Lienz and surrounding

(Jürgen M. Reitner & Manfred Linner)

Coordinates: UTM WGS84 33N E 313993, N 5204238 (Feld/Matrei, location 1 in Fig. 1a)
E 325587, N 5195977 (Oberes Törl location 2 in Fig. 1a)
E 324547, N 5187948 (Hochstein location 6 in Fig. 1a)
Site, county: Villages of Matrei, Ainet, Leisach, Assling, Oberlienz and Thurn, all province of Tyrol
Type of the slope failure: Different types of deep-seated gravitational slope deformations (DGSD)
Specific area: Isel valley, Drau valley (Pustertal)

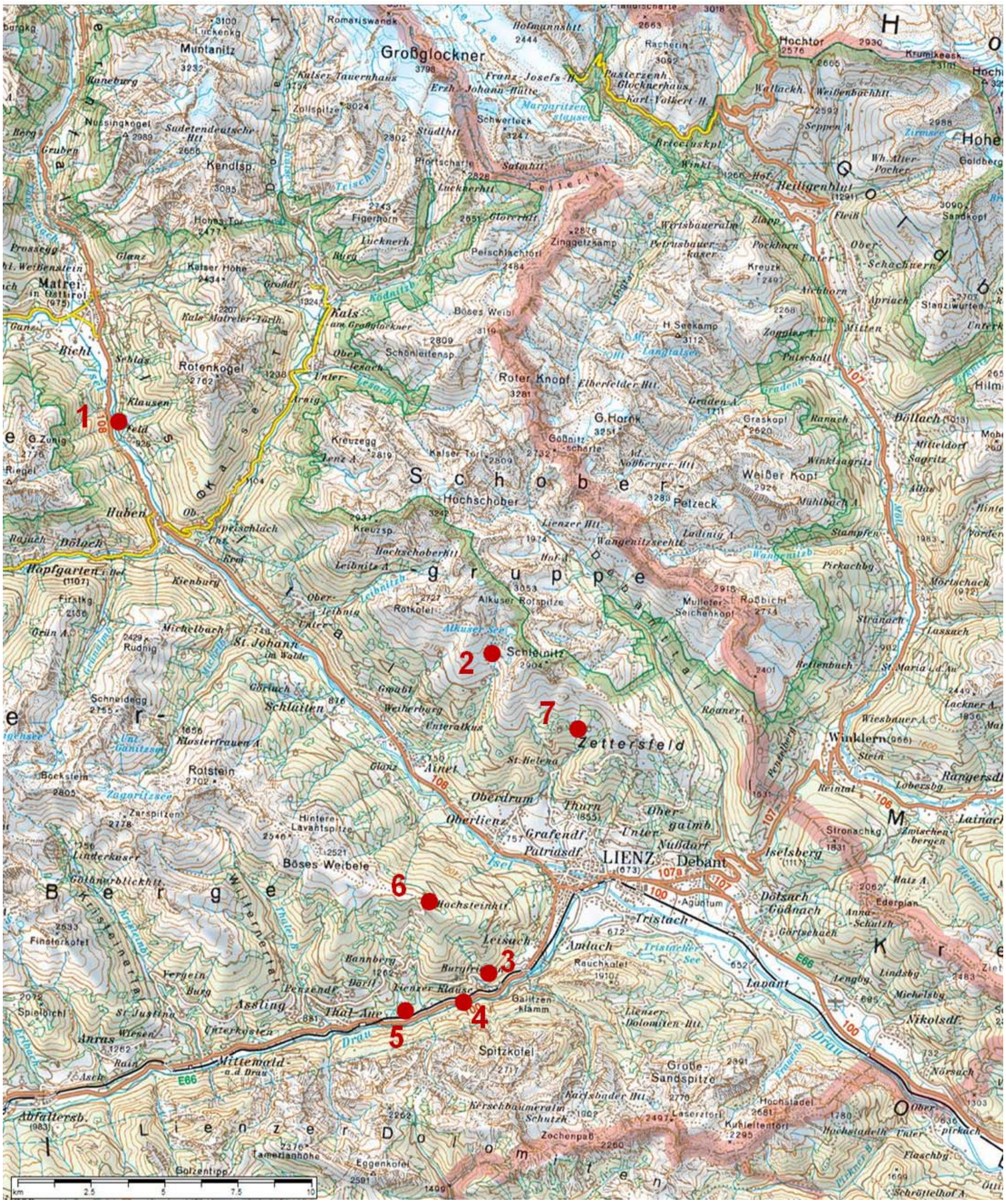


Figure 1a. Map with major locations along the excursion route.

SITE 1 (in the case of bad weather only)

On the way from Matrei to Lienz the excursion route passes the sturzstrom deposit of Feld/Matrei (location 1 in Fig. 1a), which will be studied in the field only in the case of bad weather conditions. This rock avalanche event, which blocked the Isel valley at the lower part of the Matrei basin, was considered to represent a typical "post-glacial" mass movement (VEIT, 1988). However, direct dating of boulders with ^{10}Be and ^{14}C dating of backwater deposits show that this rapid mass movement occurred about 1400 years ago.

