Mitt. naturwiss. Ver. Steiermark | Band 130 | S. 31–42 | Graz 2000

# Modes and Structural Conditions of Large Scale Mass Movements (Sackungen) on Crystalline Basement Units of the Eastern Alps (Niedere Tauern, Austria)

By Siegfried Willibald HERMANN[1], Gregor MADRITSCH[2], Helmut RAUTH[3]
and Leander Peter BECKER[1]
With 8 Figures

Angenommen am 2. September 2000

**Zusammenfassung: Erscheinungsbilder gefügekontrollierter Großhangbewegungen (Sackungen) im kristallinen Grundgebirge der Ostalpen (Niedere Tauern, Österreich).** – Im Kristallin der Niederen Tauern sind Großhangbewegungen weitaus häufiger als bisher bekannt. An ausgewählten Sackungen innerhalb der Wölzer Glimmerschiefer werden die morphologischen Merkmale und die Beziehung von Lagerungsverhältnissen der Gesteine zu morphostrukturellen Endgliedern von Sackungen aufgezeigt. Folgende Endglieder von Sackungen können unterschieden werden: (a) Wenn die Hauptfoliation der Geisteine hangauswärts geneigt ist, weist die Sackung eine deutlich reduzierte Hangneigung gegenüber stabilen Hängen auf. Am Fuß der Sackung ist deutlich ein Talzuschub entwickelt. Der Oberhang weist im Detail komplexe Geometrien der Abriß- und Bergzerreißungszone auf, ihre morphologischen Erkennungsmerkmale sind aber nur undeutlich. (b) Sackungen, die an Hängen mit hangeinwärts orientierten und steil stehenden Flächengefügen entwickelt sind, weisen konvexe Hangprofile und in der Kammregion markante Bergzerreißungsphänomene, wie Doppelgrat- und Grabenstrukturen auf. Die durchschnittliche Hangneigung dieses Typs von Sackung ist gegenüber stabilen Hängen aber nicht verflacht. Alle Sackungen weisen stets individuelle Entwässerungsnetze auf, sind empfindlicher gegenüber Erosion und sekundären Massenbewegungen als stabile Bereiche und verwischen glazial gebildete Formen.

**Abstract:** Along the Niedere Tauern mountains many more sagging-type mass movements occur than are known so far. To examine the morphological characteristics of two opposite modes of occurrence, we illustrate six examples, which all are evolved within micaschist lithologies. The following end members can be outlined: (a) Saggings that occur on slopes where the main foliation of the rocks dips roughly parallel to the slope are characterised by a remarkable decrease of the average slope inclination with respect to stable slopes beside and by closing up of the valley ("Talzuschub"). Their upper slope portions record complex but morphologically not very strongly-developed mountain splitting structures. (b) In contrast, saggings on slopes where the dip of the principle foliation is into the slope, a convex slope profile without remarkable decrease of the average slope inclination are developed. However, those examples record expressive mountain splitting, including double crested ridges and ridge top grabens in upper slope portions. The average slope inclination of this type of sagging is not different to stable neighbouring slopes. Slopes that are affected by sagging in general indicate individual drainage patterns, provoke secondary landslides, are susceptible to enhanced erosion and degenerate the glacially-shaped landscape.

## 1. Introduction

Large portions of the central Upper Styria district were mapped in detail for the occurrence of large scale mass movements in the course of MSc theses (RAUTH 1996,

---

[1] UA Mag. Dr. Siegfried W. HERMANN und Univ. Prof. Dr. Leander Peter BECKER, Institut für Geologie u. Paläontologie d. Universität Graz, Heinrichstraße 26, A-8010 Graz, e-mail: siegfried.hermann@kfunigraz.ac.at
[2] Mag. Gregor MADRITSCH, Büro Plankl-Petz & Partner, Schöndorfplatz 6, 5400 Hallein
[3] Mag. Helmut RAUTH, Lendorfgasse 13, 9061 Klagenfurt

Madritsch 1999) as well as PhD theses (Hermann 1997) to make evident the frequency of Sackung-type slope instabilities on the Niedere Tauern mountains (Fig. 1).

The family of landslides we discuss here include mass movements of very slow creeping or dormant constitution and they are in the dimension up to several square kilometers. These mass movements include the phenomenon of mountain splitting in upper slope portions, (first described by Ampferer 1939 as "Bergzerreißung") and bulging toes in lower slope portions. The latter is often connected with the closing up of the valley (termed "Talzuschub" by Stiny 1941). Both phenomena later were attributed to the term "Sackung" by Zischinsky 1966. Nowadays the meaning of Sackung corresponds to the English term "sagging of mountain slopes" as defined by Hutchinson 1988, the term "lateral spreading of ridges" as defined by Jahn 1964 and the term "deep-reaching gravitational slope deformations" as defined by Dramis & Sorriso-Valvo 1994.

