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DRAINAGE STATE, GLACIAL DYNAMICS AND KINDS OF ICE AT THE TERMINUS OF LYS GLACIER (WESTERN ALPS)

ABSTRACT: MOTTA L. & MOTTA M., *Drainage state, glacial dynamics and kinds of ice at the terminus of Lys Glacier (Western Alps).* (IT ISSN 0391-9838, 2001).

The Lys glacier is formed of superposed layers several metres thick. Most of the layers consist of granoblastic ice with centimetric crystals and little inner moraine, except at their boundary, where this increases sharply and the crystals are small with evident glaciotectonic structures. At the terminus, this pile of layers rests on a isoclinally folded stratum of ice-rich sand. Below this bed, there is granoblastic ice, which also constitutes the substrate of the depositional end moraines formed during the 1980-86: it thus seems likely that is now acting as the inert substrate of the actively moving ice, separated from it by the stratum of ice-rich sand, which would seem to represent their lodgement till. This structure is not common on the Italian side of the Alps. The peculiarity of the Lys can probably be attributed to its cyclical tendency to display rapid advances, very similar to «micro-surge» episodes, in years with high summer temperatures.

KEY WORDS: Glacial drainage, Glacial dynamics, Ice, Western Alps.

RIASSUNTO: MOTTA L. & MOTTA M., *Condizioni di drenaggio, dinamica glaciale e tipi di ghiaccio alla fronte del Ghiacciaio del Lys.* (IT ISSN 0391-9838, 2001).

Il ghiacciaio del Lys è formato da strati sovrapposti di alcuni metri di spessore. Il corpo degli strati è costituito da ghiaccio granoblastico a cristalli centimetrici povero di contenuto detritico, mentre al limite fra gli strati il contenuto detritico cresce bruscamente e i cristalli sono piccoli e con evidenti strutture glaciotettoniche. Alla fronte, la successione di strati poggia su un corpo stratoide a scistosità isoclinale di sabbia a matrice di ghiaccio. Al di sotto di esso, si trova ghiaccio granoblastico, che costituisce anche il substrato delle morene frontali deposte nel 1980-86: esso sembra costituire il substrato inerte del ghiaccio in movimento attivo, da cui è separato dallo strato di sabbia, che rappresenterebbe la morena di fondo attuale. Questa struttura non è comune sul versante italiano delle Alpi. La peculiarità del Lys potrebbe derivare da una ciclica tendenza a rapide avanzate in anni di alte temperature estive, aventi una dinamica simile a episodi di «micro-surge».

TERMINI CHIAVE: Drenaggio glaciale, Dinamica glaciale, Ghiaccio, Alpi Occidentali.

INTRODUCTION

In spite of the great number of work on the alpine glaciers, the relations among drainage state, glacial dynamic and metamorphisme (that is kinds of ice crystals) are no very well know. Since 1993 we have must to face this problem in the Lys, a complex alpine-type glacier studied for the mass balance. The inner structure of the Lys Glacier has been examined by means of geologic survey, so that the ice structures are defined. A lot of ice samples has been collected for the study in thin section.

A great deal remains to be done; this paper only show the results concerning the terminus of glacier.

DYNAMIC SETTING

The Lys Glacier covers an area of 11.8 km^2 on the southern side of the Monte Rosa group (Italy). It is bounded by the two Lyskamms (4481 and 4527 m), the Ludwigshöhe (4342 m), the Corno Nero (4322 m) and the Vincent Pyramid (4215 m), and consists of corries at the heads of steep seracs that converge on a gently sloping valley floor, where the glacier comes to an end as a steep snout 2350 m above sea level.

Accumulation and ablation processes

The corries are mainly fed by direct precipitations and to a lesser extent by avalanches. The thickness of the

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snow mantle is very much altered by wind action (Motta & Motta, 1993), so that it is not uncommon to find that the mounds most exposed to the wind present in the form of bare ice in the heart of the winter, while in the middle of the summer the upper part of the glacier is frequently covered with fresh snow on account of its high altitude. The ablation area, on the other hand, is boxed in between the walls of rather deep valleys and is little affected by the wind. Ablation is thus primarily the result of insolation and rain (Motta, 1995).

