# LANDSLIDES AND ROCKFALL IN KEUPER

# RUTSCHUNGEN UND FELSSTÜRZE IM KEUPER

# GLISSEMENTS ET EBOULEMENTS DU KEUPER

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## ZUSAMMENFASSUNG

Auch ohne direkte bauliche Eingriffe treten in den Ton-/Sandstein- bzw. Ton-/Kalkstein-Formationen von Keuper und Jura große Rutschungen auf. Die Bewertung der Phänomenologie der Rutschungen ist für Entscheidungen über Notwendigkeit und Möglichkeit von Sanierungsmaßnahmen entscheidend. Bei den Rutschungen zeigen sich deutlich die bautechnisch bedeutsamen Effekte der Tonsteinentfestigung. Daher wird neben der Beschreibung einer aktuellen Großrutschung über die bodenmechanische Bestimmung der Scherfestigkeit und die statistische Auswertung der Versuchsergebnisse berichtet.

## ABSTRACT

Even without any external factors, such as building activity, large landslides and Rockfalls occur in the clay/sandstone resp. clay/limestone formations of keuper and jura. The evaluation of the phenomena of the slides is of great importance when the necessity or possibility of stabilisation is considered. The important effects of the weakening of mudstones due to weathering are shown very clearly in landslides. Therefore in addition to the description of a recent large landslide and rockfall, the determination and the statistical evaluation of shear tests are discussed.

## RESUME

Même sans interventions extérieures telles que des chantiers et travaux de construction, de grands glissements de terrain peuvent se produire dans des formations de keuper et de jura composées d'argile et grès ou d'argile et calcaire. L'étude des phénomènes de glissement est décisive pour évaluer la nécessité et/ou la possibilité de prendre des mesures de stabilisation. Les glissements mettent particulièrement en valeur les effets principaux de l'affaiblissement des sols argileux. C'est pourquoi, au-delà de la description

d'un glissement récent de grande dimension, cet article expose en particulier la détermination et l'évaluation statistique de la résistance limite au cisaillement des sols considérés.

KEYWORDS: Mudstone, weathering, landslides, rockfall, softening, shear parameter

## 1. INTRODUCTION

On the 7th April 2001 a landslide occurred in Urbach (30 km west of Stuttgart, see fig. 1). The area affected was about 3.2 ha. and it is estimated that about 500m³ of soil and rock were involved in the slip. After the slip a rock wall about 15m high and 150m long was left standing at the head of the slip. A good view of the slip and the surrounding area is shown in fig. 2.

At the head of the slip where the ragstone is present the movements resemble a rock fall whereas at the toe of the slip it was more a creep and slip movement. (see fig. 3).

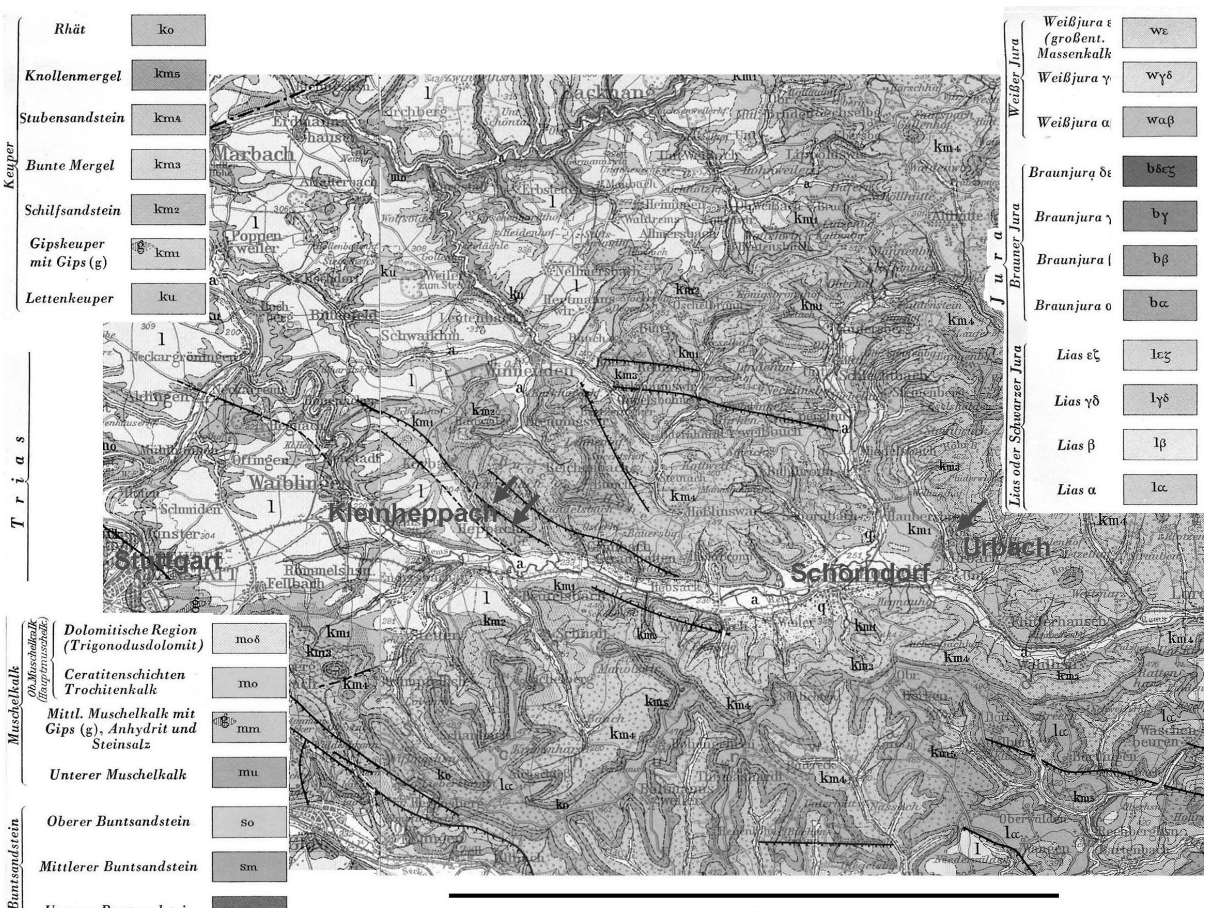



*Fig. 1: Geological situation between Stuttgart and Urbach (detail from geological map of Baden-Württemberg scale 1:200000)*