From the response of gravitational forces, especially steep sided ridges on high mountain slopes, are susceptible to Sackung-type mass movements. During the Würmian glacial period an up to 1700 meter thick ice shield covered the central portions of the Eastern Alps, including the Niedere Tauern mountain chain (van Husen 1981, 1987). Main valleys are therefore glacially-molded and characterised by symmetrical U-shaped cross sections. We have recognized that the pre-glacial valley floor in the region of Pusterwald was located 500 metres higher than present and in the region of the Sölk

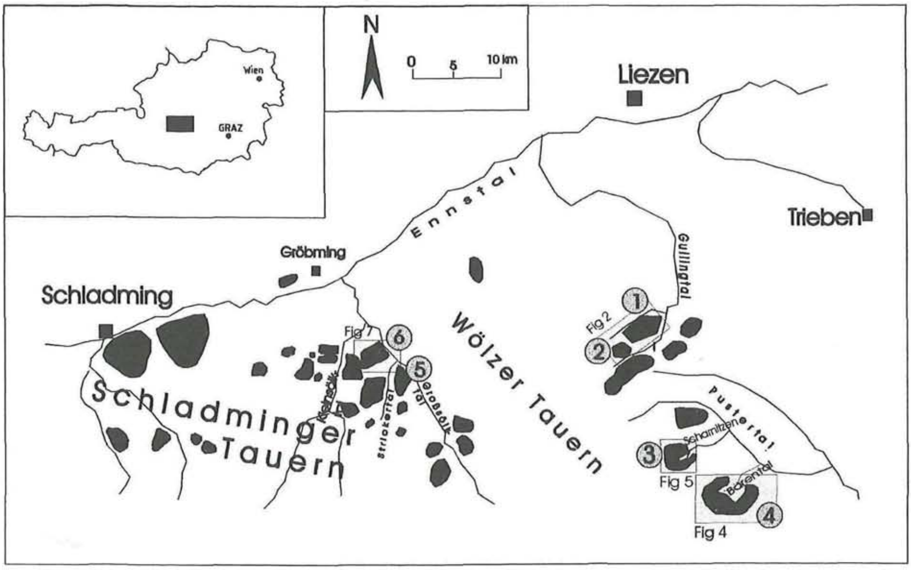

Fig. 1: Distribution of Sackung-type mass movements in northern portions of the Niedere Tauern mountains, the Schladminger Tauern mountains and the Wölzer Tauern mountains, respectively (state of knowledge: April 2000) and the allocation of sites mentioned in this paper: ①: site Weißgulling – Mt. Brennkogel, ②: site Schwarzgulling – Mt. Hintergullingspitz, ③: site Scharnitzengraben – Mt. Hühnerkogel, ④: site Bärental – Mt. Hoher Zinken, ⑤: site Großsölktal – Mt. Moditzen, ⑥: site Großsölktal – Mt. Ebeneck

Verbreitung von Sackungskörpern (Kenntnisstand April 2000) im Nordteil der Niederen Tauern (Schladminger Tauern und den Wölzer Tauern) und Lage der im Text erläuterten Fallbeispiele: ①: Weißgulling – Brennkogel, ②: Schwarzgulling – Hintergullingspitz, ③: site Scharnitzengraben - Hühnerkogel, ④: Bärental – Hoher Zinken, ⑤: Großsölktal – Moditzen, ⑥: Großsölktal – Ebeneck.

valleys it was even located up to a maximum of 1200 metres higher than present. As a consequence high slopes are frequent in the Niedere Tauern.

Here, we contribute to the morphologic and topographic features of sagging of mountain slopes in contact with crystalline host rock lithologies. We do so by illustrating six examples, selected out of 35 that we detected. These examples are developed on similar lithologies and are appropriate to emphasize the spectrum of surface morphological features, accompanying mass-movements and their control by the structural and metamorphic fabrics.

## 2. Lithology and structural setting

The six examples presented here all are in contact with the Wölz micaschist complex that covers the north-easternmost part of the Schladminger Tauern and main part of the Wölzer Tauern (Fig. 1). The Wölz micaschist complex is made up of siliciclastics and marbles that may be derived from a shelf environment of suggested Silurian to Devonian age (Becker 1981). The complex is intruded by swarms of Permian pegmatites. This basement forms a crustal scale anticlinal structure with north dipping schistosity in the northern part and south dipping schistosity in the southern part of the area of investigation.

Two main overprints at amphibolite facies metamorphic conditions can be detected from radiometric data (e.g. Hejl, 1984) as well as structural and petrological analysis (Apart & Martinelli 1991). These overprints resulted in the development of a penetrative foliation forming the main fabric. Exceptionally for the northernmost portions of the Wölz crystalline complex is that there occurred a greenschist facies metamorphic overprint during lower Cretaceous (Eoalpine) stacking of the Austroalpine nappe complex. This overprint is accompanied by non-coaxial deformation and deformation of phyllonitic schists.

In addition three more sets of foliations can be distinguished: (i) domains of a north dipping transversal crenulation cleavage that becomes a penetrative fabric in the surroundings of the Enns valley. This implies that this fabric most probably is related to an early stage of escape tectonics (Wang & Neubauer 1998). (ii) NW-SE directed and ENE-WSW directed cataclastic faults that form crosscutting fabrics of brittle structures and were developed during Miocene strike slip deformation and (iii) consistently NNE-SSW striking sets of master joints. The principle drainage network is controlled by these brittle fabrics.

In the following section we will give a brief description of the characteristic morphological features of Sackungen. The maps and photos presented reflect surface morphological structures at that time of field seasons and may change in future times. The figures 2 and 3 were generated by Rauth during field season 1995 (Rauth 1996), figure 4 was generated by Madritsch during field seasons 1997 and 1998 (Madritsch 1999), figures 6 and 7 were generated by Hermann during field seasons 1994 and 1995 (Hermann 1997). Figure 5 is a detail of the ÖLK 10 (Austrian Orthophoto Map) map sheet number 5328-102 and was shot 1986.

At each sub-section, 3.1 to 3.3 two sites are discussed together for the following reasons: (i) firstly, both examples at each subsection 3.2, 3.2 and 3.3 were mapped by the co-authers, Rauth, Madritsch and Hermann, respectively, (ii) secondly they are develoved on slopes of comparable lithology and structure and (iii) finally because of the neighbourhood of the saggings in each subsection we can assume equal slope morphometric conditions before sagging was initiated. By discussing two examples in each subsection it is easy to compare neighbouring examples by contrasting their different morphologies.

