VALLOT, 1922, f. 102) shows Brenva Glacier, although sharply turning from NW-SE to E-W, almost entirely confined to a lateral valley and Dora di Veni is not interrupted by the glacier (fig. 8). A crude panorama of the Mont Blanc massif by BOURCET in 1799 (LE ROY LADURIE, 1971, pl. 29; PEYROT, 1972, p. 122) bears little resemblance to the actual topography and incorrectly designates or locates some of the major landmarks. Brenva Glacier is shown as a broad body of ice that does not reach the floor of Val Veni. The same is shown in the maps of BACLER D'ALBE and of DE CAROLY (1799, in ALIPRANDI & *alii*, 1974, pl. 32 and 46). In view of LINCK's carefully drawn sketch of the area, which is only a few years older, the RAYMOND, BOURCET, BACLER D'ALBE and DE CAROLY renditions appear to be of little value.

19TH CENTURY

Although the position of the terminus during the first decade of the 19th century apparently has not been documented—the map of WEISS (1800), in VALLOT (1922, f. 99), is of no value, the Brenva appearing to have retreated entirely up into its lateral valley—the glacier must have been advancing nearly continuously, for by 1811 D'AUBUISSON (1811, p. 255) placed the terminus at 1 440 m altitude and about 1 km from Entrèves; although in those years the glacier was retreating, several years before it had been advancing. FAVRE (1867), however, reported that Canon Carrel of

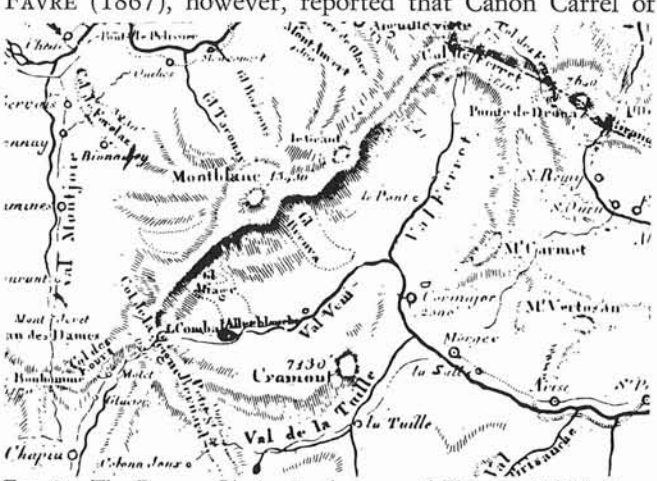

FIG. 9 - The Brenva Glacier in the map of KELLER (1813), from VALLOT (1922). Collection P. NAVA, Bergamo.

FIG. 10 - « Mont Blanc, taken near Courmayeur in the Val d'Aosta ». Drawing of FORTESCUE H. A. (October, 7, 1817). Collection P. NAVA, Bergamo.

Aosta considered that the terminus lay some 2 km from the town at that time (1810-1812) (see also SACCO, 1918, p. 35). Because of these conflicting observations, the exact position of the glacier front cannot be inferred with confidence, but in view of the fact that the maximum expansion of the glacier occurred only 7 years later in 1818, it seems likely that the terminus in 1811 probably lay within 150 to 200 m of its subsequent maximum extent. The sketch map of KELLER (1813, in VALLOT, 1922, f. 98) shows the outline of Brenva not reaching the Dora di Veni (fig. 9).

A drawing by H. A. FORTESCUE ("Mont Blanc near Courmayeur in the Val d'Aosta"), dated Oct. 7, 1817, and taken from the path to Notre Dame de la Guérison, shows the surface of the glacier clean and crevassed, and bulging over the lateral moraines which are not visible. Only one rock exposure is visible at the center of the icefall of the "Pierre à moulin". The glacier front is well downvalley of N. D. de la Guérison (ca. 250 m), approximately where the small stream descending from Mont Fréty, immediately to the West of the tunnel, joins the plain of Entrèves (fig. 10).

Although DE CHARPENTIER (1841, p. 26), KINZL (1932, p. 292), and LE ROY LADURIE (1971, p. 210) stated that Brenva Glacier reached its recent maximum extent in 1820, FORBES (1843), MARENGO (1881), SACCO (1918) and CORBEL (1963) all placed the maximum two years earlier in 1818 (figs. 11-13). At that time, according to SACCO (1918), the terminus lay only 1 km from Entrèves. FORBES (1843, p. 206) was told that in 1818 the "hermitage connected with the chapel [of Notre Dame de la Guérison] was supplied with water from a conduit which descended from the ice of the glacier which was then at a higher level". A document from the Syndic (Mayor) of Courmayeur, that FORBES viewed, stated that in 1818 the glacier damaged the chapel. The building, which was constructed in 1782-1783 (BREAN, 1976), apparently became unstable when the glacier impinged

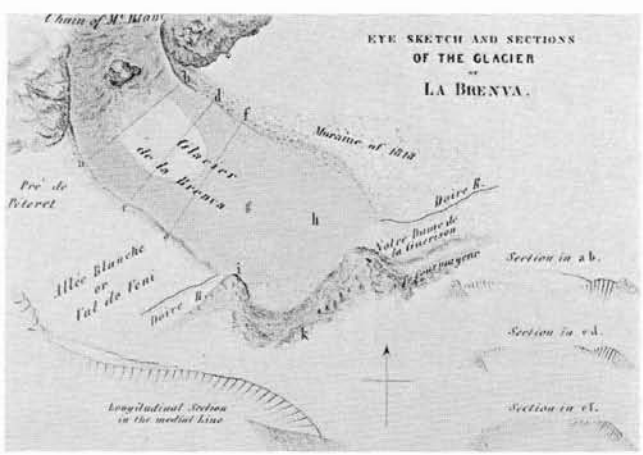

FIG. 11 - « Eye sketch and sections of the Glacier of La Brenva ». Lithograph after a survey of FORBES J. D., 1842, in FORBES (1843, Topographical Sketch n. 2). Istituto di Geologia dell'Università di Torino.

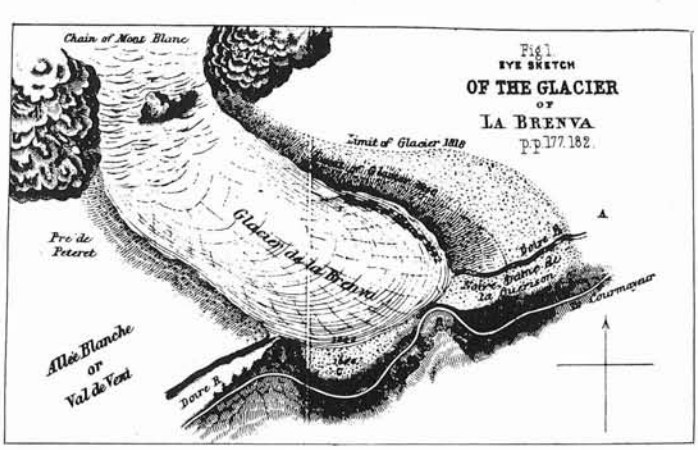

FIG. 12 - « Eye sketch of the Glacier of La Brenva ». Lithograph after a survey of FORBES J. D., 1846, in FORBES (1859, pl. 8, f. 1). University of Washington Library, Seattle.

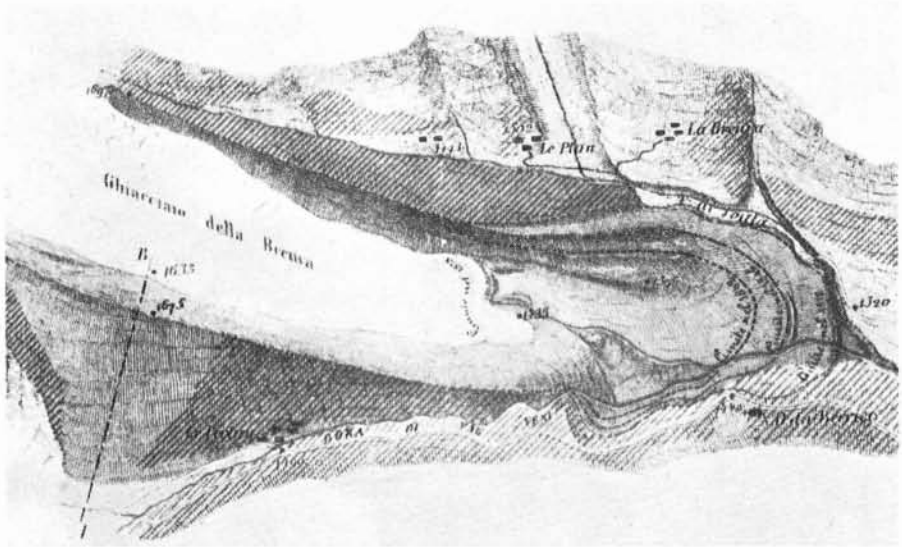

FIG. 13 - « Parte inferiore del Ghiacciaio della Brenva ». Lithograph after a survey by MARENGO (September 1879), in MARENGO (1881, pl. 1). Club Alpino Italiano, Sezione di Milano.

on its rock foundation, so another chapel was built in 1821 "50 paces" to the East. Lichenometric dating is consistent with this chronology, for the presence of a 54-mm *R. geographicum* thallus on the upper right-lateral moraine of the glacier suggests that this portion of the moraine may have become stabilized as early as 1817. According to CAPELLO (1941, p. 140), remnants of the 1818 moraines lie outside the 1940-41 moraine in the terminal zone. However, the largest lichens that we found on the outermost moraine (*R. geographicum* = 45 mm) imply that this remnant dates to about 1850. But the moraine segment is short and the measured lichens must therefore be considered as providing only a minimum age. An alternative possibility is that the outermost moraine does in fact date from the mid-19th century advance, and that moraines related to the earlier maximum expansion either were not built or have subsequently been destroyed by erosion or buried by younger outwash gravels.

