

A SUBGLACIAL GORGE: LA GORGE DU GUIL (HAUTES-ALPES)*

By J. TRICART (Strasbourg, France)

Translation by J. M. SOONS

ABSTRACT. The Gorge du Guil (Hautes-Alpes) might be regarded as a typical example of a post-glacial gorge. In fact, this is not the case. Systematic and very detailed observations based on maps of the scale of 1: 5,000 have revealed that the greatest part of the excavation of the defiles, cut across the bands of massive rocks, was accomplished by subglacial melt waters. Remnants of glacial deposits containing well-rounded pebbles, but whose finer constituents have been largely removed, occur a few metres above the present valley floor in each of these defiles. The down-cutting was very powerful, being facilitated by the crevassing of the ice, which was at the most 300 m. thick, over the ridges and in the constricted sections of the valley, and by the load carried in the englacial melt water. The sheltered and sunny climate, and the situation of the area below the limit of permanent snow also favoured erosion by melt water. By comparison, post-glacial down-cutting has been slight, not exceeding some ten metres in the massive strata, and appears to have been far less rapid than the subglacial erosion.

RÉSUMÉ. La Gorge du Guil (Hautes-Alpes) pourrait être considérée comme un cas typique de gorge postglaciaire. En fait, il n'en est rien. Des observations systématiques, très détaillées, appuyées sur des levés au 1/5,000 nous ont montré que la plus grande partie du creusement des défilés entaillés dans les bandes de roches massives avait été effectuée par les eaux de fonte sous-glaciaires. Des lambeaux de moraines lavées, a galets bien usés, se rencontrent, en effet, à quelques mètres au dessus du talweg actuel dans chacune d'elles. Cette incision a été très puissante et facilitée par le crevassement de la glace, épaisse au maximum de 300 m, sur les verrous et dans les resserréments et par la mise en charge des eaux de fonte intraglacières. Le climat abrité et ensoleillé, la position en altitude nettement en dessous de la limite des neiges permanentes ont facilité le travail des eaux de fonte. En regard, la creusement postglaciaire est très faible et n'a pas dépassé une dizaine de mètres dans les roches massives. Il semble avoir été beaucoup moins rapide que le creusement sous-glaciaire.

ZUSAMMENFASSUNG. Die Schlucht des Guil (Hautes-Alpes) könnte als typisches Beispiel einer postglazialen Schlucht angesehen werden. In Wirklichkeit trifft dies aber nicht zu. Systematische und sehr ins Einzelne gehende Beobachtungen, die sich auf Karten im Maßstab von 1: 5,000 gründeten, haben ergeben, daß die in massive Felsen eingeschnittenen Engstellen grösztenteils durch subglaziales Schmelzwasser gebildet worden sind. Überbleibsel glazialer Ablagerungen, die gut abgerundete Gerölle enthalten, deren feinere Bestandteile jedoch grösztenteils entfernt worden sind, treten einige Meter über den gegenwärtigen Talböden in jeder dieser Engstellen auf. Es fand eine mächtige Tiefenerosion statt. Dies war durch die Zerspaltung des Eises erleichtert, das über den Kämmen und den Engstellen des Tales höchstens 300 m dick war, ebenso durch die in dem Gletscherschmelzwasser enthaltenen Gerölle. Das geschützte und sonnige Klima und die Lage des Gebiets unterhalb der Schneegrenze begünstigte ebenfalls die Erosion durch Schmelzwasser. Vergleichsweise war die postglaziale Tiefenerosion gering, sie hat in den massiven Schichten etwa 10 Meter nicht überschritten und scheint viel weniger schnell vor sich gegangen zu sein als subglaziale Erosion.

THE following observations were made on behalf of the Centre de Géographie Appliquée, to provide data for a policy of control of the Guil basin, which was devastated by the floods of June 1957. A geomorphological map of the valley floor was prepared on the scale of 1: 5,000. The present account is based on material gathered together in the course of preparation of this map.

The problem of the formation of subglacial gorges is one that is still the subject of controversy. Garwood† considered that they were formed during inter-glacial periods and developed this theme in an attempt to prove that alpine rivers and not alpine glaciers caused most vertical erosion.

