

Geotechnische Aspekte von verwitterten und alterierten Graniten beim Tunnelprojekt Königshainer Berge

Geotechnical aspects of weathered and altered granite in the Königshainer Berge tunnel project

Dr. Thuro, Kurosch¹; Dr. Hecht, Lutz^{2,3}; Dipl.-Geol. Plinninger, Ralf J.³;
Dipl.-Geol. Scholz, Marcus³; Dipl.-Geol. Bierer, Sandro³ –

¹ *Engineering Geology, Institute of Geology, Swiss Federal Institute of Technology, Zürich, Schweiz*

² *CREGU – Géologie et Gestion des Ressources Minérales et Énergetiques, Département des Sciences de la Terre, Vandoeuvre/Nancy, France*

³ *Department of General, Applied and Engineering Geology, Technical University of Munich, Germany*

ABSTRACT: Intensively weathered and altered granites have been excavated during tunnelling works on two 3.3 km long motorway tubes in eastern Germany. The opportunity was given to study these zones through the implementation of a detailed field and laboratory program. As a result, each alteration and weathering stage could be characterized with rock or soil properties. Special emphasis was attached to the changes of rock porosity and the connection with rock properties. One of the primary observations was the increase in porosity with the degree of weathering and subsequently a decrease in most of the mechanical rock properties. It is of considerable importance that hydrothermal alteration contributed to an increased disintegration and decomposition by weathering processes. This also explains the pattern and unusual distribution of the weathered granite zones along the tunnel axis.

ZUSAMMENFASSUNG: Während der Bauarbeiten zu zwei 3,3 km langen Tunnelröhren für die A4 in Sachsen wurden verwitterte und alterierte Granite durchtunnelt. Dadurch ergab sich die Gelegenheit, diese Zonen mit einem detaillierten Feld- und Laborprogramm zu untersuchen. Als Ergebnis konnten die Alterations- und Verwitterungsgrade mit fels- oder bodenmechanischen Kennwerten charakterisiert werden. Besonderes Augenmerk wurde auf die Änderung der Gesteinsporosität und des Zusammenhangs mit den Gesteinskennwerten gerichtet. Eine der wichtigsten Beobachtungen war die Zunahme der Porosität mit dem Verwitterungsgrad und die gleichzeitige Abnahme der meisten felsmechanischen Kennwerte. Es ist von besonderer Wichtigkeit, dass die hydrothermale Alteration der Wegbereiter für eine verstärkte Zerlegung und Zersetzung durch die Verwitterung war. Dies erklärt vor allem das ungewöhnliche Muster und die Verteilung der verwitterten Zonen entlang der Tunnelachse.

1 Project outline

In the area of the Königshainer Berge (100 km east of Dresden, Saxonia, Germany), two 3.3 km roadway tunnels of have been built in connection with the extension of the German Federal Freeway A4 to the Polish border (Table 1). The two tubes provided an unique cross section through zones of intensive weathering and hydrothermal alteration within different biotite granites. Although no major problems were encountered during excavation, the pattern and the distribution of the weathered zones was somehow unusual. At the same time, observations have been made concerning zones of unusual altered, "greenish" granites of up to several meters thickness following steep-dipping faults.

Table 1: Project overview after (1).

Königshainer Berge tunnel project

Purpose	Extension of the German Federal Freeway A4 to the Polish border
Length	2 tubes, 3'300 m each, d=30 m
Excavation method	NATM, drill & blast excavation
Excavated cross section	Standard cross-section 80.5 m ² Emergency bay 120 m ²
Construction time	February 1996 – May 27, 1997 Opening: April 1999
Client	Federal Republic of Germany and Free State of Saxony
Overall design and project management	DEGES Deutsche Einheit Fernstrassenplanungs- und -bau GmbH
Design construction project management, geology	Müller-Hereth Tunnel- und Felsbau, Consulting Engineers, Freilassing, Germany
Construction / Joint Venture	Tunnel Königshainer Berge: Hochtief AG, Universale Bau GmbH, Schachtbau Nordhausen

