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Engineering Geology in Austria: An Outline

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6 Figures and 4 Tables

Abstract

Engineering geology covers a great deal of applied geological activities in Austria. For years the main field has been the geological input for the construction of railway tunnels and hydropower plants. Later, building highways to cross the Alps led to a highly developed field of engineering geology. The close collaboration of civil engineers, rock and soil mechanical engineers with the engineering geologists has been an Austrian tradition for more than 100 years. Thus, the International Society of Rock Mechanics as well as the famous New Austrian Tunneling Method (NATM) have their roots in Austria. The challenge for the future will be the creation of high speed rail links, crossing the Alps in great depths. Some examples of the most outstanding achievements of Austrian engineering geology are shown.

Benchmarks in the Development of Austrian Engineering Geology

Engineering geology has a long tradition in Austria. A high percentage of the country is covered by the mountain chains of the Alps, including the highest mountain peak of Austria, the Grossglockner (3797 m above sea level). Thus, the abundant natural outcrops led to early activities in mining and engineering geology. Deriving from an already highly developed mining geology from the late Middle Ages which continued to develop up to the 19th century, the importance of engineering geology increased even more with the onset of the Industrial Revolution. The construction of the railway net (since 1837) in the former Austro-Hungarian Empire until 1918 was of special importance.

Hydropower development and dam construction, as well as tunneling- and dam geology, flourished with the beginning of the electrification of the main railway routes in 1905. However, it was heavily interrupted by the two world wars. Roads and highways have been challenging the skills of engineering geologists since the 1950's. Between 1965 and 1990, the greatest part of the highway net in Austria was built, with long road tunnels being constructed under difficult geological conditions partly covered by a high overburden of up to 1500 m. The main highway net is almost finished now with mainly bypasses of towns or second tubes of existing single-tube tunnels currently under construction or in planing stages.

Within the last years, several new high-speed transalpine rail link tunnels have been made, accompanied by a general straightening of the lines in less mountainous areas. The great projects of base tunnels, which are either in the planning or in the investigation stage (e.g. the 55 km long Brenner tunnel, the 30 km long tunnel under the Koralm, and the Semmering base tunnel with a length of 22 km), will be the challenges for the ongoing 21st century.

Influenced by these great engineering projects the theory of engineering geology and the rock and soil mechanics, respectively, exerted a steady influence each other. The development of the so-called "Gefügekunde" (textural analysis) by SANDER (1948, 1950) became one of the milestones of structural geology. CLAR (1954) invented a special compass with two axes for statistical fabric analysis, which is part of the standard equipment of geologists today in Austria and abroad.

Stini edited the first volume of his famous periodical "Geologie und Bauwesen" ("Geology and Civil Engineering") in 1929, already, which was the precursor of the contemporary international journal "Rock Mechanics". L. MÜLLER-SALZBURG founded the "Salzburg Circle" in 1951, where both the Austrian Society of Geomechanics and the International Society of Rock Mechanics (ISRM) have their roots.

In fact, the worldwide applied "New Austrian Tunneling Method" (NATM) was developed in Austrian road and water tunnels in the early 1950's, e.g. in the large-diameter hydropower galleries of the Schwarzach (HORNINGER, 1959a) and Prutz-Imst plants (SCHMIDEGG, 1959) respectively.

In 1963, the NATM was introduced at the Salzburg Geomechanics Colloquium (V. RABCEWICZ, 1963) and subsequently applied in the long highway tunnels, such as Katschberg (5,439 m, built 1971-74), Tauern (6,401 m, 1971-1975) and Arlberg (13,972 m, 1974-78).

The basic concept of this method is derived from steady observation of the behaviour of the rock mass; measurement of the deformation and calculation are the other cornerstones. The surrounding rock mass is regarded as a part of the lining, taking the advantage of the self-carrying capacity. Several principles in this method have to be considered (MÜLLER-SALZBURG, 1978; MÜLLER-SALZBURG and