*Fig. 2: Aerial photograph of landslide at Urbach*

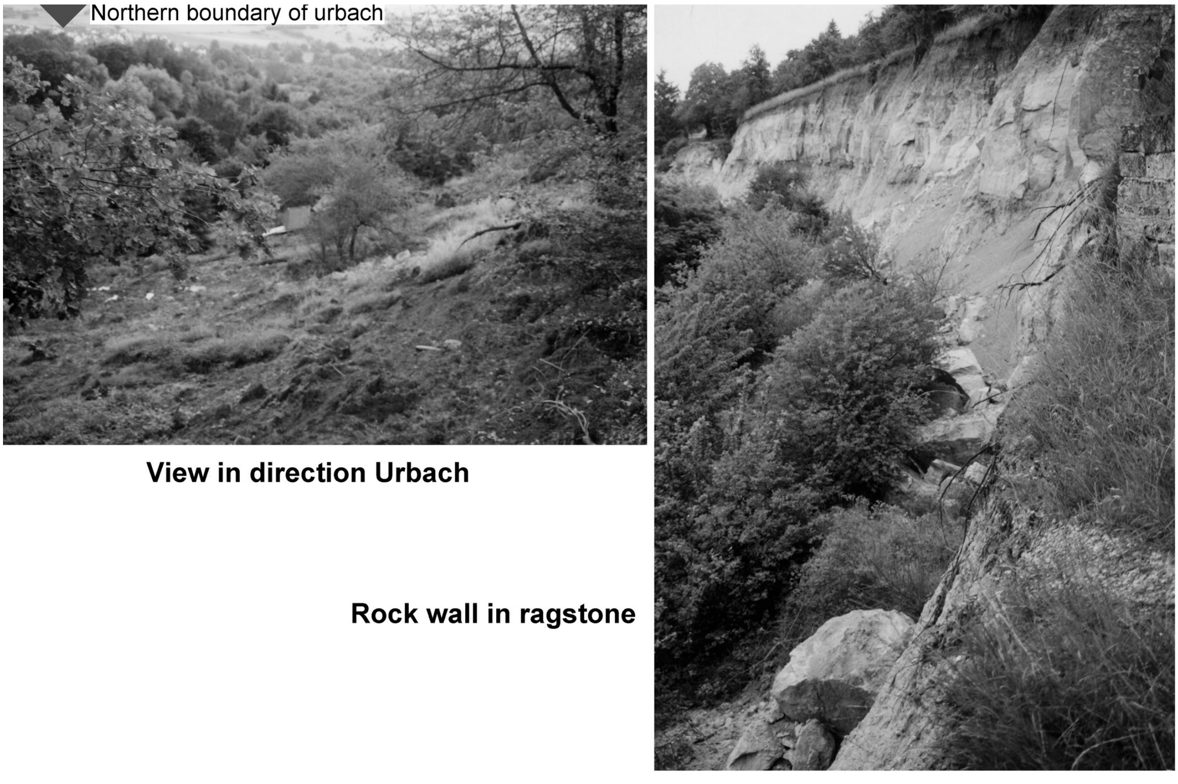



*Fig. 3: Detail photographs of landslide at Urbach*

Dr. Wallrauch from the Baden-Württemberg Authority for Geology, Raw materials and Mining was the consultant for the community of Urbach. The analysis and description in the following are taken from his report. A possible sequence of events during the slip according to Wallrauch are shown in the sketch in fig. 4.