According to VENETZ (1833; MONTERIN, 1936) the Brenva at the time of the 1818-1820 advance destroyed large larch trees on the right side of the glacier (possibly near the church) that had an age of at least 300 years indicating that the glacier had not been so extensive there for at least the preceding three centuries.

The glacier was still in proximity to the chapel in 1819 when a procession from Aosta reached the building and removed religious items (VIRGILIO, 1883).

A watercolor by Hans Conrad ESCHER VON DER LINTH painted on August 2, 1820 and reproduced in BACHMANN (1980) shows a close view of the glacier from a position opposite the right-lateral moraine near Belvedere (Albergo Val Veni) (fig. 14). The broken surface of the glacier rises well above the crest of the moraine, which apparently was devoid of trees. A contemporary painting by Jules Louis-Philippe COIGNET (RAOUL-ROCHETTE, 1826) shows a distant view of Brenva Glacier from a point between La Saxe and Entrèves, near Ponte delle Capre) (fig. 15).

FIG. 14 - « Am Fuss des Brenva Gletschers an der Sudseite des Mont Blanc im Piemont ». Watercolor of ESCHER VON DER LINTH H. C. (August 2, 1820). From BACHMANN (1980), by kind permission of ZANICHELLI Editore, Bologna.

FIG. 15 - « Mont-Blanc taken from the valley of Courmayeur ». Engraving after a painting by COIGNET J. L. P. (ca. 1820), published in RAOUL-ROCHETTE (1826). Collection P. NAVA, Bergamo.

The terminus, although obscured by trees, apparently lay reasonably close to the outermost moraines. A view from Courmayeur, published in a book attributed to William ROSE (1827), shows the front of the glacier clearly visible (fig. 16).

After 1818, or since 1821 according to DE CHARPENTIER (1841), the glacier entered a period marked by sub-

stantial recession. In a view from Courmayeur drawn before 1832 the glacier terminus is no longer visible suggesting that retreat was underway (LINTON, 1832). An engraving by J. D. HARDING, which was copied from the COIGNET work, was published by Auldjo (1828).

A later watercolor of Monte Bianco and Brenva Glacier made on August 6, 1839 by Alphonse ROUSSEAU (PEYROT, 1972, p. 279; VIVIAN, 1975, pl. 19) also shows the terminus reaching the floor of the Val Veni, but the right-lateral margin in the frontal zone is depicted as lying far below and upvalley from a road or path that probably led past the rebuilt chapel of Notre Dame de

FIG. 16 - « Courmayeur ». Engraving published in ROSE (attributed to, 1827, pl. 7). Collection P. NAVA, Bergamo.

FIG. 17 - « Le Mont Blanc et l'Allée Blanche ». Watercolor by ROUSSEAU A. (August 6, 1839). From PEYROT (1972), by kind permission of Tipografia Torinese Editrice.

la Guérison, fig. 17). If the scene is accurately drawn, then by 1839 the glacier had retreated some 200 m behind its 1818 limit.

Many maps were published in these years (DUBOIS, 1825; ANONYMOUS, 1829; KELLER, 1832; WOERL, 1835; MAYER, 1836; all in VALLOT, 1922, figs. 101, 103, 107, 108, 109) but they all are of little value, depicting Brenva as a small glacier nested high in a cirque, far from the axis of the main valley.

The map of the "Etats de Sardeigne" (1841, in VALLOT, 1922, f. 112) on the other hand, shows Brenva

FIG. 18 - The Brenva Glacier in the map « Etats de Sardaigne » (1841), from VALLOT (1922), Collection P. NAVA, Bergamo.

Glacier well developed along the floor of Val Veni, but the River Dora still lies beyond the ice margin (fig. 18).

By 1842 the front of the glacier had retreated well behind the 1818 limit, but the exact amount is uncertain. PORRO's (1902) estimate of 1000 m is much too great, for it would necessitate an advance of nearly a kilometer during the next seven years. MARTINS & GASTALDI (1850, p. 10) suggested the recession was 160 m, a value apparently derived from FORBES (1847), whereas SILVESTRI (1925) mentions a figure of about 250 m. A map of FORBES (1843; 1859) which lacks a scale, shows the 1842 terminus, and beyond it a body of drift dating to the 1818 advance (figs. 11 and 12); based on comparison of landmarks, we estimate the distance of recession as about 200 $\pm$ 25 m. This value is comparable to that measured on a map by MARENGO (1881) which shows the two drift limits separated by about 250 m (fig. 13). In a frontal view, the glacier terminates just below the rock buttress on which the new chapel has been built, and the Dora emerges from a subglacial tunnel (figs. 19 an 20) (FORBES, 1843, pl. 4; FORBES, 1859, pl. 7). A lithograph in FORBES (1843, pl. 5; PEYROT, 1972, p. 290) depicts the right margin of the glacier rising

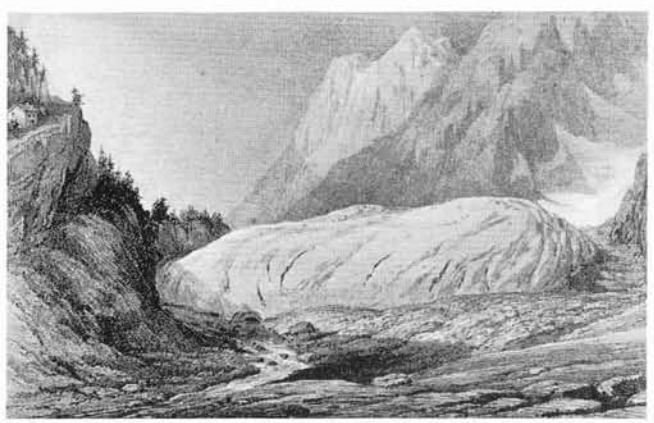

FIG. 19 - « The Glacier of La Brenva in the Allée Blanche, from Entrèves ». Lithograph after a drawing by FORBES J. D., 1842, in FORBES (1843, pl. 4). Istituto di Geologia dell'Università di Torino.

above the lateral moraine (fig. 21); the left-lateral moraine is not seen, implying that on that side as well, the glacier rose above the moraine crest. Such conditions signify a healthy state; the terminus apparently lay close to its present (1980) position.

Between 1842 and 1846 the glacier again advanced (MARENGO, 1881), through a distance of approximately 60 m (MARTINS & GASTALDI, 1850), until it lay only about 100 m from the 1818 limit (FORBES, 1859) (fig. 12). A watercolor view of the Mont Blanc chain by Alphonse ROUSSEAU painted on August 3, 1845 shows clean ice of the glacier apparently still rising above the nonforested right-lateral moraine (PEYROT, 1972, p. 295). During the summer of 1845 alone, the glacier advanced about 22 m (FORBES, 1859; MARENGO, 1881). The advance resulted in a thickening of the lower glacier until the ice surface lay only about 30 m below the chapel of Notre Dame (FORBES, 1859) (fig. 22).

A watercolor by Henry HOGARD dated August 27, 1849 and reproduced by BERNARDI (1965) and a lithograph from the same watercolor (HOGARD, 1852), reproduced by PEYROT (1972, p. 340) show the upper surface of the glacier below the crest of the 1818 right-lateral moraine and its terminus reaching the South side of the valley below the chapel (fig. 23). According to KING (1858, p. 40) this was the same year that the glacier achieved a new maximum. However, SILVESTRI (1925) inferred that the advance lasted until 1850. LE ROY LADURIE (1971, p. 188) noted that the glacier was in an advanced position in 1842 and 1851, with the front located near the line reached during the maximum advance. During this new maximum, the glacier nearly reached the moraine of 1818 and rose to the pathway to the chapel of "La Berrier" (Notre Dame de la Guérison) (KING, 1858). In 1850 the surface of the glacier lay only a few meters below the floor of the chapel and higher than the crest of the adjacent moraine (VIRGILIO, 1883; SACCO, 1918). FORBES (1859; SACCO, 1918) attributed this terminal advance to a "great fall of snow in the winters of 1843/44 and 1844/45". A moraine segment that may date to this interval and that lies about 250 m beyond the present terminus has a 45 mm *R. geographicum* growing on it, suggesting that it stabilized during or before 1853-1854; it also support a larch tree that started growing sometime before 1870. An undated engraving by J. DUBOIS, possibly attributable to the 1840's (P. NAVA, personal communication) but attributed

FIG. 20 - « Glacier of la Brenva in 1842 ». Lithograph after a drawing by FORBES J. D. in FORBES (1859, pl. 7, f. 1). University of Washington Library, Seattle.

FIG. 21 - « Glacier of La Brenva, showing the structure of the ice ». Lithograph after a drawing by FORBES J. D., 1842, in FORBES (1843, pl. 5). Istituto di Geologia dell'Università di Torino.

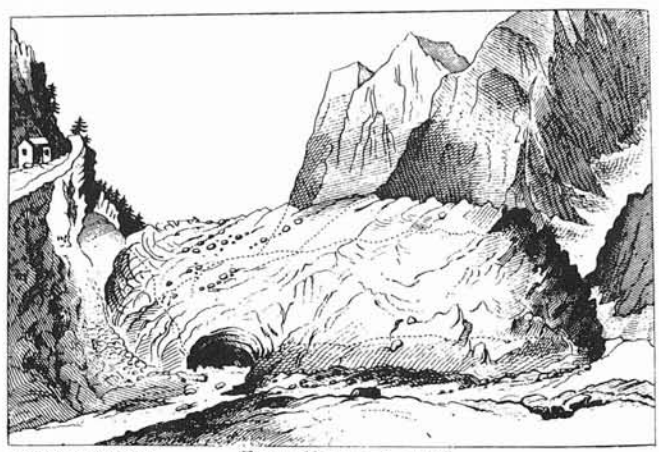

FIG. 22 - « Glacier of la Brenva in 1846 ». Lithograph after a drawing by FORBES J. D., in FORBES (1859, pl. 8, fig. 2). University of Washington Library, Seattle.