## 3. Examples

### 3.1. Sackung Weißgulling – Mt. Brennkogel (number 1 in Fig.1) and Sackung Schwarzgulling – Mt. Hintergullingspitz (number 2 in Fig. 1)

The uppermost portion of the Gulling valley splits into two parallel valley segments (Fig. 1), the Schwarzgulling valley to the south and the Weißgulling valley to the north (Fig. 2). The ridge in between these valleys consequently is aligned parallel to ENE-WSW directed cataclastic fault zones (Hermann 1997). The schistosity is gently and consistently dipping to the north (Fig. 2). Straight-lined mountain splitting structures between mount Brennkogel and mount Hintergullingspitz, including double crested ridges, multiple crested ridges and ridge top grabens. Closing up of central portions of Weißgulling valley indicate deep reaching slope instabilities in both directions, to the south and to the north (Fig. 2).

At mount Brennkogel an E-W trending single scarp in the manner of a single normal fault geometry can be traced along a distance of 1100 meters. That structure generates an asymmetric half graben indicating movement to the north and therefore a Sackung type slope instability towards the Weißgulling river. East of mount Brennkogel the single scarp splits into a set of multiple scarps to form an area of mountain splitting. Below that area rock fall debris and blocky talus is deposited. West of mount Brennkogel main scarp is accompanied by uphill facing scarps. These form counterscarps of antithetic displacement but also a broad ridge of mountain splitting. Multiple crested ridges near the cote 1848 elevation are developed as their morphological expression. There, ephemeral ponds are fixed to the exposure of displacement surfaces (Fig. 3).

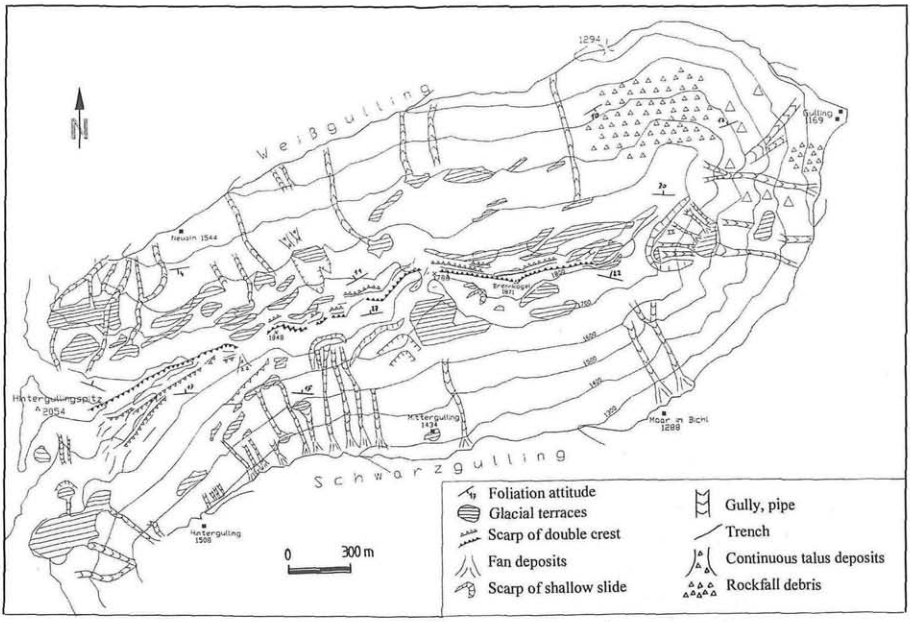

Fig. 2: Morphological map of site Weißgulling – Mt. Brennkogel (1) and Schwarzgulling – Mt. Hintergullingspitz (2). For location see Fig.1.
Morphologische Karte der Hangbewegungen Weißgullingtal – Brennkogel (1) und Schwarzgullingtal – Hintergullingspitz (2). Lage siehe Fig.1.

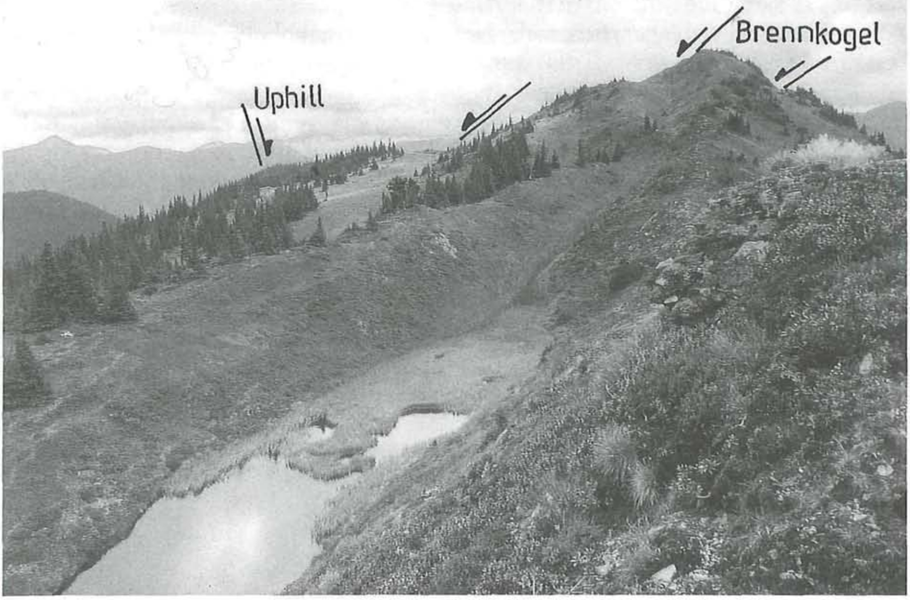

Fig. 3: The multiple crested ridge at Mt. Brennkogel was generated by synchronous displacement of conjugate synthetic normal faults (single scarps and double crests) and antithetic faults (uphill facing scarps). The rigde top valley of the main scarp in the foreground is traced by an ephemeral pond.
Mehrfachgrate am Brennkogel bilden sich durch gestaffelt angeordnete Abriße an konjugiert entwickelten Abschiebungsbahnen, synthetische Abschiebungen erzeugen Einfach- und Doppelgrate, anithetische Abschiebungen erzeugen hangparallele Leisten (Uphills). An das Kammtälchen der Hauptabrißkante ist ein Nackensee (Vordergrund) gebunden.