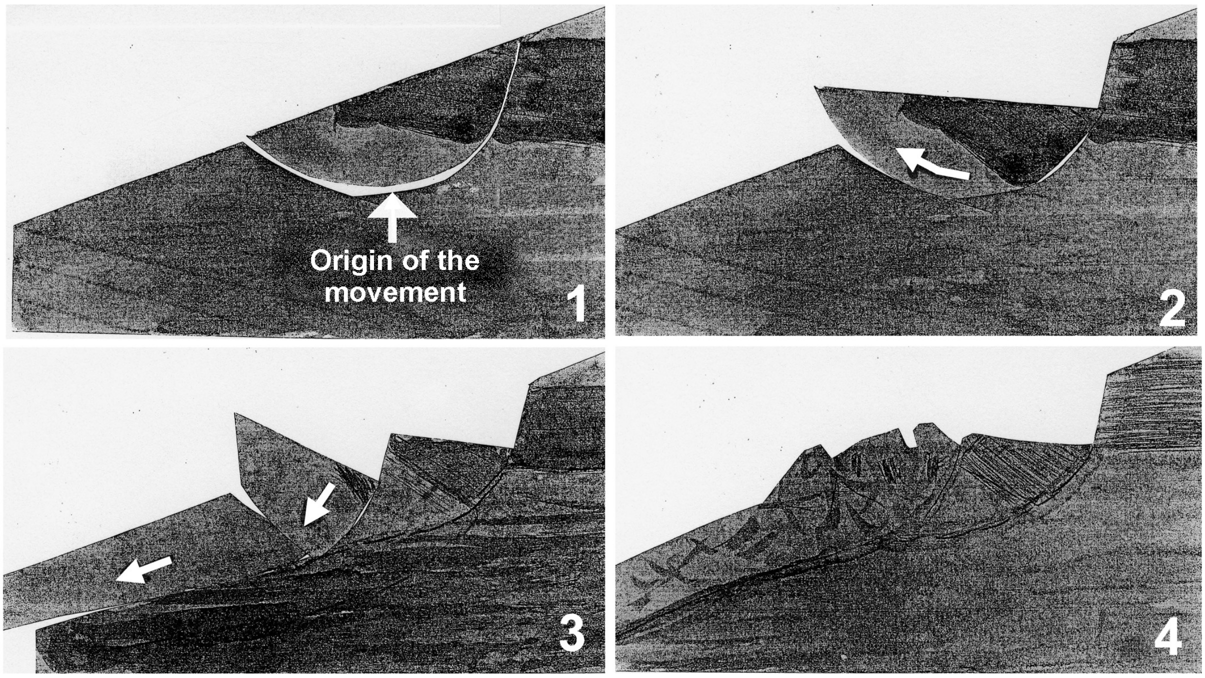



*Fig. 4: Possible sequence of movements during the land slip at Kirchsteigtobel Urbach*

## 2. PHENOMENOLOGY OF LANDSLIDES IN KEUPER MARL

Typical for landslides in Baden-Württemberg is that at the head of the slip there are generally limestone or sandstone layers which are underlain by clay stone. According to estimates by Wallrauch a land slip