It is thought, therefore, that certain observations made in the alpine valley of the Guil, a tributary of the upper Durance, will be of interest. These were facilitated by the damage produced by the catastrophic flood of June 1957, which ravaged the Queyras, devastating the

* A very large number of works has been published on the problem of gorge formation and the action of subglacial streams. These are not cited here, since a suitable choice would be difficult to achieve and could not fail to be arbitrary.

† Garwood, E. J. Features of Alpine scenery due to glacial protection. *Geographical Journal*, Vol. 36, No. 3, 1910, p. 310-39.

whole of the valley floor and causing extensive sapping and undercutting of the sides. The road was carried away and has had to be remade over a distance of some twelve kilometres, and this also produced valuable new exposures.

The Queyras is a high altitude mountain basin, its floor lying between 1,300 m. and 2,000 m. a.s.l. It is dominated by summits ranging from 2,400 m. to 2,800 m. a.s.l., culminating in Viso at just over 3,000 m. a.s.l. It was therefore much affected by the Quaternary glaciation, the Würm snow line apparently lying at about 1,600 m. a.s.l. Down-stream from this basin the valley of the Guil narrows where it crosses a series of nappes involving mainly limestone which is much more resistant than the *schistes lustrés* of the Queyras. This gorge stretches for some fifteen kilometres from the neighbourhood of Château-Queyras to Guillestre, and varies in form, the vertically-walled gorges, which characterize the most massive limestones (see Figs. 1 and 2, p. 651), alternating with small basins where the valley floor widens to 100-300 m. between slopes of 50° or more. These widenings mark less coherent strata, such as the strongly jointed quartzites at Le Veyer, the finely bedded and closely jointed limestones at Furfande, and pockets of Triassic shales and cellular dolomites as at La Fusine. The problem is to decide whether the gorge was cut by melt water after the withdrawal of the glacier which joined that of the Durance at Guillestre, or whether it was cut under the ice itself in the course of the Würm glaciation.

The favourable conditions under which this study was undertaken have made it possible to demonstrate that the gorge predates the Würm deglaciation. Numerous morainic deposits have been found on the floor of the gorge itself, even in certain of its narrowest sections. These phenomena will be described briefly, and the conclusions that may be drawn as to their origin will then be considered.

Sizeable patches of moraine extending down to the floor of the valley may be found in the first basin at the upper end of the gorge, that of La Fusine, where the Guil is joined by the Rivière d'Arvieux. These may possibly be explained on the assumption that the basin is due to glacial over-deepening, and that the La Chapelue gorge, which links it with the widening downstream at Le Veyer, and the Gorge de l'Ange Gardien, linking it with the basin downstream of Château-Queyras, are both the result of post-glacial down-cutting across its bounding ridges. Indeed, it could serve as a text-book example: the La Fusine basin has been excavated in weak strata—shales, gypsum and cellular dolomite—while the two ridges are formed of resistant massive limestone. Altogether the area presents a magnificent example of the effect of differential glacial erosion, with local over-deepening of weaker rocks. This interpretation is, however, only partially correct. Important patches of glacial deposits have been found in the La Chapelue gorge i.e. downstream from the La Fusine basin.

These deposits are of ground moraine, plastered against the valley side and preserved in one of its irregularities. They thus occur in a pocket, descending almost to the river, but are to a large extent hidden by coarse scree derived from the limestone walls of the gorge. The bed of the river, with its enormous potholes, has been lowered only some 5 m. below the glacial deposits. Where this till is exposed it may be seen to be so compacted that no impression can be made on it with the bare hands; the clayey material has been washed out and the consolidation of the mass by lime-impregnated water has begun. The pebbles are appreciably rounded, and some traces of stratification, in beds and lenses, may be observed in places. All these features indicate that this is water-sorted ground moraine, deposited under the ice by melt water concentrated in the more deeply cut parts of the glacier bed. As the main mass of the glacier down-stream re-ascended to cross the La Chapelue ridge the melt water under the glacier was brought in summer into contact with the rock, which would have been the more easily reached at this point where the very abrupt break of slope, under a glacier that was never very thick (about 300 m.), must have given rise to numerous crevasses. This melt water, in part under hydrostatic pressure and abundantly furnished with abrasive material, rapidly cut a gorge which was then occupied by a pro-glacial stream after the withdrawal of the