West of the Hintergullingspitz a single scarp forms an impressive ridge top valley of strong asymmetry. The scarp can be traced more than one kilometer. The maximum displacement in central portions is about 120 meters. Below this (at Hintergulling – "Alm" at cote 1508 elevation), glacial terraces are down shifted by the same amount. In contrast to the Brennkogel the scarp at mount Hintergullingspitz indicates displacement to the south facing slope towards the Schwarzgulling river. It´s western branch leads into numerous minor scarps as well as counterscarps to form an area of mountain splitting. The eastern branch of the scarp at the Hintergullingspitz overlaps the western branch of the scarp at the Brennkogel and consequently form bilateral gravitational spreading of the mountain ridge as shown by Jahn 1964 and Hutchinson 1988.

Those portions of the slopes which are affected by Sackung-type mass movements systematically are drained by shallow gullies and pipes (Fig. 3). The sub-parallel pattern of this type of drainage can also be used as indicator for instabilities and is in contrast to the more dendritic drainage pattern of the neighbouring stable slopes. As a further indicator for slope instabilities, dismembering of glacial molded plateau areas on the convex bulging slope to the Weissgulling river was noticed.

### 3.2. Sackung Scharnitzgraben – Mt. Hühnerkogel (number 3 in Fig. 1) and Bärental – Mt. Hoher Zinken (number 4 in Fig. 1)

Mesoscale open folds at site mount Hühnerkogel are formed by the east and west dipping foliation planes, whereas a flat lying foliation at site mount Hoher Zinken was recognised. Both, the Scharnitzen valley and the Bärental valley, delineate a subordinate NE-SW trending drainage system with respect to the Pustertal valley (Fig.1). They follow one of the main joint sets (Madritsch 1999) and portray NW exposed glacial cirque landscape of basin like surface geometry.

At each of these examples, mountain splitting can be noticed along a distance of several kilometers, concentric copying the glacial cirques of upper most portions of at the Scharnitzen valley and the Bärental valley. Local drainage network and shallow gullies run radially from alpine pasture towards the central bottom of the glacial cirques. This is very well-demonstrated at the example Bärental – mount Hoher Zinken (Fig. 4). At that site east of the Hoher Zinken a complex mountain splitting area is controlled by the interaction of main scarps and counterfacing scarps to generate microscale horst and graben structures. Particularly down slope to the north a large rotational landslide is located (Fig. 4).

Fig. 5 illustrates how two prominent scarps form a well-defined triple-crested ridge structure near mount Hühnerkogel. Towards the saddle Stallertörl this structure transforms into a set of en enchelon oriented scarps. The north facing slope towards valley Scharnitz is characterised by terraced slope morphology including uphill facing counter scarps, which frequently carry small ephemeral ponds. North of the Hühnerkogel an active block glacier as indicated by a steep front at an elevation of 2100 meters within a coarse talus occurs.

### 3.3. Sackung Moditzen (number 5 in Fig. 1) and Sackung Ebeneck (number 6 in Fig. 1)

The examples of mount Moditzen and Ebeneck are located near the Sölktal-lineament (Tollmann 1977) which represents an antithetic dextral strike slip fault with

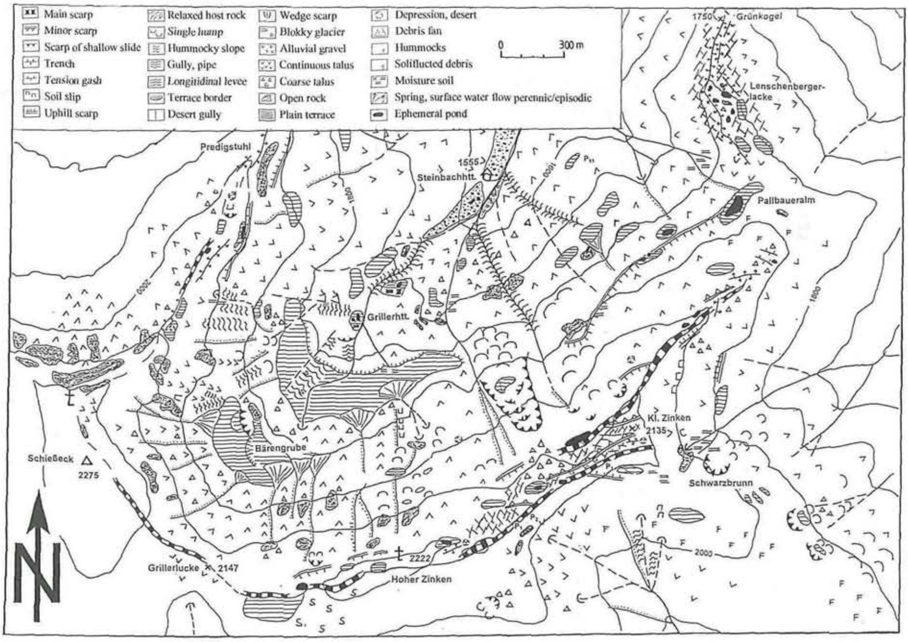

Fig. 4: Morphological map of site Bärental – Mt. Hoher Zinken (4). For location see Fig.1.
Morphologische Karte der Sackung Bärental – Hoher Zinken (4). Lage siehe Fig.1.

respect to the Ennstal fault system (HERMANN 1997). In the surroundings of the NNW-SSE oriented Sölktal valley, NNE-SSW directed subvertical master joints do control local drainage network (see Fig. 1), e.g. the Kleinsölktal valley and the Strickertal valley.