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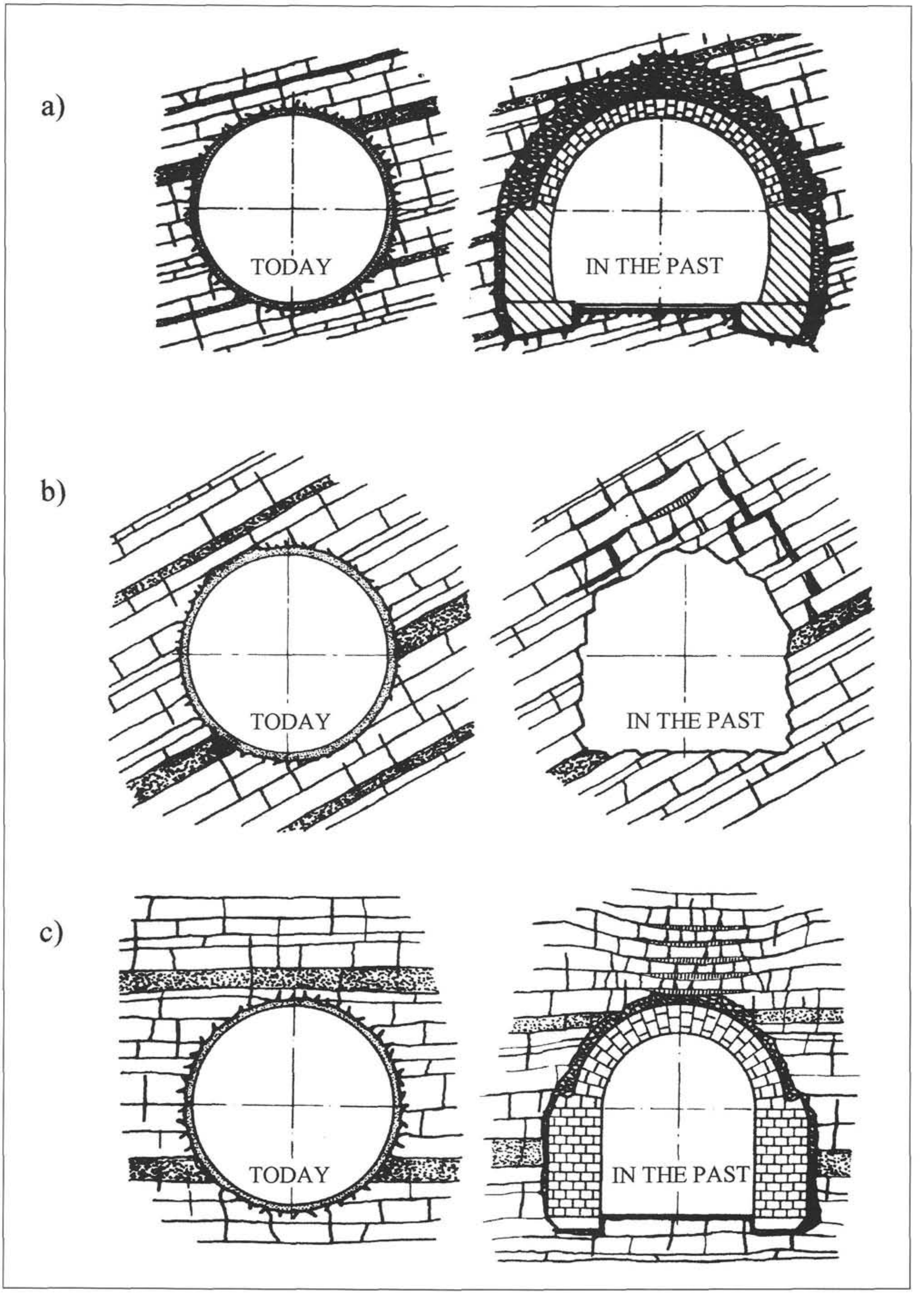

a)
TODAY
IN THE PAST
b)
TODAY
IN THE PAST
c)
TODAY
IN THE PAST

FECKER, 1978; CLAR and DEMMER, 1982): the most important of them are (see Fig.1):

- the maintenance of the individual strength of the rock mass,
- round tunnel shape,
- flexible thin lining,
- in situ measurements of deformations and steady geological documentation.

The present-day examples in Fig. 1 show only round tunnel shapes made by tunnel boring machines. Nevertheless, the principles are valid, especially for drill and blast excavation.

The influence of engineering geology on basic geological sciences has been crucial, too. For instance, the existence of some of the Austro-Alpine nappes have been proved by several tunnels and galleries, besides many other geological details (e.g. MATURA and SUMMESBERGER, 1980):

- the existence of the Tauern window (by the rail tunnels – BECKE, 1906 – and the water galleries of the Glockner-Kaprun hydropower system – HORNINGER, 1959b);
- the basal salt and gypsum layers as the decollement levels of some nappes (e.g. Bosruck rail tunnel: GEYER, 1907, NOWY and LEIN, 1984; water pipeline of Vienna: GATTINGER, 1973)
- the nature of upper tectonic boundary of the Engadine window (by the pressure tunnel for the Kaunertal power plant; HORNINGER and WEISS, 1980); and
- the flat-lying Austroalpine nappes on Penninic units exposed at the northern Tauern slopes (Tauern road tunnel: TOLLMANN, 1986; DEMMER, 1976).

Water supply

During the occupation by the Roman Empire some aqueducts for the military centres were constructed in the future Austrian area. In the Middle Ages, the first water tunnel through the Mönchsberg in Salzburg was made by the monks of St. Peter's Abbey in 1130 (HORNINGER and WEISS, 1980).

In the period of industrial growing, the town of Vienna rapidly expanded at the rate the great megacities of today. Eduard SUESS, Professor of Geology and member of the local municipal council, combined fundamental geological and socio-medical research in his book "The Ground of Vienna" (SUESS, 1862). Nowadays, there exists an excellent and modern geological-geotechnical-hydrogeological map of Vienna; (PLACHY et al., 1985). Groundwater, churchyards and centers of epidemic have been shown in their connections, which led to the first Viennese water pipeline (KARRER, 1877) bringing fresh spring water by gravity over a distance of 120 km from the karstic systems of the Northern Calcareous Alps (SCHUBERT, 2000, this volume). These pipelines include several tunnels, aqueducts and some hydropower plants. In 1910, this pipeline (partly conducted in galleries) was enlarged by a second system, one of the most modern systems at this time. Today, 90 percent of the city of Vienna is supplied by this water system, which of course became enlarged by adding several great springs. To guarantee a sustainable drinking water supply for the citizens, the government of Vienna initiated a karst research program in the 1990's, which investigates the complex system atmosphere, vegetation, soil, rock and water in an interdisciplinary approach (SCHUBERT, 2000, this volume; GOLDBRUNNER, 2000, this volume).

The share of karstic springs for water supply in Austria is quite high today; the cities of Innsbruck (AMPFERER, 1949; KLEBELSBERG, 1953), Kufstein, Villach, Salzburg, and Graz, as well as many smaller communities, obtain their drinking water from partly karstified carbonate rocks (SCHUBERT, 2000, this volume). Thus, more than 50 percent of the Austrian freshwater supply derives from springs out of the Northern Calcareous Alps.