glacier beyond this point. In other words, the cutting of the gorge dates from the glacial period itself, and not from the deglaciation. Incision following the withdrawal of the ice has been slight—a matter of 4-6 m. only, which is nevertheless appreciable in view of the exceptionally massive character of the limestone. A serious flood, like that of June 1957, which had spectacular effects wherever the Guil flowed over unconsolidated material, had no effect on the bedrock in the gorge; a few fallen blocks were moved, but no visible abrasion of the rock took place.

In addition to the considerations set out above, the theory of a subglacial origin for the gorge is also consistent with two other geomorphological facts:

(1) The complete absence of late-glacial lacustrine deposits in the La Fusine basin upstream from the gorge, where such deposits could hardly have failed to form after the retreat of the glacier if the escape of melt water had been prevented by a barrier at La Chapelue. It is significant that in this basin only bedrock, till, screes and post-glacial hill-wash can be observed.

(2) The existence of a pro-glacial fan in the widening at Le Veyer, immediately downstream from the La Chapelue gorge. The apex of this fan is at the outlet of the gorge, and its level agrees with that of the floor of the gorge. As is the case in the gorge, the Guil has incised itself into the fan for a few metres only. The fan is well preserved under the thin post-glacial fan of the Riou Vert 300 m. down-stream from the farm of La Chapelue. Examination of the fan was made possible by extensive sapping, and revealed that the typical Würm till, characterized by coarse blocks of green rock, is overlain by material deposited in a small barrage lake. This material consists of laminated beds of silty sand, 1-5 mm. thick, deposited in an undisturbed body of water (associated with slow horizontal movement of the water and the settling out of fine material) which alternates with thin lenses of calcareous gravels representing flood deposits. These lenses show a parallel inclined bedding, and the pebbles are always less than 2 cm. long. The fan must therefore have been formed in a small lake occupying a glacially over-deepened section of the valley, corresponding to the plain of Le Veyer. It is late-glacial, and was produced by melt water streams from the nearby glacier. The pebbles and finer gravels are essentially of local origin. The agreement between the height of the apex of the fan and that of the outlet of the gorge demonstrates that the latter was already formed when the ice withdrew from the ridge across which it is cut.

The glacial over-deepening of the Le Veyer plain is a reflection of the lithology. It coincides with a band of very well-jointed conglomerates and slightly metamorphosed sandstones, which break down easily into blocks barely reaching 1 m.³ in size. Glacial erosion was thus particularly easy in these formations, which are, moreover, continuing to nourish impressive screes. At its lower end the small late-glacial lake was apparently dammed by a landslide, which affected the gypsum and cellular dolomite on the right bank downstream from the hamlet of Le Veyer, occurring immediately after deglaciation. This barrier of unconsolidated debris persisted only for so long as was necessary for the Guil to cut a channel through it—i.e. for but a short time.

Down-stream the Le Veyer basin is closed by a further occurrence of particularly massive limestones. At the bridge on the Bramousse road the Guil has cut a short curving channel into them, about a hundred metres long. A very careful investigation at this point, in view of the siting of a flood channel, showed that this incision is the result of superimposition. On the right bank a small fan formed by the Torrent de la Petite Balme masks an accumulation of water-sorted ground moraine which has plugged a channel cut in the solid rock. Here again it seems that a gorge was formed by a subglacial stream. However, as this was in a section of the valley where there was no well-marked ridge, it was short and not very deep. It was infilled by glacial deposits prior to the retreat of the ice, and did not guide melt water when deglaciation took place. Instead the melt water, following a lower course along the edge of the mass of till, cut into the bedrock to produce the present superimposed channel.