FIG. 23 - The Brenva Glacier in a watercolor by HOGARD H. dated August 27, 1849. From BERNARDI (1965), by kind permission of ZANICHELLI Editore, Bologna.

ca. 1870 by PEYROT (1972, p. 438), shows Brenva Glacier in an advanced position, with its front near to the village of Entrèves.

GASTALDI in 1851 (PORRO, 1902, p. 927) and KING in 1855 (KING, 1858, p. 39 and map dated 1856; VACCARONE, 1884; SACCO, 1918) both observed that the Dora di Veni passed through a tunnel beneath the glacier, thereby implying that the ice may still have rested against the southern wall of the valley. A distant view of the glacier in 1851 (or possibly a year or two earlier) by Théophile LADNER (1851; PEYROT, 1972, p. 335) shows the front in an advanced position, the right margin resting against the rock cliff below the chapel of Notre Dame, and the Dora emerging from a subglacial tunnel (fig. 24). At that time the jagged upper surface of the glacier rose above the crest of the largely nonforested right-lateral moraine, as depicted in a lithograph (fig. 25) by Andrea GASTALDI completed in about 1850 and printed in 1853 (GASTALDI, 1853; PEYROT, 1972, p. 343), and as observed in 1855 by KING (1858, p. 44). A map of the Mont Blanc massif (STATO MAGGIORE SARDO, 1869) showing the condition of the glaciers as surveyed in 1856, places the terminus of Brenva Glacier somewhat downvalley (ca. 200 m) from the chapel (fig. 26). The Dora apparently passed beneath the glacier at the time of the survey, a condition similar to that in 1855 depicted by KING (1858, pl. opposite p. 40) (fig. 27). KING noted that between 1854 and 1855 the margin had retreated about 50 yards (ca. 46 m) from a large granite boulder that it had been touching. A sketch map by PITSCHNER (1864), probably surveyed in 1850-1855, also shows Brenva Glacier interrupting the Dora River (fig. 28).

According to MARENGO (1881), between 1846 and 1878 the glacier retreated more than 1000 m. Although PORRO (1902) inferred that the recession was uninterrupted, we have discovered no direct observations that indicate whether, in fact, recession characterized this

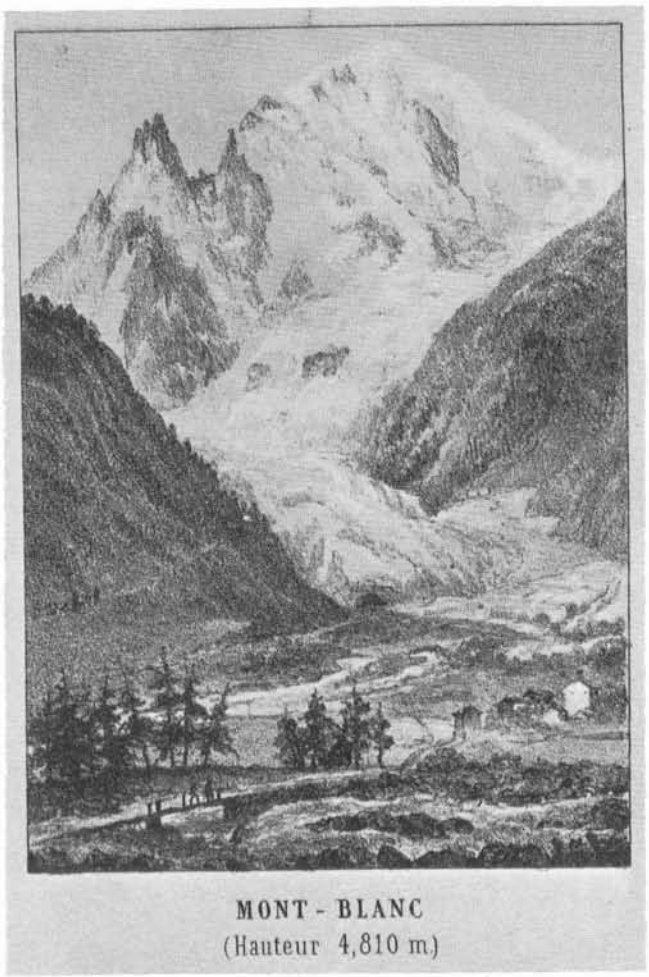

FIG. 24 - « Mont-Blanc », detail from « Vues principales de la cité et de la Vallée d'Aoste ». Lithograph of GONIN E. after drawings by LADNER T., printed by DOYEN et C., 1851. Biblioteca Reale, Torino.

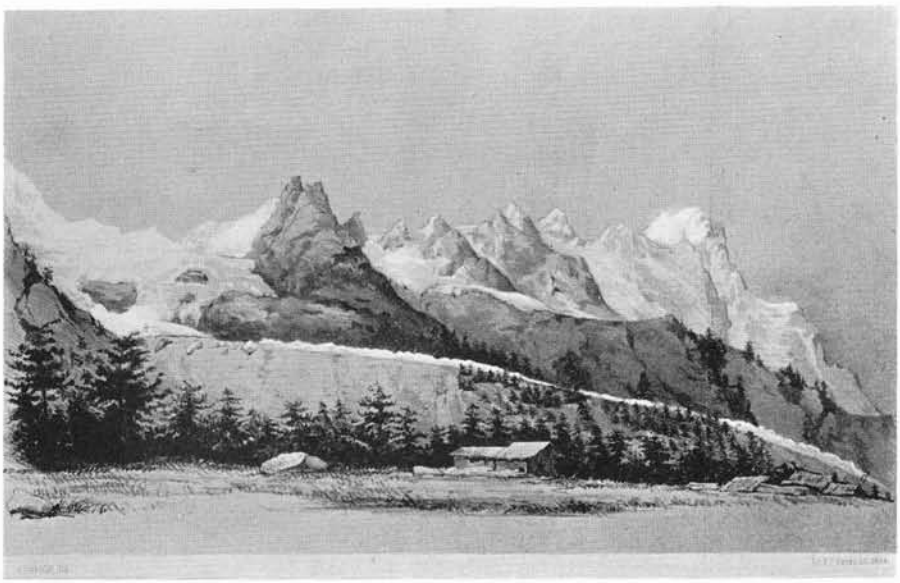

FIG. 25 - « Estremità della morena laterale destra della Brenva vista dalla sega meccanica ». Lithograph after a drawing by GASTALDI A., ca. 1850, in GASTALDI (1853, pl. 5). Istituto di Geologia dell'Università di Torino.

FIG. 26 - « STATO MAGGIORE SARDO - Carta delle Provincie continentali del Reame Sardo. Foglio 21 - M. Bianco. Riconosciuto sul terreno nell'anno 1856 - Pubblicato nell'anno 1869 ». Scale 1:50.000. Biblioteca Nazionale, Torino.

entire interval. At least two glaciers on the French side of the massif (Mer de Glace and Glacier d'Argentière) experienced a minor advance in the mid- 1860's (LLIBOUTRY, 1964-1965, v. 2, p. 720), so possibly the recession of Brenva Glacier was not continuous as inferred. SACCO (1918) stated that between 1855 and 1865 the recession was slow and irregular and marked by some minor halts, whereas after 1865 the retreat was rapid and continuous until 1878.

A Swiss map of the Mont Blanc massif dating to 1861 (TOPOGRAPHISCHE KARTE DES SCHWEIZ, 1861)

FIG. 27 - « The Glacier of La Brenva - Val d'Entrèves ». Engraving after a drawing by KING S. W., 1855, in KING (1858, pl. opposite p. 40). Biblioteca Regionale, Aosta.

(fig. 29) places the terminus of Brenva Glacier close to the valley margin near Notre Dame de la Guérison and several hundred meters below the bend of Torrente Brenva at the point where it reaches the floor of the main valley. The Dora di Veni is entirely ice free. A somewhat later map of the massif (fig. 30) published by WHYMPER (1871) and based on his exploratory travels between 1860 and 1869 and on other contemporary maps (ADAMS-REYLLY, 1863-1865; DUFOUR, 1865; MIEULET, 1865) shows the terminus of Brenva Glacier (probably about 1864-1865) close to the Dora di Veni, approximately where the modern terminus lies. Illustrations by the DOYEN Brothers (PEYROT, 1972, p. 442) and VIOLLET-LE-DUC (1876, f. 46) dating to about 1870 (figs. 31 and 32) show the terminus well up the valley. The left margin descends steeply below the main icefall and the unforested proximal slope of the left-lateral moraine extends beyond. The map of VIOLLET-LE-DUC (1876), surveyed between 1868 and 1875 shows the terminus about 650 m upvalley from N. D. de la Guérison; the front is depressed and irregularly shaped (fig. 33). By 1879-1881 the glacier had retreated substantially, for its active terminus then lay about 1 km upvalley from the position it had occupied about 1818 (MARENGO, 1881; LE ROY LADURIE, 1971, p. 188) (fig. 34). This is in accord with MARENGO's (1881) map (fig. 13) and with a photograph taken about 1878 and reproduced by SACCO (1918, f. 12), both of which show the glacier in a

