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Fluidisation of Alluvial Deposits by Large Rock Slides

A. von Poschinger (1)

Bayerisches Geologisches Landesamt (Hess-Str. 128, 80797 München, Deutschland (Tel.: +49-89-9214-2600; Fax: +49-89-9214-2647; email: georisiken@gla.bayern.de))

1. The general situation

In the vicinity of the Flims rock slide in Switzerland a very special kind of gravel deposit is exposed. The Flims slide is the largest in the Alps, its volume is estimated to be 8-12 km^3. Based on radiocarbon dating it is thought to have happened at about 8.200 y BP (not calibrated). An almost compact pile of Jurassic and Cretaceous limestone has rushed down from the Flimserstein to the Vorderrhein valley. The inclined bedding planes, partly covered by syn-sedimentary clay-rich layers, were activated as sliding planes. The deposits did not spread out, but have largely preserved their original rock structure, even if they were completely crushed. Only few kilometres east of the Flims slide another important rock slide took place: the Tamins rock slide. Its volume is estimated to 1-1.6 km^3 It came down from the Säsagit mountain under geotechnical conditions very similar to those of the Flims slide and concerns almost the same stratigraphic units. Unfortunately, no exact dating has been possible until now. Preliminary results by surface exposure dating on 36Cl indicate an age that is close in age to that of the Flims event (pers. comm. S. Ivy-Ochs). In front of the Flims deposits and partly also on top of it as well as between the deposits of the two large slides special gravel were deposited, that will be discussed below.

2. The specific sediments at Bonaduz

The village of Bonaduz is located on a horizontal plain right between the Flims and the Tamins deposits, built up by this special gravel. The plain is interrupted by small hills, consisting of Helvetic rock material and called “Cresta”. The plain has an altitude of 660 m a.s.l. and extends over 6 km from Reichenau in the north to Rhäzüns in the south. Also the gravel deposits continue further south of the morphological bottleneck of the Hinterhein valley between Rhäzüns and Rothenbrunnen. Here, in the so called

Domleschg, only along the foot of the slopes on both sides of the Hinterrhein river relict terraces with the typical gravel can be found. These scattered outcrops reach up to Cazis and so another 6 km to the south. Between Cazis and Thusis the horizontal surface of the Bonaduz gravel at 660 m a.s.l. crosscuts the slightly inclined young Hinterrhein sediments and is buried by those. The volume of the Bonaduz gravel, assuming a former complete fill of the Hinterrhein valley to the level of 660 m a.s.l., has been estimated by Kippel to 0,6 km^3. For the Domleschg it is possible that the whole valley was not filled, but only the lateral margins. Nevertheless, the volume has several 100 x 106 m^3

2.1 Older interpretations

The Bonaduz gravel had already many different interpretations. First, they have been thought to be a glacial till. Later on a glaciofluvial origin was assumed. The interpretation as a delta sediment followed as well as an outbreak flood sediment of the rock slide lake. A completely new theory had been created by Pavoni, who assumed a kind of a debris flow, triggered by the Tamins rock slide.

2.2 Actual knowledge

In the vicinity of the rockslide deposits several different facies of gravel can be observed. The most prominent are a) the typical Bonaduz gravel, b) a coarse diamictite and c) squeezed sands and silts.

2.2.1 Bonaduz gravel

The Bonaduz gravel are best exposed in the large quarry at the Reichenau railway station. There they are more than 60 m thick and show fining-upward. The sedimentation starts with rather coarse gravel, including finer gravel, sand, silt and fines. Going higher up the maximum grain size becomes gradually smaller, but the content in fines remains almost stable. The greatest part of the sediment is built up by fine gravel, also sandy and silty. It is grading into sands, still getting finer and finer to the top. This whole sequence shows no signs of any fluvial transport such as bedding or sorting. All transitions are gradual. Nevertheless, after a recent frost peeling of the sub-vertical face of the quarry, some fine structures could be observed. These are very large flow structures, reaching tens of metres in height and following more or less the lines of homogeneous grain distribution. The grain form of the gravel is related to the grain size. Components greater than about 1 cm in general are well rounded. Instead, the components of the fine gravel and sand fraction are angular. Obviously, they have been broken shortly before the deposition. Already Pavoni had described sub-vertical pipes or tubes that lack any fines. He interpreted these features as vertical drainage pipes for an upward transport of the water during the settling. Due to the different bedrock

lithologies in the catchments of the Vorder- and the Hinterrhein rivers, an attribution of the gravel components to a source area is possible. A recent investigation by Kippel determined that the Bonaduz gravel within the Hinterrhein valley consist to a great part of material of the Vorderrhein valley. Accordingly, they must have been transported from the Vorderrhein valley to their present position in an upstream direction. The very homogeneous gravel contain different kinds of inclusions. They are concentrated in the central parts and lacking at the bottom or at the uppermost parts. The fragments of lake bottom sediments have already been mentioned. These laminated sediments have a random orientation. The size varies between several decimetres and a few metres. The contact to the gravel is always sharp without any mixing. Rather similar to these very common fragments of lake sediments are rare remnants of silty debris flow deposits. They show no layering, but contain angular components of debris in a fine matrix. Furthermore, within these sediments some pieces of wood were found and gave the possibility for radiocarbon dating. A special situation can be observed at the outcrops within the morphological bottleneck between Rhäzüns and Rothenbrunnen. There, “clouds” of different silts and also of gravel are intensively mixed one into another. The features resemble a viscous fluid. Obviously, also many wood fragments had been enclosed. They are completely rotten now, but left the remaining cavities, even showing the detailed wood structure along the contacts to the fine silt. A third kind of inclusion within the Bonaduz gravel contains rock slide blocks or debris. Even the loose debris has a sharp contact to the surrounding gravel without any mixing. The gravel along the contact show an orientation parallel to it. So, at the Reichenau quarry, inclusions of several metres in size seem to swim within the gravel. At other sites also larger components, finally up to the size of the Cresta hills (s. below) are included.