of the size of the one near Urbach occurs about every ten years. The typical stratigraphic sequence for land slips in keuper in the case of the slip near Urbach is a change from the lower marls to ragstone of the lower triassic formation. Fig. 5 shows the slip zone in the sequence of the trias formation.

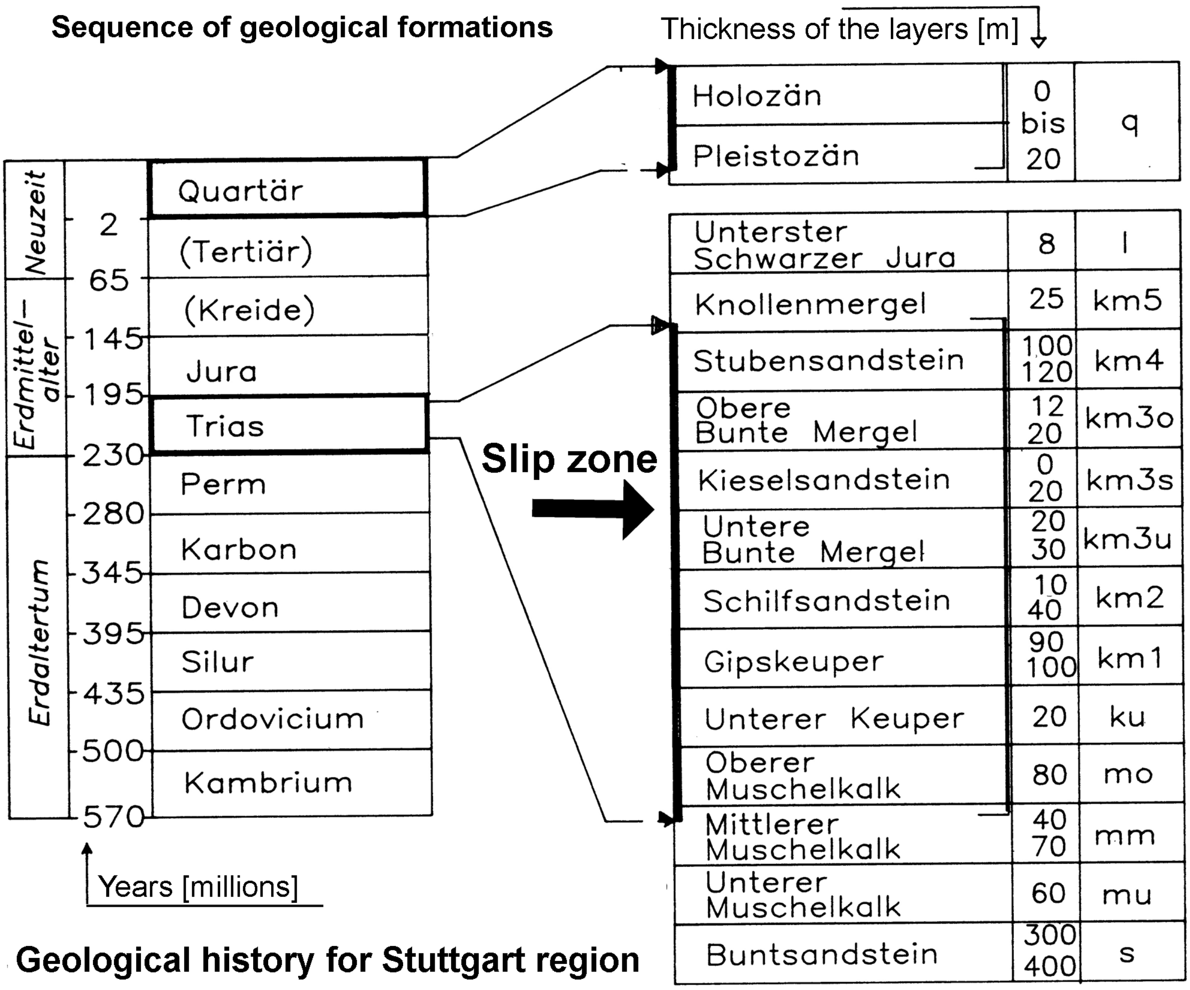
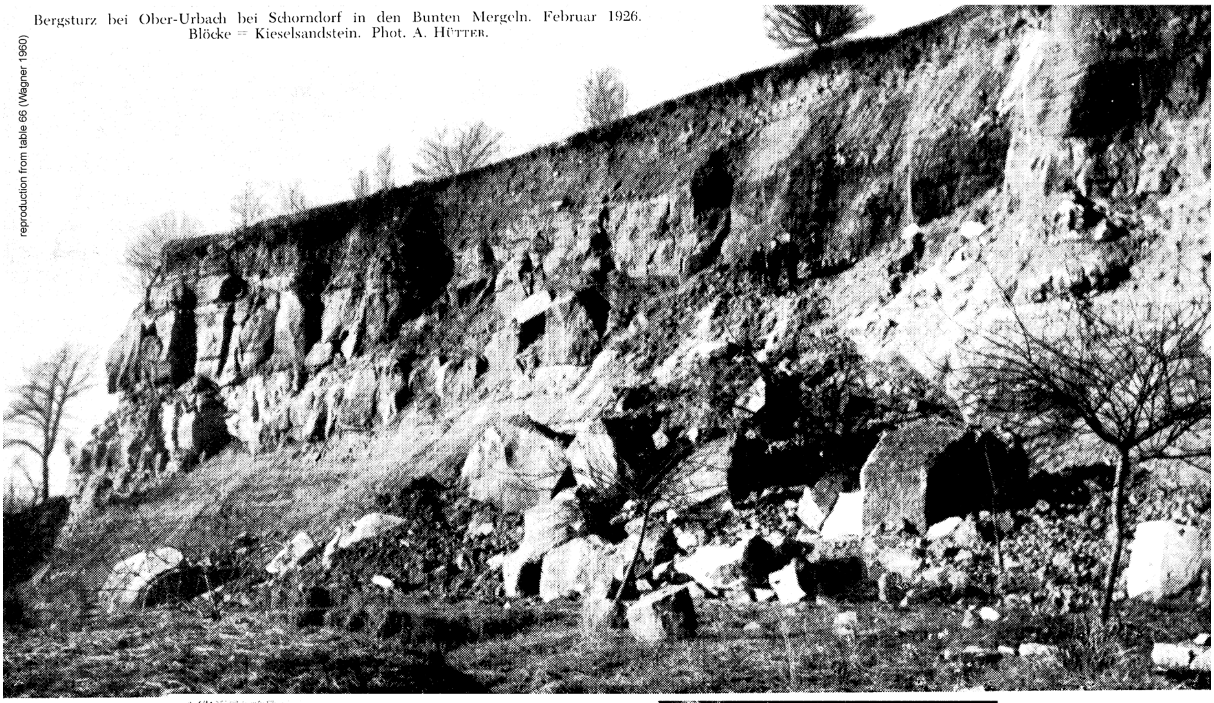