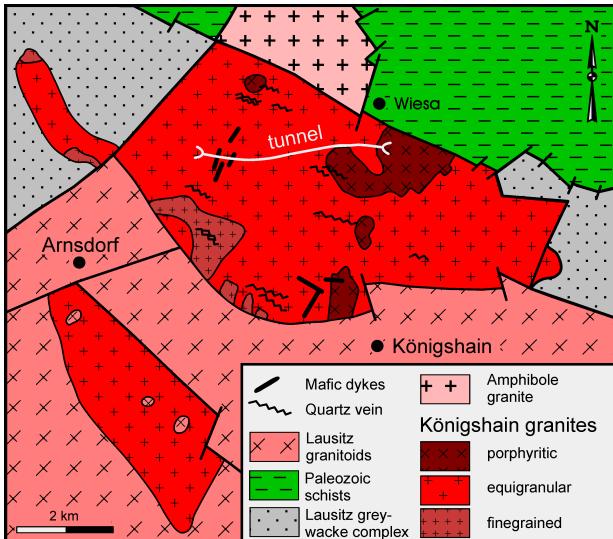


Figure 1: Geological sketch map of the Königshainer Berge project area.

Accordingly, a series of weathered and altered zones have been studied intensively by means of a detailed engineering geological investigation and subsequent rock and soil sampling, testing and monitoring. The main topics of the extensive field studies and laboratory work were:

1. To characterize each weathering and alteration stage according to the rock or soil properties (e.g. mineral composition, microfabric, compressive and tensile strength, Young's modulus, specific destruction work, cohesion, friction angle, grain size distribution, etc.)
2. To correlate the pattern of weathering and alteration in the rock mass along the tunnel section with the discontinuity system.
3. To distinguish the effect of weathering and hydrothermal alteration on mineralogy as well as on geotechnical rock properties.
4. To derive relationships between weathering grade and several technical properties (e.g. drilling velocity for blastholes and the consumption of explosives at the tunnel face).

In this paper, only few selected geotechnical aspects of the different disintegration stages of the Königshain granites are presented.

2 Hydrothermal alteration of the granites

Situated in the most eastern part of Germany, the tunnel cuts through two mica granites (age app. 300 million years) of the Lausitz granodiorite complex. After a complex geologic history, the region was exposed to erosion and weathering following the late Cretaceous / early Tertiary (app. 65 million years old, (2, 3)).

Three types of granites are distinguished in the Königshain area (4), of which the equigranular

(light-grey to red in colour) and the porphyric type (coloured blue-grey to white-dotted) have been encountered during tunnelling works (Figure 1). Only some dikes of fine-grained granite (white-yellow to blue-grey) occur within the equigranular type.