Nevertheless, some efforts have been made to use joint water entering underground structures to meet the drinking demand. These are not only limited to the Northern Calcareous Alps, but also in magmatic and metamorphic rocks (SAMETZ and OBERLEITNER, 1991).

Hydropower plants

Alpine hydropower started with small hydropower plants having only small reservoirs (or none at all) in the foothills of the Alps in the late 1880's. The reservoir capacities increased, especially for the high-altitude seasonal storage with high-head plants in the valleys of the Central Alps (STINI, 1955; DEMMER, 1978) with the increasing demand of the industry and forced by the small winter runoff (10-30% of the annual discharge depending on the sea level). On the other hand, the major river developments in the densely populated valleys led to low-head run-of-river plants of the river barrage type.

One of the first great high-pressure plants with areservoir was the Achensee (Achen lake) power plant (constructed 1924-27; AMPFERER and PINTER, 1927), which used a natural lake without a dam but with the first high-pressure shaft, which was continuously geologically documented (Fig. 3).

Under the level of the natural lake, the gallery was driven by the aid of a caisson. Above all, the inclined lot had to meet some severe water inflows coming from karstified limestones, of about 300 l/sec, which could not be mastered at that time. As a result it was finished from the other side with some delay.

All the 131 Austrian dams listed in the "World Register of Dams" have as the main purpose the supply of electric power- the flood control is provided as asupplement free of charge (DEMMER, 1991).

The majority of Austria's dams is situated in the Central Alps within the formerly glaciated region of the Alpine valleys. The highest arch dams are founded in these formations: Kölnbrein (height = 200 m) and Zillergründl (height = 186 m), just as the highest embankment dams: Gepatsch (height = 153 m) and Finstertal (height = 150 m), and the highest gravity dams: Vermunt and Tauernmoos (height = 53 m each).

In terms of engineering geology, the foundation conditions usually induced no great problems of water loss from the reservoir or with regard to the foundation treatments.

← Fig. 1
Some of the principles of the NATM (after MÜLLER-SALZBURG and FECKER, 1978). In this paper there are 24 principles, some for horse-shoe shaped tunnels, too.

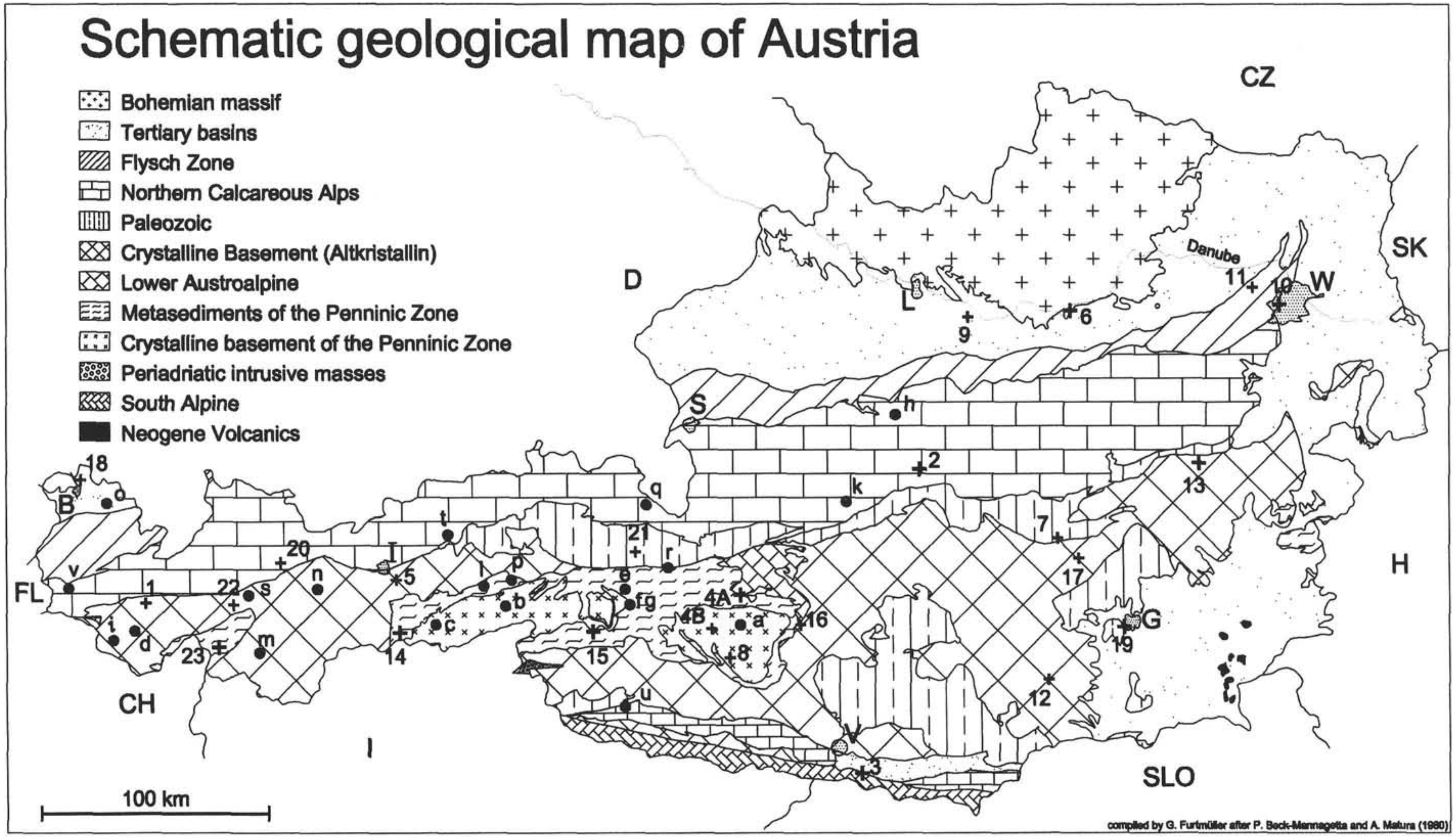


Fig. 2

Schematic geological map of Austria with the most important sites. Abbreviations and numbers:

- Cities (as mentioned in the text) W: Vienna, G: Graz, S: Salzburg, I: Innsbruck, B: Bregenz, V: Villach
- \+ Rail tunnels: 1: Arlberg, 2: Bosruck, 3: Karawanken, 4B: Tauern, 5: Inntal, 6: Säusenstein, 7: Galgenberg, 8: Kaponig, 9: Sieberg, 10: Lainz, 11: Wienerwald, 12: Koralm, 13: Semmering, 14: Brenner
- \+ Road tunnels: 1: Arlberg, 2: Bosruck, 3: Karawanken, 4A: Tauern, 15: Felbertauern, 16: Katschberg, 17: Gleinalm, 18: Pfänder, 19: Plabutsch, 20: Roppen, 21: Schmitten, 22: Landeck, 23: Finstermuenz
- ● Dams: a: Koelnbrein, b: Zillergruendl, c: Schlegeis, d: Kops, e: Limberg, f: Drossen, g: Mooser, h: Klaus, i: Vermunt, k: Salza, l: Gmuend, m: Gepatsch, n: Finstertal, o: Bolgenach, p: Durlaßboden, q: Dießbach. Hydropower plants mentioned in the text: r: Schwarzach, s: Prutz-Imst, t: Achensee, u: Drau, v: Walgau. The sites along the Danube river are not indicated separately.

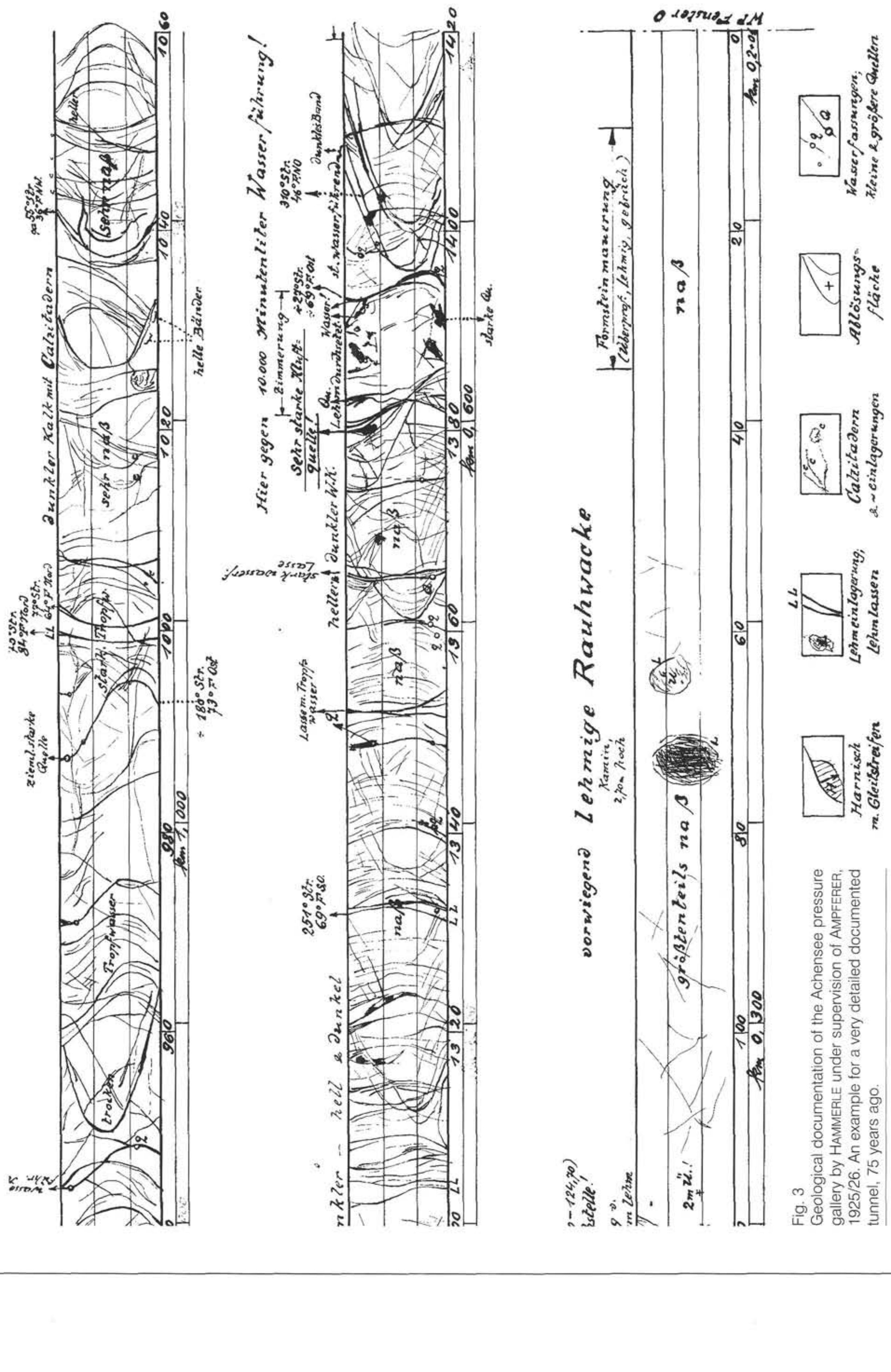


Fig. 3
Geological documentation of the Achensee pressure gallery by HAMMERLE under supervision of AMPFERER, 1925/26. An example for a very detailed documented tunnel, 75 years ago.