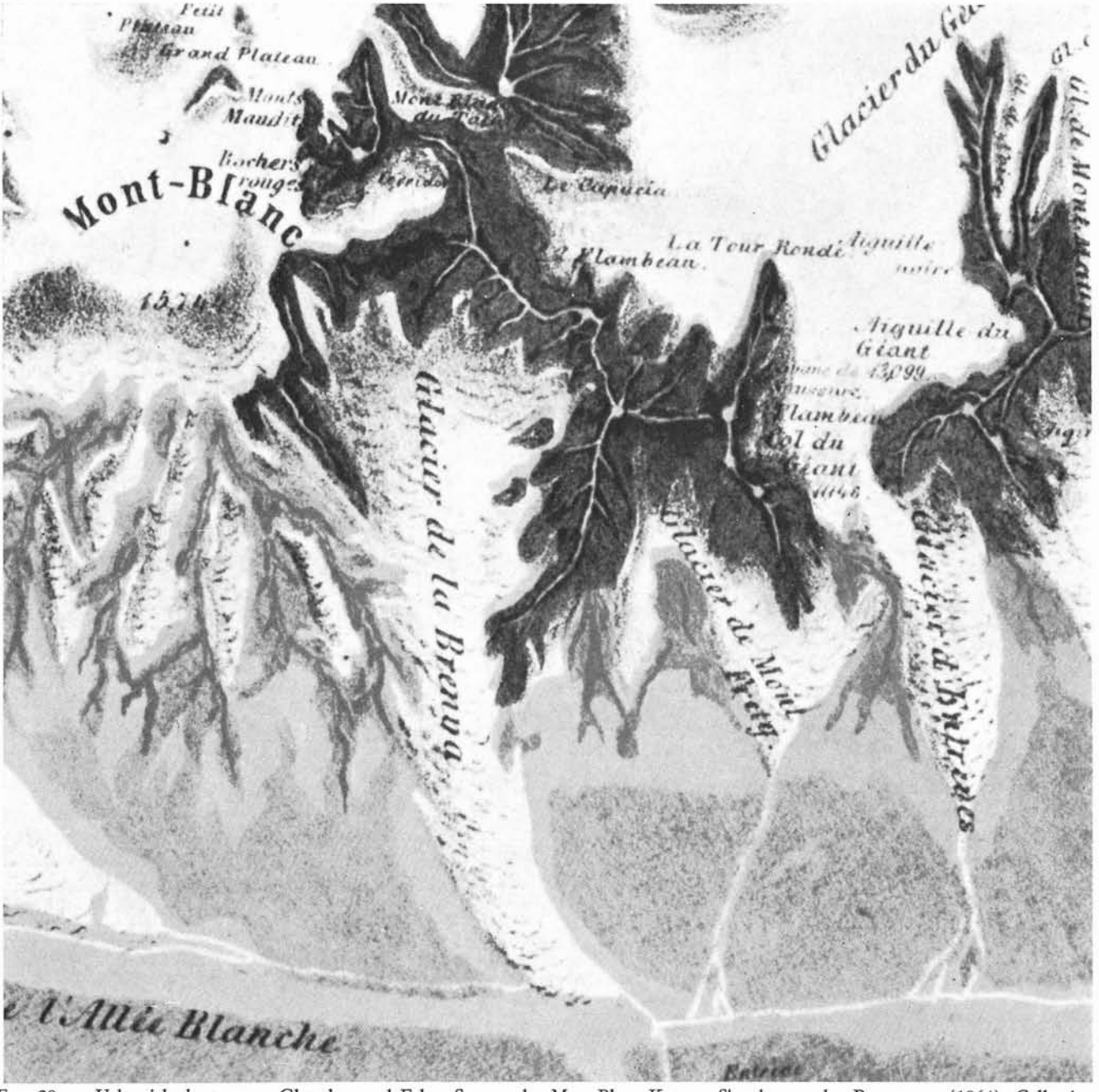

FIG. 28 - « Uebersichtskarte vom Gletscher und Felsen-System der Mont-Blanc Kette ». Sketch map by PITSCHNER (1864). Collection P. NAVA, Bergamo.

shrunken state. Between 1878 and 1879 the terminus advanced about 30 m according to MARENGO (1881). Between 1878 and 1881 the total advance was about 50 m (VIRGILIO, 1883). A sketch map by VALBUSA (1924) places the front of the glacier in 1882 about 680 m upvalley from Notre Dame de la Guérison (fig. 35).

A photograph taken in 1890 and in the private collection of the CARPI family of Planpincieux shows the upper surface of Brenva Glacier standing about 20 m below the crest the upper right-lateral moraine, on which a mature forest is growing. Another picture (1890) in the same collection shows a prominent convex, strongly crevassed frontal zone. The terminus apparently was advancing at that time, for PORRO (1903) referred to a pronounced advance in 1890-1891, at which time the Chalet Proment was abandoned. A photograph taken in 1894 (SACCO, 1918, f. 13) shows the greatly expanded front of the glacier in contact with an end moraine. A map by BARBEY, IMFELD, and KURZ, published in 1896, shows the terminus with a convex regular shape about 550 m upvalley from N. D. de la Guérison (fig. 36).

SACCO (1918) stated that the advance was continuous between 1878 and 1895 and amounted to about half a

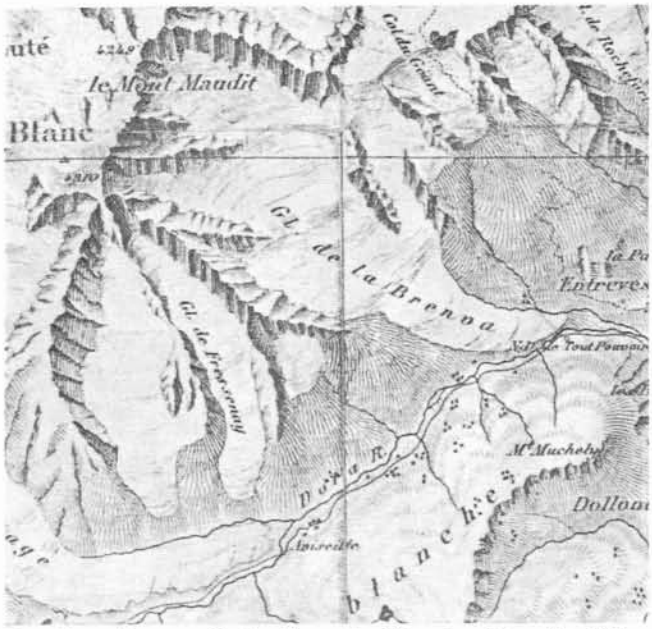

FIG. 29 - « Topographische Karte des Schweiz - Blatt 22, 1861 ». Scale 1:100.000. Istituto di Geologia dell'Università di Torino.

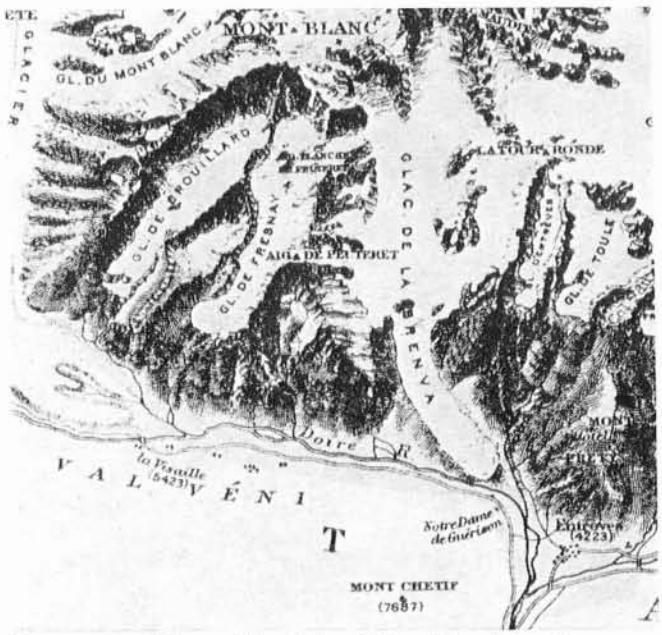

FIG. 30 - Detail from « The Chain of Mont Blanc (after the surveys of capt.n MIEULET, gen.l DUFOUR & M.r REILLY A. A.) ». Map at scale 1:100.000 (ca. 1860-1865) from WHYMPER (1871). Club Alpino Italiano, Torino.

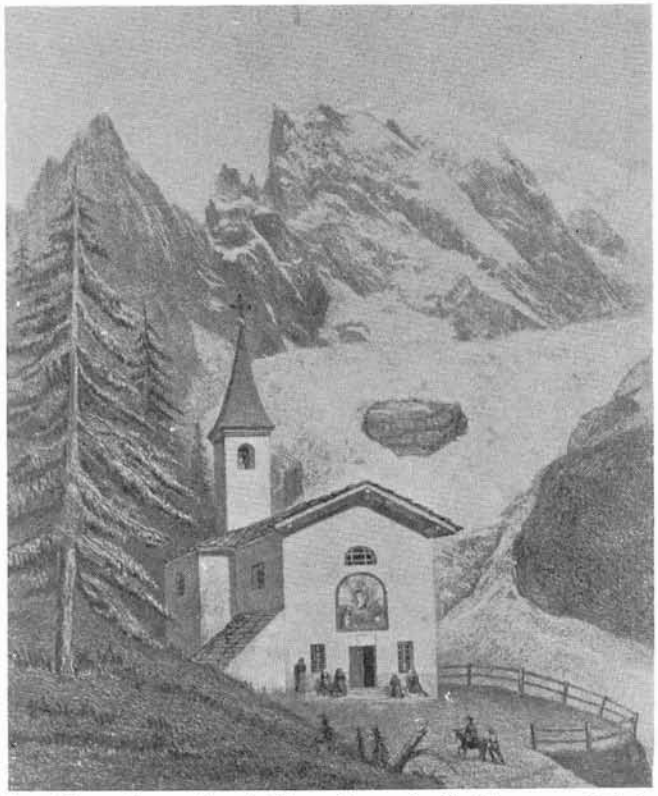

FIG. 31 - « Sanctuaire de Notre Dame de Guérison au pied du Mont Blanc à Courmayeur (Italie) ». Lithograph by F.res DOYEN (ca. 1870). From PEIROT (1972), by kind permission of Tipografia Torinese Editrice.