Surface morphology

The glacier displays three morphologies corresponding to three altitude bands: the topmost part, which is above the 3300 m level and roughly coincides with the feed area, is dominated by wind-moulded shapes with *congères* (snow dunes) and *sastrugi*; the middle band (2800-3300 m) is very steep and mainly shaped by the collapse of seracs in the form of reworked fans and vertical scarps; the lowest part, known as the Lys Plateau, is dominated by forms of differential ablation due to the combined effect of the sun and the rain. The action of the sun, in relation to the thickness of the supraglacial ablation till, tends to bring out the centre of the flows, where the albedo is high because the ice is almost clean, and their sides are covered with several decimetres of supraglacial till that are quite enough to protect the ice below. Rain is channeled into the depressions between the centre and edges of the flows and accentuates the differential ablation by carving out distinct troughs, with the result that the morphology consists of longitudinal ridges composed of bare and dirty ice.

Transport processes

The Lys displays the dynamic regime typical of Alpine glaciers: a cold base flow regime at the higher altitudes (Smiraglia & Rossi, 1998), and a wet base flow regime elsewhere. In the seracs, movement takes place below through basal sliding. On the vertical scarps that break into the flows one can see that over a zone of plastic flow there lies a zone of brittle ice in which deformation results in crevasses, and movement is mainly the outcome of tilting and icefalls. On the Lys Plateau, conglomeratic ice fans formed of collapsed serac fragments are the source of surficial bare ice flows which move faster than those fed from the plastic flow zones. Friction at the flow boundary generates shear structures, such as crevasses en échelon. Air photos show that the flows run parallel to each other and that some come to a stop uphill and never reach the main snout (fig. 1). Here, too, the surficial part of the flows consists of a crevassed zone of brittle ice. The thickness of the ice suggests that there is an underlying plastic behaviour zone, at least in the upper part of the Plateau. Near the snout, movement of the lower flows seems primarily due to slippage along weakly sloping shear planes.

THE GLACIER FRONT STRUCTURE

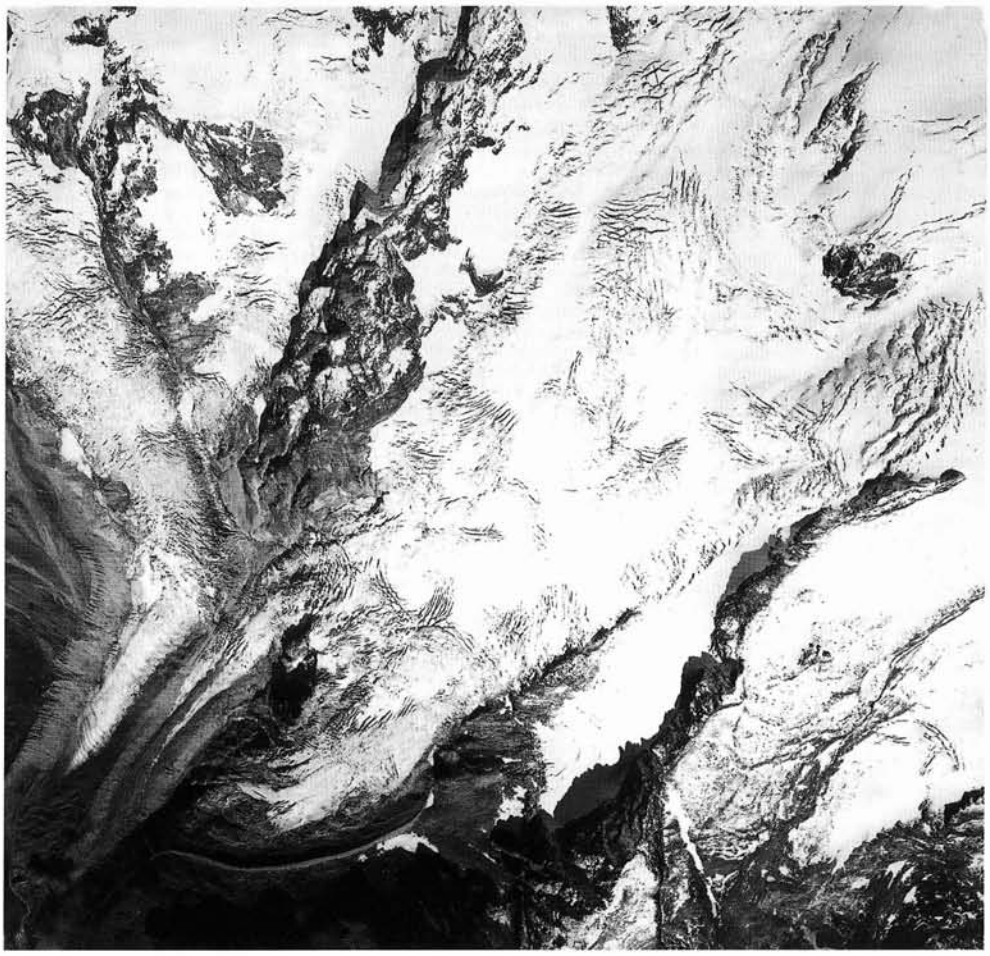
Since 1993, the inner structure of the ablation zone and the petrography of its ice have been investigated as part of research on mass balance conducted by the Italian Glaciological Committee and facilitated by the presence of natural sections formed by collapsing of the snout and abandoned intraglacial galleries. The inner structure near the terminus is formed of superposed layers several metres thick. These are not derived from fracturing along low-angle shear planes of the same flow, but from separate feeders which, in the case of the upper layers, have been identified on air photos of the reworked fans at the head of the Lys Plateau. When viewed in section across the flow direction, these layers are seen as thin lenses somewhat inclined from the horizontal. The englacial cavities that form at the boundary between the layers (fig. 2) are often partly filled by blue cave ice produced by refreezing of their percolating water (a in full-page ill.).