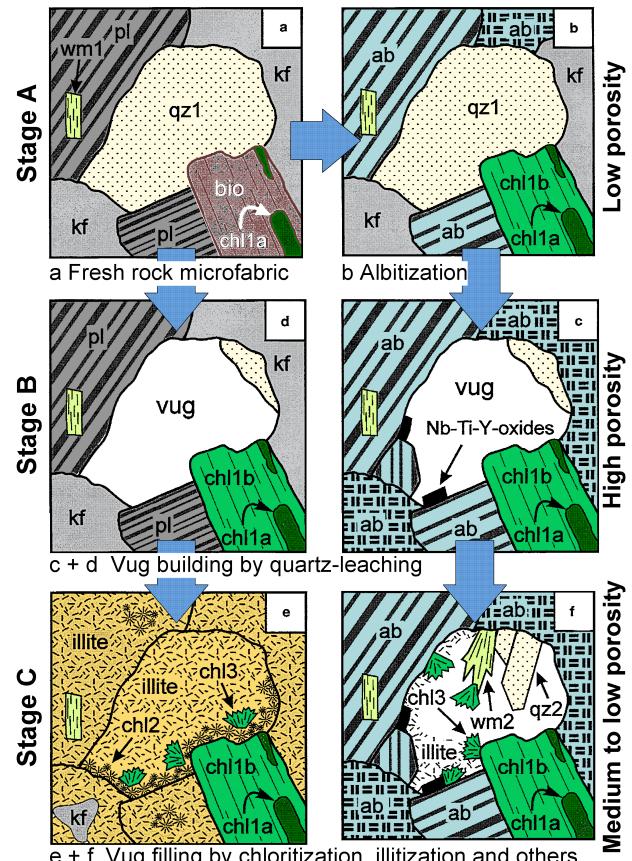


Figure 2: Hydrothermal alteration paths, stages and indication of their pore volume. kf – K-feldspar, pl – plagioclase, ab – albite, qz – quartz, wm – white mica, bio – biotite chl – chlorite.

Some parts of the Königshain granites underwent two stages of hydrothermal alteration before burial, as suggested by (5). The altered granites (described as episyenites) show a variable composition due to the alteration paths they followed (Figure 2). In comparison, the unaltered granites typically contain pink to reddish feldspars, the altered granites show white feldspars due to albitization or sericitization. With progressive chloritization, the granites obtain a green-spotted to dark green colour. More significant, however, is the increase of pore volume due to quartz-leaching in stage B. In stage C, the produced pores cannot be filled completely by blastesis of new minerals such as clay minerals, micas and quartz (Figure 3). Therefore, the maximum porosity is obtained in stage B. Unfortunately, due to predominant weathering of the altered granite, only little

material could be gained for rock testing in the laboratory.

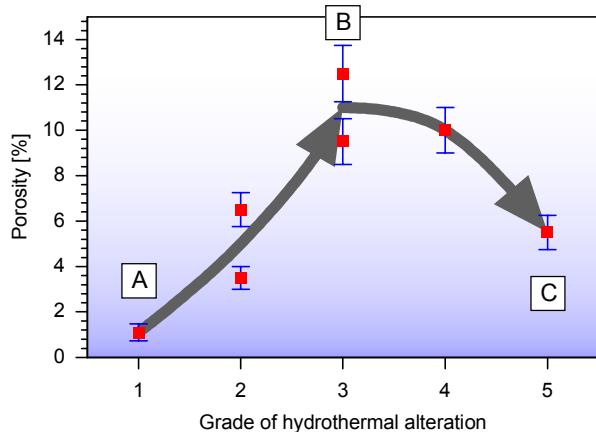


Figure 3: Development of porosity with the grade of hydrothermal alteration. Stages A – B – C refer to Figure 2.

The unconfined compressive strength – determined by point load tests – changes significantly with porosity and the grade of alteration (Figure 4). Although porosity is increasing again in Stage C, compressive strength decreases due to the weak sericite and clay minerals.

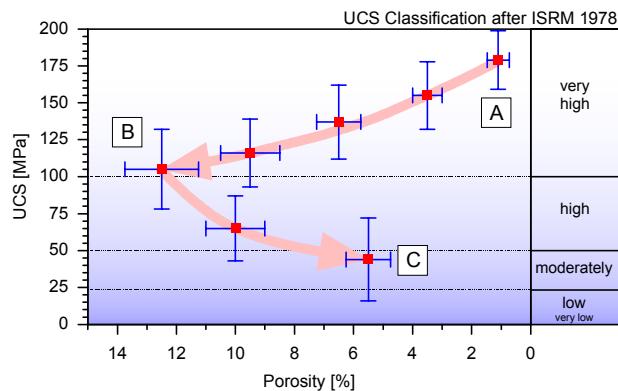


Figure 4: Development of unconfined compressive strength with porosity and alteration.

3 Weathering grades of the granite

It is remarkable, that only after the endogene alteration processes had finished, the rock has been exposed to the exogene processes of weathering. The change of mineral content and the increase of pore volume promotes the action of mechanical disintegration and chemical decomposition.