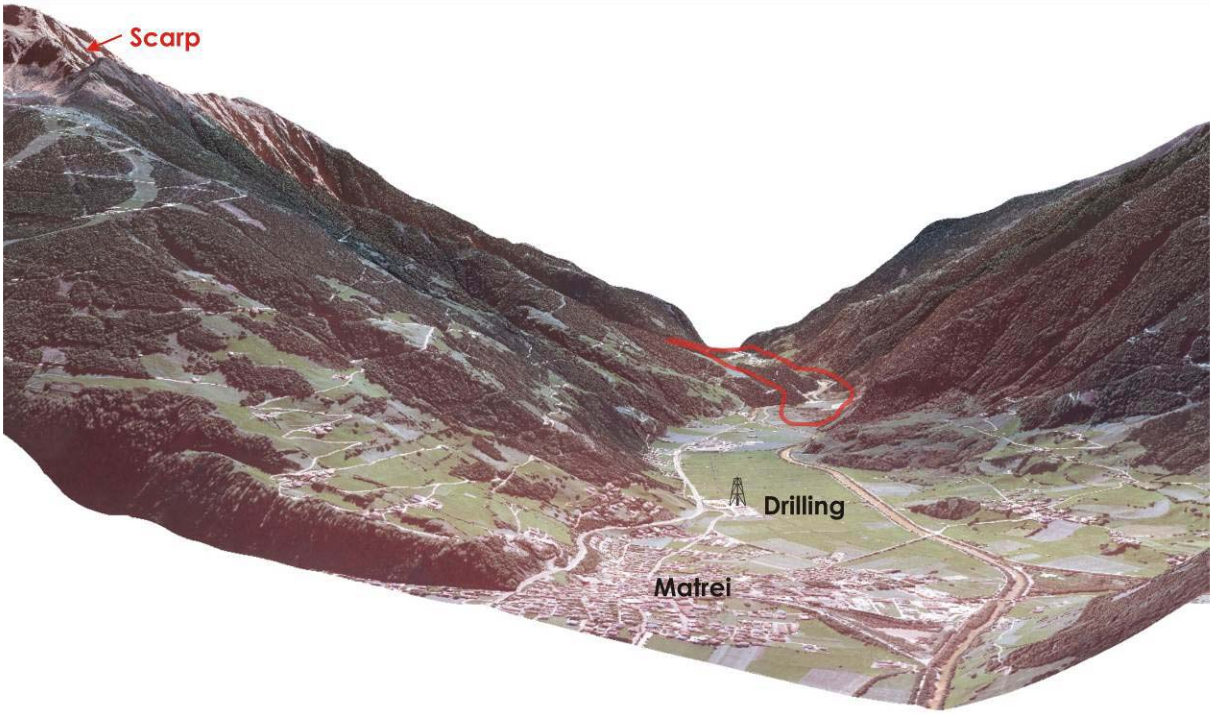


Figure 1b. View from Matrei towards S (= downstream). The flat area of the Matrei basin with the meandering river Isel is in the foreground. The sturzstrom barrier has a red contour. The drilling site indicates the location of the ^{14}C dated backwater sediments (REITNER et al., 2006).

SITE 2

The first regular excursion site (location 2 in Fig. 1a) after Glunzerberg (Matrei) is located in the lower part of the valley of the river Isel, on the southern flank of the mountain range Schobergruppe above the village of Ainet and the settlement of Unteralkus (indicated in the map).

Two textbook examples of rock-slope failure (RSF) by deep-seated toppling (for details see REITNER & LINNER, 2009) show the importance of pre-existing Alpine tectonic structures, e.g. strike-slip faults, for toppling formation, and document specific geomorphological and rock mechanical conditions at the toe and at the flanks as a prerequisite for the preservation of toppling structures.

The study area is dominated by micaschist and paragneiss and situated in Eastern Tyrol northwest of Lienz, close to a major NW-SE trending strike-slip fault (Isel fault). The upper slope is characterised by a saw-tooth morphology due to a series of up to 1.5 km long antislope scarps with an upslope trend towards lower dip (80° to 45°) and with up to 300 m wide graben structures in the topmost part. The pattern of these linear structures shows a striking similarity with that of the vertically oriented brittle structures (faults) linked to the major fault system. These features together with the hydrological regime (no surface flow, location of the springs) indicate a deep-seated gravitational slope deformation (DGSD). A bulging toe, typical for the RSF of sackung (sagging) as defined by ZISCHINSKY (1966, 1969), is absent.

Kinematic analyses according to GOODMAN & BRAY (1976) demonstrate toppling as the only plausible RSF mechanism due to interlayer-slip along this set of discontinuities (faults and joints).

Flexural toppling is inferred to be the dominant mode of RSF, whereas the block-flexural mode is apparent in the topmost area where discontinuities have been rotated beyond the limit of flexural toppling. The observed rock disintegration with open joints can be described as the result of an initial collapse along the existing discontinuities.

Glacial over-steepening during the Last Glacial Maximum (LGM) followed by the loss of support in the early Lateglacial phase of ice-decay most probably caused the onset of the RSF. At present, the mass-movements towards the main valley seem to have ceased due to a self-stabilizing effect of the flexural-toppling mode at the lower part of the DGSD. In addition (secondary) rock creep along the flanks, especially in the area of the heavily disintegrated graben structures towards the tributary valleys, may also have had a major impact on slope stability due to the reduction of load in the topmost part. This unloading at the flanks in combination with the orientation of the cross-joint system (re-activated foliation gently dipping into the slope), which prevent a downward slip, and the absence of fluvial erosion at the toe, caused the preservation of these rare toppling structures.

A transition from toppling to sackung (POISEL, 1998), the major RSF in crystalline rocks in Alpine valleys, did not occur in these cases. However, as a strictly structure-controlled process, toppling is regarded as a significant initial phase of RSF development. Thus, its impact on valley shaping and landscape evolution especially in the longitudinal valleys of the Alps appears to be underestimated.