*Fig. 5: The slip zone in the sequence of geological formations*

About 700m south of the slip which occurred in April 2001 a slip took place on the Alten Berg in the nineteen twenties. This slip was much bigger than the present one and was a danger for the village of Urbach. The state of the slip in 1923 is shown in fig. 6.

Fig. 7 in the annex shows a detail of the geological map. The interrelationship between geology and topography as well as the position of the old slip at Alten Berg relative to the present slip at Kirchsteigtobel can be seen. From the map it can be seen that both slides started where the change in slope takes place. At Kirchsteigtobel the average slope in the area of the slip is about 40% (20°). Above the slip the slope of the land is 10% (6°). According to an old map from 1901 the original slope of the slip area at Alten Berg was about 80% (39°) and the land above the slip had a slope of 20% (11°). From this old map it is clear that the slip in 1920 (see fig. 6) was not the first in recent times in this area.




picture from the archives of the mayor's office Urbach

*Fig. 6: Pictures of the slip on the Alten Berg*

A few decades after the slip on the Alten Berg the authorities allowed building directly at the foot of the slip so that houses reach right up to the foot of the slip. The present building at the foot of the Alten Berg slip east of Urbach is shown in red in Fig. 7.

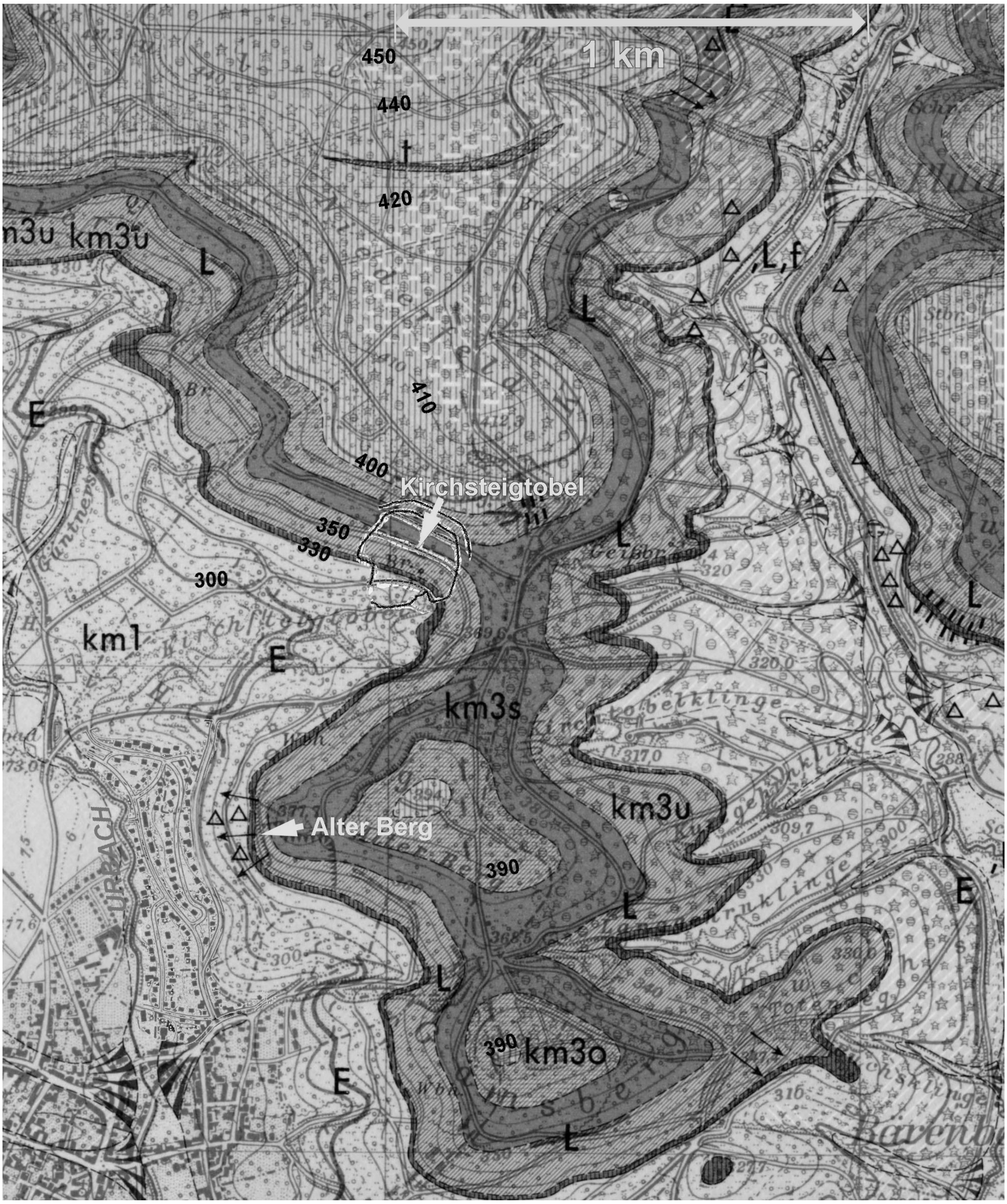



*Fig. 7: Geological Map of Urbach*

The slip in Urbach was most probably caused by water seeping out of the sandstone into the under lying marls. With weathering clay stone looses strength which causes settlements. A detailed description of the weathering of clay stones can be found in Wallrauch (1969). A result of the settlements in the marl is that fissures occur or open in the sandstone above it. Slips are more predominant in Spring after the heavy winter rains and melting snow and on slopes facing south-west. The prevailing winds in Spring are also south-westerly.

In the following table the most important publications of landslides within a radius of 60 km. Around Stuttgart are compiled.

| Landslide/Rockfall | Geological Formation | Publication |
|---|---|---|
| Zaiserweiher/Hamberg/Maulbronn<br>Enzkreis<br>(35 km nordwestlich von Stuttgart) | Bunte Mergel<br>1976 | GUDEHUS/WICHTER (1977)<br>GOLDSCHEIDER/WICHTER (1982) |
| Tanheimer Steige/Hechingen<br>Zollernalbkreis, L 360<br>Bisingen – Onstmettingen<br>(60 km südlich von Stuttgart) | Braunjura (Dogger)<br>1980 | GOLDSCHEIDER/WICHTER (1982)<br>GUDEHUS ET AL. (1985) |
| Kleinheppacher Kopf<br>(10 km westlich von Stuttgart) | Bunte Mergel<br>1985 | MEINIGER, W./SCHANZ, V./<br>WICHTER, L. (1985) |
| Stuttgart-Killesberg<br>(Stadtrand Stuttgart) | Gipskeuper | ROGOWSKI, E./<br>CRIENITZ, S. (2002) |
| Umgehung Lorch (B 29)<br>(40 km westlich von Stuttgart) | Bunte Mergel<br>1984 | WICHTER, L./MEINIGER, W. (1985)<br>(1985) |

## 3. SOIL MECHANICS ANALYSIS

The keuper marls in south west Germany a very heavily over consolidated and the soil mechanical properties vary from those of soft rock to those of soft silty clay depending on the intensity of the weathering.

If one wants to analyse land slips or even predict them using the methods commonly used in soil mechanics one has to check how reliable the shear parameters of the weathered clay stone are. There are especially three aspects to be checked.

1. Which zones of the slip masses are of importance and where should the samples be taken.
2. Is the scattering of the test results so small that only a few test are necessary in order to make a reliable prediction.
3. Is the maximum or residual strength of importance.

In the following the expected scattering in triaxial tests on weathered keuper clay stones is investigated.