Figure 5 shows the stages of weathering in the microfabric of the granite by disintegration and decomposition into a clayey-silty soil material. Grades (I – VI) refer to the ISRM weathering grades (6). An additional grade called “II-III

slightly to moderately weathered” could be distinguished. In the following diagrams, the grades therefore are counted in arabic numerals from 1 to 7 (with VI = 7 residual soil, V = 6 completely weathered and so on).

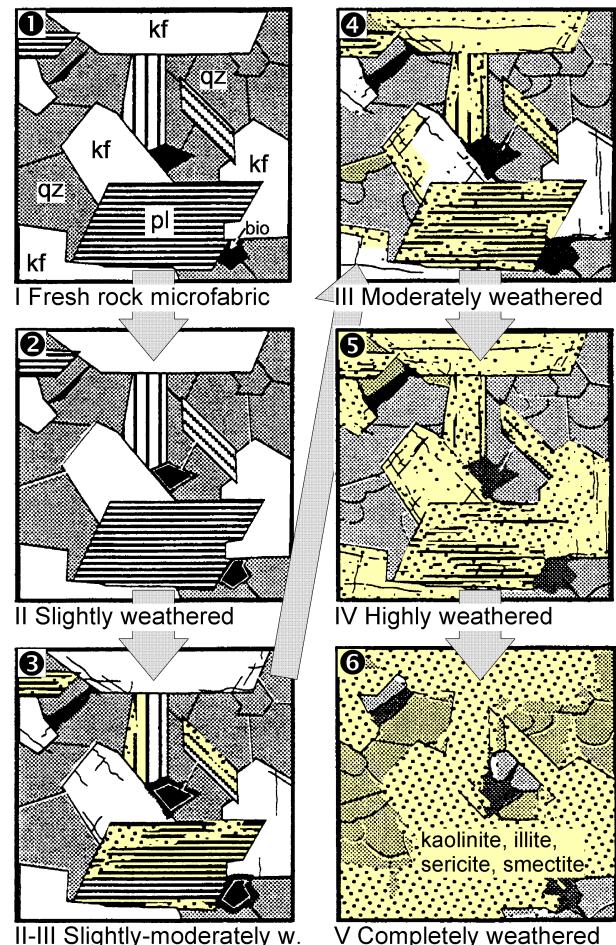


Figure 5: Weathering grades in the microfabric (leaving out grade VI = Residual soil).

Apart from mineralogical changes, porosity is increasing considerably and dry density of the rock material is decreasing simultaneously (Figure 6).

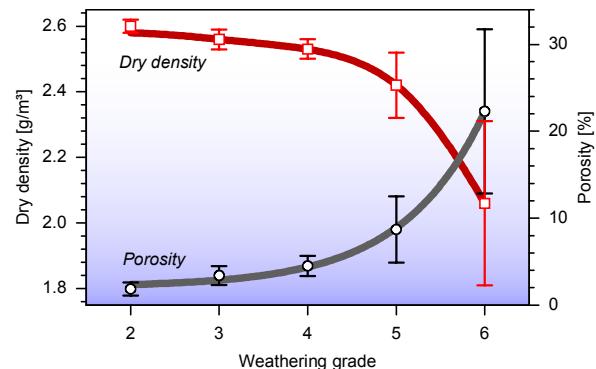


Figure 6: Connection of the weathering grade with dry density and porosity (pore volume). High/mean/low values are plotted for each grade.

