

Dating a rock slide by the $^{230}\text{Th}/^{234}\text{U}$ method: the Fern Pass, Austria, as an example.

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For the statistical assessment of the likelihood of landslides, it is important to obtain accurate time constraints on past events. Under suitable circumstances, the $^{230}\text{Th}/^{234}\text{U}$ method can provide such dates, over a period extending back to c. 500 ka. We demonstrate this for the case of the Fern Pass rockslide, Austria, where the $^{230}\text{Th}/^{234}\text{U}$ age obtained on breccia-cementing carbonate crusts is in agreement with results from ^{36}Cl exposure- and ^{14}C ages, but considerably more precise than either.

With a volume of about 1 km³, the rockslide of Fern Pass is third largest of the Eastern Alps. It is situated in the western part of the Northern Calcareous Alps. The Sturzstrom originated from the southernmost portion of the Lechtal thrust nappe, and left a deeply incised, east-facing scar. The area is dominated by the Hauptdolomit Formation (Norian). Within this, the Seefeld Formation is intercalated, constituting a few hundred meters thickness of black shales and platy, organic-rich dolostones and limestones. This is overlain by the Plattenkalk Formation (upper Norian) and bedded limestones and marls of the Kössen Formation (Rhaetian). The scarp area of the rockslide consists mainly of Seefeld Formation and, subordinately, of Plattenkalk and Kössen Formation.

In the proximal to medial part of the rockslide, scattered, angular boulders up to about 10-15 meters in exposed diameter project above ground. In the upper to middle south-facing slope of toma hills, along the southern flank of projecting boulders more than about 4 m in exposed width, at several locations adjacent to boulders, carbonate-cemented breccias were found. The breccia clasts are of the same lithologies as the rest of the rockslide mass. In the breccias, no indications for aquatic transport, such as bedding or stratification, and sorted beds or strata, were seen. The breccias comprise decimeter-sized patches and "crusts" up to about 20-30 cm thick on the sides and in the immediate understorey of projecting boulders. In all observed cases, the subaerially-exposed width of boulders associated with breccias is about four meters at least. At boulders of smaller exposed size, no breccias were observed. The most complete diagenetic successions adjacent to boulders include thin, isopachous to slightly mammillary crusts of micrite, overlain by an isopachous fringe of dog tooth spar. Remnant pore space is open. Both aragonite and calcite occur as cement. Outward and downward from the boulder surface, the fringe of dog tooth spar thins and tapers out within a few centimeters, and lithification is only by crusts of micrite. Still farther out, the micrite crusts become patchy and then vanish, and the deposit is unlithified.

Three locations of carbonate-cemented breccias and one location of tufa limestone were sampled and $^{230}\text{Th}/^{234}\text{U}$ analyses were carried out in the institute of Geological Sciences in Bern, using a mixed $^{229}\text{Th}/^{236}\text{U}$ spike and multicollector ICP mass spectrometry. U concentrations were very high, varying from 95 to 179 ppm, in accord with elevated radioactivity of springs in the landslide mass. Th concentrations varied between 8.5 and 16 ppb. The $^{230}\text{Th}/^{232}\text{Th}$ vs $^{234}\text{U}/^{232}\text{Th}$ isochron method yielded a date of 4150 ± 100 a (95% confidence limit). Previously, a ^{36}Cl exposure date of 3300-5300 a was obtained on a slide surface, and an extrapolated ^{14}C minimum age of 4000 ± 650 a on dammed torrent deposit material (Prager et al., in Press). The three dates are thus in agreement.

Like the ^{14}C age, the $^{230}\text{Th}/^{234}\text{U}$ result gives a minimum age for the rockslide event. We argue, however, that the breccias were cemented rapidly after the catastrophe. Immediately after the event, the rockslide sediment was rich in chemically reactive carbonate-rock flour produced by dynamic disintegration. In contact with meteoric waters undersaturated in calcium carbonate, part of the rock flour dissolved (dolostone rock flour in part may have dissolved incongruently), such that mainly calcium and a minor amount of magnesium entered into pore waters. At moderate supersaturation for calcium carbonate, the growth rates of both aragonite and calcite depend on the ion product of calcium and bicarbonate (Gutjahr et al., 1996 a). Without or at low concentrations of inhibitors such as Mg, then, calcite precipitates. Because of dolostone dissolution, however, presence of Mg^{2+} ions may have prevented calcite precipitation and favoured crystallization of aragonite (Gutjahr et al., 1996 b). Further, at high CaCO_3 supersaturation, aragonite growth is favoured even in the absence of cationic inhibitors of calcite growth, (Meldrum & Hyde, 2001). For the cement, potentially high degrees of supersaturation during precipitation are supported by the stable isotope ratios of oxygen and carbon that record marked kinetic effects, probably mainly from evaporation. This occurred in the south-facing exposed cavities adjacent to large boulders. Thus both the presence of Mg^{2+} soon after the rockslide event and high degrees of supersaturation of pore waters may have favoured early aragonite precipitation.

The conditions favourable to early breccia cementation in exposed cavities may exist in many landslide masses. The distribution of U in such cement can be readily assessed by β -scanning radiography, so that material for dating can be targeted. The high U content of bedrock (in particular the black shales) is a special feature of the Fernpass area. Cements with U contents an order of magnitude lower would however still be easily dateable with $^{230}\text{Th}/^{234}\text{U}$, provided the detrital content is low, and areas with lower regional U content are thus not excluded. $^{230}\text{Th}/^{234}\text{U}$ dating could thus have broad validity as a method for determining the age of landslide events.

REFERENCES

- Prager, C., Ivy-Ochs, S., Ostermann, M., Synal, H.-A. & Patzelt, G. (in Press) Geological considerations and age of the catastrophic Fernpass rockslide (Tyrol, Austria). *Geomorphology, Spec. Issue, Large slope instabilities: from dating, triggering and evolution modelling to hazard assessment*.
- Gutjahr, A., Dabringhaus, H. & Lacmann, R. (1996 a) Studies of the growth and dissolution kinetics of the CaCO_3 polymorphs calcite and aragonite. I. Growth and dissolution rates in water. *J. Crystal Growth* 158: 296-309.

Gutjahr, A., Dabringhaus, H. & Lacmann, R. (1996 b) Studies of the growth and dissolution kinetics of the CaCO₃ polymorphs calcite and aragonite. II. The influence of divalent cation additives on the growth and dissolution rates. *J. Crystal Growth* 158: 310-315.

Meldrum, F. C. & Hyde, S. T. (2001) Morphological influence of magnesium and organic additives on the precipitation of calcite. *J. Crystal Growth* 231: 544-558.