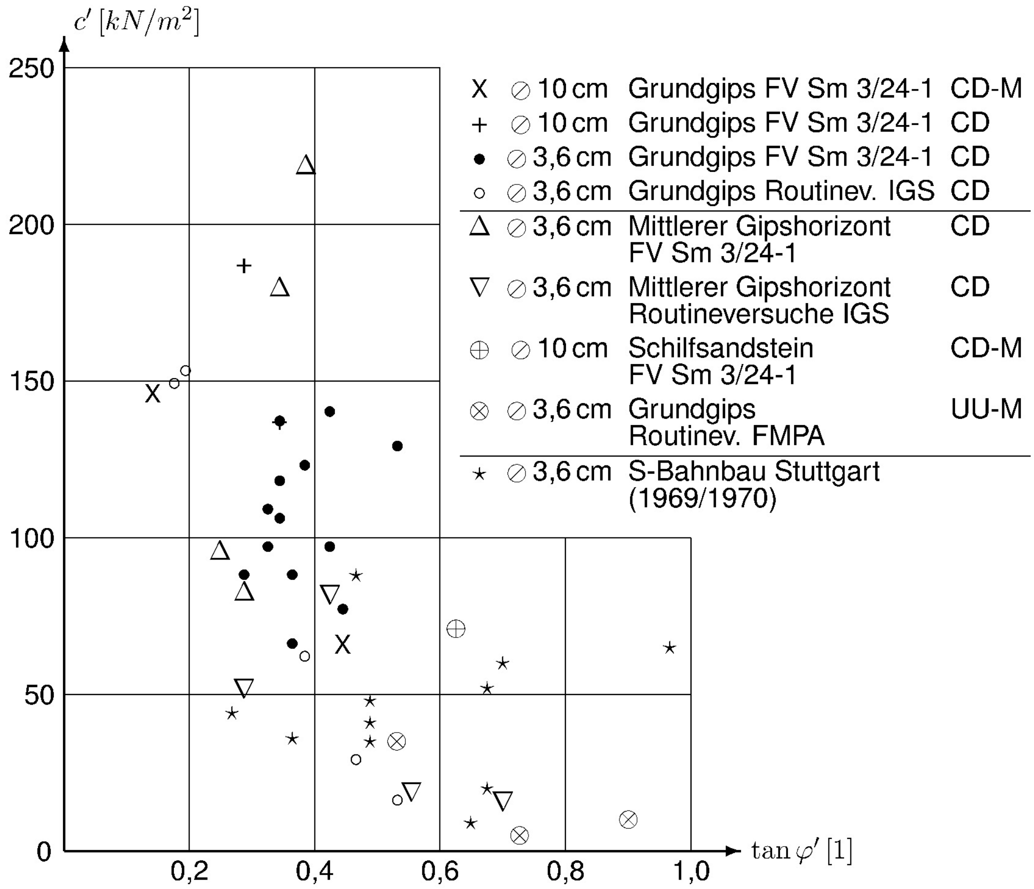



*Fig. 8: Results of 45 triaxial test on weathered clay stone with 0.8 < Ic < 1.0 (mainly gypsum marl from Stuttgart)*

From the many laboratory test carried out during the building of the underground railway in Stuttgart during the seventies and also from a DFG research programme (Smoltczyk et al.1985) there were 45 tests with consistencies between 0.8 and 1.o which could be evaluated. The results are shown in figs. 8 to 10.

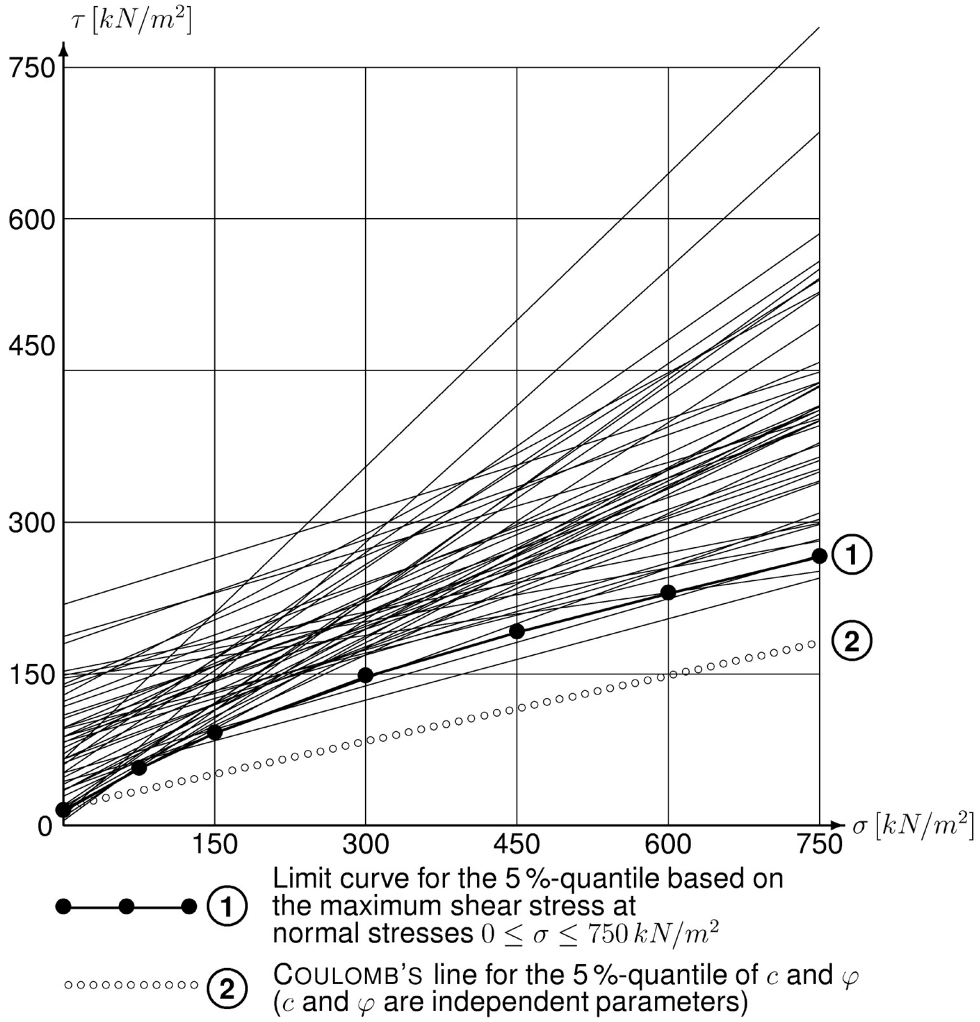



*Fig. 9: Coulomb envelopes in the τ / σ- diagram with curves for the 5%-quantile of the maximum shear stress and the straight line for the 5%-quantile for cohesion and shear angle (independent parameters)*

If one selects the 5%-quantile as a criteria for the characteristic value then the simplest method is to look upon the values of c and φ as independent values and calculate the 5%-quantile for each value. The results of such an analysis are shown in fig. 9. The line using these values is clearly much lower than the experimentally determined curves. This shows that the chosen method must be wrong because the c and φ are not independent parameters and the 5%-quantile may not be calculated for each parameter on its own.