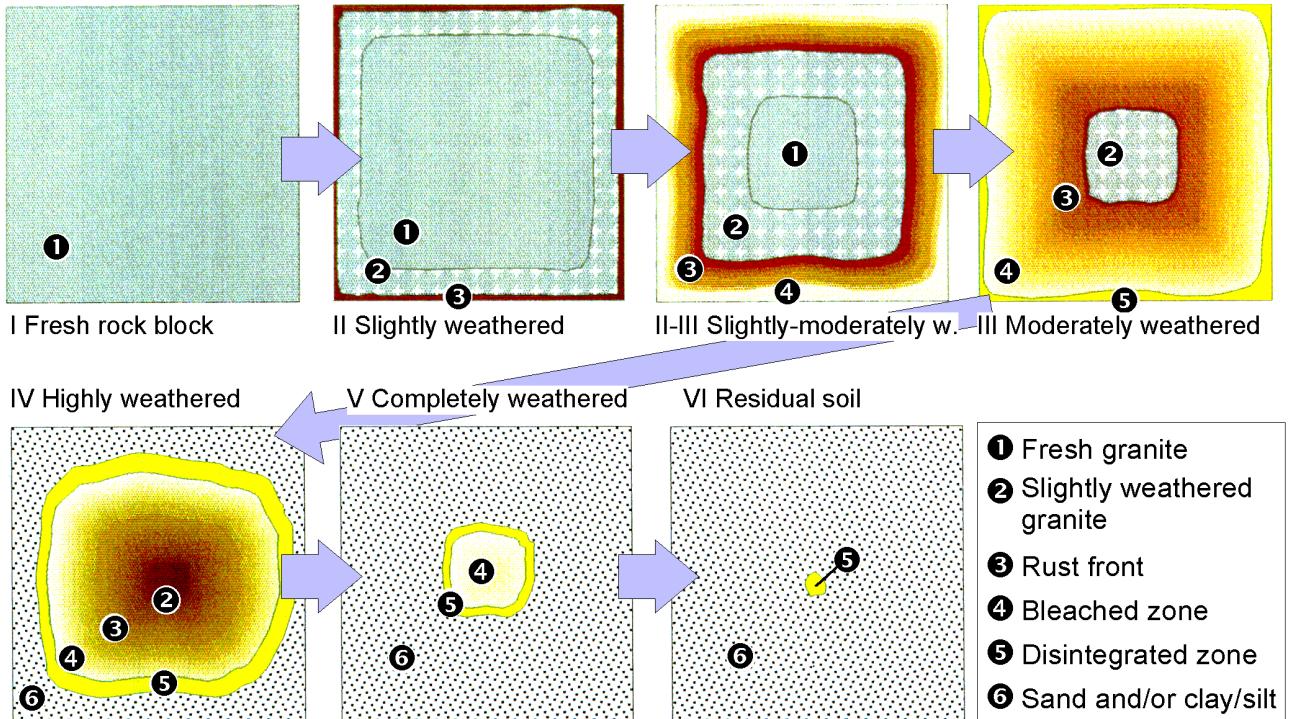


Figure 7: Grades of weathering in a Königshain granite block according to the ISRM grades (6).

At the same time, the rock mass undergoes changes (Figure 7) due to weathering. The process begins with the fresh granite ① (grade I = 1, which has not been encountered during tunnelling works). Subsequently, a typically reddish-brown rust front ② and a zone of microscopic weathered granite ③ moves from the wall rock into the rock mass (grade II = 2). A bleached light-brown to yellow-white zone ④ then marks the end of the solid rock (grade II-III = 3). The disintegrated zone ⑤ in grade III (= 4) consists mainly of clay and silt as the material of the wall rock decomposes. This proved to be the most dangerous material encountered, because of the low friction angle of the material and its tendency to shear along existing discontinuities. In grade IV (= 5) the granite disintegrates into a mixture of ⑥ sandy and/or clayey and silty material. In the completely weathered material (grade V = 6) the rust colours have disappeared and the residual soil (grade VI = 7) only holds remnants of the disintegrated granite.

Accordingly, the physical properties of the rock change in a similar manor. Figure 8 shows the unconfined compressive strength correlated to the different weathering grades. Since the weathering classification is always determined in the rock mass, the correlation is poor with a large standard deviation between values. Nevertheless, a trend can be seen. Only when the UCS is plotted against dry density or porosity (Figure 9) is a good correlation found with a fitted curve.

