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DEFORMATION OF HIGH SLOPES IN DIFFERENT ROCKS AFTER WÜRMIAN DEGLACIATION IN THE GAILTAL (AUSTRIA)

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In the southern part of the Eastern Alps extended mass movements in different rocks are described.

In a sequence of crystalline rocks (mainly mica schists and phyllonite) and sediments (sandstone, siltstone and limestones) various types of mass movements due to mechanical properties of the rocks occurred. Therefore a great-scale bending along with rotational gliding and toppling of the bigger blocks can be recognized in the mica schists in the major parts of the slopes. This slope failure leads to a complete disintegration of structures in the phyllonites.

In the sedimentary part of the sequence the brittle limestone as the competent part failed above the soft incompetent base. The main reason for this mostly active deformation of the slopes is glacial erosion causing overdeepened valleys and steep slopes. Especially active parts are caused by strong river erosion.

All these phenomena are temporarily closely related to the development of the glaciers.

INTRODUCTION

In the Eastern Alps mass movements of any size are very common phenomena and occur in all lithological units. The mechanism of the slope failure depends strongly on the property of the rocks and their tectonical structures (Fig. 2).

Causing and triggering of this slope deformation is mostly closely related to glacier activities (e.g. erosion, retreat). So, many of them started with the downmelting of the ice (Fig. 1). Many are still active slow moving rock masses, thus being extremely important to engineering geology.

The below described example of mass movements in different materials from the southern part of Austria was recognized during mapping and later on was investigated in greater detail in terms of morphology, mechanism and temporal development.

BEDROCK

Gailtal Crystalline: The broad ridge is built up by mica-schists. Embedded are quartzite, graphitic schists partly rich in lydite (Heinisch, 1987). These are narrow, long-stretching layers (Fig. 2). Comparing with the more ductile, heavily jointed mica-schists, these materials are brittle. They are the competent part of the sequence in terms of tectonical deformation as well as slope failure. The whole sequence strikes E.–W. and dips 80–90° north. Only in the phyllonite zone, in the northern part, dipping about 80° to the south occurs. The main foliation in the thin-layered mica-schists is showing the same orientation.

The northernmost part of the mica-schists shows an intensive tectonization causing a retrograde metamorphism (phyllonites) (Heinisch, 1987) and a loss of strength and an increased ductility. A tectonically embedded lens of gneiss is again heavily jointed.

To the north the dipping of foliation turns to lower values (60–50°). This is more or less parallel to the general bedding of the permo-mesozoic sequence topping the crystalline basement. The lowermost part of this permo-mesozoic sediment is forming an imbrication structure with the crystalline.

Permo-triassic sediments: This sequence is built up by conglomerates, sand and siltstone, topped by thin-bedded and finally massive limestone dipping about 50° to the north. In terms of mechanical properties the

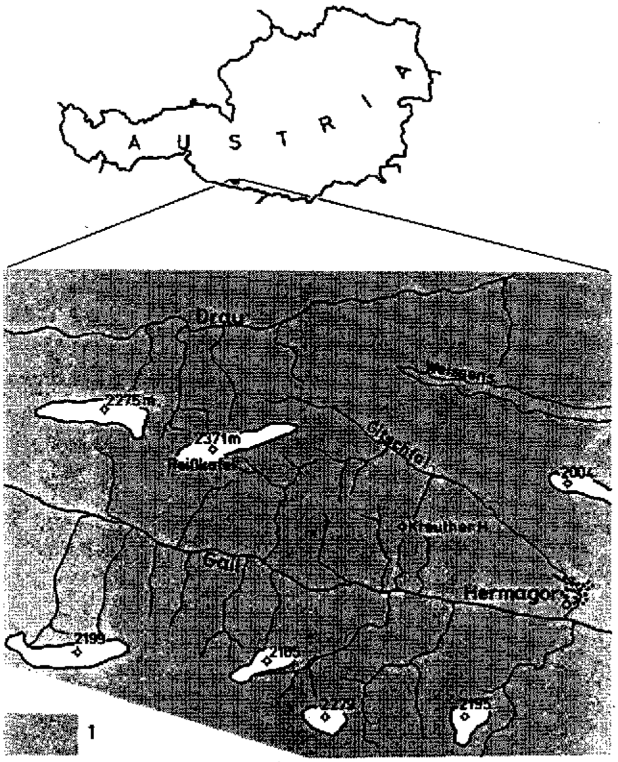

FIG. 1. Position of investigated area: 1, ice cover during last glaciation.