FIG. 32 - « Le Glacier de la Brenva ». Engraving after a drawing by VIOLLET-LE-DUC (1868-1875), in VIOLLET-LE-DUC (1876, f. 46). Club Alpino Italiano, Sezione di Milano.

kilometer. Although PORRO (1903) reported that the maximum was reached in 1890-1891, SILVESTRI (1925) suggested that the advance culminated in 1897, as did CAPELLO (1941, f. 4). SACCO (1918), however, inferred that retreat occurred after about 1895. A photograph dating to 1894 shows the terminus resting against a fresh moraine (SACCO, 1918, f. 13) whereas photographs taken in 1897 (SACCO, 1918, f. 14; PORRO, 1903, Station 1, f. A) show the terminus behind what appears to be recently deglaciated terrain, so it seems likely that the culmination occurred sometime between 1891 and 1895. In 1897 the terminus lay about 40-50 m behind its 1894 position (SACCO, 1918) and some 540 m from a triangulation station (Masso Valbusa) that was located on or near the outermost (1818) moraine loop (CAPELLO, 1941). A map by SILVESTRI (1926) shows the glacier front in August, 1897 and a map by VAL-

BUSA (1927) locates the 1897 position about 315 m behind the line where the front lay in 1927 (figs 34 and 37).

A photograph in the CARPI collection taken in 1899 shows the debris-covered glacier surface standing an estimated 30 to 40 m below the crest of the main right-lateral moraine in the reach immediately below the icefall, implying that the terminus probably lay well upvalley from the early 19th century terminal moraine.

20TH CENTURY

Continued slow recession characterized the first decade of the 20th century during which time the terminus retreated between about 80 and 100 m (REVELLI, 1911; CAPELLO, 1941). The recession rate increased between 1911 and 1914 (SILVESTRI, 1925) (fig. 34), but a renewed advance began in 1913 (SACCO, 1921) or 1914 (SILVESTRI, 1925), and by 1916-1917 photographs show

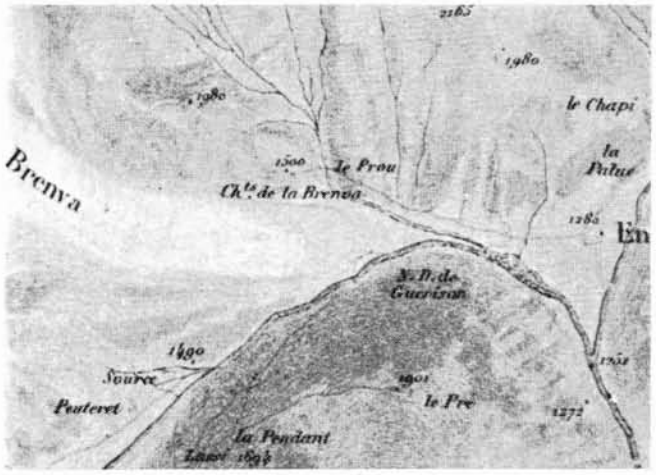

FIG. 33 - Detail from « Le Massif du Mont Blanc », 1:40.000 map, surveyed by VIOLLET-LE-DUC E. (1868-1875), published in 1876. Biblioteca Nazionale, Torino.

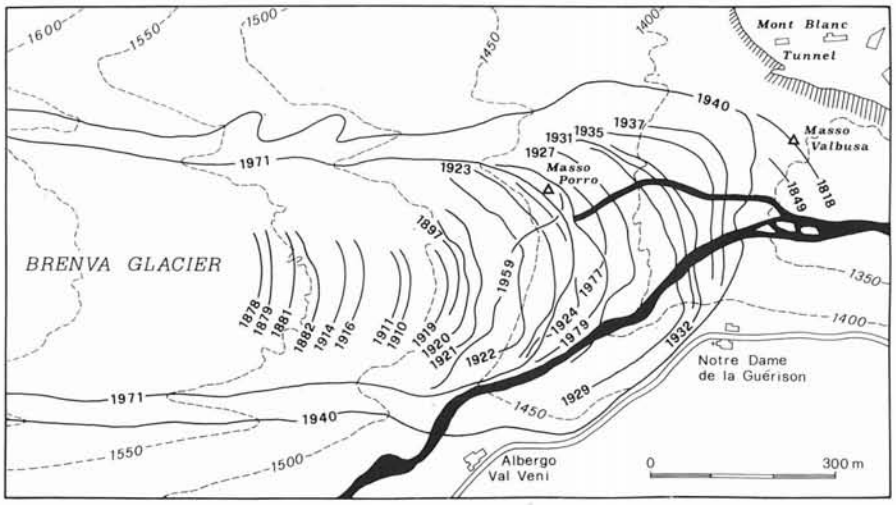

FIG. 34 - Map showing frontal positions of Brenva Glacier since 1878. Data from: MARENGO, 1881; VALBUSA, 1924; SILVESTRI, 1926; VALBUSA, 1927; CAPELLO, 1941; CAPELLO, 1971; LESCA, 1971; field observations (1940-1979).

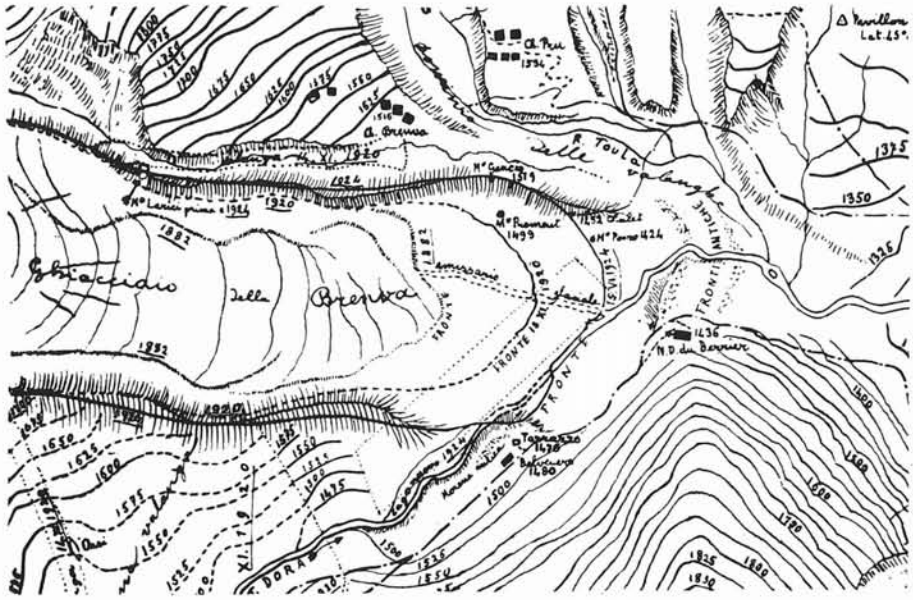

FIG. 35 - « Schizzo topografico del dominio frontale del Ghiacciaio della Brenva ». Topographic sketch by VALBUSA (1924). Istituto di Geologia dell'Università di Milano.

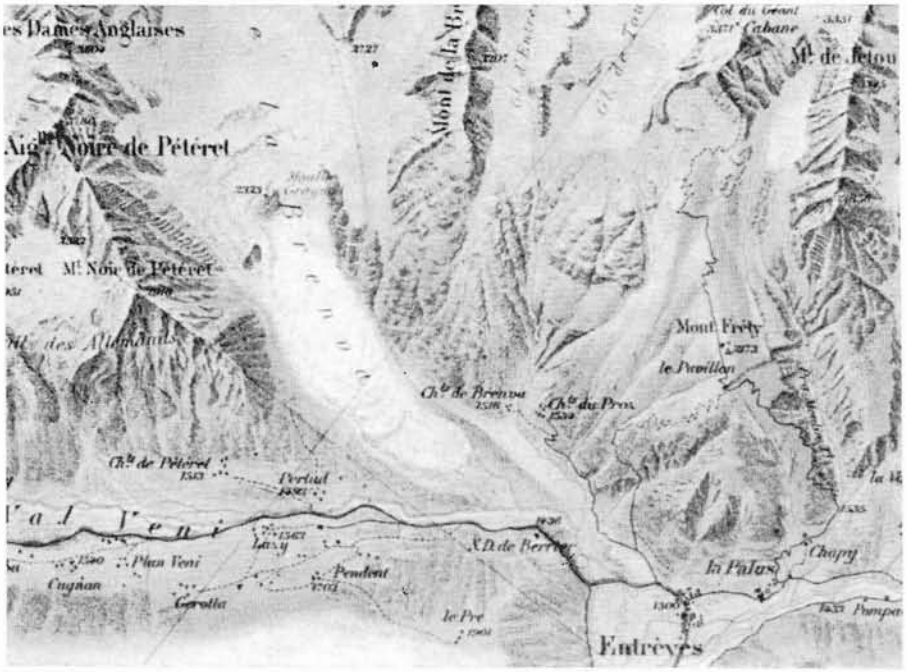

FIG. 36 - Detail from « La chaine du Mont-Blanc », 1:50.000 map published by BARBEY, IMFELD & KURZ (1896). Biblioteca Nazionale, Torino.

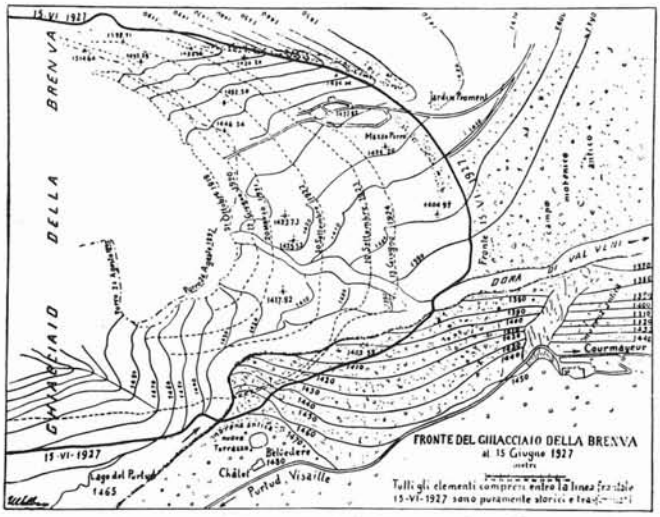

FIG. 37 - « Fronte del Ghiacciaio della Brenva al 15 Giugno 1927 ». Topographic sketch by VALBUSA (1927). Istituto di Geologia dell'Università di Milano.