Morphometric conditions of mount Moditzen show relics of an table mountain, which is not a very common relief within the crystalline basement of the Niedere Tauern mountains. The plateau is exposed from 1920 meter to 1970 meter elevation and forms a gentle NE dipping rectangle square north to the peak of mount Moditzen. This plateau

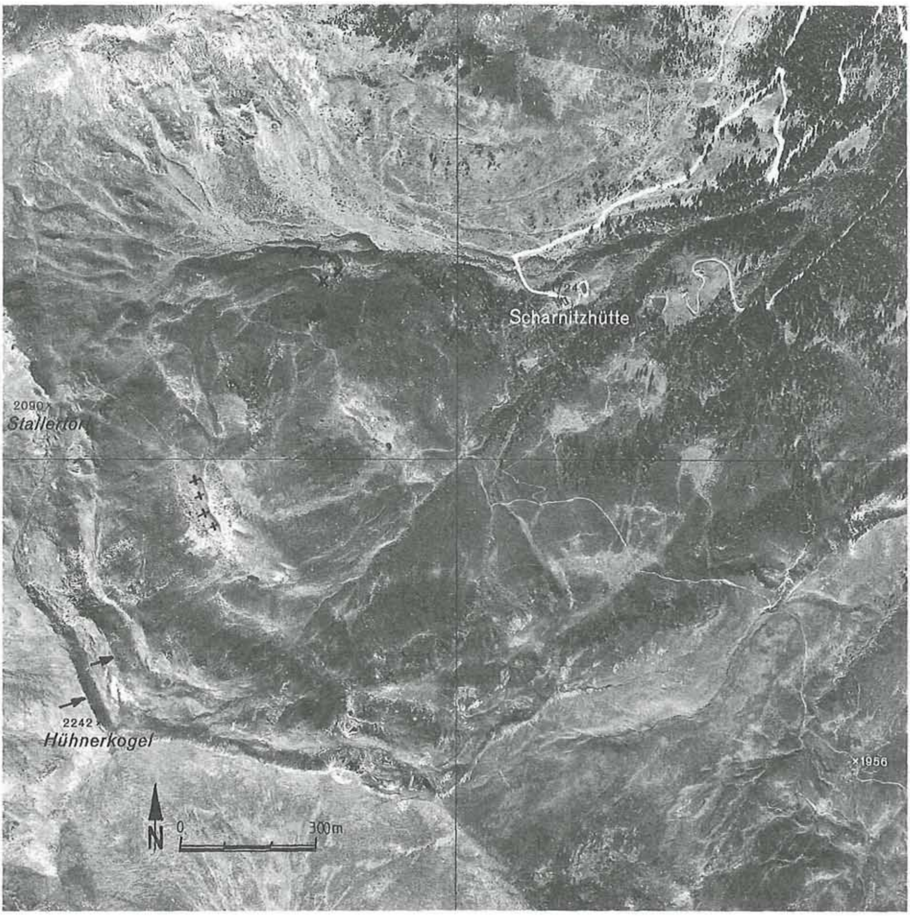

Fig. 5: © BEV – 2000, Vervielfältigung mit Genehmigung des BEV – Bundesamtes für Eich- und Vermessungswesen in Wien, Zl. 38163/00. Orthofotographic view of site Scharnitzengraben – Mt. Hühnerkogel (3). (detail of ÖLK 10, sheet number 5325-102, Wildalmhütte). Two main zones of gravitational displacement (arrows mark main scarp and record the direction of movement) are forming a three times crested rigde including two main ridge-top graben north and nortwest of Mt. Hühnerkogel. Near the saddle Stallertörl ridge top grabens transform into en enchelon oriented crests of mountain splitting. Black cross lines mark the front slope of a block glacier.

Orthofoto-Ansicht der Sackung Scharnitzgraben – Hühnerkogel (3), (Ausschnitt aus ÖLK 10, Blatt 5325-102, Wildalmhütte). Wien. Zwei Hauptabschiebungen generieren einen Dreifachgrat nördlich und nordwestlich des Hühnerkogel (Pfeile markieren Abrißkanten und weisen in Bewegungsrichtung. Am Sattel Stallertörl leiten die zwei Kammgräben in gestaffelte Zerrgräben einer Bergzerreißungszone über. Die schwarzen Kreuze markieren die Stirn eines Blockgletschers.