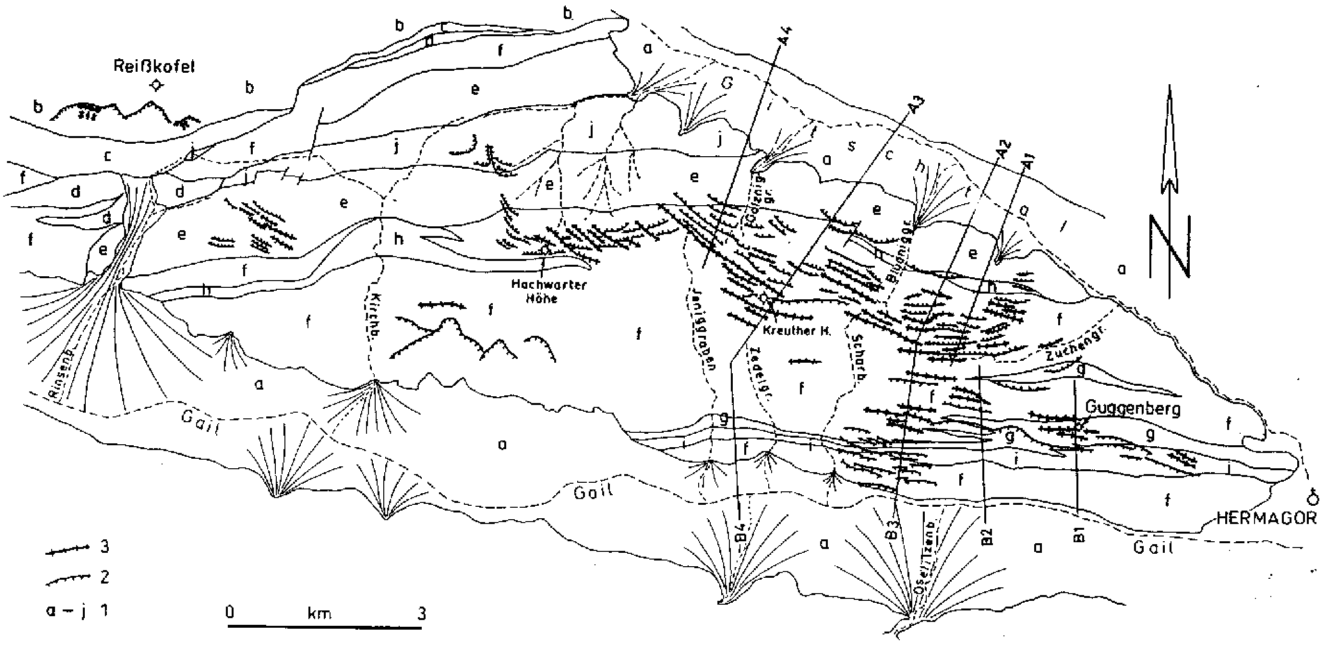

FIG. 2. Investigation area; 1a, filling of glacially eroded and overdeepened valley; 1b, massive limestone; 1c, thin-layered limestone; 1d, conglomerates, sand- and siltstone; 1e, phyllonite; 1f, mica-schists; 1g, graphitic schists; 1h, greenstone, amphibolite; 1i, quartzite; 1j, gneiss; 2, scarps; 3, long-stretching linear, and ridge-top depressions.

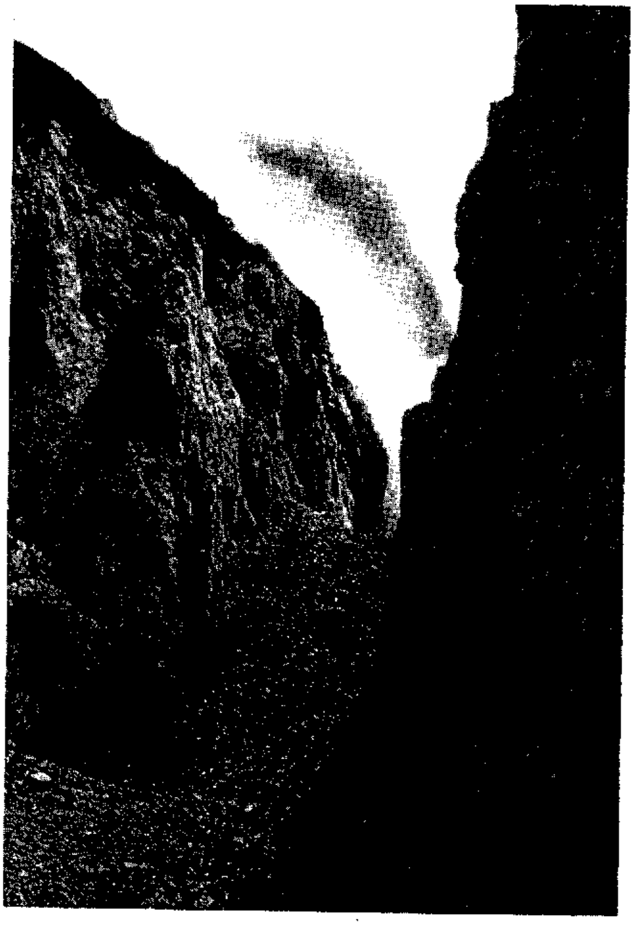

PLATE 1. Gap on the westerly side of the cirque-like feature. Notice the vertical walls and fresh talus. For position see Plate 2 and Fig. 4.

limestones are the competent part of the sequence (Bechstädt, 1978).