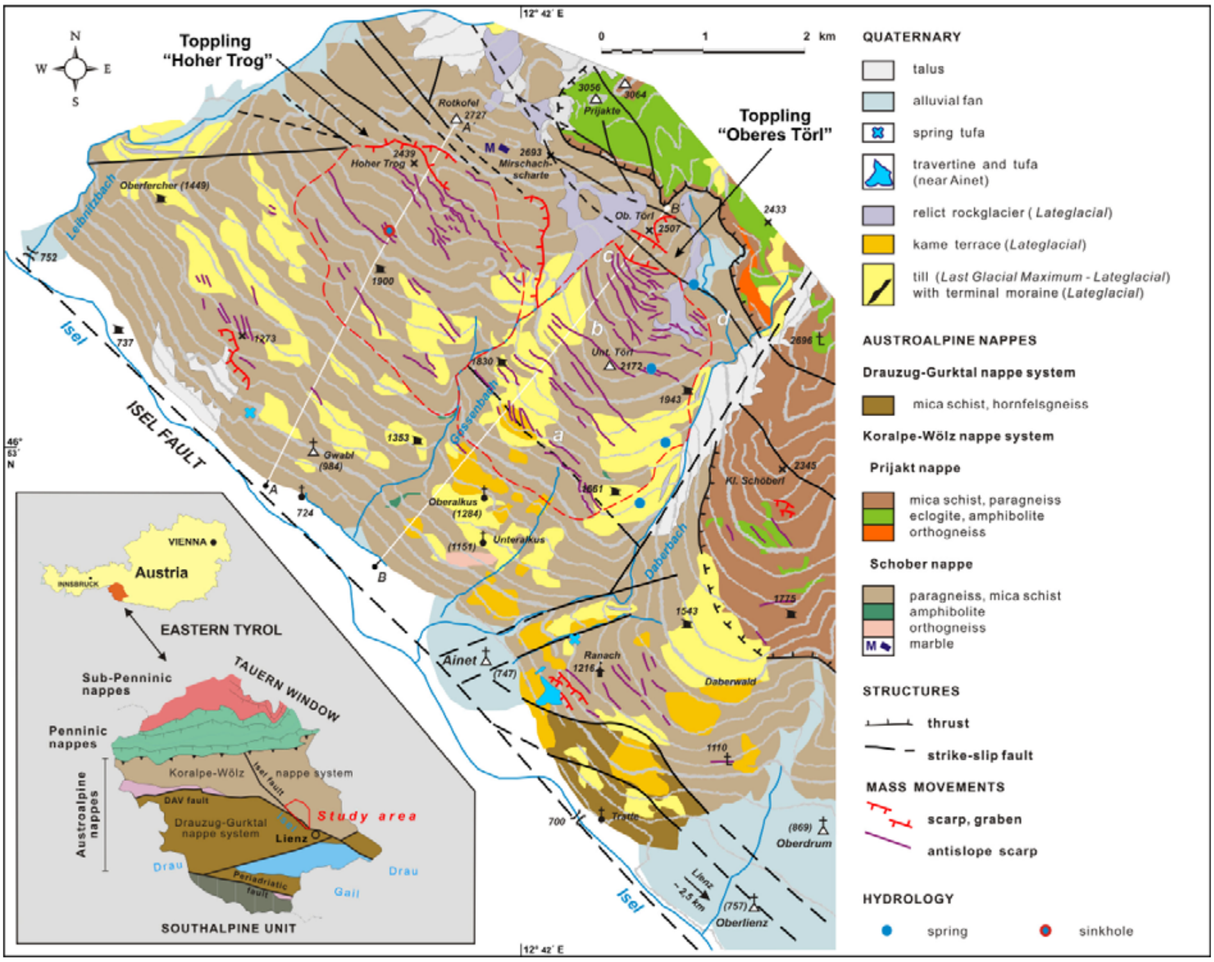


Figure 2a. Location of the study area, general tectonic setting and geological sketch map of the southwestern part of the Schober Group with the slopes of Oberes Törl and Hoher Trog (compiled and simplified after LINNER 1994, 1995, 2005, and REITNER, 2003 – references see REITNER & LINNER, 2009). The location of the geological cross sections (A-A´and B-B') is indicated by white lines. The positions of letters a, b, c and d denote regions of the Oberes Törl slope, their structural data are displayed separately in Fig. 4.

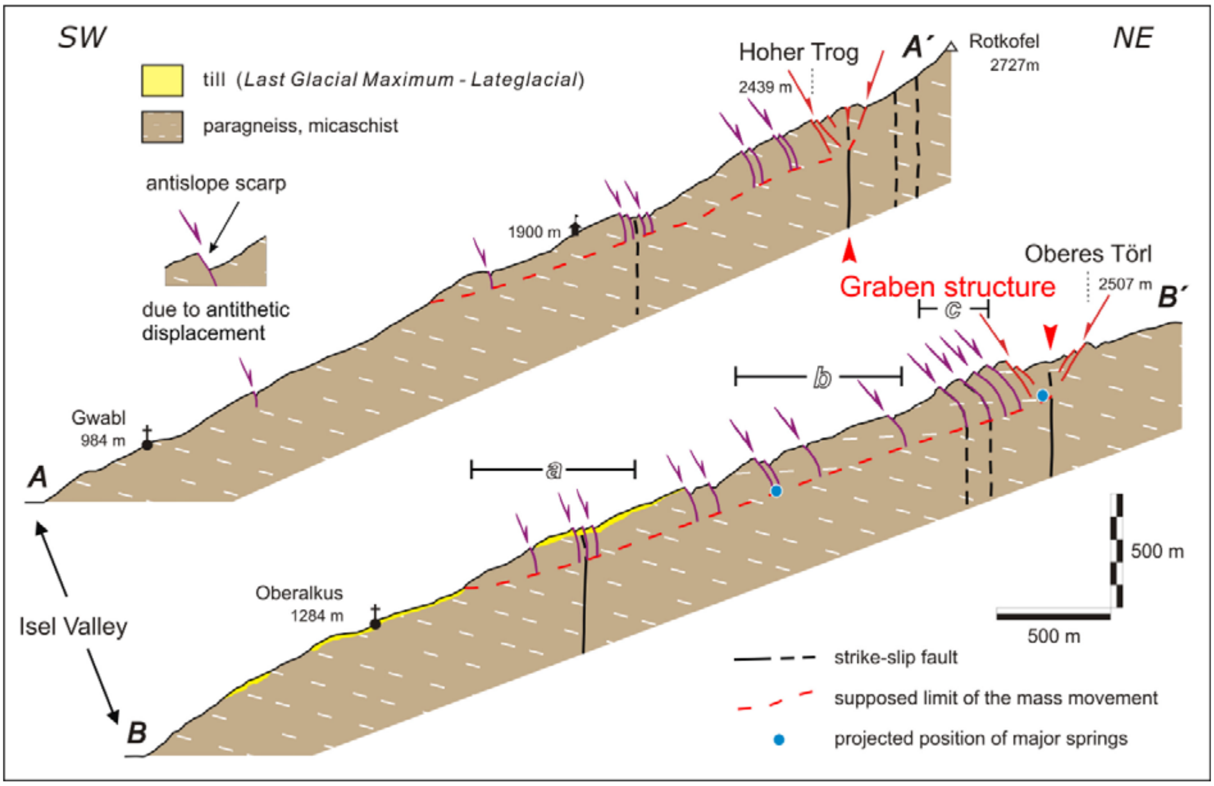


Figure 2b. Geological cross sections of the slopes Oberes Törl and Hoher Trog (for locations see Fig. 1). Faults are indicated by black lines. White dashed lines denote the apparent orientation of foliation. The estimated depth of movement and collapse (rock disintegration along pre-existing joints) based on the springs occurring in the lateral position (projected into the slope body) is shown by the red line. The regions of the structural data displayed in Fig. 4 are indicated by a, b and c.

Figure. 3a. View of the slopes of Oberes Törl and Hoher Trog with multiple linear elements (antislope scarps). (1) Oberes Törl, (2) Unteres Törl, (3) Hoher Trog, (4) Rotkofel, (5) Mirschachscharte, (6) Prijakt, (7) Gossenbach creek.

Figure 3b. Typical antislope scarp developed in mica schist/paragneiss at the slope of Oberes Törl in 2340 m asl. White bar (1) indicates the size of a person located at the outcrop shown in Fig. 3c.

Figure 3c. Detail of Fig. 3b. View of the NE dipping fault/joint plane with foliation gently dipping towards South and thus intersecting the fault/joint plane at a low angle. Vertical traces denote NE-SW striking joints.

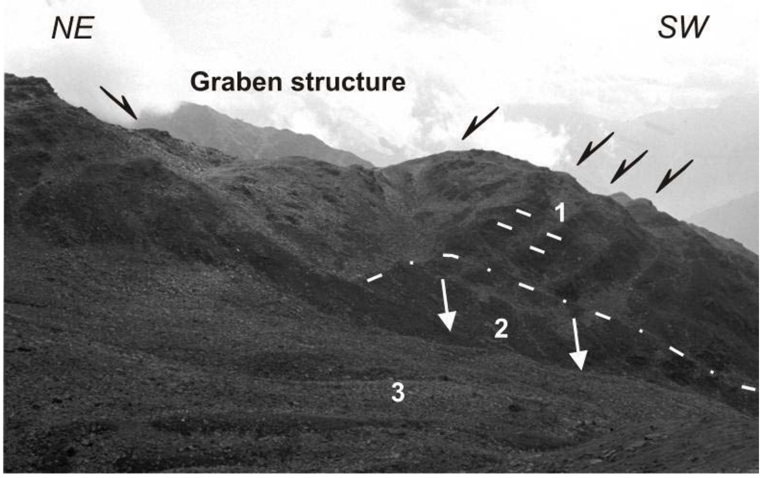


Figure 3d. Graben structure at Oberes Törl followed by a series of antislope scarps as indicated by the arrows (view towards SE). White lines (1) indicate the daylighting foliation gently dipping towards South (structural data of the part below this graben are shown in stereo plot c of Fig. 4). Dashed line and white arrows (2) denote secondary mass movement detaching along NE-SW striking joints towards tributary valley of Gossenbach with relict rock glacier of Lateglacial age (3).