The foundation conditions of the Kölnbrein arch dam (1974-1977), however, during the first investigation periods seemed to indicate satisfying conditions. During the first filling, however, substantial seepage was measured near the dam base, due to cracks both in the dam foundation and in the bedrock (DEMMER and LUDESCHER, 1985). A lot of additional grout holes (filled by cement grout and artificial resin polyurethane) tightened the seepage. In the late 1980's an additional support shoulder was constructed with special pillow elements, which led to adequate smaller movements of the dam, as well as to a satisfactory decrease of the water losses.

Special grout treatment was made for the Schlegeis (MIGNON, 1972) and Zillergruendl arch dams (NOWY, 1984) too (Fig. 4).

Great risks arose, however, in some partly unstable reservoir slopes (e.g. Durlassboden and Gepatsch reservoirs). The Gepatsch-dam, Austria's highest rockfill dam, did not cause troubles for geological reasons at the dam site itself, after having moved from the previously evaluated site. Yet serious problems arose in the course of the first partial filling of the storage basin in summer of 1964 due to sagging phenomena at the left valley slope, only a few hundred metres lakeward from the dam crown, a large rock slide (about 20 Mio m^3) occurred. Previous investigations could define ancient slides. By one of the four inspection galleries it became evident that the slide was caused by impounding and was affected with a wide rock slab, which had already crept down over the moraine post-glacially. Finally, a line of indirect conclusions led to an understanding of the sagging process as initiated and governed by uplift. The cautiously balanced stepwise increase of the impoundment was successful, with only small further creeping accompanied by numerous geodetic and geotechnic measurements, stability calculations and laboratory tests (HORNINGER and WEISS, 1980; TENTSCHERT, 1998).

Embankment types had to be adopted for less satisfying sites, where bedrock is covered with thick overburden. A classic example is the 83 m high Durlassboden earthfill dam, which was constructed on a valley fill, consisting of unconsolidated sediments of extremely heterogeneous composition: repeated alternations of moraine, ancient landslide material and former lacustrine and fluvial deposits with fans of talus material descending from the flanks. Particularly careful foundation treatment by borehole grouting was required to improve the foundations. The reservoir is surrounded by ancient sagging masses, which have been investigated exemplarily (CLAR and ZISCHINSKY, 1968).

As anywhere else in the world, dam design for limestone locations in Austria focused on the permeability problem for

Table 1
The highest dams of Austria, as well as sites mentioned in the text. For technical literature see also AUSCOLD (1991). H – height. For locations, see Fig. 2.

Dam	Type	H (m)	Completed	Foundation rock	Power plant	Geology by *:
Concrete dams						
Koelnbrein	arch	200	1977	gneiss, granite	Malta-Kolbnitz	LUDESCHER, (1990); DEMMER and LUDESCHER, (1985)
Zillergruendl	arch	186	1986	gneiss	Häusling	NOWY, (1984)
Schlegeis	arch	131	1971	gneiss	Roßhag	MIGNON, (1972)
Kops	arch/ gravity	122	1965	gneiss	Partenen	LOACKER in: Vorarlberger Illwerke (1970)
Limberg	aruch	120	1951	calcareous micaschist	Limberg	HORNINGER
Drossen	arch	112	1955	schist	Kaprun	HORNINGER, (1968)
Mooser	gravity	107	1955	gneiss, schist	Kaprun	HORNINGER, (1959b)
Klaus	arch	55	1975	dolomite	Klaus	DEMMER
Vermunt	gravity	53	1931	gneiss	Partenen	REITHOFER; Ministerium für Verkehr und Verstaatlichte Unternehmen (1956)
Salza	gravity	53	1949	limestone		STINI, (1955)
Gmuend	arch	39	1945	quartize	Zell a. Z.	HORNINGER and KROPATSCHEK, (1967)
Rock and earthfill dams						
Gepatsch	rock	152	1965	granite gneiss	Prutz	SCHMIDEGG
Finstertal	rock	150	1980	gneiss	Silz/Kühtai	TENTSCHERT, (1996)
Bolgenach	earth	102	1978	sandstone, shale	Langenegg	INNERHOFER and LOACKER, (1982)
Durlaßboden	earth	83	1971	schist	Funsingau	MIGNON, (1972)
Diessbach	rock	29	1963	dolomite	Saalfelden	BRANDECKER et al., (1965)