MORPHOLOGY

The triassic limestones form a sharp crest with steep slopes to north and south above the gentle slope formed in both silt- and sandstone as well as crystalline.

Below the highest point (Reißkofel, 2371 m) there is a south-facing cirque-like feature (in the following called cirque) cutting through the whole sequence from the crystalline to the top.

The slopes on both sides of the cirque are interrupted by gaps filled with fresh talus. These are open joints about 10–30 m wide, partly with parallel vertical walls (Plate 1). These structures are running parallel to the Gail valley as is the striking of the underlying incompetent rocks (Figs 2 and 4). Within the cirque a large rock mass is separated from the backwall by an identical structure with the same orientation (Fig. 4). Orthogonal to this well developed joint system less distinct joints are recognizeable on both sides of the cirque (Fig. 4). The mass within the cirque shows a strong structural disintegration into blocks of any size and an increasing loosening toward the lower parts. From this, disintegrated rock masses and the joints on both sides, a huge steep debris cone develops in the Rinsenbach, dominating the whole Gail valley (Fig. 2).

In the area of the Gailtal Crystalline a wide ridge with gentle slopes is developed. The north-facing slope shows a smooth topography with a steeper convex

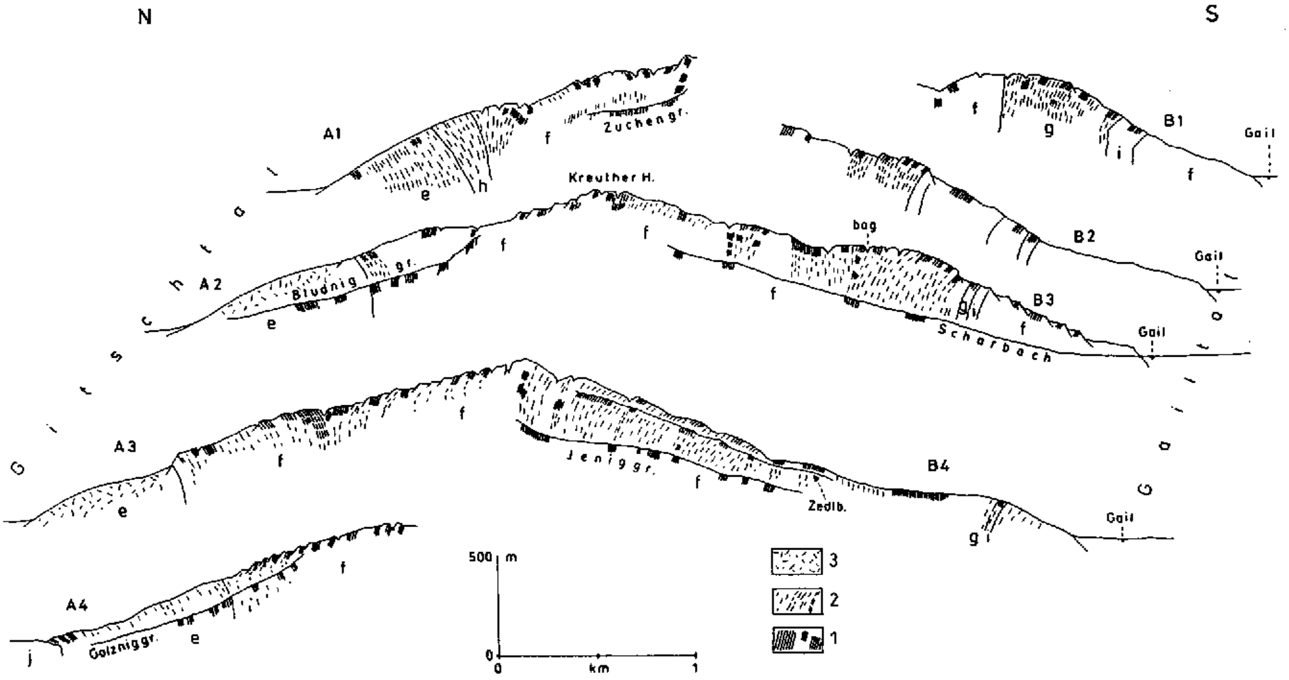

FIG. 3. Profiles: 1, homogeneous zones, exposed; 2, striking and dipping measurable in small outcrops; 3, completely disintegrated phyllonites. Further legend and position of profiles see Fig. 2.