Figure 3e. Paragneiss with a closely spaced vertical NW-SE striking joint set and foliation dipping gently into the slope.

Figure 3f. Open joints within the rock mass of Oberes Törl indicate collapse, i.e. dilation, along pre-existing joints.

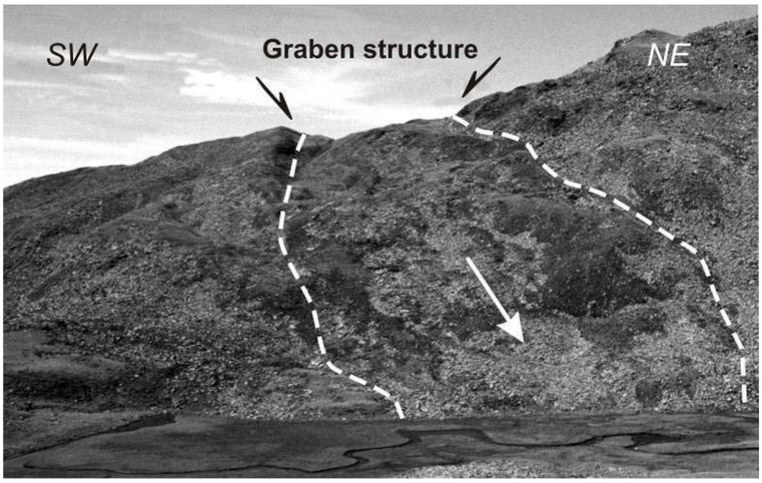


Figure. 3g. View towards NW onto the eastern flank of the graben structure of Oberes Törl (dashed line and white arrow, see also Fig. 3d) with rock mass creeping towards the valley of Daberbach creek.

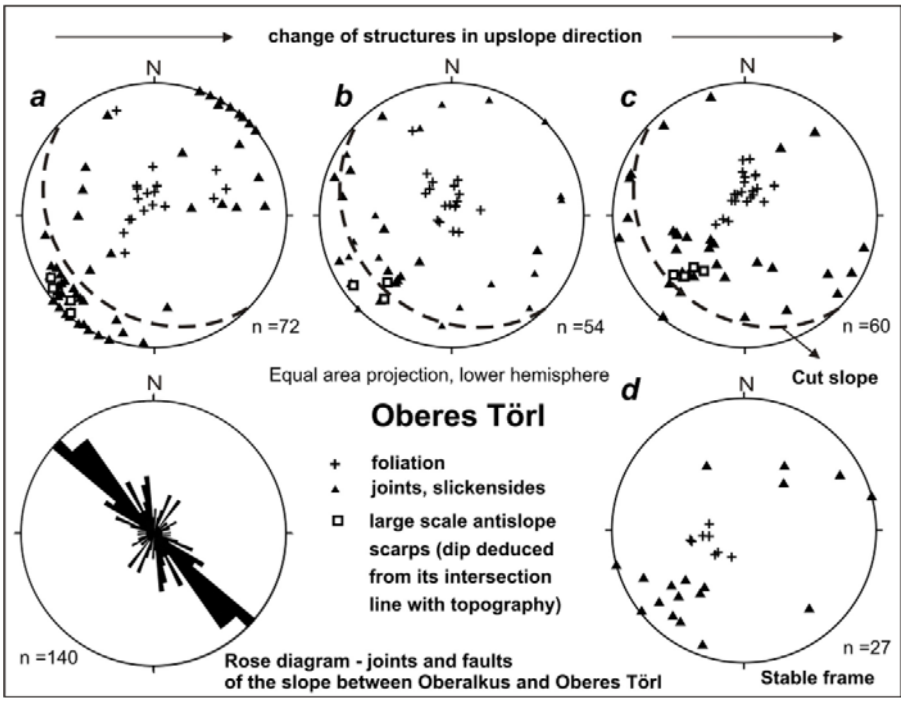


Figure 4. Slope of Oberes Törl: Stereo plots of joints, foliation and antislope scarps from the slope segments above Oberalkus (a; approximately 1400–1900 m a.s.l.), around Unteres Törl (b; approximately 2000–2200 m a.s.l.) and from the uppermost counter-slope scarps adjoining to the graben structure (c) exposed at the NW flank (see Figs. 1, 2 and 3d). Great circles denote the orientation of the slope with an average gradient of 25°. The plots a–c show an upslope change of these structural elements i.e. concurrent decrease of dip angle of antislope scarps and NE dipping joint system. The orientation of foliation shows a shift from E-SE to S-SW. Downward decreasing rotation of structural elements is also evident by comparison to data from an area 1 km SE of the graben (stereo plot d - “stable frame”; location indicated in Fig. 1) with a subglacially shaped surface and no indication of mass movements. The rose diagram of joints and slickensides displays the dominance of a NW-SE striking joint system parallel to the Isel fault over those with a N-S and NNE-SSW trend.

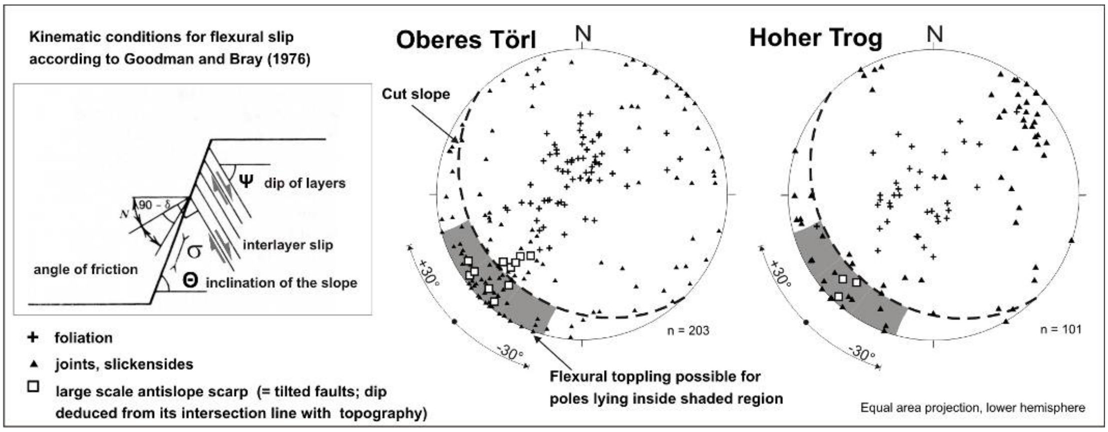


Figure 5. Stereo plots of structural data (poles of joints, foliation and antislope scarps) of the upper slope segments of Oberes Törl and Hoher Trog and kinematic analyses for flexural toppling according to GOODMAN & BRAY (1976). The great circles display the cut of the slopes with an average gradient of 25° towards SE. As a simplification, the friction angle along joint surfaces is disregarded (see text). Flexural toppling due to interlayer slip is possible for vertical to NE-oriented discontinuities, whose poles fall into the shaded area. This is true for joints and antislope scarps parallel to the Isel fault, which resemble tilted faults from the slopes Hoher Trog and the lower part of Oberes Törl (see also Fig. 4a). The formation of antislope scarps located at the upper part of Oberes Törl (see also Fig. 4b-c) with a dip less than 65° and, hence, with poles plotting outside, cannot be explained solely by flexural toppling.