It is better to calculate the 5%-quantile for the maximum shear stress at various normal stresses. If one does this for the normal stresses 0, 75, 150, 300, 450, 600 and 750 kN/m² then one obtains the curve shown in fig. 9. The way the analysis is carried out is shown if fig. 10 for the normal stress 75 kN/m².

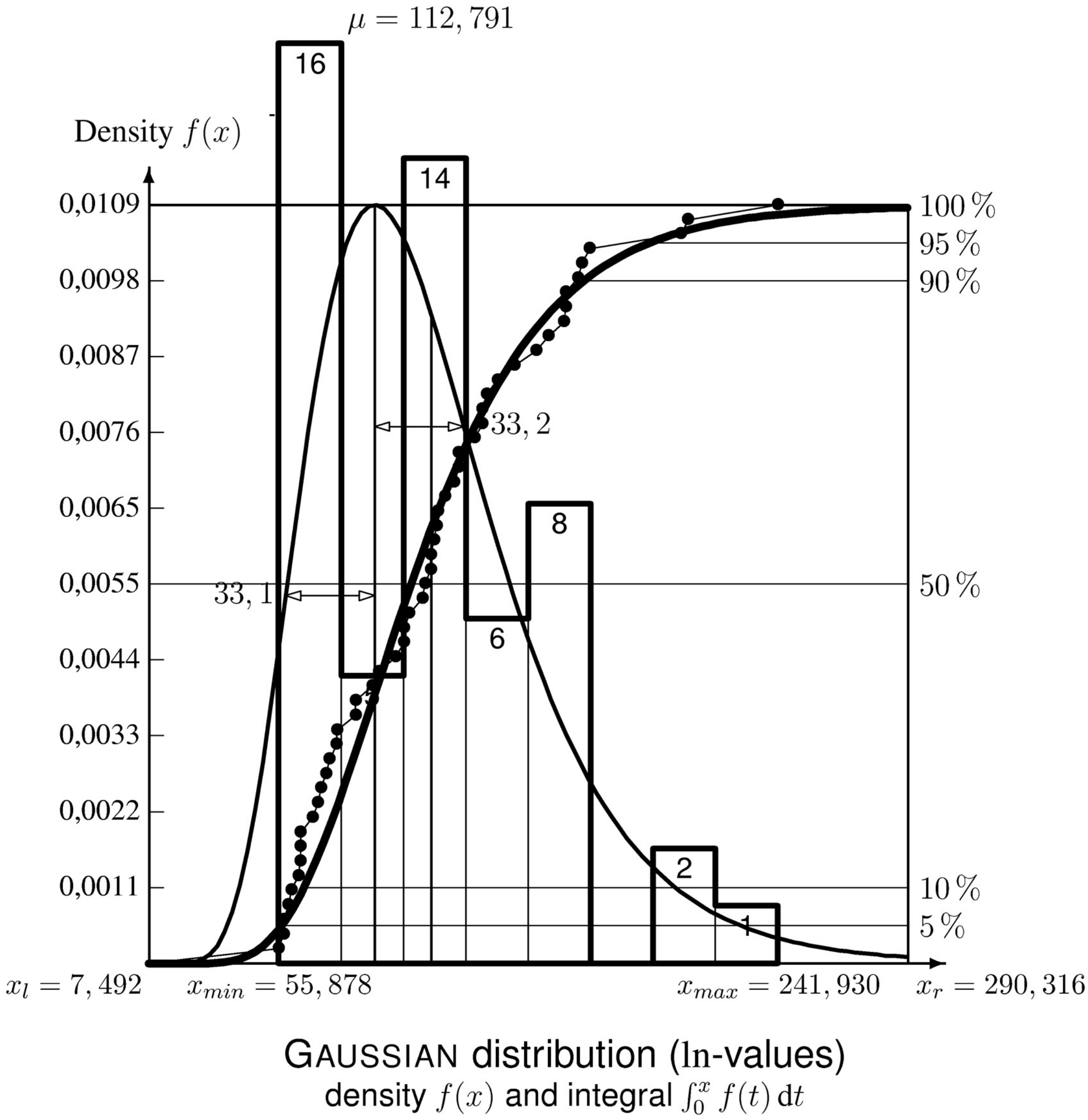



*Fig. 10: Statistic of the maximum shear stress at a normal stress of 75 kN/m²*

Because the coefficient of variation with a value of 38% is relatively high the 5% curve lies well below the curve for the average values of the shear curves. The 5% curve shows the well known phenomena that with increasing normal stress the slope of the shear envelope decreases.

In order to obtain the usual parameters c and φ the envelope was approximated to a straight line for various stress intervals. The following values of the following table were obtained.

| Region of normal stress $[kN/m^2]$ | 0 – 150 | 0 – 300 | 0 – 750 |
|---|---|---|---|
| Angle of friction $\varphi\ [^o]$ | 27 | 23 | 18 |
| Cohesion $c\ [kN/m^2]$ | 16 | 23 | 41 |

The large scattering of the shear parameters shows clearly that for a given project it is not possible to give characteristic values for cohesion and shear angle based on a few shear tests. The shear tests carried out for individual projects only give one an idea of the magnitude of shear strength. Characteristic values can only be selected based on the average values of test results if one can and may build according to the observation method.

For stabilisation and repair of slip areas the shear parameters obtained by stability calculations with a factor of safety of one are more important than the results of laboratory tests.