Another case of superimposition was observed further down-stream. This also occurred in massive limestones at the defile of the Grande Balme. The narrow floor of the glacial valley here lies on the left bank of the Guil, and is plugged with till which descends at least to the level of the modern channel, and possibly lower. The stream has here cut a small gorge at the foot of the limestone slope, to the right of the old channel. This post-glacial incision is, like those already mentioned, of moderate dimensions, the stream having cut into the solid rock to a depth of only 5-8 m., even though its gradient is here steep, and its velocity invariably high.

An important subglacial gorge occurs at the entry of the tributary Torrent de Cambalaz. In this sector, the Guil has again produced a gorge in the massive limestones which is as narrow and impressive as that of La Chapelue. At several points overhangs have been formed which have resulted in scree development. This sector is almost 400 m. long, and separates two relatively wide sections with less steep sides, and thus appears to have been cut across a ridge. As at La Chapelue, till is preserved in both the embryonic basins on either side of the gorge, while glacial deposits also occur within the defile itself.

At the confluence of the Torrent de Cambalaz a very well marked flattening may be noted on the right bank of the Guil, about 10 m. above the valley floor. This marks a channel some 10-30 m. wide, cut in the solid rock, and similar to that in which the Guil now flows. Undercutting here revealed till at the surface including boulders of varying size, some of which were over 1 m. in length, and with little in the way of a finer matrix, but with some traces of water-sorting. This deposit is 5 m. thick, and has the appearance of ablation moraine, deposited as the ice rapidly melted out *in situ*. At lower levels the fine matrix becomes even scantier, and there is a concentration of fragments of less than 0.8 m. in length, with a marked abundance of pebbles of 10-20 cm. long, mostly well water-worn. The sandy and gravelly matrix shows no sign of water-sorting, but includes some pockets of very finely bedded alternating silts and sands. The thickness of this bed varies between 0.5 and 1.0 m. and appears to be a deposit originally formed by englacial waters, but later disrupted when the ice on which it was resting melted. Finally, in the recesses at the base of this gorge, there is a deposit in which laminae of silt and sand, alternating in the manner of varves, are interspersed with gravelly lenses in which the individual pebbles are not more than 5-10 cm. long, and are fairly well worn. This material is slightly compacted, and has traces of fractures and displacements suggesting compression, which can only have been caused by the ice. In its upper part, it may be observed that pebbles from the overlying gravel bed have fallen into the varved deposits, where they have distorted the laminations. This indicates that the pebbles fell into the softer material when this was unconsolidated and could therefore give beneath their weight.

The interpretation of this fine section presents no difficulties. A gorge was cut across the ridge of massive limestone by subglacial melt water. Contraction of the glacier resulted in its detachment from the floor of the valley, thus favouring the free movement of melt water. In the recesses of the gorge, or possibly as a result of the formation of temporary barriers by the movement of the ice, slowly moving water allowed the settling out of fine material to form the laminated silts and silty sands. Rock fragments frozen into the floor of the glacier above occasionally fell and were buried in this material, which was not frozen. Then, as conditions became warmer, increasing numbers of these fragments were dropped, and the subglacial stream was only able to remove some of the finer material and to round off the coarser blocks. Last to be deposited was the overlying till, probably as an ablation moraine. Here, as at La Chapelue, the cutting of the gorge across the limestone barrier took place subglacially. A slight complication arose as a result of the rather greater width of the floor of the glacial valley at this point. The till deposited was relatively abundant, and the late-glacial stream failed to follow exactly the line of the subglacial gorge. Instead, on the left bank of the old channel a new channel was partly superimposed on the solid rock. The post-glacial incision is not more than about 10 m. deep.

Three main points may be established by these observations:

(1) That glacial erosion is very closely adapted to structural detail. It emphasizes lithological differences insofar as these affect the cohesion of the rocks. Where rocks are strongly bedded or jointed they are easily attacked. In contrast, massive rocks are less easily affected. This differential erosion demonstrates that the Guil glacier effected most of its erosion by sapping—a normal phenomenon in the case of an ice tongue of moderate slope (mean inclination 2.5 per cent) but restricted between steep, uninterrupted valley walls. The bed of the glacier was very uneven, reversed slopes coinciding with constrictions of the valley, while widenings in the form of closed basins occur downstream in rocks more susceptible to sapping.