SITES 3, 4 and 5

After passing the city of Lienz the excursion route continues into the upper Drau valley (Pustertal). Along the scenic road ("Pustertaler Höhenstraße") two cases of adjacent mass movements (Lienzer Klause & Mordbichel; locations 4 & 5 in Fig.1a) exemplify the challenge of landslides in an Alpine setting (location 3 in Fig. 1a). This includes the identification of failure mechanisms, dating landslides and their heritage in the sense of blocked rivers and re-activation phases up to now.

The results of geological mapping in combination with drill-core data showed that the emplacement of both medium sized rock masses (V = 0.01–0.04 km^3) made up of calcareous rocks was the result of catastrophic rockslides descending from the steep flanks of the Lienz dolomites. Such a mechanism was possible due to the presence of marls and claystones as the weakest lithologies of the whole sequence. The deformation of these rocks at the base of the landslide masses resulted in shearing and even in fluidal structures. In contrast, the predominantly dolomitic lithology of one landslide shows a high degree of fragmentation with very angular clasts. However, the geometry of this deposit does not indicate fluidization as is known from typical sturzstrom events.

The age of the landslides was constrained in one case by ^{36}Cl exposure dating of dolomite boulders. ^{14}C dating of wood and other organic remains at the base of the landslides provided maximum ages. The dating of terrace deposits in the backswamp area of one landslide yielded further geochronological information. A sequence exhibits the onlap of lacustrine organic-bearing sediments due to blocking of the river Drau on a pre-existing landscape indicated by a soil. Both events took place in the last 4000 years, thus in a period when human settlement was already established in the Alps. The long-term legacy of these mass movements is evident not only by an unbalanced river profile along the river Drau but also by catastrophic re-activation in 2010, mobilizing 900,000 m^3 and blocking again the river Drau.

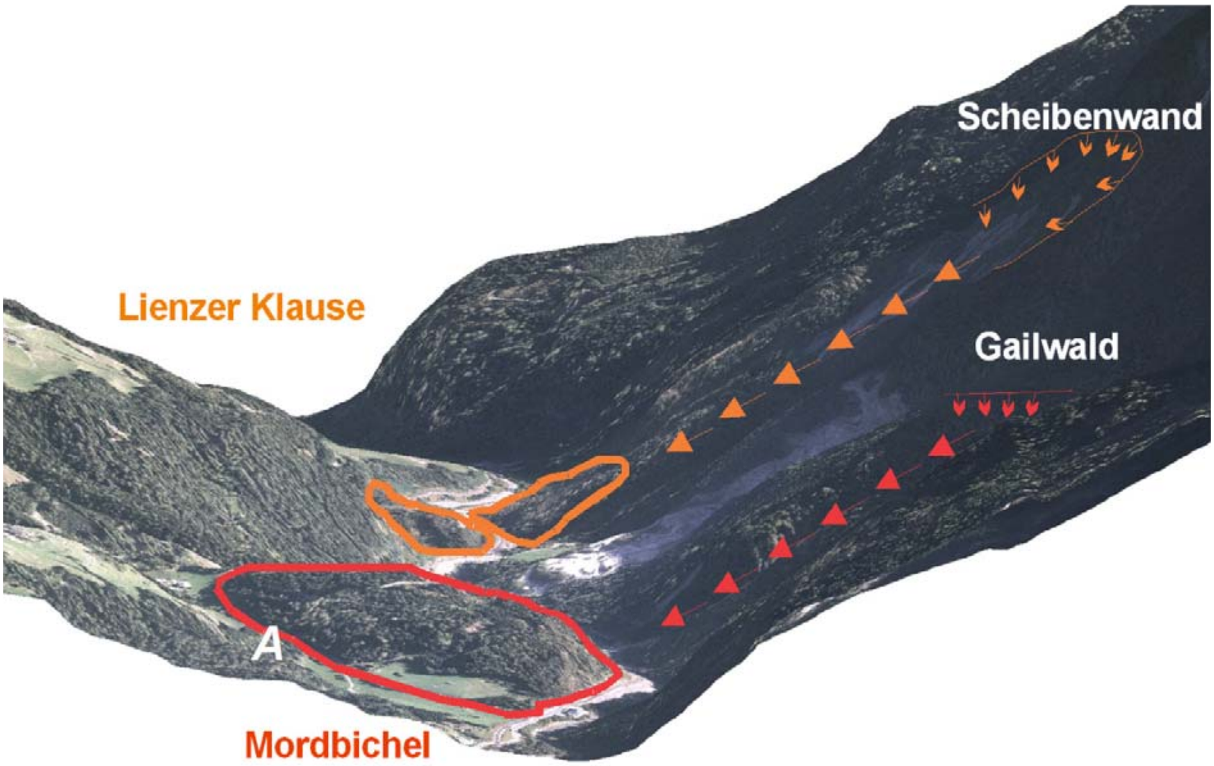


Figure 6. View along the Drau valley (Pustertal) towards ENE (in direction of the river flow). The slide masses and scarps of "Gailwald-Mordbichel" and "Scheibenwand–Lienzer Klause" are evident.