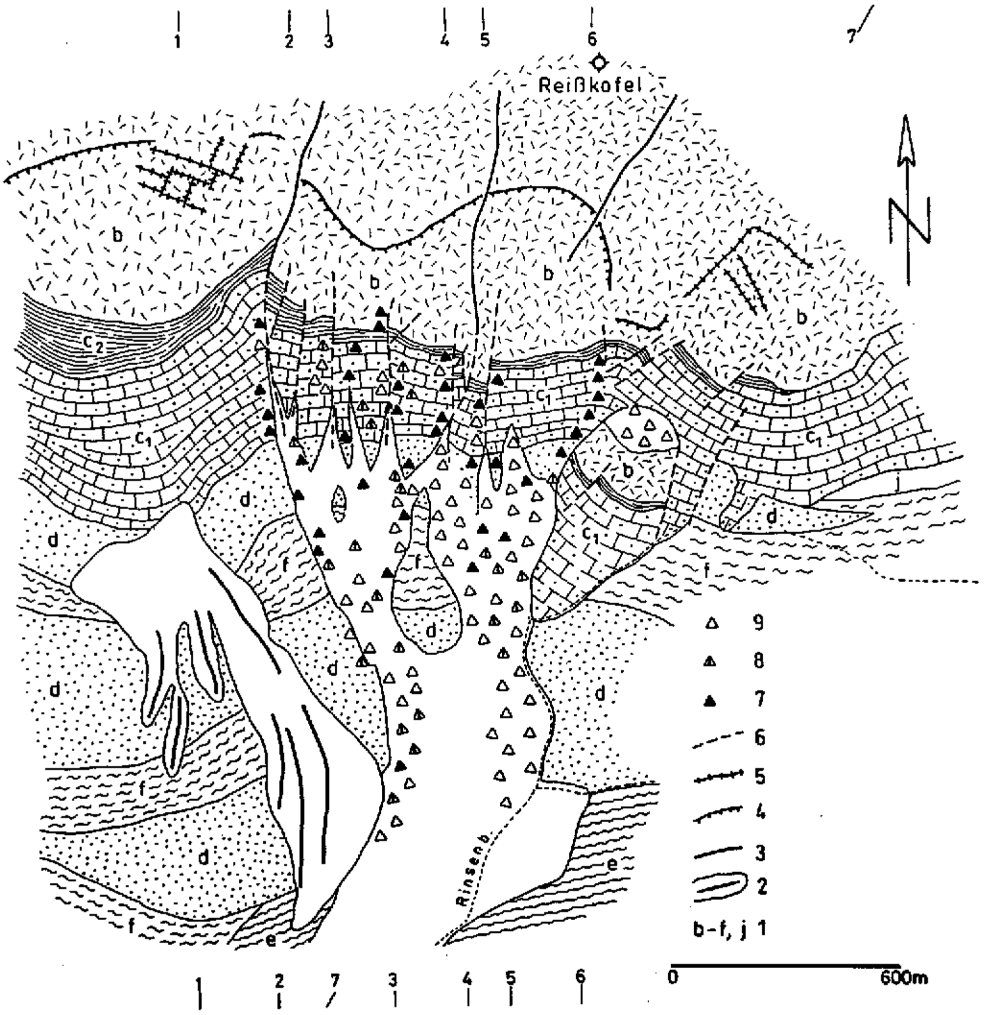

FIG. 4. Sketch map of the cirque-like feature: 1, see Fig. 2; 2, glacier deposits and lateral moraine; 3, faults; 4, scarp; 5, open joints (gaps); 6, faults formed during sagging; 7, limestone blocks 10 m^3, fresh and unweathered; 8, limestone blocks partly covered with grass and bushes; 9, limestone blocks completely covered, also with trees.

surface in the lowest part. The south-facing slope shows a more complex relief comparing with the north-facing slope. Between Rinsenbach and Scharbach the slope generally shows no significant morphological peculiarities besides a big scarp in the middle part (SW Hochwarter Höhe). Here the lower part of the slope has sagged down about 100 m.

The slope east of Scharbach is staircased by a series of scarps and horizontal linear depressions in the middle part of the slope. One of these structures converts into a distinct, up to 100 m high, scarp in the east (around Guggenberg). It is partly formed by 20 m high walls even in the lydite-bearing graphitic schists! The staircased part of the slope appears fresh and unweathered in the lowest part above the Gail valley. Especially, the last step appears as a 20–40 m high rock wall dissected by the river Gail, which is being pushed northward by the very active torrent Oselitzen (Fig. 2).

The topmost part of the ridge shows a great number of linear depressions. These features are mostly 20–50 m wide and up to 10 m deep. The length ranges from 200–1000 m. The main direction is parallel to the Gitsch valley, slightly discordant to the striking of the mica-schists. In the area north of Hochwarter Höhe a pronounced system of scarplets striking E.–W. appears, dissecting the locally NW–SE striking mica-schists. Comparing with the depressions described above these scarplets appear fresh and unweathered, showing a zigzagging course controlled by the bedrock structure (Fig. 6).

STRUCTURES

Permo-mesozoic sediments: The most impressive structures on the south flank of Reißkofel are the two gaps on either side of the cirque (Plates 1, 2 and 3). They are formed within the massif limestone which dips about 50° to the north. This limestone block is dissected only by some NS running obvious faults (Fig. 4). It does not show any other major joints or faults. So these gaps and the other parallel striking joints are actually formed without a tectonical predisposition. The reason seems to be toppling of the limestone units caused by squeezing out of the lower more ductile basement (Poisel, 1990) as a result of the oversteepening of the slope by glacial erosion.