2.2.2 Diamictite

A different kind of gravel is found at the front of the Flims deposits and partly also on top of it. Furthermore, it is exposed at the basement of the Bonaduz gravel. The most important deposit of these gravel is within the Rabiusa gorge near Versam. The diamictite contains very coarse gravel with a high content of finer gravel, sand and silt. Similar to the Bonaduz gravel they lack any sedimentary structure. In contrast to those they show no grading, no pipes and no silt inclusions. The components in the Rabiusa valley enclose as well material from the catchment of the Rabiusa in addition to from the Vorderrhein. Accordingly, the material must have been transported up the valley. The similarity of some features to the Bonaduz gravel is striking. It also has caused some confusion. So, the outcrop in the Rabiusa gorge north of the bridge has been attributed by Abele to the Bonaduz gravel. The outcrop at the Schiedberg ruin near Sagogn shows clearly that a transition between these two facies exists. In its lower part this outcrop shows the typical diamictite. Going upward, the diamictite grades

into to typical Bonaduz gravel, starting with coarse gravel, gradually becoming finer. This is an indication that both had the same source of material and the same trigger, but only under certain circumstances could the special facies of the Bonaduz gravel develop. In that sense, the composition of the diamictite is probably close to that of the original sediment.

2.2.3 Cresta hills

Since the detailed investigations by Nabholz, Remenyik, Pavoni and Scheller no important new information about the Cresta hills has been reported. Several borings in the Bonaduz gravel have confirmed that the single hills have no connection in the underground, but are separate components within the gravel mass. These components can have any dimension from few metres up to more than 100 metre length and several 100.000 m^3 volume. It is commonly accepted that these rock masses must have been transported from the Helvetic nappes north of the Vorderrhein to their present position. Also their rock slide nature is established. Still open is the question about their exact origin, about the transport mechanism and about the relation to the Tamins or to the Flims rock slide.

2.3 Interpretation

Close to the hypotheses of Pavoni, the Bonaduz gravel are interpreted as the sediment of a fluidized material. Accordingly, the following processes are proposed as a theory. The fluidisation occurred during the impact of the Flims rock slide mass. This caused a shock to the alluvium in the Vorderrhein valley, which was built up by fluvial gravel and by glacial lake sediments. At the centre of the impact, the loose gravel could not support the heavy and sudden stress generated at the few grain to grain contacts. Consequently, many of the grains crushed, until a dense package with a maximum number of grain contacts was possible. With the loss of void space and the sudden load the pore water pressure increased exponentially. The alluvium became very mobile and was squeezed out by the slide mass. It started to travel, in first line downstream. Only a reduced volume also found its way upstream. The special grain size produced by the crushing enabled a very high density of the flowing masses. Within this, single components could be transported without being exposed to great shear stress. Accordingly, the prevalent flow regime must have been laminar with little turbulence only. During the flow, the larger components settled down and so the upper parts got relatively finer, creating the fining upward grading. The indistinct flow structures in the Bonaduz gravel suggest an almost sudden freezing of the flow. Only the internal, finer parts moved slightly longer than the coarse parts. The difference between the diamictite and the Bonaduz gravel is assumed to be caused by a different kind of transport and by the water content. The drainage pipes indicate an important amount of water in

the Bonaduz gravel. It is quite possible that the former lake Bonaduz, dammed by the Tamins rockslide barrier, was still existent during the Flims event. So, the Bonaduz gravel may have been mobilised within the lake. The diamictite instead was mobilised under air and pushed into the Rabiusa valley and upstream into the Vorderrhein valley. The transitional forms between these two facies indicate such a common origin with different following processes. On its way down the Vorderrhein valley the flowing masses arrived at the deposits of the already existing Tamins rock slide. Its main barrier diverted parts of the giant stream to the south into the Hinterrhein valley. Separate rock slide deposits of the Tamins slide were picked up, incorporated as components and transported further upstream. At the point of diversion, the upstream surface of the Tamins deposits were polished and scratched by the debris stream. Parts of it, including large amounts of water of Lake Bonaduz, overflowed the rockslide barrier of Ils Ault, that became well rounded on its top and cleaned from almost all loose boulders. This part of the stream went on down the Rhine valley and caused an important sediment input to Lake Constance. Probably it was also responsible for the transport and the deposition of the large “Toma” hills at Domat-Ems and even at Chur, 8 km downstream the Tamins barrier. There, features similar to the Cresta hills have been interpreted until now as local rock slide deposits from the nearby Calanda mountain. Many features instead indicate the same origin as the Cresta hills.

3. Outlook

The origin of the Bonaduz gravel is not a mere academic question. Obviously, it was a catastrophic process that has never been eye-witnessed until now. But it is not unique. In the surroundings of several other large rock slides similar features occur. So it is a process with a certain probability that has to be taken into account for future hazard assessment.