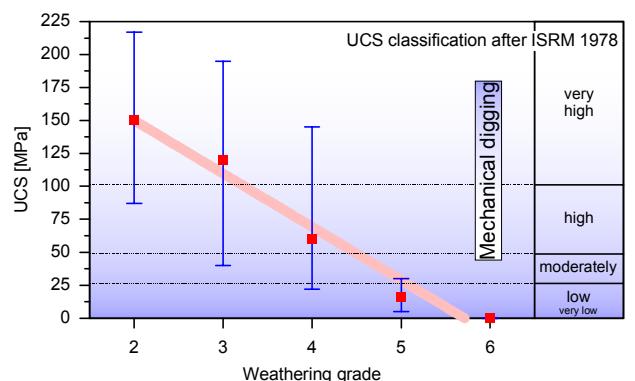


Figure 8: Unconfined compressive strength versus weathering grade (max/mean/min values).

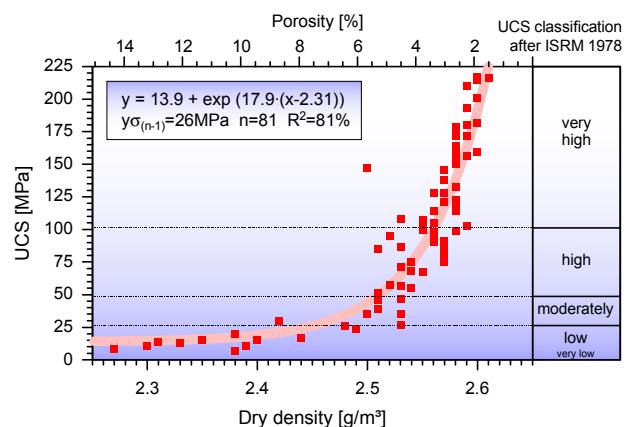


Figure 9: Unconfined compressive strength versus dry density and porosity (single values).

In addition to the compressive strength, tensile strength, and Young's modulus, the specific destruction work (integral of the complete stress-strain curve, after (7), Figure 10) shows a close

correlation with porosity. Also technical properties are significantly influenced as can be seen in Figures 12 and 13. Mean values of blasthole drilling rates and consumption of explosives with standard deviations are given.

Several soil properties are also affected in the stages of grade V (6) and VI (7). For example, the grain distribution is shifted from coarse to fine grain size with increasing weathering grade.

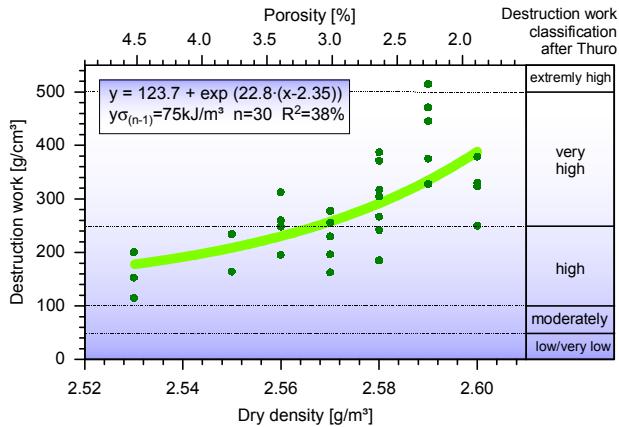


Figure 10: Specific destruction work versus dry density and porosity.

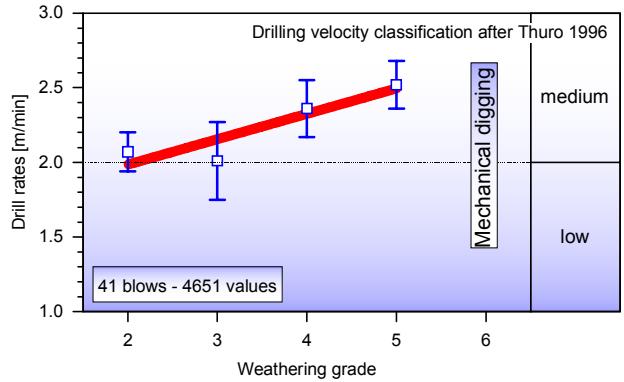


Figure 12: Drilling rates of blastholes versus weathering grade (classification see (8)).