On both sides N.–S. striking joints are intersecting these E.–W. oriented major joints in the upper part of the displaced mass (Fig. 4). These joints are paralleling the cirque walls showing sharper unweathered edges comparing with the E.–W. joints. These features also do not follow any tectonical or sedimentological predisposition.

The central part of the cirque is dominated by the huge sagging mass (Zischinsky, 1966; Hutchinson, 1988) of heavily jointed and disintegrated limestone. A significant horizon (Plattenkalk) allows to reconstruct the amount of this creeping displacement. So this ca. 50 m thick horizon shows a maximum dislocation of 170 m against its appearance on both sides of the cirque (Fig. 4). Thereby some internal dislocations of larger parts along freshly formed N.–S. striking faults become obvious. During the movement a translation and rotation of blocks occurred, especially in the thin-bedded limestone, due to the great number of also newly formed joints and fissures (Plate 4). Thereby the outermost parts show greater disintegration with a narrow transition to more compact ones (Fig. 5). In these units striking and dipping of sedimentary stratification is more or less disorientated.

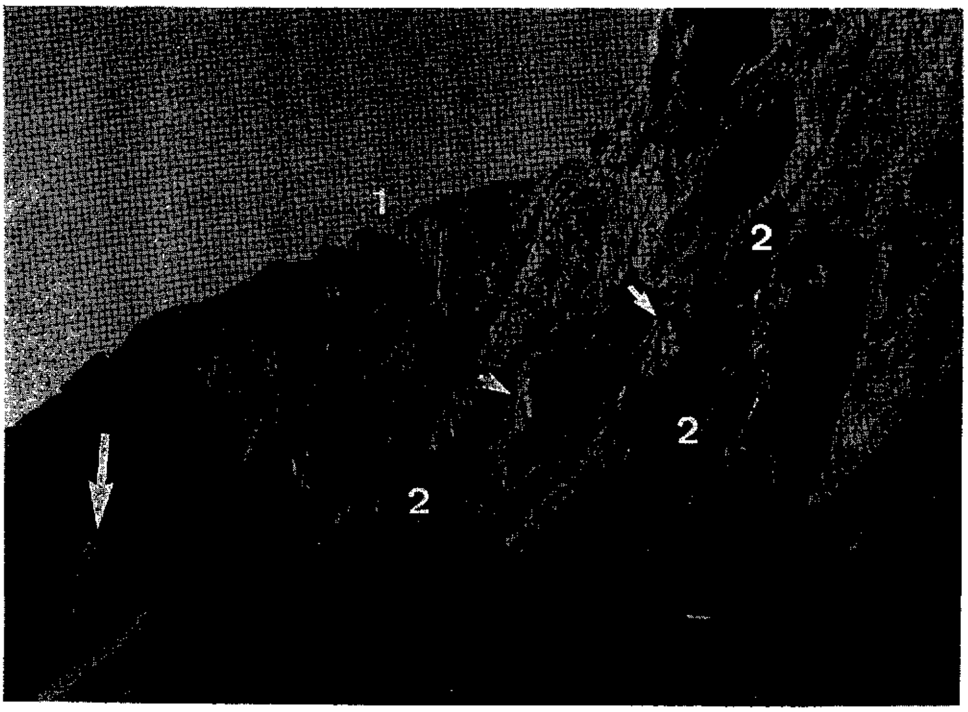

PLATE 2. The cirque-like feature looking toward west: 1, gap, see Plate 1; 2, disintegrated mass in the central part; Arrows, disintegrated massive limestone on top of the mass; Main source area of the blocks 10 m^3; Big arrow, Plattenkalk, see Fig. 5.