The body of these layers consists of debris-free, medium-grained (according the classification of apparent grain size of Robinson, 1978), inequigranular, weakly interlocking aggregates of irregular-shaped ice crystals (b in full-page ill.). The boundary is marked by debris-bearing, strongly foliated, fine to medium-grained ice. At the base of the frontal scarp, this pile of layers rests on a 10-40 cm (fig. 3) thick, isoclinally folded and clearly glaciotectonic stratum of ice-rich sand with parallel-to-flow foliation (fig. 4). Below this bed, there is debris-poor granoblastic ice with large crystals (c in full-page ill.) that also constitutes the substrate of the recent end moraines that formed during the latest advance (1980 to 1986). Movement of this ice can almost certainly be ruled out. It occupies the upper excavation corrie that hosts the proglacial lakes known as the «sources of the Lys». It is, in fact, almost certainly dead ice remaining from the period when the glacier extended over the sill of the corrie, in other words prior to the retreat that took place between 1934 (IGMI, 1935) and 1939 (Monterin, 1940). It now acts as an immobile substrate over which the upper layers slide at more than 1-6 m/yr^{-1} (Motta, 1996). The layer of sand that marks the separation surface may be supposed to represent the lodgement till of the still actively moving part of the glacier, whose glaciotectonic disturbances seem to indicate that bed deformation (Ehlers, 1996) is a component of its movement, at all events near the front.

ORIGIN OF THE LAYERED STRUCTURE

Examination of the air photos shows that the layered structure of the Lys snout cannot be solely due to lateral superposition of the flows that make up the tongue. It has thus been tentatively ascribed to variations in the relative significance of the individual branches of the glacier. These variations can readily be reconstructed from the exhaustive pictorial and written records covering the last 200 years held in the archives of the Italian Glaciological Committee. The relative sizes of the flows are determined

FIG. 1 - Air photo of of the lower part of Lys Glacier. Aut. S.M.A. n. 468, 21.10.94.



by the shape of their feeder zones. At present, the most important corries are those above the 4000 m line, whereas when the equilibrium line was lower (e.g. in the 1920s) the vast sub-flattish area between 3000 and 3600 m became completely a feeder zone and was more important. In some years, such as 1991-93 and 1997-98 in this decade, its flows reach the Plateau and pass independently over the almost motionless mass of ice remaining from previous advances without attaching to it. The flows originating from the reworked fans behave in the same way. In favourable years, they form at the base of the walls surrounding the Plateau and a layered structure is thus already present at its head. The flows of older ice, in fact, are the substrate of more recent, actively fed flows with a steeper longitudinal profile and hence presumably faster.

As they move downhill, the surficial flows tend to spread outwards over others in increasingly extensive and thinner layers, whose lateral borders, thanks to differences in the morainic cover, are readily visible on air photos for as far as two-thirds of the Plateau, after which they are eventually masked by the gradual emergence of the ground moraine.

SUBGLACIAL DRAINAGE

A very low, extensive entrance housing the subterranean uphill continuation of the shallow lake alongside the front is often formed at the terminus. Its surface is at approximately the same level as the summit of the ice stratum below the sand bed. The collapse structures associated with the entrance extend a few metres uphill from the rim of the snout, suggesting that the lake do not continue very far into the glacier. It is probably soon replaced by subglacial channels similar to those abandoned and directly accessible (fig. 5). The latter display a horizontally compressed elliptical section and are locally anastomosed to the point of acquiring the appearance of a vast subhorizontal cavity whose roof is supported by isolated pillars. This cavity evolution remind the karstic one. The isolated subglacial channels remind the young karstic morhology, which more behaving like «subterranean river» of Martel. The interconnected cavities are the more advanced, meaning a network tending to form a single flowing mass, according the Grund's theory. However, on a little scale, Iken & Truffer (1997) suppose a