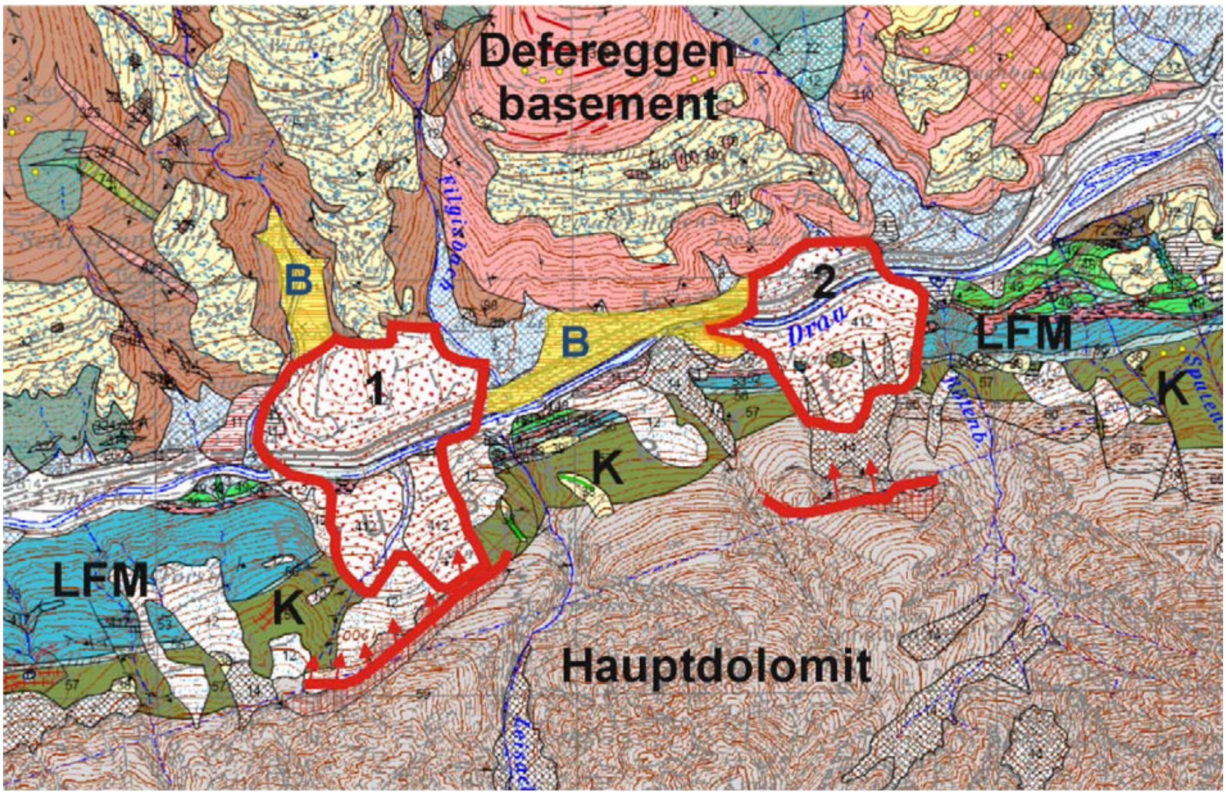


Figure 7. Simplified geological map with main units indicated: Hauptdolomit – dolomite, Kössen Formation (K) – marly limestone and claystone, Liasfleckenmergel (LFM) – marl; B – sediments of former backwater area; 1 – Mordbichel; 2 – Lienzer Klause.

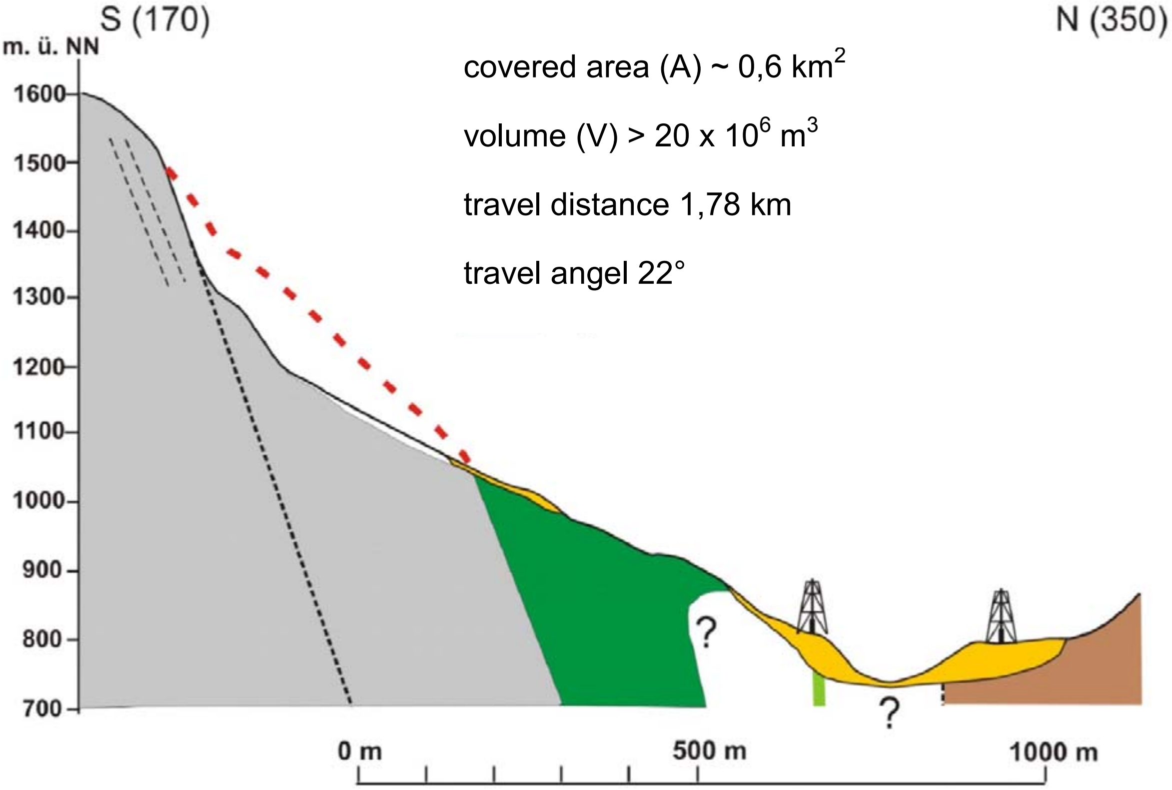


Figure 8. Cross-section of the Lienzer Klause with the location of the drill holes and the general extent (REITNER, work in progress).

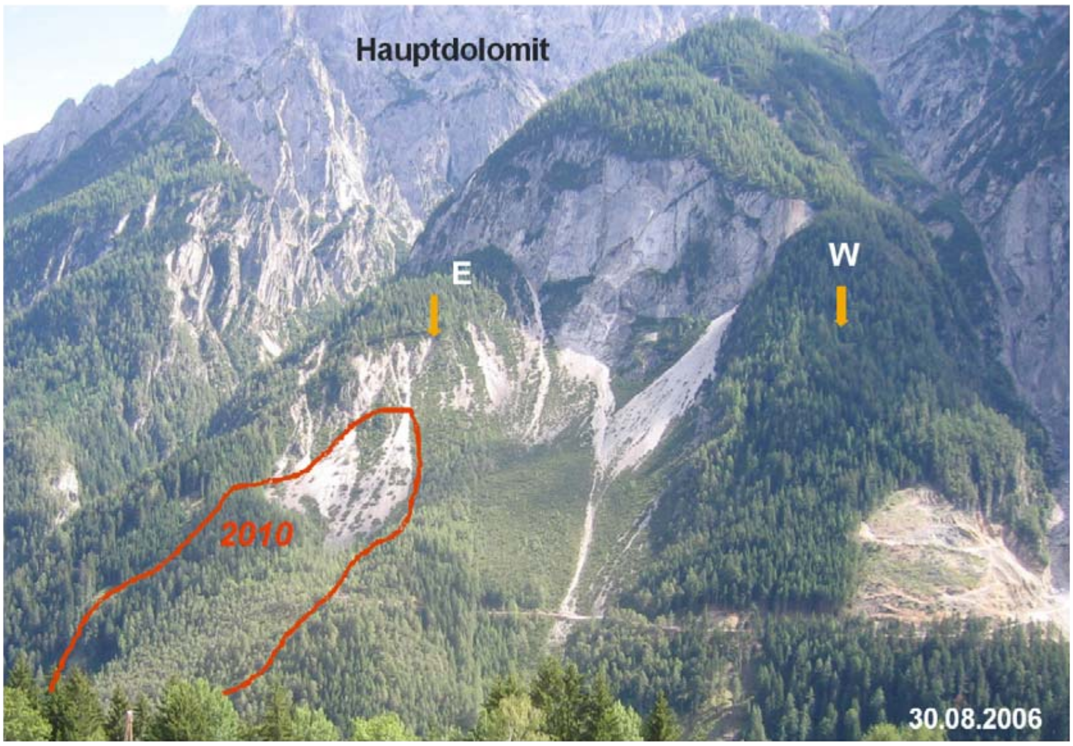


Figure 9. View from the opposite valley flank on the scarp area of Lienz rockslide and parts of the deposits. The extent of the re-activation in February 2010 is indicated.