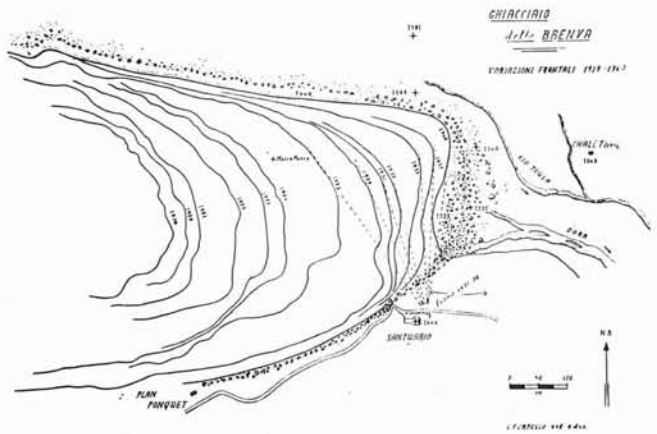

FIG. 38 - « Ghiacciaio della Brenva ». Topographic sketch by CAPELLO C., 1940, in CAPELLO (1941). Istituto di Geologia dell'Università di Milano.

a steep advancing terminus (SACCO, 1918, f. 16 and 17). Between 1917 and 1919 the front advanced about 100 m, overriding small recessional moraines (fig. 34). It advanced another 37 m in the following year (SACCO, 1921), by which time the front of the glacier had reached the approximate position it had occupied during the ca. 1895 maximum (figs. 37 and 38).

On November 14 and 19, 1920 large rockfalls that originated on a spur of Monte Bianco di Courmayeur traveled some 5 km down Brenva Glacier. The rock debris overtopped both the left- and right-lateral moraines. The bulk of the sediment came to rest on the glacier surface, on the distal slope of the right-lateral moraine, and on the adjacent floor of Val Veni (fig. 3) (VALBUSA, 1921; 1931; OROMBELLI & PORTER, 1981). In 1977 *R. geographicum* thalli on the rockfall deposit were as large as 22 mm in diameter and *A. cinerea* attained 55 mm (fig. 3). Unlike most other nearby glaciers, which began to retreat after about 1920-1926, Brenva Glacier continued to advance. This anomalous behavior apparently was due to the thick mantle of rock debris on the ice surface which strongly affected the glacier mass balance by inhibiting ablation. Sherman Glacier in coastal Alaska experienced a similar response following a large rockfall that was triggered by the major earthquake of 1964 (MARANGUNIC, 1972). In the two years following the rockfall, Brenva Glacier advanced more than 100 m. The glacier reached the chalets at Plan Ponquet in 1923-1924 (CAPELLO, 1941) and the Dora di Veni passed through a tunnel beneath the ice (DESIO,

TABLE 1

HISTORICAL DOCUMENTS PROVIDING INFORMATION ON THE EXTENT OF BRENVA GLACIER.

figure	date	data type (*)	source(s)
	17th century		
	1600	D	LE ROY LADURIE, 1971, p. 151-152.
	1600 (?)	D	MATTHES, 1942, p. 206; LE ROY LADURIE, 1971, p. 221, 327.
	1691	D	ARNOD, 1961, p. 19; LE ROY LADURIE, 1971, p. 187-188.
	1691-1694	D	DRYGALSKI & MACHATSCHEK, 1942, p. 214; GROVE, 1966, p. 133.
	18th century		
4	1767	E	JALLABERT, *in* DE SAUSSURE, 1786, v. 4, pl. 3; LE ROY LADURIE, 1971, pl. 25.
	1776	D	BOURRIT, 1776, p. 54.
5	1778 (?)	M	PICTET, *in* DE SAUSSURE, 1786, v. 3; ALIPRANDI & *alii*, 1974, pl. 44.
6	1781	E	BARTOLOZZI, *in* DE SAUSSURE, 1786, v. 4, pl. 5.
7	1795 (?)	W	LINCK Jean Antoine, *in* VIVIAN, 1975, pl. 19; PEYROT, 1972, p. 109.
8	1797-1799	M	RAYMOND, *in* VALLOT, 1922, f. 102.
	1799	E	BOURCET, *in* LE ROY LADURIE, 1971, pl. 29; PEYROT, 1972, p. 122.
	1799	M	BACLER D'ALBE, *in* ALIPRANDI & *alii*, 1974, pl. 32.
	1799	M	DE CAROLY, *in* ALIPRANDI & *alii*, 1974, pl. 46.
	19th century		
	1800	M	WEISS, *in* VALLOT, 1922, f. 99.
	1810-1812	D	FAVRE, 1867, p. 74.
	1811	D	D'AUBUISSON, 1811, p. 255; SACCO, 1918, p. 34.
9	1813	M	KELLER, *in* VALLOT, 1922, f. 98.
10	1817	D	FORTESCUE (Collection P. NAVA, Bergamo).
	1818	D	FORBES, 1843, p. 205.
11	1818	M	FORBES, 1843, Topographical Sketch No. II.
12	1818	M	FORBES, 1859, Pl. 8, f. 1.
13	1818	M	MARENGO, 1881, pl. 1.
	1819	D	VIRGILIO, 1883, p. 67.
14	1820	W	ESCHER VON DER LINTH, *in* BACHMANN, 1980, pp. 114-115.
15	ca. 1820	E	COIGNET Jules Louis-Philippe, *in* RAOUL-ROCHETTE, 1826, table 32.
	ca. 1820	E	HARDING J. D. (after sketch by COIGNET) *in* AULDJO, 1828, pl. 7.
16	ca. 1820-1825	E	ROSE, 1827, pl. 7; PEYROT, 1972, p. 209.
	1825	M	DU BOIS, *in* VALLOT, 1922, f. 103.
	1829	M	ANONYMOUS, *in* VALLOT, 1922, f. 107.
	pre-1832	E	LINTON, 1832, f. 90.
	1832	M	KELLER, *in* VALLOT, 1922, f. 101.
	1835	M	WOERL, *in* VALLOT, 1922, f. 108; ALIPRANDI & *alii*, 1974, pl. 72.
	1836	M	MAYER, *in* VALLOT, 1922, f. 109.
17	1839	W	ROUSSEAU Alphonse, *in* PEYROT, 1972, p. 279; VIVIAN, 1975, pl. 19.
	ca. 1840 (?)	E	DUBOIS (undated), *in* PEYROT, 1972, p. 439.
18	1842	M	ETATS DE SARDAIGNE, in VALLOT, 1922, f. 112.
11	1842	M	FORBES, 1843, Topographical Sketch n. II.
12	1842	M	FORBES, 1859, pl. 8, f. 1.
19	1842	E	FORBES, 1843, pl. 4.
20	1842	E	FORBES, 1859, pl. 7, f. 1.
21	1842	E	FORBES, 1843, pl. 5.
	1842	D	MARTINS & GASTALDI, 1850, p. 10.
	1845	W	ROUSSEAU Alphonse, *in* PEYROT, 1972, p. 295.
	1846	D	FORBES, 1859, pp. 177-179.
12	1846	M	FORBES, 1859, pl. 8, f. 1.
22	1846	E	FORBES, 1859, pl. 7, f. 2.
13	1846	M	MARENGO, 1881, pl. 1.
	1846	D	MARENGO, 1881, p. 7.
	1846	D	MARTINS & GASTALDI, 1850, p. 10.
23	1849	W	HOGARD Henri, 1852, pl. 11; BERNARDI, 1965, p. 208; PEYROT, 1972, p. 340.
	1849	D	KING, 1858, p 40; SACCO, 1918, p. 39.
25	1850	E	GASTALDI Andrea, *in* GASTALDI, 1853, pl. 5; VIRGILIO, 1883, p. 68; SACCO, 1918, p. 38.
	1850	M	D'OSTERWALD, *in* VALLOT, 1922, f. 110.
	1851	D	PORRO, 1902, p. 927.
24	1851 (?)	E	LADNER Theophile, *in* PEYROT, 1972, p. 335.
28	ca. 1850-1855	M	PITSCHNER, 1864, pl. 9.
	1854	D	KING, 1858, p. 40.
	1855	D	KING, 1858, p. 40.
	1855	M	KING, 1858, pl. opposite p. 34; ALIPRANDI & *alii*, 1974, pl. 49.
27	1855	E	KING, 1858, pl. opposite p. 40.
26	1856	M	STATO MAGGIORE SARDO, 1869, f. 21, Monte Bianco, Scale 1:50.000.
29	1861 (?)	M	TOPOGRAPHISCHE KARTE DER SCHWEIZ, Blatt 22, 1861, Scale 1:100.000.
	ca. 1860-1865	M	DUFOUR, 1865, Scale 1:40.000.
	ca. 1860-1865	M	MIEULET, 1865, Scale 1:50.000.
	1863-1864	M	ADAMS-REILLY, 1865, Scale 1:80.000.
30	1860-1865	M	WHYMPER, 1871, map 4; ALIPRANDI & *alii*, 1974, pl. 41.
31	ca. 1870	E	Frères DOYEN, *in* PEYROT, 1972, pp. 441-443.
32	ca. 1868-1875	E	VIOLLET-LE-DUC, 1876, f. 46.