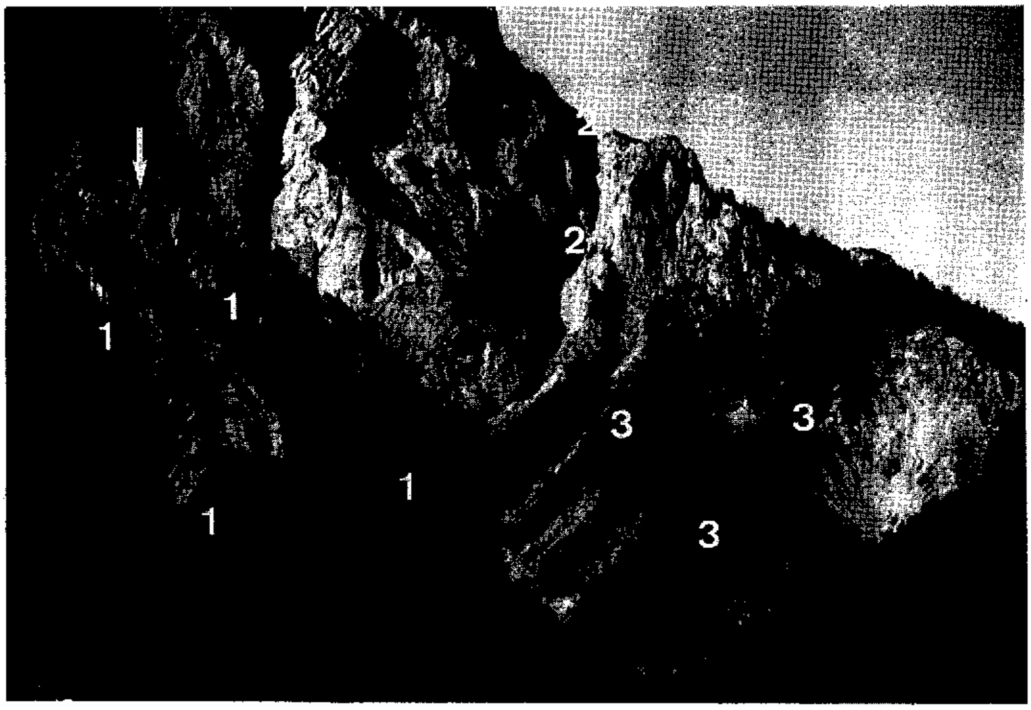

PLATE 3. East part of cirque: 1, disintegrated mass in the central part; 2, gap on the east side; 3, sagged, strongly disintegrated mass, see Plate 5; Arrow, see Plate 2.

However, this sagging mass has moved 100–170 m, its middle parts showing the greatest amount of displacement. During this process these thin slices near the surface moved faster showing a stronger disintegration and loss of clear orientation of the sedimentary structures.

On the east side one of these slices of limestone has moved about 200–300 m over the underlying siltstone disintegrating more and more until eventually it turned into talus (Fig. 5, profile 7 Plate 5). The reason for this sagging mass is also the incompetent silt- and sandstone as well as the underlying phyllonites in the basement.

An interesting phenomenon are blocks of the top-

PLATE 4. Detail of the sagging mass in the central part. One of these outermost slices with a narrow transition to the more compact part of the mass is shown. See also Fig. 5.

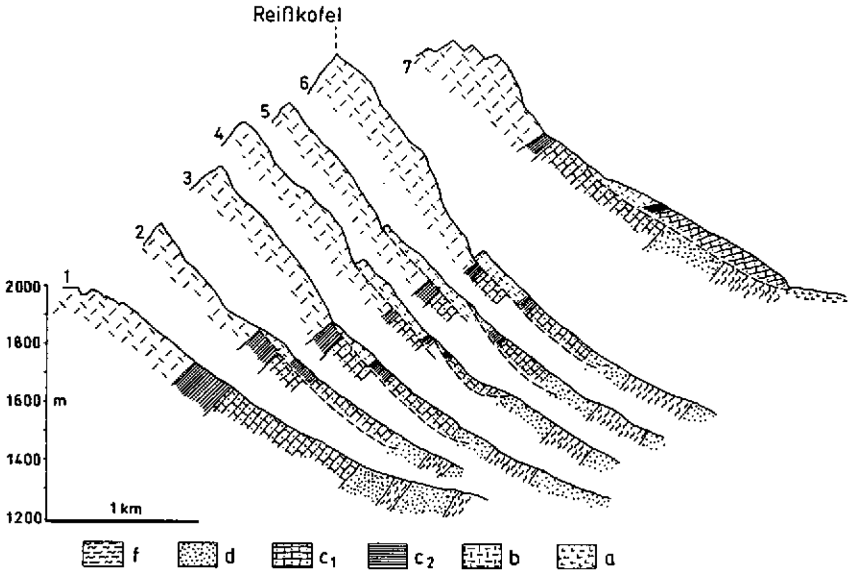

FIG. 5. Profiles in the sagging mass: f, mica-schists; e, phyllonite; d, conglomerates, sand- and siltstone; c1, thin-bedded limestone; c2, Plattenkalk; b, massive limestone; a, talus.

most massive limestone (Wettersteinkalk), more than 10 m^3 (up to 100 m^3) in size, covering the uppermost parts of the debris cone (Fig. 4). These blocks probably come mostly from the backwall of the cirque as well as from the uppermost part of the moved masses (Plates 2 and 3). During the toppling of parts (after loosening from the back by joints) of the massif limestone, downvalley dipping joints were formed allowing the rock blocks to tumble down (Poisel, 1990). These blocks on the surface of the debris cone show a difference in weathering and vegetation cover (grass and trees), indicating a long period of deposition and an ongoing production of these blocks.