Figure 10. In February 2010 a re-activation of parts of the rockslide mass resulted again in the blockade of river Drau (picture courtesy of Baubezirksamt Lienz).

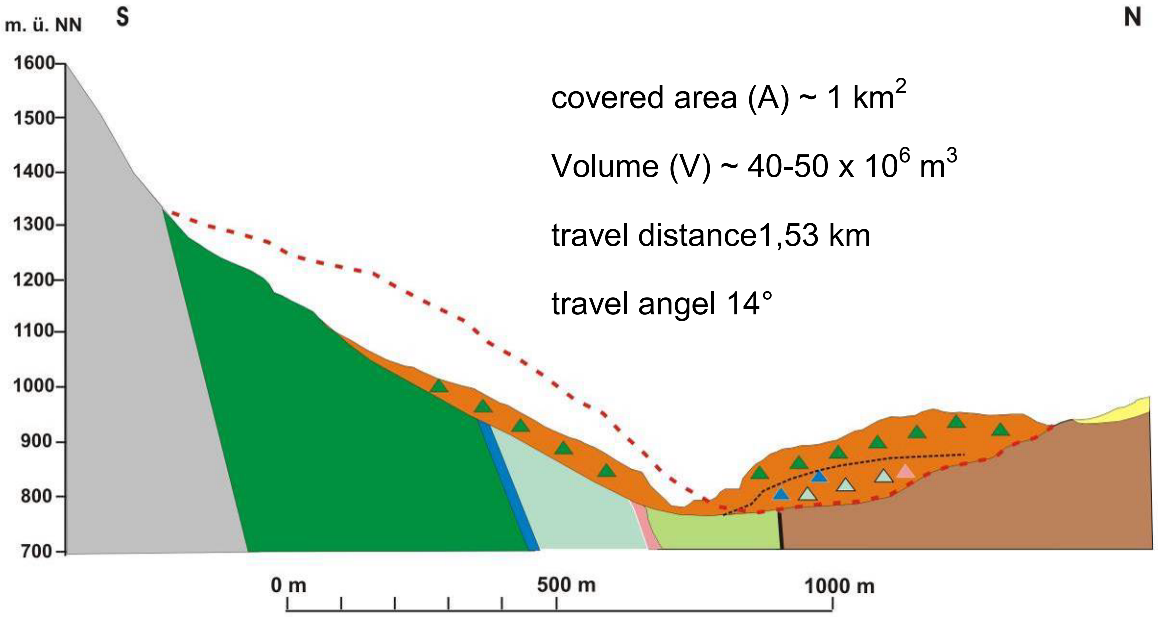


Figure 11. Cross-section of the Mordbichel rockslide and the general extent (REITNER, work in progress).

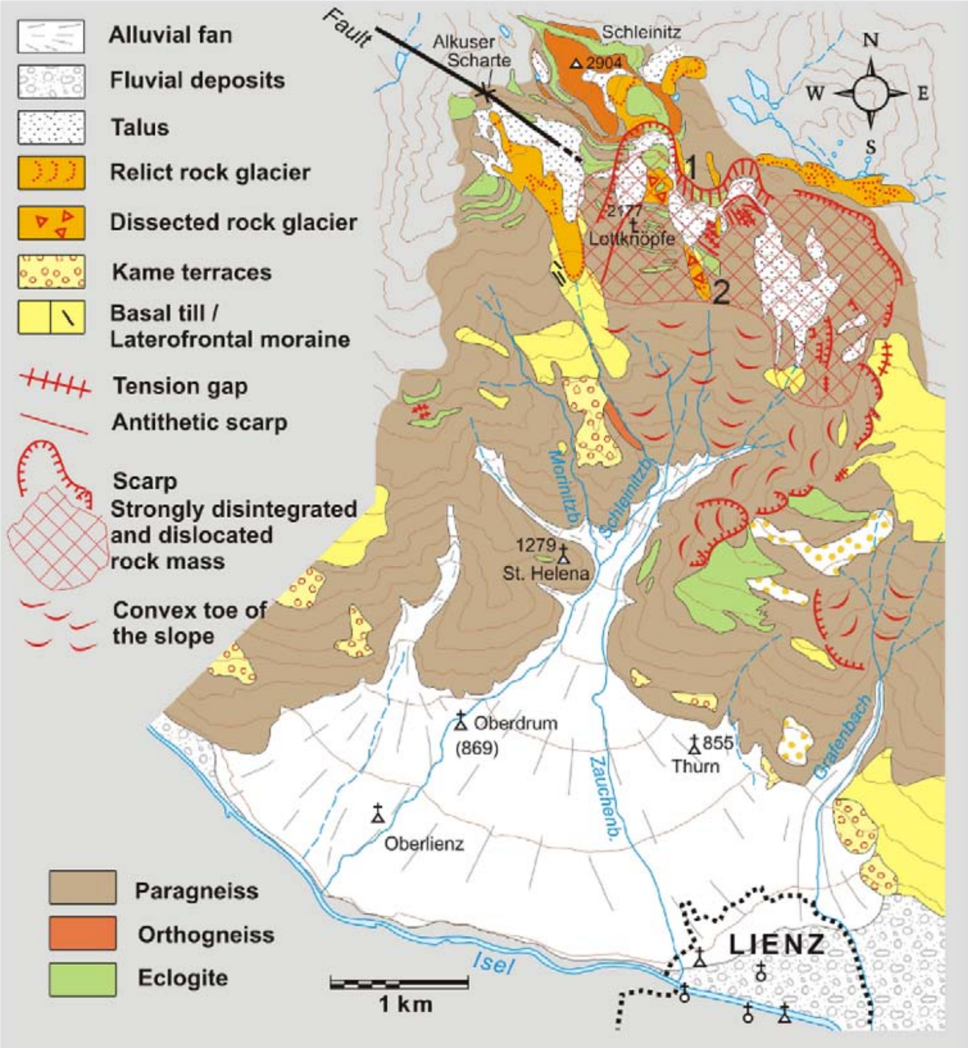
Figure 12. The Kössen Fm. (limestone / claystone) in typical outcrop (a), already disintegrated due to collapse in a creeping slope (b), and completely deformed at the base of the Mordbichel rockslide (c) (location A in Fig. 6).

SITE 6

Finally we will arrive at the mountain peak Hochstein (2057 m asl.; location 6 in Fig. 1a), where a perfect overview on tectonic evolution, mass movements and glacial shaping will be provided.