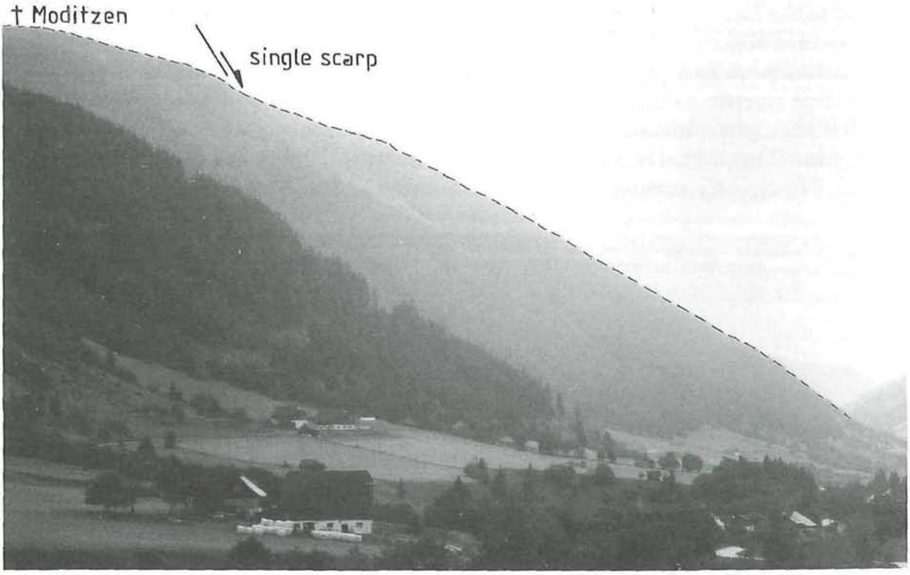

Fig. 6: Convex slope profile of example Großsölktal – Mt. Moditzen (5), view to the north. Arrow marks a zone of disintegration and mountain splitting at the plateau. The U-shaped slopes profile has been rubbed through bulging. For location see Fig. 1.
Im konvex geformte Hangprofil der Sackung Großsölktal – Moditzen (5) sind glaziale Formen (Trogschulter, Trogwand) verwischt, Blickrichtung Norden. Der Pfeil markiert den Bereich der Bergzerreißung und der Hauptabrißkante. Lage siehe Fig.1.

is contoured in the mean through a northeast dipping schistosity. Nevertheless, the north-easternmost portion of the plateau ridge is degenerated by mountain splitting. The slope below shows a convex slope profile (Fig. 6) and contrasts U-shaped valley cross sections of stable slopes (e.g. the southwest facing slope of mount Moditzen). Within middle slope portions several shallow scarps, always connected to active erosional systems, are developed. Prolongation of the Sackung is limited through a narrow spacing set of master joints to the southeast (Hermann 1997).

The Sackung at site mount Ebeneck distinctively illustrates the features of a "Talzuschub"- structure. A convex bulging toe cycles into the storage lake Großsölk. Beyond the Ebeneck average slope inclination has decreased down to 22° and contrasts stable slope conditions, which are in the range of 30° to 35° in that area. Within the sagging mass, several families of scarps and dry longitudinal gullies occur to cut the unstable slope into distinct portions (Fig. 7). In lateral extension active centers of erosion are set apart. Limitation to the north is given here by the incident of transversal crenulation cleavage steeply dipping north.

## 4. Discussion

On the basis of extensive field mapping a high number of slope instabilities could be detected within the Niedere Tauern mountains (Fig. 1). The sackung-type mass movements we have studied have the following characteristics, but not all of them may be developed at each site:

- A main graben or several grabens along the ridge crest.
- Double crested to multiple crested ridges.

- Uphill-facing scarps or counter-scarps.
- Ephemeral ponds.
- Bulging of the lower part of the slope.
- Closing up of the valley.
- Occurrence on the upper flanks of glaciated valleys.
- A local relief of more than 500 meters.

The assemblage of these features as a result of near surface strain can be explained by the reorganisation of pre-existing discontinuities. That causes higher porosity and lower resistance to erosion. Consequently all the slopes which are affected by Sackungen indicate an individual drainage pattern, and carry secondary landslides (see Fig. 4 and Fig. 7). We suggest that numerous rock fall debris and coarse blocky talus can be assigned to the presence of Sackungen (see Fig. 2 and Fig. 5).

