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LARGE SCALE TOPPLING, ITS RELATION TO ALPINE TECTONICS AND ITS TIMING: EXAMPLES FROM THE EASTERN ALPS

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Slope deformation by toppling is a type of slow, deep-seated mass movement that is underrated regarding its occurrence as well as its potential consequences. With its simple but rigorous structural control – discontinuity planes (e.g. schistosity, joints) dipping steeply into the slopes – this kind of slope failure seems to have a close relationship to tectonics. Modern geological maps of the Eastern Alps indeed show the connection between toppling and big alpine shear zones or, more often, brittle deformed strike slip faults established during Miocene lateral extrusion.

One of the most impressive textbook examples of toppling is situated in Eastern Tyrol northwest of Lienz and north of the NW-SE trending Isel-valley, which follows the Miocene Isel valley strike-slip fault. In this area the altitudes range from 700 m a.s.l. (valley floor) to 2900 m a.s.l.. The crystalline rocks of the Schober Gruppe consist mostly of mica schists and gneiss with some amphibolite and eklogite layers in the upper parts. They show a variable strike and a mostly gentle dip as a result of intensive ductile deformation. However, brittle features like joints and small strike-slip faults parallel to the Isel valley dip steeply either towards NE or SW. During the Last Glacial Maximum (LGM = Würm Hochglazial; $\sim$ 24-21 kyr cal BP) the Isel glacier reached an altitude of up to 2300 m a.s.l..

The slope above Oberalkus (1284 m a.s.l.) shows a sawtooth pattern due to a series of obsequent (= uphill facing) scarps running approximately parallel to the Isel valley. These distinct features can be traced for 1 km and more. A bulging toe of destructed rock below Oberalkus is missing. Structural analysis reveals that the set of joints and small faults striking parallel to the Isel valley and dipping steeply (80˚-90˚) into the slope were activated during this block flexural toppling (Goodman & Bray 1976).

The slope moved forward by these antithetic scarps resulting in a tensile stress in the uppermost part and leading to the formation of a 300 m wide graben structure S' of Ob. Thörl (2507 m a.s.l.). The morphological features indicate a depth of movement of at least 150 m.

The mass movement is believed to have started during the phase of ice decay subsequent to the LGM (21-19 kyr calBP), when the due to glacial erosion oversteepened slopes lost support in the course of downmelting of the Isel glacier (*cf* Reitner et al. 1993). The accelerated loosening of rock masses especially in altitudes of permafrost (above 2000 m a.s.l.) provided the material for rock glaciers to develop. The movement continued throughout the Holocene and is still active today as indicated by antithetic scarps affecting rock glacier deposits of the younger part of the Oldest Dryas ($\sim$ 15-14,5 kyr calBP) , as well as by a broken travertine of Bølling age (Boch et al., 2005) and by tilted ice margin sediments which resulted in a "drowned forest" of larch (*larix*).

Due to the absence of a convex lower slope, the deformation provided very little material for debris flows. This becomes evident when comparing the relatively small-sized alluvial fan to its hypertrophic counterparts in catchment areas deformed by classical "Sackungen" (sagging; Zischinsky, 1966). However, as a result of progressive disintegration and accompanying change of material behaviour, the type of slope deformation can change from pure toppling to typical "Sackung". This change is evidenced by the results of geological mapping in various areas of the Eastern Alps.

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