FIG. 2 - Example of layers and intraglacial cavities with characteristic elliptical section formed at the boundary between the layers. Height of the wall: about seven meters.

similar evolution, from «Rothlisberger» channels to «interconnected cavities», for the swiss Findelengletscher. It is a plausible theory that the Lys points to periodical evolution of the subglacial drainage system similar to that which they suggest for the Findelengletscher in keeping with the marked variations in tongue speed recorded in recent years (Motta, 1996). The abandoned galleries are usually obstructed by ice that has shifted along discontinuity surfaces or by cave ice fillings. These fillings usually start from the roof and take various forms. In 1996, for example, there was a layer composed of needle ice with 15-20 cm long perpendicular to the roof. In 1997, a vast cavity (fig. 6) was partly blocked by a uniform 150-200 cm thick stratum of large-crystal granoblastic ice, while in the rest of the cavity the roof displayed an erosive, scalloped morphology covered with a millimetric skin of stalactitic ice and there were ice stalagmites on the floor (fig. 7). These morphological and structural differences are probably determined by the presence or absence of

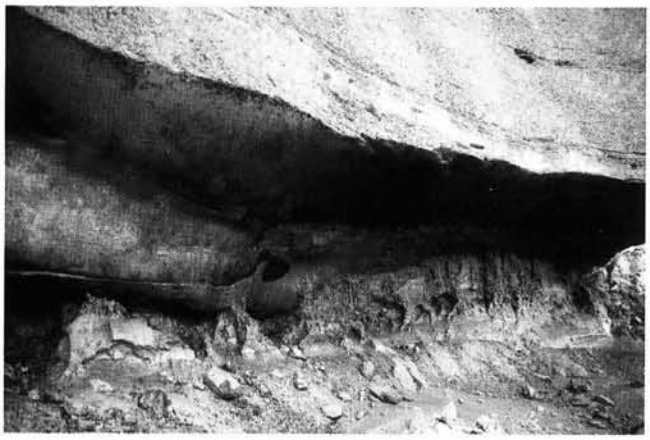
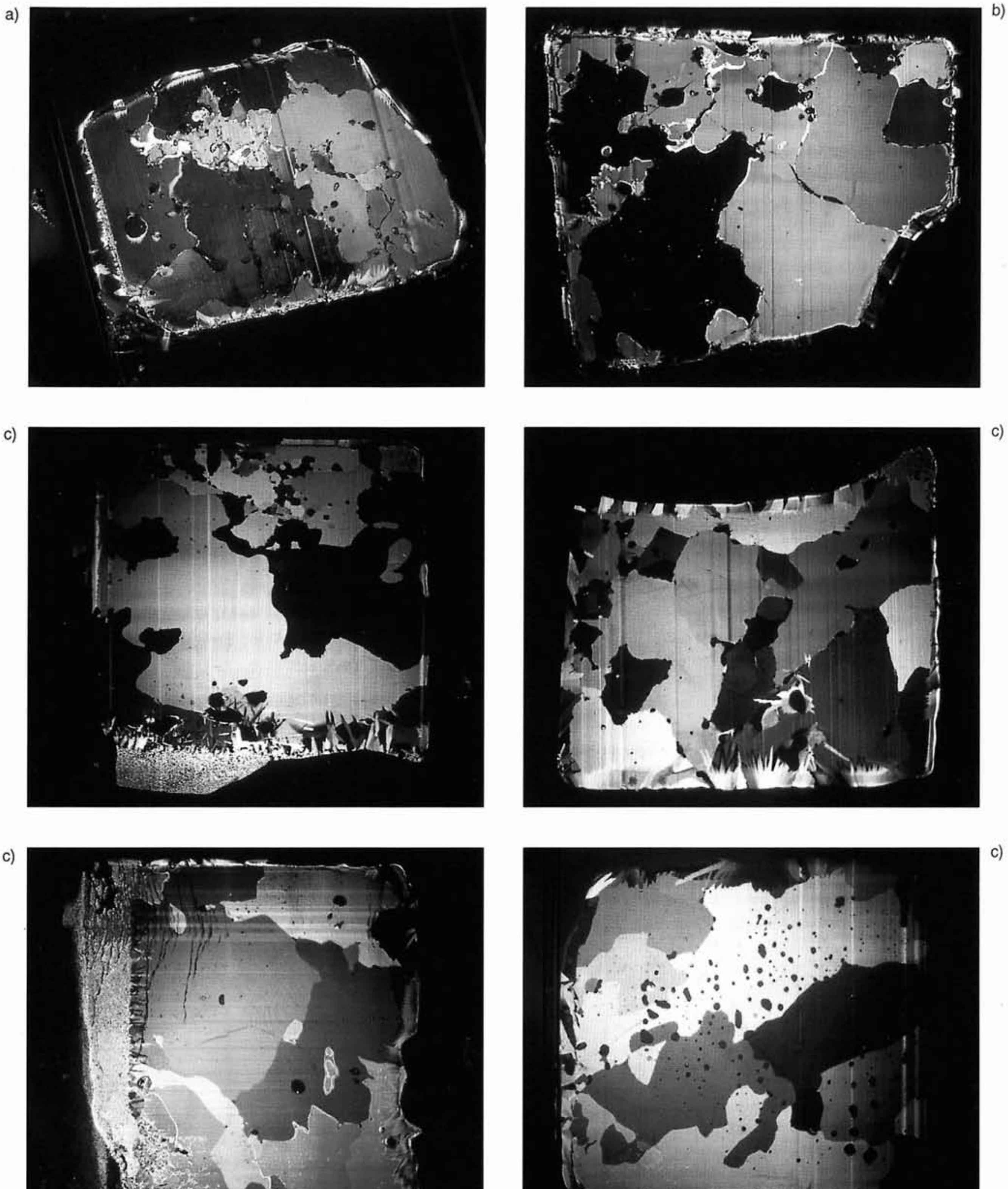