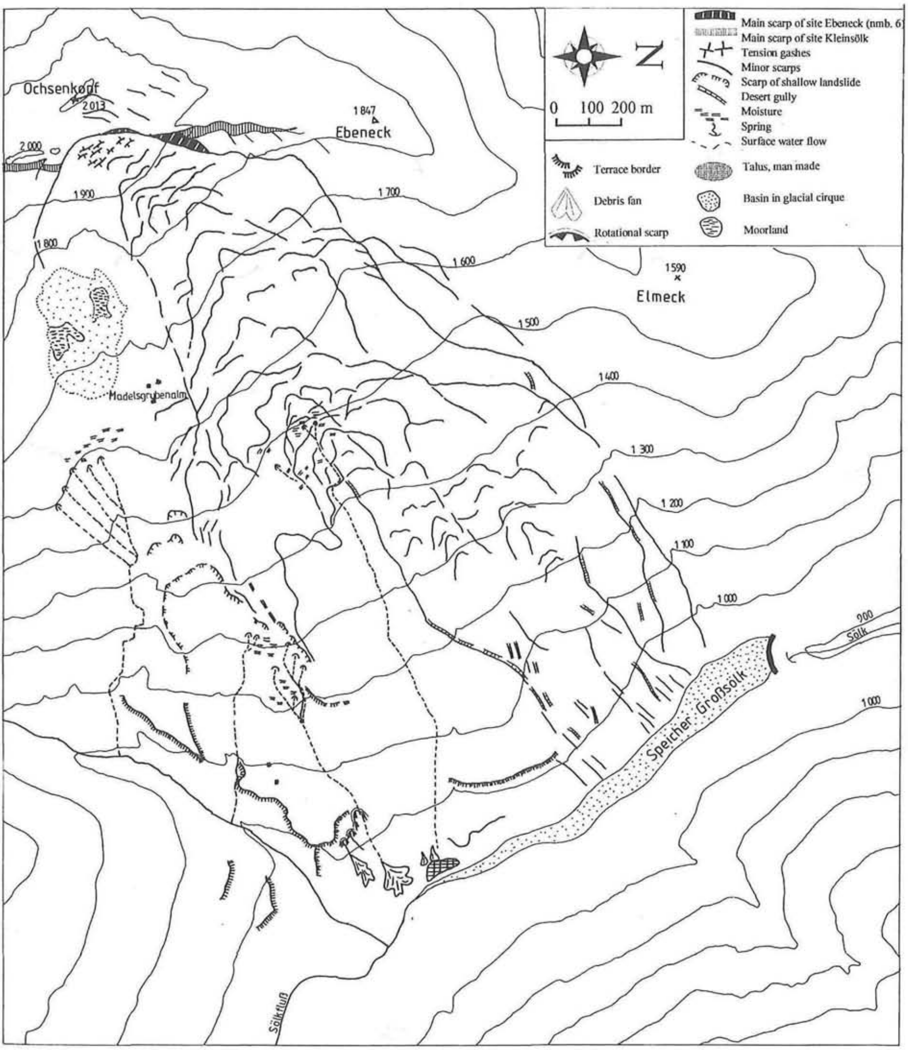

Fig. 7: Morphostructural map of site Großsölktal – Mt. Ebeneck (6). For location see Fig.1.
Morphostrukturelle Karte der Sackung Großsölktal – Ebeneck (6). Lage siehe Fig. 1.

It is widely accepted that evidence of planar discontinuities is a main factor for the stability of high slopes and therefore the occurrence of sackung–type mass-movements is connected to high and steep slopes of strongly-foliated host rock lithologies (e.g. MOSER 1993). On the other hand, slope height and slope stability are limited by the materials involved as well as the orientation of the main planar discontinuities with respect to the slope faces (HOEK & BRAY 1981). Hence, slopes that are situated on lithologies with a foliation running out of the slope are more susceptible to Sackung type mass-movements. This was already predicted by STINY 1941.

Detailed documentation of the structural inventory of those slope instabilities were presented here. All of them are developed on similar lithologies, which gives evidence that this prediction is valuable for the examples of Brennkogel, Moditzen and Ebeneck, partly valuable for site Hühnerkogel and example Hoher Zinken but is not valuable for the example Hintergullingspitz. That means that initiation of about 35% of these slope instabilities is not controlled by the orientation of main foliation. But we have seen that orientation of discontinuities clearly controls the mannerism of sackung–type mass-movements that is shown in the cartoon of Fig. 8. The fact that orientation of discontinuities controls surface morphology of sackungen very well is exemplified by the ridge in between Weißgulling valley and Schwarzgulling valley (Fig. 2), where the ridge can be divided into two sections (western section: site 1 and eastern section: site 2): The western section including the Sackung Weißgulling-Brennkogel is characterised by complex but not exhaustive mountain splitting in upper slope portions, decreased average slope angle, and the presence of bulging toe in combination with closing up of Weißgulling valley (Talzuschub). The easternmost section including the Sackung Schwarzgulling-Hintergullingspitz is defined by one single scarp, the set up of an double crested ridge and a ridge top graben. There is no bulging at the toe and no closing up of the valley below.

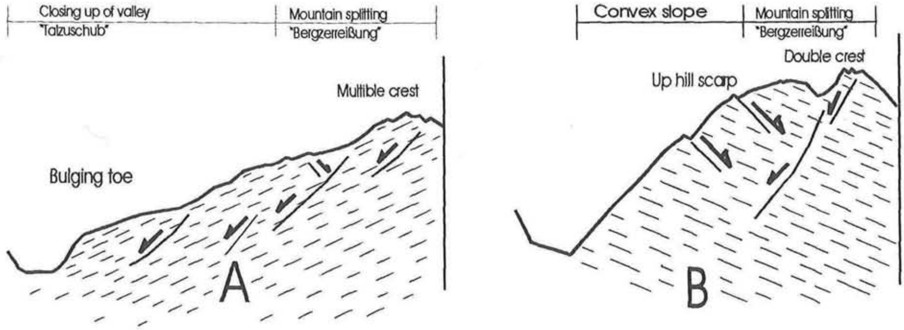

Fig. 8: Compilatoric scetch of the two endmembers of sackung-type mass-movements with respect to their control on host rock fabric. If schistosity is running out of the slope then main average slope inclination has decreased and has become concave on upper slope and convex on lower slope and the main morphological features are complex mountain splitting including multiple scarps, sensitive middle slope, bulging toe (a). If schistosity is running into the slope the average slope inclination not necessary has decreased with respect to stable slopes but main morphological features as double crested ridge with ridge top graben, uphill-facing counter-scarps and a convex slope profile (b).
Schematische Darstellung der morphologischen Endglieder von Sackungen in Abhängigkeit von den Lagerungsverhältnissen. (a): Bei hangauswärts geneigtem Flächengefüge ist eine deutliche Hangverflachung gegeben. Der Oberhang ist konkav, der Hangfuß stets vorgeschoben (Talzuschub). Bergzerreißung durch Mehrfachgrate sowie eine "unruhige" Oberflächenmorphologie im Mittelhang sind charakteristisch. (b): Bei hangeinwärts fallendem Flächengefüge zeigen Sackungen markante Doppelgratstrukturen und hangparallele Gräben ("Uphills") im oberen Hangabschnitt. Ein konvexes Hangprofil ist kennzeichnend typisch.

A similar situation occurs at the example mount Ebeneck (6). There, double sided spreading of the ridge is given by two large Sackungen. First, the Ebeneck sackung, located on the east facing slope into the Großsölk valley and second the Ochsenkopf sackung (Fig. 7) located in the Kleinsölk valley. At the former, the schistosity dips out of the slope, at the latter it dips into the slope. Because of this, the total distorted rock mass of the Ebeneck sackung displays an extreme bulging of the toe, while Ochsenkopf sackung (Fig. 7) is crowned by a prominent single scarp with a ridge top valley structure (see Becker & Hermann 1998).