* Names without year: only in internal reports, not published

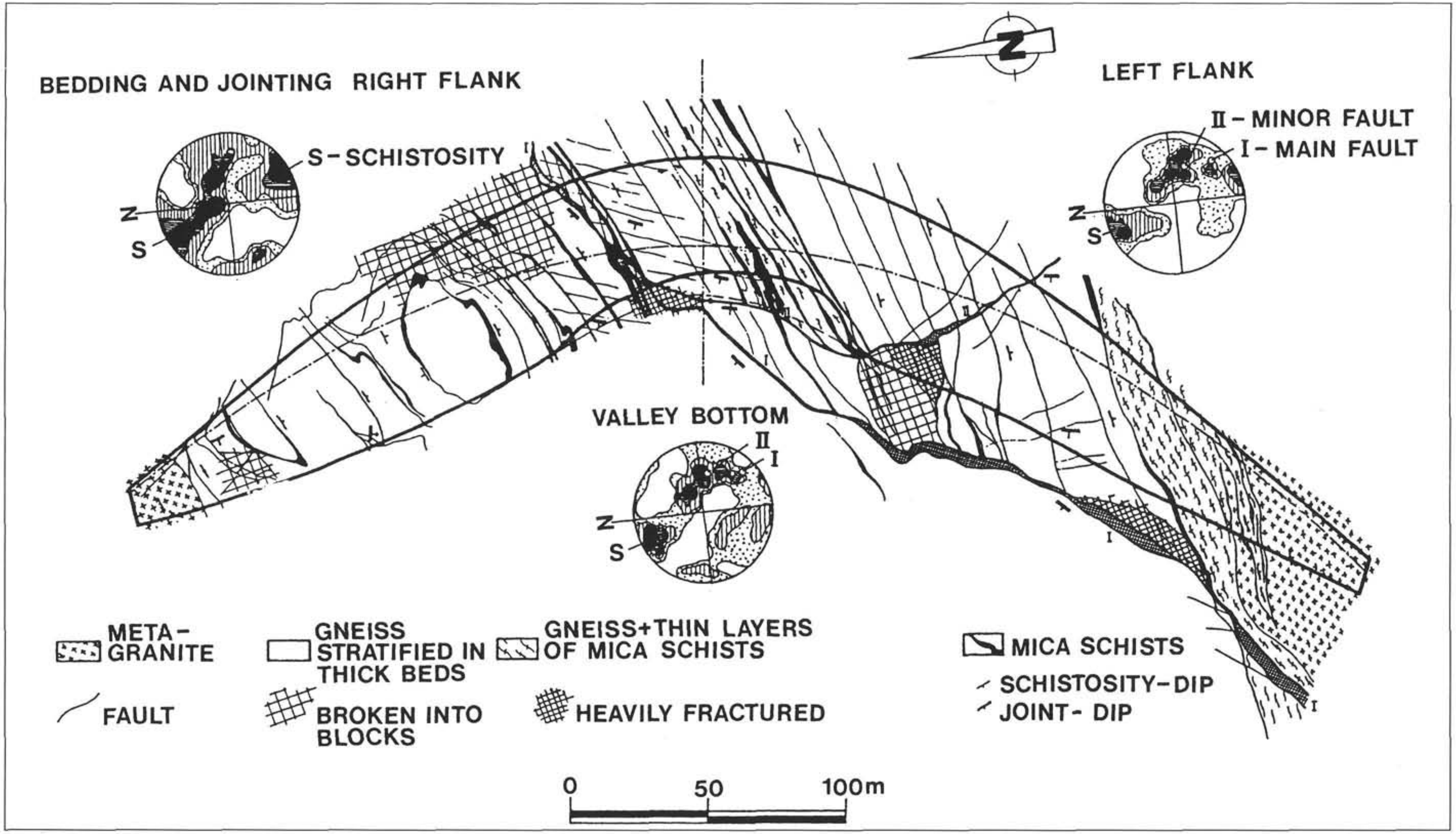


Fig. 4
Dam foundation of Zillergruendl arch dam (after NOWY, 1984).

the basins. Detailed hydrogeological studies for the dam design allowed the construction of the 53 m high Salza dam and the 36 m high Diessbach rockfill dam in spite of the visible presence of karstic phenomena. Special geological investigations have been followed by individually designed grout courtains (BRANDECKER et al., 1965).

An outstanding example is the foundation treatment of the Klaus arch dam (height = 55 m). An extreme permeability was found in boreholes in some areas of the dolomitic limestone. On the other hand, a perched groundwater table existed at different levels. Therefore only a single courtain of contact grouting was sunk to a depth of only 15 m.

The 37 m high Gmuend dam was the first arch dam ever constructed in Austria (1943-1945). Twenty years after completion, considerable rockfalls occurred in summer 1963, downstream from the site. Due to unexpectedly rapid loosening of the muscovite-quarzite, the abutment and the dam had to be treated. This is a good example of the premature decay of unfavourable jointed rock mass within the normal life-span of a dam (HORNINGER and KROPATSCHEK, 1967).

The greatest capacity for electric power production, however, is installed along the Danube river, the largest river of Austria, where 30 percent of Austria's hydropower is generated. The Austrian share of 350 km has a chain of 10 river plants, where the character of the foundations changes with the mileage of the river. Whereas the sites situated upstream are founded on the bedrock of the crystalline basement (WEISS and JUNG, 1995), the plants situated in the lowlands are founded mainly in Tertiary shales and sands (FENZ et al., 1970; MAKOVEC and GRASINGER, 1985). Special treatment was necessary to protect the groundwater in the overburden of the foundation rock, mainly consisting of Quaternary gravel and sand (FRIK et al., 1997).

Hydro tunnels

The adduction galleries and the pressure galleries and shafts, respectively, cross complicated nappes within the Alpine thrust belt. Thus, a great deal of fault and shear zones had to be crossed. Therefore, the prediction of geological tunnel conditions always have to consider the structural style and the rock mechanic features of the rock series.

The high head and therefore high pressure (up to 150 bar) led to thorough investigation and treatment of the rock masses. Extraordinary high primary stresses occurred in zones of young uplift areas of the Alps (SEEBER et al., 1979).

Some problems arise related to high water inflow at high pressure, not only in the hydro tunnels (TENTSCHERT, 1991) but also in traffic tunnels (KNOLL et al., 1994). The highest inflows occurred by crossing water bearing faults in the carbonate rocks, sometimes exceeding one cubic meter per second. The greatest problem, however, is usually not the amount of water, but the water pressure affecting the lining (LOACKER, 1971; PIRCHER, 1987; SCHNEIDER, 1988).