(2) That considerable erosion was performed by melt water prior to the deglaciation. As the whole of the gorge section is below the Würm snow line this was more abundant in summer, the more so as a result of the sheltered situation of the area, which thus enjoyed a very sunny climate. Aided by the numerous crevasses which must have resulted from the particular character of the relief, the melt water was concentrated under the ice, where it was in contact with the bedrock. Its erosive action was most effective on the sector with reversed slopes, a fact which may be postulated from the probably greater abundance of crevasses which there favoured their descent, and which is demonstrated by the results of this activity. Melt water erosion was therefore most effective at precisely those points where that of the glacier was least. It may be recognized both by the cutting of subglacial gorges, sometimes of considerable depth, and by the shaping of many of the pebbles found in the deposits. The various ridges described above were already cut by the gorges before deglaciation took place.

(3) That post-glacial fluvial modification of the valley floor has been at a minimum, and that post-glacial erosion has been in no way responsible for cutting across the ridges. The river inherited a bed from the subglacial stream whose long profile was very much less irregular than that of the glacier itself; also it has only carried out limited amounts of erosion since. Even though the gradient is fairly high and the volume of water large, the Guil has not lowered its channel into the massive limestones by more than a few metres since deglaciation. All our observations on this point agree, varying between 4-6 m. and about 10 m. (This last figure was obtained in the gorge of Cambalaz, where it was not possible to determine exactly the level of the subglacial valley floor.) These figures are very small, in spite of the opportunities for solution of the limestone by very cold water from melting snow. It is evident that the erosion of coherent rocks in the river bed proceeds very slowly, even though this is a mountainous area; it probably takes place even more slowly than was the case under the conditions in which the subglacial stream worked, when there were abundant supplies of abrasive material.

Many of the characteristics of the gorge of the Guil, which one might be tempted to consider, in the light of current theories, as due to post-glacial fluvial modifications, are in fact the work of melt water contemporaneous with the glaciation, and are therefore older than was at first assumed.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of Mlle A. R. Hirsch, Technical Assistant, and of Mlle A. Nogueira and T. Cardoso da Silva, both holders of bursaries at the Centre.

MS. received 3 September 1959



Fig. 1. The Gorge du Guil up-stream from La Chapele looking up-stream. Note the head of the late-glacial fan under the meadow

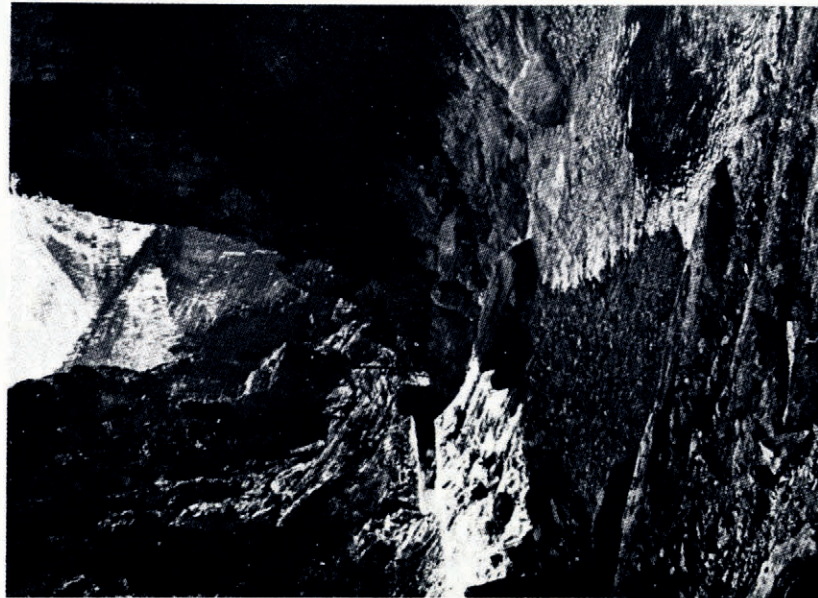


Fig. 2. The gorge up-stream from La Chapele looking down-stream from point 1250. The moraines were observed near the camera station