At the examples 3 and 4, configuration of mountain splitting continuously transforms from double crested ridges, respectively into multiple crested ones, while walking around the scars at more or less constant north dipping schistosity (Fig. 4). Running out schistosity is the causing factor for slope instability is displayed at example Moditzen. There, only the northeast facing slope, which tends parallel to shistosity, is affected by a Sackung.

## 5. Conclusions

In Fig. 8 the extremities of sackung-type mass-movements are shown. Those we can deduce from the sites investigated within strongly-foliated schists. There is no clear evidence that orientation of foliation primary is a triggering factor for Sackungen because slopes indicating foliation running into the slope also are destabilized at comparable terminal conditions (glacial morphometry, lithology, climate).

At the one extreme, if main foliation runs out of the slope (Fig. 8A) (that can be realized either if the (i) slope is steeper than the foliation and both dip in the same direction or (ii) if there is a large difference between slope angle and dip angle of the foliation, then the intersection between slope and foliation must be less steep than the slope), we always observe a remarkable decrease of the average slope inclination through the action of Sackungen and the slope has become convex at the lowermost slope portions and more concave in upper slope portions. Mountain splitting features are complex but not strongly-developed and are always given by a set of scarps including uphill-facing scarps, tension gashes and single cracks. Middle slope portions indicate scarps related to more shallow planar slides and rotational slumps.

On the other extreme, if schistosity runs into the slope (Fig. 8B), there is no remarkable decrease of slope inclination. In this case slope instability is determined by prominent features at the top of the ridge including double crested ridges and ridge top graben structures.

## Acknowledgements

We gratefully acknowledge discussions with Harald Fritz, Jürgen Loizenbauer, Kurt Stüwe and Wolfgang Unzog. We thank Walter Kurz for the review of an early version of the manuscript.

## References

Apart R. & Martinelli W. 1991: Variszische und Alpidische Entwicklungsgeschichte des Wölzer Kristallins (Steiermark, Österreich). – Mitt. Ges. Geol. Bergbaustud. Österr. 37: 1–14.

Becker L. P. 1981: Zur Gliederung des Obersteirischen Altkristallins (Muriden). Mit Bemerkungen zu den Erzvorkommen in den einzelnen Kristallinkomplexen. – Verh. Geol. B.-A. 1981 (2): 3–17.

Becker L. P. & Hermann S. 1998: Eine rezente Großrutschung im Kleinen Sölktal der zentralen Obersteiermark. – Mitt. Ref. Geol. und Paläont. Landesmuseum Joanneum, SH 2: 65–80.

DRAMIS F. & SORRISO-VALVO M. 1994: Deep-seated gravitational slope deformations, related landslides and tectonics. – Eng. Geol. 38: 231–243.

HEJL E. 1984: Geochronologische und petrologische Beiträge zur Gesteinsmetamorphose der Schladminger Tauern. – Mitt. Ges. Geol. Bergbaustud. Österr. 30/31: 289–318.

HERMANN S. 1997: Tiefreichende Hangbewegungen im Kristallin der Niederen Tauern. – Unpubl. Ph.D. Thesis, Naturwiss. Fak. University of Graz, 191+36 pp.

HOEK E. & BRAY J.W. 1981: Rock slope engineering. 3rd ed. – The Institution of mining and Metallurgy, London.

HUTCHINSON J. N. 1988: Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. – 5th Int. Symp. Landslides, Vol.1: 3–35. Lausanne.

JAHN A. 1964: Slow morphological features resulting from gravitation. – Zeitschr. Geomorph. Sd. 5: 59–72.

MADRITSCH G. 1999: Aktive und inaktive Massenbewegungen in den Wölzer Tauern im Raum Lachtal-Pusterwald. – Unpubl. MSc. Thesis, Naturwiss. Fak. University of Graz, 108 pp.

MOSER M. 1993: Was wissen wir über Talzuschübe? – Geotechnik Sonderband, 4–14. Stuttgart.

RAUTH H. 1996: Bergzerreißung und Talzuschub am Beispiel Brennkogel-Gulling, Steiermark. – Unpubl. MSc. Thesis, Naturwiss. Fak. University of Graz, 73 pp.

STINY J. 1941: Unsere Täler wachsen zu. – Geol. Bauwes. (Wien) 13: 71–79.

TOLLMANN A. 1977: Die Bruchtektonik Österreichs im Satellitenbild. – N. Jb. Geol. Paläont. Abh., 153, 1-27.

TOLLMANN A. 1987: The alpidic evolution of the Eastern Alps. – In: FLÜGEL H. W. & FAUPL P. (eds): Geodynamics of the Eastern Alps. Wien, Deuticke.

HUSEN VAN D. 1981: Verbreitung, Ursachen und Füllung glazial übertiefter Talabschnitte an Beispielen in den Ostalpen. – Eiszeitalter u. Gegenwart 29: 9–22.

HUSEN VAN D. 1987: Die Ostalpen in den Eiszeiten. – Populärwiss. Veröff. Geol. B.-A., Wien.

WANG X. & NEUBAUER F. 1998: Orogen-parallel strike-slip faults bordering metamorphic core complexes: the Salzach-Enns fault zone in the Eastern Alps, Austria. – J. Struct. Geol. 20: 799–818.

ZISCHINSKY U. 1966: Bewegungsbilder instabiler Talfanken. – Mitt. Ges. Geol. Bergbaustud. 17: 127–168.