Use of Tunnel Boring Machines in Austria

Although the first prototype of a full face Tunnel Boring Machine (TBM) drove a pilot tunnel at the Channel tunnel more than 100 years ago, TBM-tunnels in Austria appeared comparatively late. It was in 1967, when a 267 m long section of a water adduction gallery in the Central Alps was driven, just to test the machine in hard crystalline rocks such as granite and micaschist.

At the end of the 1970's the number of TBM-tunnels raised rapidly, mainly for hydropower (pressure and adduction galleries; PIRCHER, 1980; RIENÖSSL and DÖPPER, 1991). The smallest diameter was 2.14 m (Böckstein gallery, Salzburg), and the largest was 6.25 m (Walgau pressure gallery in Vorarlberg).

TBMs for other utilities (traffic, pipelines) with greater diameters have not yet been driven in Austria. Some pilot tunnels with smaller diameters for traffic tunnels only, or traffic tunnels especially for inclined cable rails in summer skiing areas (diameters 3.5-5 m) have been excavated. The latter are inclined shafts for tourist purposes (glacier skiing areas). In summary, during in the last 45 years there have been up to 300 km tunnels driven by the TBM, 90 percent or 270 km of which have been driven for hydropower plants.

Some investigations for full face TBM with diameters of about 10-12 m are now in progress for two-track rail tunnels of the new high speed links (Brenner: KÖHLER, 1978; Wienerwald: POISEL and TENTSCHERT, 1999).

Table 2
Hydropower tunnels constructed between 1950 and 1993.

Type	Drill & Blast	TBM
Adduction galleries	315	110
Pressure galleries	270	160

Railway

The first crossing of the Alps by rail was accompoished by the Semmering Railway (1848-1852). Many viaducts and tunnels in difficult rocks were built. Within this project, the first railway tunnel of Austria was excavated in the years 1848-1852 (FÖTTERLE, 1850). This tunnel of 1430 m length had to be driven through totally disintegrated quartzites and schists and, in addition to the two tunnel mouths, needed 10 shafts to meet this challenge (Fig. 5). Thirty years later, tunneling techniques have been improved greatly. The best examples are the long Alp-transverse tunnels, such as the 10.2 km Arlberg road tunnel (construction time 1884-1888, this was as long as the period of time used for the breakthrough of the road tunnel 90 years later !!), where the tunnel has been driven as a two-track-line, whereas the feeder line was only one-track, the Karawanken tunnel (1904-1906) with a length of 8.1 km or the Tauern tunnel (length: 8.5 km, constructed 1906-1909). The geological input at this time was mainly the cross geological structure, but already by this time the first investigations and considerations in the mechanical behavior of the rock masses took place (WAGNER, 1884).

The Austrian railway net showed nearly no change up to the 1970's, but the rediscovering of the rail took place in the late 1980's.

The still ongoing rise of the Central Alps could be measured along a nivellement at the Tauern rail link. The repeated measures have shown a maximum uplift of six centimeters since 1910 (SENFTL and EXNER, 1973).