(cont.)

figure	date	data type (*)	source(s)
33	1868-1875	M	Viollet-le-Duc, 1876, Scale 1:40.000.
13	1878	M	Marengo, 1881, pl. 1; Capello, 1941, p. 131.
	1878 (?)	P	Sacco, 1918, f. 12.
	1878	D	Capello, 1941, p. 137.
13	1879	M	Marengo, 1881, pl. 1.
	1879	D	Capello, 1941, p. 137.
	1881	D	Le Roy Ladurie, 1971, p. 188.
	1881	D	Virgilio, 1883, p. 68.
	1882	M	Istituto Topografico Militare, 1882, scale 1:50.000.
35	1882	M	Valbusa, 1924, f. 8.
	1890	P	Carpi Collection, Planpincieux.
	1890-1891	D	Porro, 1903, p. 156.
	1894	P	Sacco, 1918, f. 13.
	1895	D	Sacco, 1918, p. 42.
36	1896 (?)	M	Barbey, Imfeld & Kurz, 1896, scale 1:50.000.
	1897	M	Silvestri, 1926, pl. facing p. 228.
37	1897	M	Valbusa, 1927, p. 16.
	1897	D	Silvestri, 1925, p. 197.
	1897	G	Capello, 1941, f. 4.
	1897	D	Capello, 1941, p. 137.
	1897	D	Porro, 1902, p. 923.
	1897	P	Porro, 1903, f. A and D.
	1899	P	Carpi Collection, Planpincieux.
	20th century		
	1900 (?)	M	Mathews, 1900.
	1903	P	Porro, 1903, f. B.
	1910	D	Revelli, 1911, p. 6.
	1910	D	Capello, 1941, p. 137.
	1911	D	Revelli, 1912, p. 238.
	1911	D	Capello, 1941, p. 137.
	1914-1940	G	Capello, 1941, f. 4 and 6.
	1914-1924	G	Silvestri, 1925, opposite p. 200.
	1916	P	Sacco, 1918, f. 16.
	1917	M	Sacco, 1918.
	1919	P	Sacco, 1921, p. 9.
	1919	P	Valbusa, 1923, f. 1.
	1919	P	Valbusa, 1924, figs. 5 and 6.
	1919-1923	M	Silvestri, 1926, pl. opposite p. 228.
37	1919-1927	M	Valbusa, 1927, p. 16.
38	1919-1940	M	Capello, 1941, p. 132.
	1920	M	Valbusa, 1921 p. 107.
	1920	P	Valbusa, 1921, figs. 1, 2, 6, and 13.
	1920	P	Brocherel, 1923, pp. 251-253, 255.
	1920	P	Gignoux, 1949, p. 88.
	1920-1924	M	Valbusa, 1924, f. 8.
	1921	P	Sacco, 1921, p. 10.
	1921	P	Valbusa, 1921, f. 2.
	1921	M	Valbusa, 1921, p. 107.
	1921	P	Dainelli, 1926, p. 140.
	1923	P	Valbusa, 1923, f. 2.
	1923	P	Valbusa, 1924, f. 2.
	1923-1928	G	Valbusa, 1927, p. 10.
	1924	P	Dainelli, 1926, p. 141.
	1924	P	Valbusa, 1924, figs. 1, 3, and 7.
	1924	P	Valbusa, 1927, p. 15.
	1925	P	Sacco, 1927, f. 1.
	1927	P	Valbusa, 1927, pp. 14, 20.
	1929	P	Capello, 1936, f. 6.
	1929	P	Capello, 1941, figs. 1 and 3.
	1929	M	Istituto Geografico Militare, 1929, scale 1:25.000.
	1929	P	Sestini, 1930, f. 16.
	1930	P	Capello, 1941, f. 5.
	1938	P	Heybrock, 1941, figs. 1 and 2.
	1940	P	Capello, 1941, f. 7.
	1945	P	Sacco, 1947, f. 2.
	1947	M	Istituto Geografico Militare, 1947, scale 1:25.000.
	1959	M	Capello, 1971.
	1959	P	Capello, 1971, f. 3 and 4.
	1968	M	Istituto Geografico Militare, 1970, scale 1:25.000.
	1969	P	Lesca, 1972.
	1971	P	Lesca, 1972.
	1972	M	Lesca, 1972.
	1972	P	Lesca, 1972.

(*) D = description, E = etching or painting, W = watercolor, M = map, P = photograph, G = graph.

FIG. 39 - The terminus of Brenva Glacier as seen from point opposite the Chapel of Notre Dame de la Guérison in the summer of 1979.

1926). The position of the terminus in 1929 is depicted on the 1:25,000-scale map of ISTITUTO GEOGRAFICO MILITARE; the front is about 70 m upvalley from the chapel and the mouth of the ice tunnel is placed at an altitude of 1379 m. By 1931 the glacier had impinged on the rock buttress of Notre Dame de la Guérison (CAPELLO, 1941). In 1940-1941 it almost surrounded the buttress and achieved a new maximum just short of the two 19th-century end moraines that mark the greatest extent of the glacier during the Holocene (CAPELLO, 1941; VANNI, 1942).

After the culmination of the advance, the glacier began to recede and during the next 14 years the terminus retreated at an average rate of 17 m/year, but with periods of less-rapid recession in the early 1950's and early 1960's. A minimum was reached between 1965 and 1967 (LESCA, 1972), at which time the terminus must have been close to the maximum position it reached during the advance of 1891-1894. Renewed advance was detected in 1967 (LESCA, 1972) or 1968 (CERUTTI, 1971), and by 1979 the glacier (fig. 39) was still advancing (LESCA, 1977; 1979; 1980).

TIME SERIES

The various data on position of the terminus have been used to construct a time series depicting terminal fluctuations of Brenva Glacier (fig. 40). Where uncertainty exists in the location of the terminus, a horizontal bar instead of a point is plotted, and enveloping lines encompass the horizontal band within which the terminus is inferred to have lain. The degree of uncertainty increases substantially in the period prior to the 1818 culmination, for few control points are available and these are based on written descriptions, lithographs, and paintings, the interpretation of which involves a degree of subjectivity. Although scattered data exist for the period prior to 1760, they are too few and their quality is too uncertain to make extension of the curve reliable.

It is apparent from JALLABERT's drawing (1767) that by the time of DE SAUSSURE's early visit, Brenva Glacier was in an expanded condition and probably terminated within several hundred meters of its subsequent maximum position in the early 19th century. The inferred culmination shown in the 1770's is based only on circumstantial evidence such as BOURRIT's description, which implies that the glacier was in an advanced state about 1776, and regional data which indicate that other glaciers in the Western Alps advanced during that decade and reached a secondary maximum. BARTOLOZZI's etching (1781) shows a condition similar to that indi-

TABLE 2

TERMINAL VARIATIONS OF BRENVA GLACIER BETWEEN 1910 AND 1940 (AFTER CAPELLO, 1941, TABLE 2).

Year	Distance from Masso Valbusa (m)	Advance since previous year
1910	650	
1911	660	
1914	760	
1915	750	10
1916	720	30
1917	670	50
1918	630	40
1919	560	70
1920	530	0
1921	510	20
1922	440	70
1923	400	40
1924	370	30
1925	-	-
1926	-	-
1927	270	-
1928	-	-
1929	210	-
1930	-	-
1931	180	-
1932	160	20
1933	145	25
1934	125	20
1935	105	20
1936	90	15
1937	75	15
1938	65	10
1939	55	10
1940	45	10

Total advance (1914-1940): 715 m.

cated by JALLABERT, implying possible recent recession, but in LINCK'S painting (ca. 1785) the glacier appears to be healthy and advancing. D'AUBUISSON'S description indicates that in 1811 the glacier was retreating, although apparently it had been advancing several years before. Based on these observations we have indicated a minor fluctuation in the first decade of the 19th century, but this interpretation could be in error.

The culminating Holocene advance was reached in 1818 according to FORBES (1843; 1859), after which recession characterized the next two decades. Data are inadequate to demonstrate whether or not this retreat was continuous. The subsequent readvance to a maximum in about 1850 is rather well documented by historic accounts, drawings, and maps, but is has not been possible

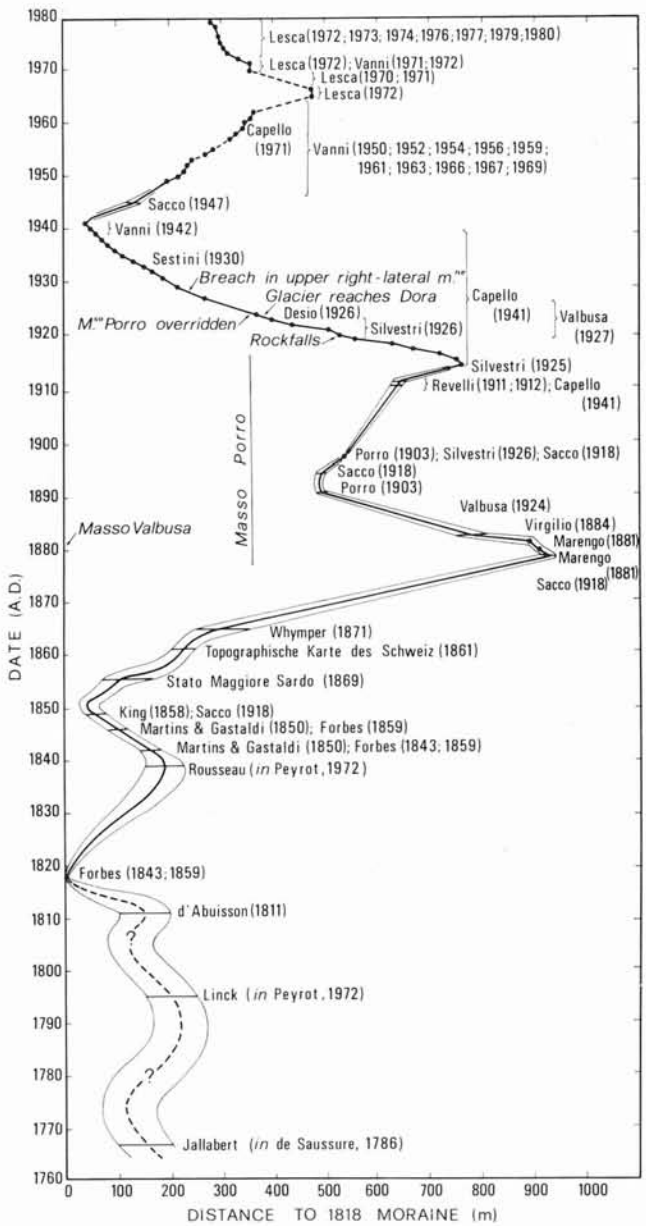

FIG. 40 - Time-series plot showing fluctuations of Brenva Glacier since 1760.