## 4. REMARKS TO STABILISATION AND REPAIR

When discussing the repair and stabilisation of slips it is of great importance whether one assumes the slip body consists of a heavily fractured body or whether it is a slipping of several rock like blocks.

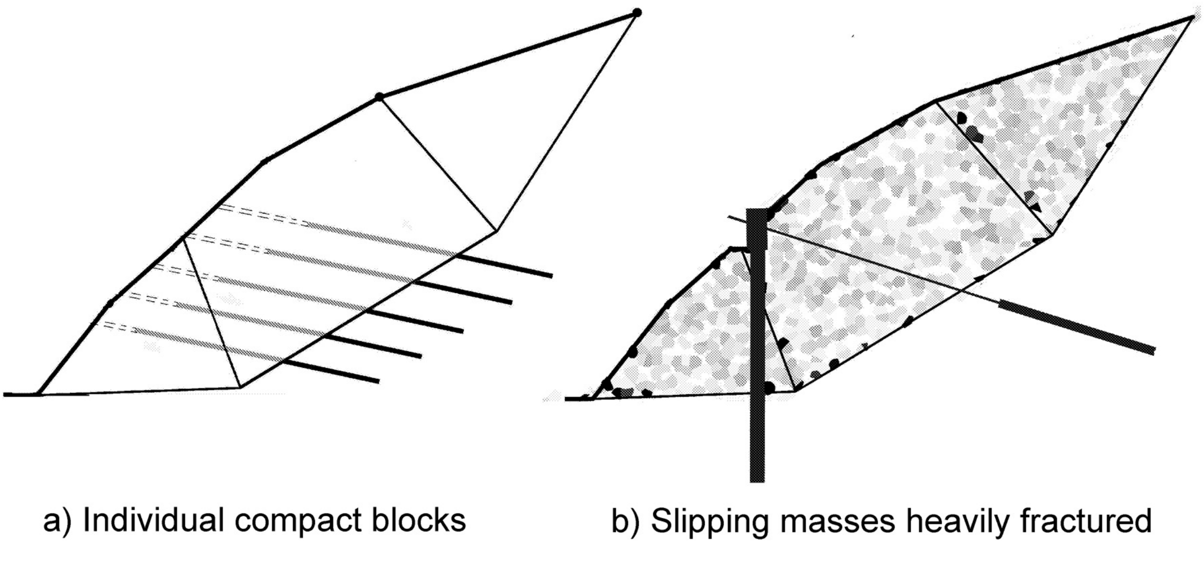



*Fig. 11: Possibilities for repair and stabilisation*

On the assumption that the slip consists of completely fractured bodies then stabilisation can only be achieved using large piles, closely spaced small piles or anchored bored pile walls with a head beam. If the slip can be considered as individual rock blocks as shown in fig. 10a then stabilisation can be achieved using anchors as shown. Another method is to use piles.

According to the experience of Wallrauch slips in keuper marls generally occur as heavily fractured bodies. He prepared the sketch in fig. 12 for a slip in Kleinheppach which illustrates the principles. (Further details of the slip in Kleinheppach are given in FMPA 1985).

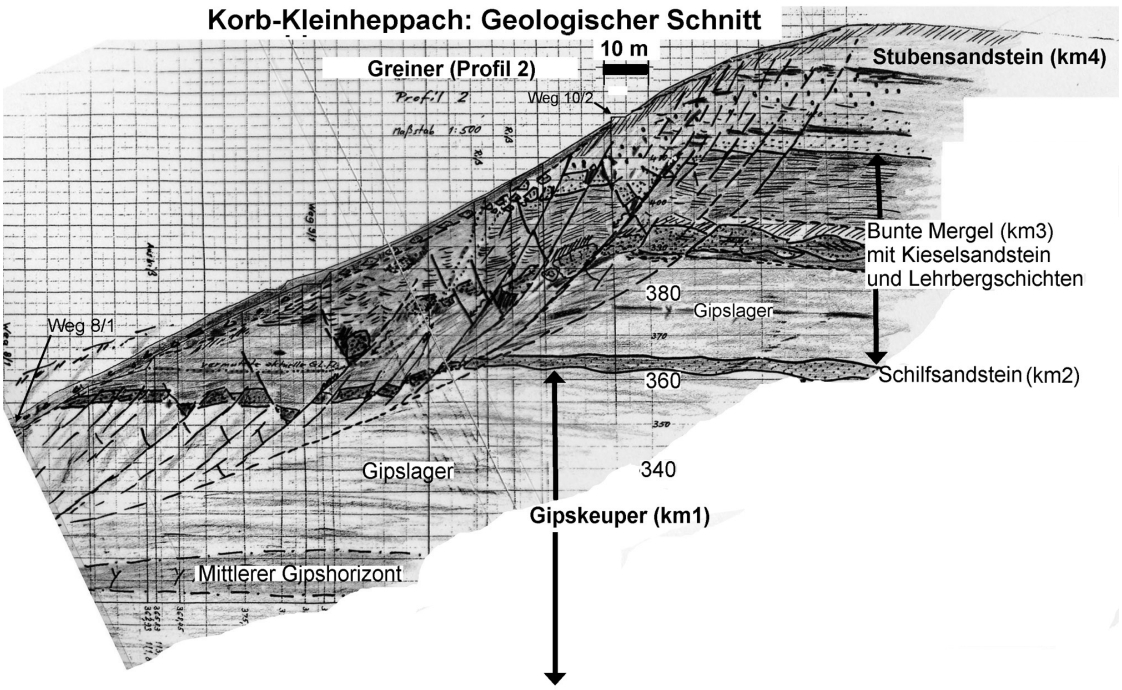



*Fig. 12: Fracturing of slipped masses of the example of a keuper Landslide at Kleinheppach*

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