CRYSTALLINE ROCKS

The original structures of the rocks described above are visible in the deep cuts of some creeks and rivers (e.g. Scharbach, Kirchbach). About the same striking and dipping can be observed along the whole main ridge east of Reißkofel as far as Hermagor. In some places around the long-stretching linear depressions, extended homogeneous zones, in terms of internal structure, can be recognized. With little variation they frequently show the same striking and dipping as the deep valleys. The opening of these ridge-top depressions (Tabor, 1971) by extension has not caused a

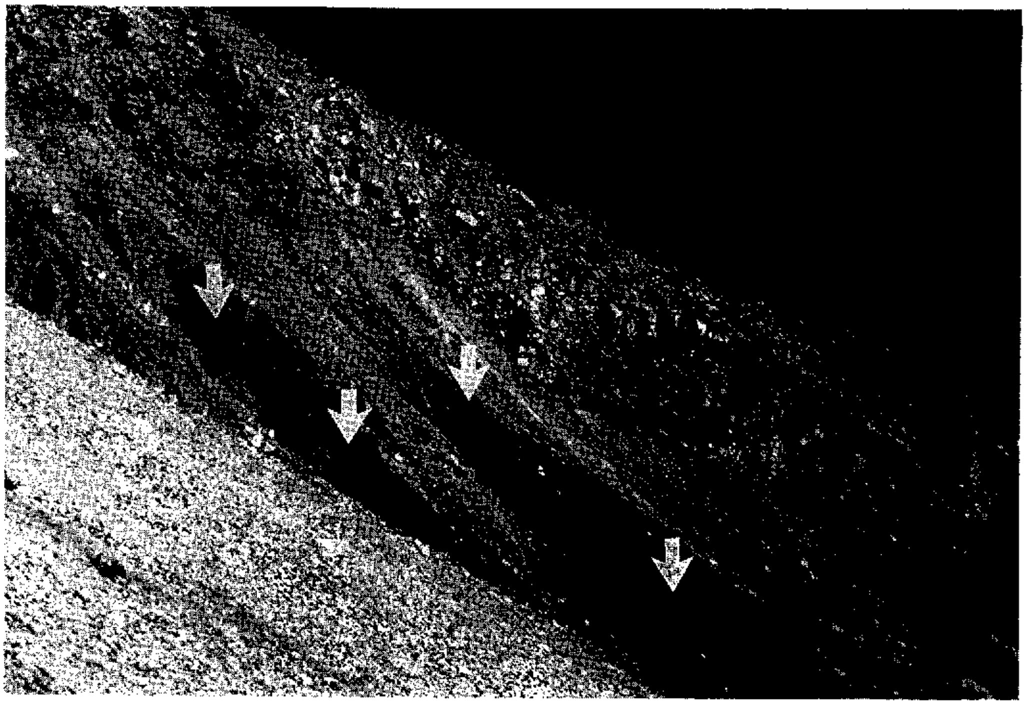

PLATE 5. Detail in the tongue area of the disintegrated mass. More or less disintegrated limestone on top of siltstone (dark dots in the foreground marked by arrows).

PLATE 6. Area of Hochwarter Höhe. Both generations of scarps are marked by arrows.

pronounced modification of dipping beyond statistical variation.

North of the main ridge these homogeneous zones along scarps and depressions show more or less a dipping between 80 and 60° to the north (Fig. 3, A2 and A3). This rotation of the larger rock units is probably caused by sliding, being also indicated by the abundant scarps. From the middle part of the slope towards the north, in all homogeneous zones along the scarps, dipping is turned to the south. It starts from more or less vertical to 20–10° at the lowest parts of the slope. Parallel to this development an increasing disintegration of the rocks occurred. In some places on the walls of the deeply incised (up to 100 m) creeks a bending of the structures from the original to the rotated ones is visible (Fig. 2).

This zone is identical with the convex part of the slope, and mainly with the distribution of the phyllonites. Nevertheless, the heavily deformed phyllonites are forming the steep toe showing the active movement of this part of the slope. In one place the loose, disintegrated phyllonite is even overthrust on top of the gneiss (Fig. 3, A4). This shows an overwhelming of the gneiss unit embedded within the phyllonite by this so-called Talzuschub (Stiny, 1941, 1942).

Summarizing, these structures can be interpreted as huge sagging (Zischinsky, 1966; Hutchinson, 1988) of the whole northfacing slope towards the Gitsch valley.

Probably shortly after the downmelting of the glacier the lower part of the slope started failing by toppling to the north. Probably simultaneously to this, the extension toward the north in the upper part triggered rotational sliding (scarps) and finally caused the ridge-top depressions along the whole ridge, parallel to the Gitsch valley.

Only in the westerly part around the wide, deeply incised headwaters of two creeks (N. Hochwarter Höhe) appears a second generation of scarps circling the headwaters (Fig. 2). These are younger than the others which is indicated by the fresh and unweathered morphology. Also their zigzagging course is controlled by the older ones (Plate 6).

South of Hochwarter Höhe the lower steep part of the slope is a sagged rock mass separated from the upper slope by a scarp nearly 100 m high. The short depression in the higher slope may have been caused by rotation and movement of greater homogeneous zones, also indicated by the rarely exposed rocks.