TABLE 3

TERMINAL VARIATIONS OF BRENVA GLACIER BETWEEN 1939 AND 1979.

year	advance (m)	retreat (m)	source
1939-40	15		Vanni, 1942
1940-41	10		Vanni, 1942
	begin retreat		
1941-42		5	Vanni, 1945
1946-47		10	Vanni, 1950
1947-48		?	Vanni, 1950
1948-49		?	Vanni, 1950
1949-50		20	Vanni, 1952
1950-51		10	Vanni, 1952
1951-52		5	Vanni, 1954
1952-53		8	Vanni, 1954
1953-54		?	Vanni, 1956
1954-55		15	Vanni, 1956
1955-56		?	Capello, 1959
1956-57		?	Capello, 1959
1957-58		10 (?)	Vanni, 1961
1958-59		15 (?)	Vanni, 1961; Capello, 1964
1959-60		2 (?)	Capello, 1964; Vanni, 1966
1960-61		10 (?)	Capello, 1964; Vanni, 1966
1961-62		5 (?)	Capello, 1966; Vanni, 1966
1962-63		?	Capello, 1966; Vanni, 1967
1963-64		?	Vanni, 1967
1964-65		?	Vanni, 1969
1965-66		?	Vanni, 1970; Lesca, 1972
	begin advance between 1965 and 1967		
1966-67		?	Vanni, 1970; Lesca, 1972
1967-68		?	Vanni, 1970; Lesca, 1970
1968-69		?	Lesca, 1970
1969-70		?	Lesca, 1970; Vanni, 1971
1959-70	120		Lesca, 1972
1970-71	20 (or stationary ?)		Vanni, 1971; Lesca, 1972
1971-72	20		Lesca, 1972a
1972-73	15-20		Lesca, 1973
1973-74	10		Lesca, 1974
1974-75	5-10		Lesca, 1976
1975-76	2-3		Lesca, 1977
1976-77		?	...
1977-78	several m		Lesca, 1979
1978-79	ca. 10		Lesca, 1980

to locate the position of the terminus prior to and after the culmination more closely than to within about 30-50 m. A decrease in the retreat rate is depicted between about 1860 and 1865; possibly the glacier halted or readvanced during this interval, as did at least some glaciers on the French side of the massif, but we have found no positive evidence of such a halt or minor readvance in the case of Brenva Glacier.

A renewed advance began in 1878-1879 and the glacier reached a new culmination sometime between 1890 and 1895. Two decades of persistent recession followed. Recording of annual measurements of the position of the terminus was begun in 1914 and documents a long, steady advance over the next quarter century. The rate of advance, which had begun to slacken about 1920, increased after the major rockfalls of that year and then continued at a steadily decelerating rate until a new maximum was achieved in 1940-1941, at which time the terminus overrode most of the mid-19th century moraine and lay only about 50 m behind the 1818 limit. Few observations are available for the decade of the

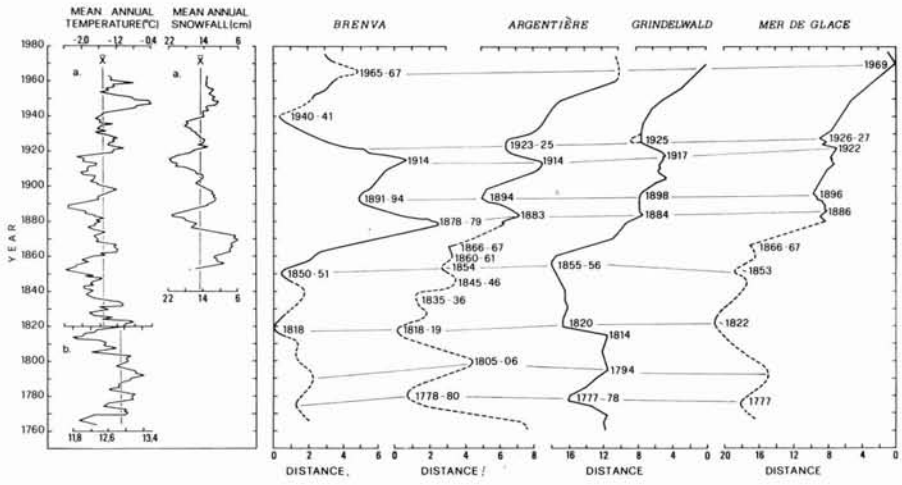

FIG. 41 - Climatic data from: (a), Great St. Bernard Pass (5-year running means, 1820-1960, data from JANIN, 1970); (b) from Milano (5-year running means, 1760-1820, data from SANTOMAURO, 1955). Time series showing fluctuations of Brenva Glacier (this study) compared with those for Argentière Glacier (VIVIAN, 1975; REYNAUD, 1978), Grindelwald Glacier (MESSERLI & *alii*, 1978), and Mer de Glace (VIVIAN, 1975). Distance in hm.

1940's, but by the time glacier observations resumed after the Second World War the glacier terminus had retreated some 150 m from its 1940 limit. Recession continued until about 1965, after which time renewed advance was observed that continued into the 1970's.

COMPARATIVE DATA

Published time series depicting terminal fluctuations of other glaciers in the Alps during the past several centuries are few in number and of varying reliability. Data on annual movements is available for many glaciers, but typically covers only the last several decades or, in a few cases, the last half century. Among the best documented is Grindelwald Glacier in the Bernese Oberland for which a record has been compiled by MESSERLI & *alii* (1978) that extends back through the 17th century. Measurements of the terminal position of Mer de Glace and Argentière Glacier on the French side of the Mont Blanc massif extend back to the last decades of the 19th century (REYNAUD, 1978), and curves of inferred earlier variations have been published by VIVIAN (1975, f. 31) and LLIBOUTRY (1964-65, f. 18.1). The frontal variations of these representative glaciers are compared with those of Brenva Glacier in fig. 41. Although the curves differ in detail, there are striking similarities between them. Each of the glaciers experienced episodes of advance preceding culminations in the 1770's and close to 1820. The subsequent advance of Brenva Glacier to a secondary maximum about 1850 is paralleled by the other glaciers which reached maxima about 1853-1856. Although the culmination of 1818-1822 was the greatest for Brenva and Argentière glaciers and for the Mer de Glace, Grindelwald glacier was about 100 m more extensive during the 1855-56 maximum than durring that of 1820. The marked recession during the 1860's and 1870's is well documented in all cases. Each glacier also experienced readvance in the 1880's which culminated during the following decade. The early decades of the 20th century were marked by retreat and then by a distinct readvance to a new maximum in the 1920's. However, at this point the curve for Brenva Glacier departs from the general trend, for rather than returning to a dominant recessional mode like the other glaciers, it continued to advance after the major rockfalls of 1920 to reach a new maximum about 1940-41, after which it too began to recede. By the 1960's the glaciers were again approximately in phase, with a new minimum being reached between 1960 an 1970.

Although the dominant pattern is discernable in each of the curves, the peaks and troughs are not all coincident. Rather, there is a distinct lag in terminal response among the glaciers which increases as a function of increasing glacier length. Because the glaciers lie within the same broad climatic zone, their activity indices are probably similar, so the detected lag in terminal response most likely reflects the time it takes for any mass-balance perturbation to pass from the equilibrium line to the terminus. For the glaciers in question, this clearly should take longer for the Mer de Glace (13.5 km) than for Grindelwald Glacier (11 km), Argentière Glacier (9 km), or Brenva Glacier (6 km).

METEOROLOGICAL RECORD

The pattern of terminal fluctuations shown by a glacier reflects its mass-balance history which in turn is closely related to weather conditions (MEIER, 1965; HOINKES, 1968). Weather records for most mountain regions are sparse and short in length, but an exceptionally long record has been maintained at Great St. Bernard Pass, situated only 18 km from Brenva Glacier (JANIN, 1970). The station, which lies at an altitude of 2479 m, has recorded temperature continuously since 1818 and precipitation since 1851. Comparison of this record with the time series of terminal fluctuations reconstructed for Brenva Glacier shows some striking parallels (fig. 41). During the period of record, intervals characterized by low mean annual temperature tend to coincide with intervals of high snowfall. Episodes of glacier advance follow closely upon such intervals. Conversely, with rising temperature and decreasing snowfall a shift to terminal recession is generally observed. An exception in the case of Brenva Glacier is the interval

between 1920 and 1940 when the glacier experienced an anomalous advance, presumably caused by the extensive mantle of rockfall debris that covered much of the terminal zone and inhibited ablation.

Although the temperature-precipitation record from Great St. Bernard Pass covers less than two centuries and can only be compared with terminal fluctuations of Brenva Glacier since about 1850, the close parallel between frontal variations and changes in mean annual temperature apparently continues back at least to the middle 18th century. A continuous temperature record beginning in 1763 has been kept by the Osservatorio Astronomico di Brera in Milano (SANTOMAURO, 1955), and it closely parallels the curve from Great St. Bernard Pass over the past 160 years. If glacier variations are compared with temperature fluctuations for the preceding 57 years (1760-1820), one finds that the glacier advance which culminated in 1818 coincided with an interval of low mean annual temperature at Milano, as did the advance that is believed to have reached a maximum in the 1770's (fig. 41). During the intervening period, when the glacier was less extensive, temperatures at Milano were as much as 1.5 °C milder.

The meteorological record from Great St. Bernard Pass covers less than two centuries, but its relationship to the reconstructed time series of terminal variations of Brenva Glacier suggests that earlier intervals of glacier expansion were also probably related to times when winter accumulation was higher than the long-term mean and air temperature, especially during the ablation season, was below average. The advances that culminated in 1818 and 1850 apparently were the largest of the Holocene, but similar climatic regimes probably were responsible for the radiocarbon-dated advances that occurred during the early part of the Little Ice Age and about a millennium ago. The similarity in character between the Brenva time series and those of other representative glaciers in the northwestern Alps implies that throughout this interval the regional weather pattern was relatively coherent and constituted a primary control on glacier behavior. However, the anomalous advance of Brenva Glacier in 1920-1940 stands out as an example of a major terminal fluctuation that was unrelated to the general climatic trend of that period.

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