FIG. 3 - Structure of the glacier snout showing the superposed layers on a foliated sand stratum and dead ice.

FIG. 4 - Sample of the foliated sand stratum.

FIG. 5 - Subglacial channel illuminated by a crevasse and with clear evidence of a transition from phreatic conditions (circular section ceiling) to vadose conditions (meanders and dome pits).



TAV. I - a) Horizontal section of cave ice composed of poligonal, equidimensional, very large crystals divided into subdomains and not or medium interlocking. The crystals are rather iso-oriented with a subvertical c axis - b) Large crystals typical of the body of the moving layers, similar to those of the cave ice, but associated with intergranular debris and some bubbles - c) Dead ice marked by the presence of many non-oriented bubbles and large, long lobed crystals medium to large interlocking. Right: horizontal sections. Left: vertical sections.

the circulating air that encourages scallop erosion (L. & M. Motta, 1997; fig. 8).

CONCLUSIONS

The present substrate of the Lys snout is formed of dead ice over which slides the active part of the glacier with the interposition of a bed of unconsolidated sediment with pervasive shearing that constitutes the present ground moraine. This overriding is not an exception in the dynamics of this glacier. Its active part, in fact, consists of a pile of superposed layers in which the uppermost and most recent run over those below. This type of structure, however, is not a common feature of Alpine glaciers, at least on the Italian side. The nearby Tsa de Tsan glacier, for example, whose size, feeding pattern, terminal tongue formed by seracs and snout located on a flattish valley floor all liken it to the Lys, has a much simpler structure with no superposed layers and ice substrate. The peculiarity of the Lys may be a consequence of its tendency to advance very quickly, almost in the form of surge episodes, (Aliverti & Others, 1973) in years with high summer temperatures.

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FIG. 6 - Relicts of interconnected cavities isolated by glacier retreat. The floor consists of a foliated sand stratum and stalagmitic ice resting on dead ice.

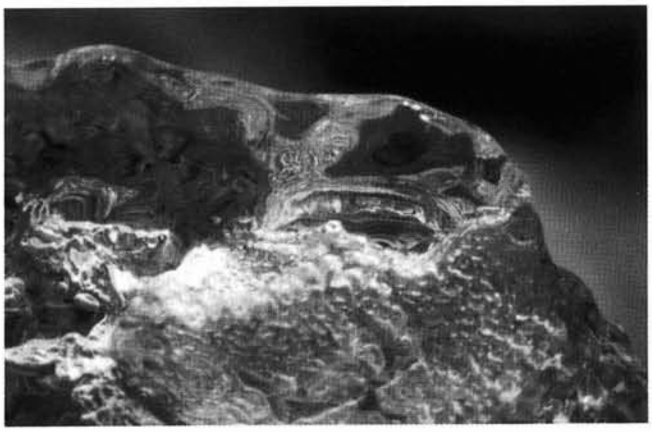

FIG. 7 - Stalagmatic ice accumulated on the floor of an abandoned subglacial channel.

FIG. 8 - Scallops at the mouth of a subglacial channel.