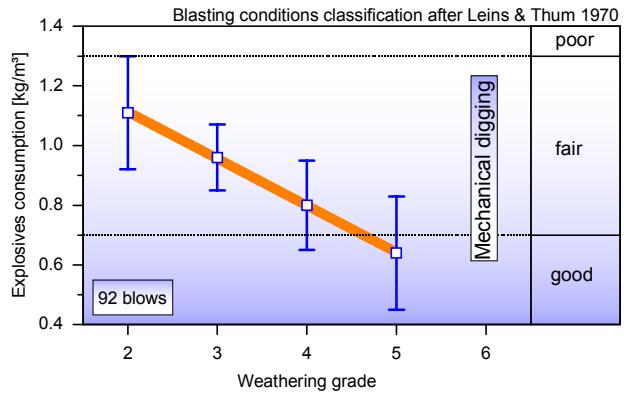
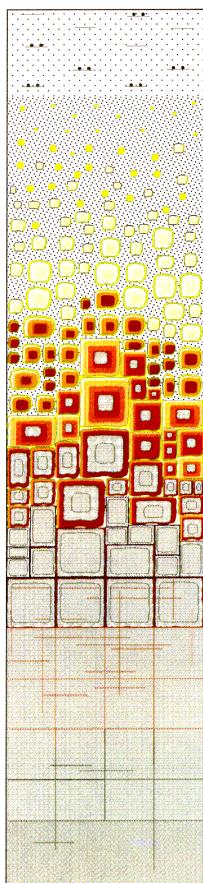


Figure 13: Consumption of explosives versus weathering grade (classification see (9)).



Weathering grades	UCS [MPa]	TS [MPa]	E [GPa]	$\frac{\text{UCS}}{\text{SPZ}} [-]$	W_d [kJ/m³]	D_d [g/cm³]	P [%]	ϕ [°]	c [kN/m²]
VI - 7 Residual soil						1.3 - 1.8	50 - 30	40° - 30°	35 - 15
V - 6 Completely weathered						1.8 - 2.3	30 - 13	30° - 20°	20 - 10
IV - 5 Highly weathered	0.5 - 25	0.05 - 2	10 - 20	5 - 12	10 - 100	2.3 - 2.52	13 - 5	20° - 10°	50 - 25
III - 4 Moderately weathered	25	2	20	8	100	2.50 - 2.56	6 - 3.5		
II-III - 3 Slightly - moderately weathered	120	15	40	12	150	2.54 - 2.58	4.5 - 2.5		Not possible to obtain data
II - 2 Slightly weathered	120 - 250	10 - 25	40 - 60	12 - 25	150 - 550	2.58 - 2.62	2.5 - 1		
I - 1 Fresh rock mass						2.62 - 2.64	1 - 0.5		

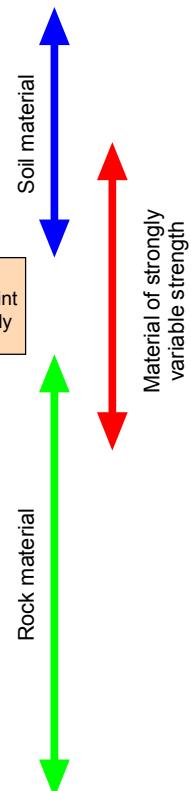


Figure 11: Weathering profile and some physical rock properties. UCS – unconfined compressive strength, TS – tensile strength, E – Young's modulus, W_d – specific destruction work, D_d – dry density, P – porosity, ϕ – friction angle, c – cohesion (determined through direct shear tests).