The most striking mass movement structure is evident on the opposite flank of the Isel valley with the Lottknöpfe sagging mass (location 7 in Fig. 1a) dissecting a former cirque with rock glacier deposits and moraines and the hypertrophic alluvial fan of Lienz.

Figure 13a. The southern slope of the mountain range Schober Gruppe near Lienz with the hypertrophic fan of Lienz. Its headwater SE of the peak Schleinitz is characterized by deep-seated gravitational slope deformations.



Geological map according to LINNER (1995, unpubl. map) and REITNER (1999,unpubl. map)

Figure 13b. Map of the Sackung (sagging mass) Lottknöpfe. Localities of the dissected rock glacier (1 and 2) are indicated (REITNER, unpublished)

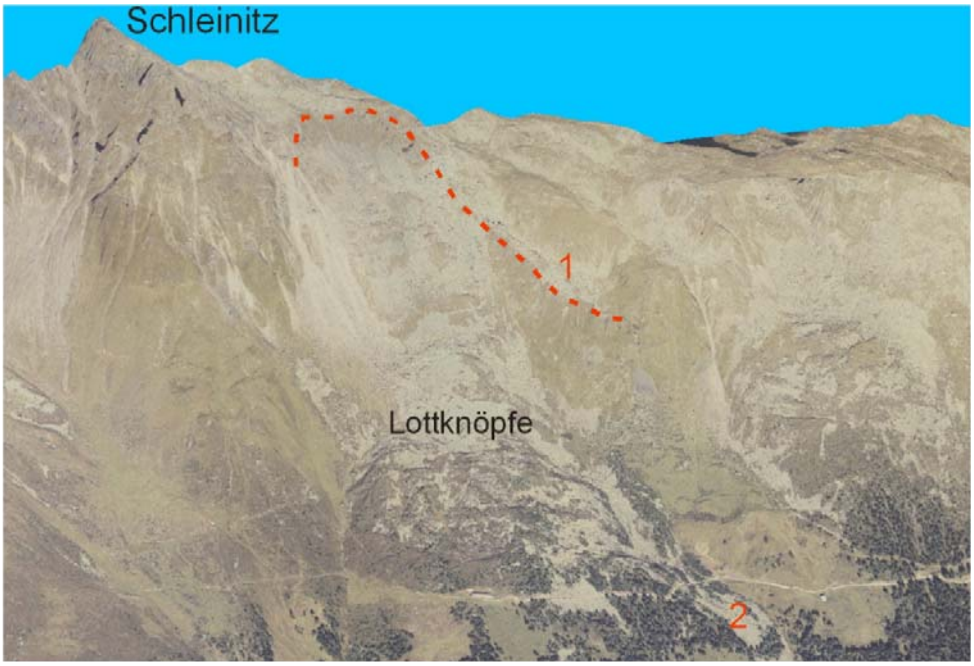


Figure 15. View towards N onto the disintegrated rock mass of Lottknöpfe with the scarp (red dotted line) above and the location of the dissected rock glacier (1 & 2). The upper (original) and the lower (moved) part are indicated (localities 1 and 2).

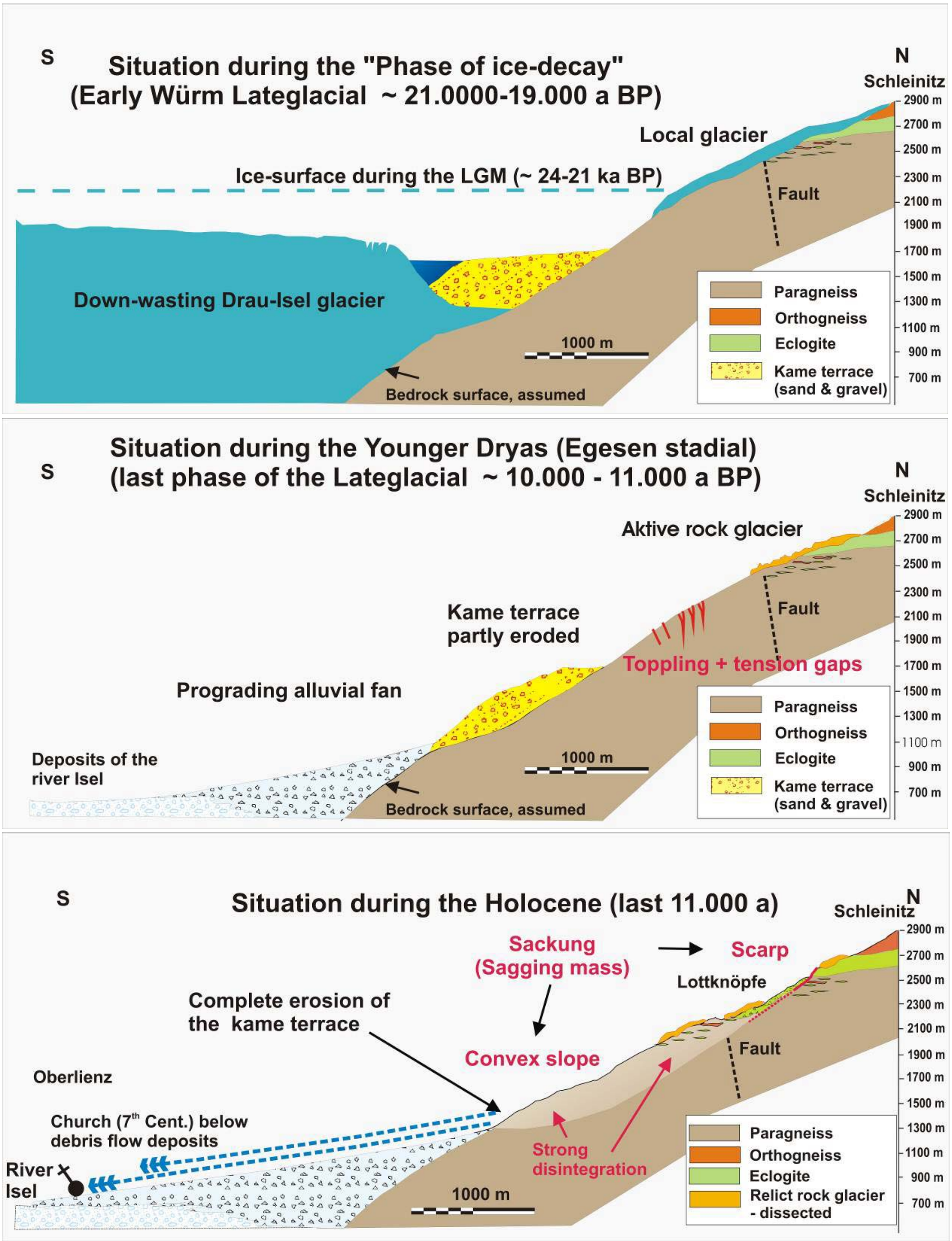


Fig. 16: Evolution of the mass movement Lottknöpfe in relation to the glacial and permafrost chronology. The sackung started after the Younger Dryas according to the dissected relict rock glacier deposit (REITNER, work in progress).

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