More to the east, below Kreuther Höhe, the same morphological pattern can be recognized. Here the steep southfacing upper part of the slope also shows some depressions without any lithological reason. Here a large-scale bending (Ter Stepanian, 1965) in this part of the slope is indicated by the outcrops in two small creeks (Fig. 3, B4). In this area the lower part of the slope seems to be undisturbed, maybe caused by stiffer quartzitic material and quartz-rich mica-schists.

The slope east of Scharbach shows a lot of very distinct depressions in the upper part. Here the structures also indicate a great-scale bending maybe with toppling (De Freitas and Watters, 1973; Goodman, 1976; Holmes and Jarvis, 1985; Giraud *et al.*, 1990) of some of the homogeneous zones causing these depressions. One of them is bearing a small bog 8 m thick.

The structures of the staircased lower parts point to a detachment of the rock masses without obvious rotation. The fresh unweathered scarps, especially in the lower part are indicating a young, maybe ongoing movement.

In the south-facing flank, slope deformation did not start with the failure of weak, very ductile material (e.g. phyllonite) in the lower part. Here, we believe, the overdeepening (about 300 m) of the Gail valley trough caused the mass movement by toppling and deep-reaching bending.

TIME

The time when the process of slope deformation started is unknown. Glacial or ice-marginal sediments (not shown on the map) are very rare in the described area but common east and west of it. Apart from some small remnants at the toe of the north slope (in less deformed areas, e.g. gneiss) we believe that most of the sediments are destroyed or have been destabilized by mass movements and finally been eroded by the creeks.

In one place in the middle part of the south-facing slope (near Guggenberg) undisturbed ice-marginal sediments are deposited on top of a rotated and subsided block with contact to the backwall. This indicates the beginning of the slope failure simultaneously with the downmelting of the glacier ice. The loss of the support of the slope (oversteepened by ice erosion) leads to the first failures. This activity is probably also enhanced by the occurrence of the overdeepened troughs in the Gail valley which was filled with water at this time.

So the sagging mass below Hochwarter Höhe with its high scarp as well as the high scarp at Guggenberg may have been formed under these conditions. Later on these masses became more stable by sediment filling of the trough causing a decrease of displacements. Only where the Gail river was pushed to the north by the violent torrent Oselitzenbach and constantly forced to erode the slope did it lead to a lateral spreading of the lower part of the slope (Fig. 3, B3).

A better defined time marker is represented by the small bog NW of Guggenberg, located in one of the E.–W. running depressions. Here, 8 m of peat developed after the depression was created. Due to the pollen content, the organic sedimentation started at least 12,000 BP during the Older Dryas or shortly before. This may be interpreted as that the slope deformation and mass movement evidently took place after the downmelting of the ice and slowed down later. Besides the filling of the overdeepened valley trough, increasing vegetation may have played a major role, protecting the slope from soaking with meltwater and rain.

Only in the northwestern part of the ridge (Hochwarter Höhe) the fresh unweathered scarp circling the headwaters of the two creeks indicates a young and higher activity. From these scarps, short-lived open cracks and a quickly changing drainage system in the past were reported from local people.

The actual mass movements in the permo-triassic sequence on Reißkofel probably started also simultaneously with the downmelting of the Gail glacier after the last glaciation. At this time the E.–W. striking joints formed or were activated on both sides of the cirque. For a short time, after the Gail valley had become ice-free the cirque was still occupied by a glacier.

This glacier tongue deposited several moraines, showing an ice retreat in many steps (Fig. 4). This ice retreat presumably happened during the early Late Glacial period before the end of Oldest Dryas, due to low elevation and south-exposition (van Husen, 1990). Maybe during, but at least after deglaciation of the cirque, the orthogonal joint system formed. The mechanism can be explained as a new jointing in the competent limestone after the loss of the supporting local glacier. This movement toward the cirque may have slowed down the other one to the south (Poisel, *pers. commun.*). According to measurements at the west side of the cirque the recent movement toward the east is more rapid than toward the south (Poisel, *pers. commun.*).

The cirque itself was formed by the breakdown of the limestone caused by the incompetent sand and siltstones below the triassic limestones. This development was probably triggered by the deep incision of Rinsenbach south of Reißkofel (Fig. 4). Slope deformation started on the river's right hand side probably in the eastern part of the cirque and mainly prograded to the west.

The similar situation east of Rinsenbach, in the headwaters of Kirchbach (Figs 2 and 4), did not lead to the same development. This may be due to a slightly different lithology, another relation of the incompetent to the competent rocks in thickness, and less incision of the rivers.

Hence, this breakdown of the limestones and the forming of the cirque-like feature began at least after the last but one glaciation. It already existed before Würm because it was filled by a local glacier immediately after the downmelting of the big valley glacier in the Gail valley, which has filled the area almost to the elevation of Reißkofel (Fig. 1).

The sagging mass in the center started moving again, and disintegration of structures took place and is still going on, generating a large amount of debris feeding the huge debris cone below the cirque (Fig. 2). By this disintegration, most of the huge blocks originated in the upper part of the mass. This process was a permanent one and is still going on, which is proved by the different weathering and vegetation cover of the blocks (Fig. 4).

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