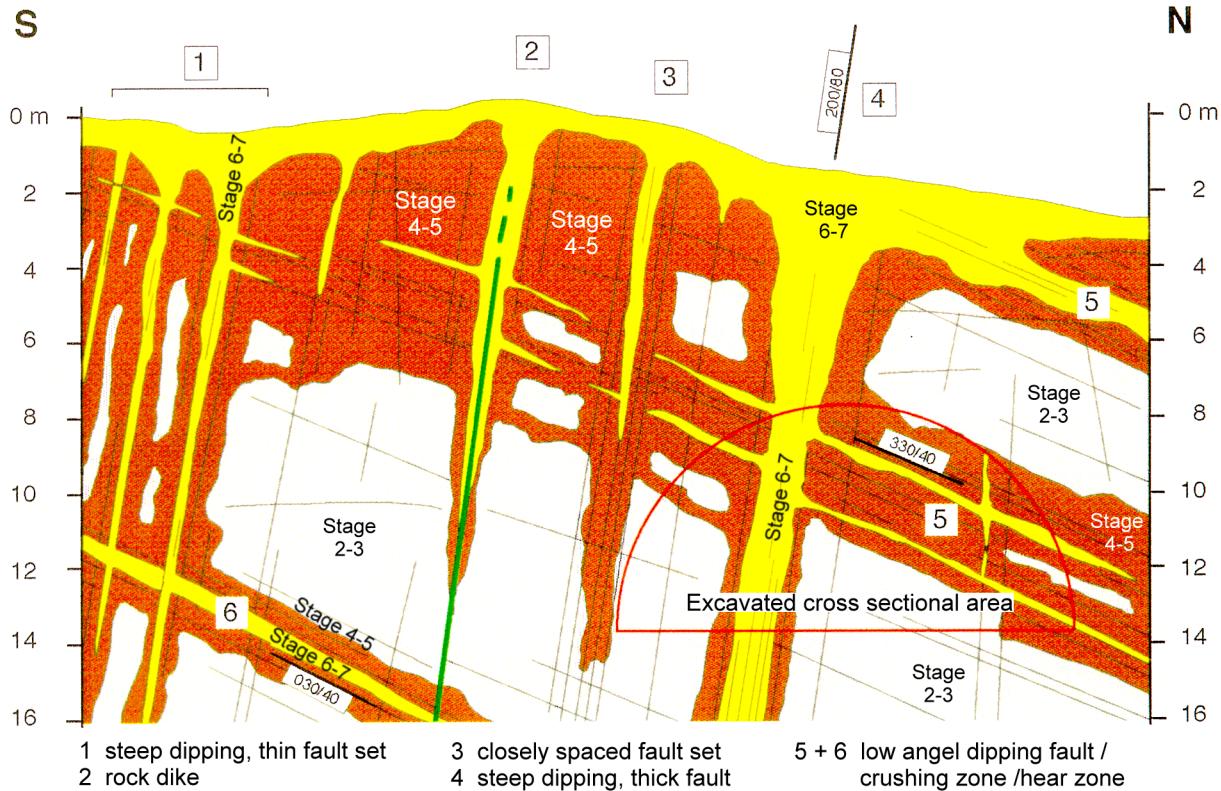


Figure 14: Model of weathering in the Königshainer Berge tunnel project with the dimension of top heading (excavated cross section area). Stages in arabic numerals refer to Figure 11.

4 Conclusion

Figure 11 gives an overview of the rock and soil properties determined for each weathering grade. Compared to (10) some differences have been encountered concerning description and characterization of the weathered rock mass. In the Königshainer Berge tunnel project, hydrothermal alteration has induced increased porosity in the rock mass. The hydrothermal solutions ascended in dikes following faults and the joint system and produced a finger-like pattern of altered material which easily could be exposed to weathering from the surface. Figure 14 shows the derived model of the weathered rock mass with respect to the scale of the tunnel.

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