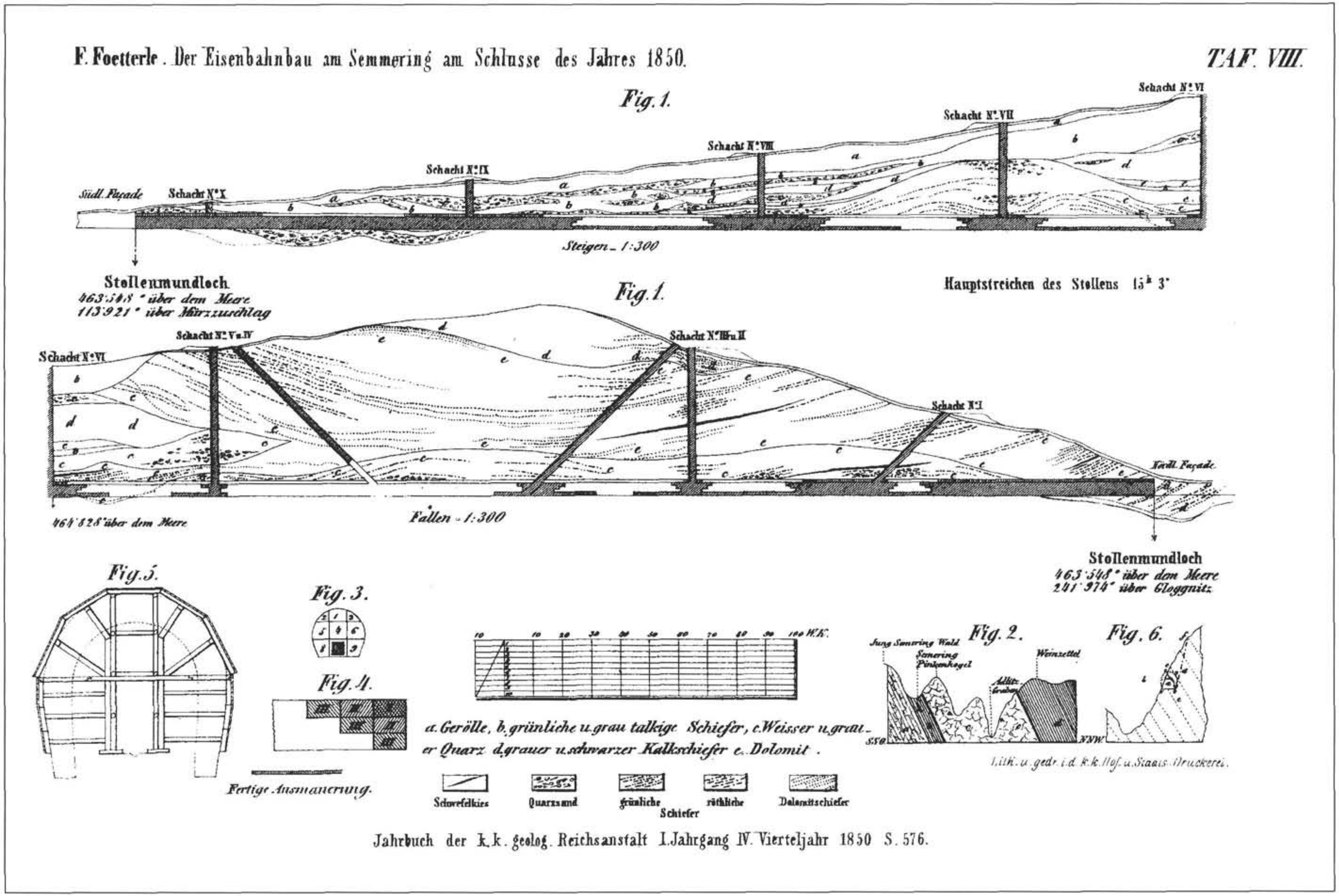


Fig. 5
Geological cross section of the old Semmering tunnel (after FÖTTERLE, 1850). This first railway tunnel of Austria (length only 1430 m) was driven from 10 starting points(!!).

Table 3
The longest railway tunnels in Austria. For locations, see Fig. 2.

Tunnel	Constructed	Length (m)	Rock spectrum	Geology by: *
Arlberg	1880-84	10,250	micaschist, phyllonite, gneiss	WAGNER, (1884); RZIHA, (1885)
Bosruck	-1902	4,767	gypsum, carbonate rocks	GEYER, (1907)
Karawanken	-1906	7,925	carbonate rocks, marlstone	TELLER, (1910)
Tauern	1906-1909	8,550	phyllite, schist	BECKE, (1906)
Inntal	1989-94	12,756	phyllite	BAROUNIG and KÖHLER, (1996); LEIMSER and KÖHLER, (1994)
Säusenstein	1990-94	4,692	gneiss, schist, granulite	STIPEK and JODL, (1992)
Galgenberg	1993-96	5,462	phyllite, greywacke	BERGMAIR et al., (1996); HARER et al., (1996)
Kaponig	1994-99	5,131	schist, gneiss	RIEDMÜLLER et al., (1999); KNITTEL, (1995)
Sieberg	1996-99	6,480	mudstone, shale	POLESCHINSKI and MÜLLER, (1999)
Planning stage				
Lainz	2000-2006	12,200	marl, sandstone, limestone, marlstone, gravel, sand	NOWY and LEITHNER, (1999)
Wienerwald	2001-	13,000	sandstone, marlstone, shale	NOWY and LEITHNER, (1999)
Koralm		30,000	gneiss, amphibolite, eclogite, schist	HARER and RIEDMÜLLER, (1999)
Semmering		22,700	schist, greywacke, quartzite, phyllite	RIEDMÜLLER et al., (1992); RIEDMÜLLER, (1995); KAISER and MERINGER, (1996)
Brenner		53,000	schist, granite, phyllite	KÖHLER, (1978)
Cable Rail				
Kaprun	1972	3,300	prasinite, gneiss	MIGNON
Pitztal	1982	3,500	gneiss, granite	TENTSCHERT
Wurten	1989	2,700	gneiss	

* Names without year: only internal reports, not published.

Trans-European Railway Link

The first large section of the new international Trans-European Railway Link is the Inntal tunnel – at present, the longest railway tunnel of Austria. In contrast to the tunnels of the first generation, this tunnel, as the bypass of the town of Innsbruck, does not cross a mountain chain, but it is already a part of the new Brenner axis linking Germany and Italy in the future. Though having only overburden of max. 300 m, heavily crushed and faulted rock occurred with great deformations of the lining. This difficult zone was interpreted as an ancient mass movement and the tunnel crossed the base with a small angle (LEIMSER and KÖHLER, 1994).

The great challenge of the ongoing new century will be the base tunnels of Semmering, Koralm, Wienerwald and Brenner, all presently in the planning stage. For these deep-situated tunnels high emphasis is put on the shape and the geotechnical behavior of the fault zones already in the investigation stage. Therefore, a lot of geological and geophysical surface and borehole logging is calculated and evaluated by a multiple parameter analysis (BAROUNIG and KÖHLER, 1996; HARER and RIEDMÜLLER, 1999; GAICH et al., 1999). An exploration gallery has already been driven for the first great base tunnel through the Semmering massif. Due to struggles between political lobby groups there is no drive at present. The five kilometres of the driven pilot tunnel cleared the complex geological structure and lowered the water level (DIEWALD, 1997; KAISER and MERINGER, 1996).

Yet even smaller projects for increasing the speed of existing lines afford new tunnels of considerable length, though they have the comparatively low overburden of about 100 m (Fig. 6a, b) These tunnels in the foreland basins of the Alps and in Quaternary terraces show the complex composition of the glacial and periglacial sediments (VAN HUSEN, 1999).

Vienna Metro

The net of the Vienna Metro began as an extension of the former city railway (Stadtbahn). The ground net of today's Metro started in 1969, now having a total length of 68 km – partly in tunnels, partly above ground (MARTAK et al., 1993).

The ground consists mainly of Quaternary and Tertiary sediments which have been excavated by means of the New Austrian Tunneling Method, except for some sections in the inner city. A great deal of care had to be taken in these locations to protect the numerous historical monuments, which have sometimes been passed at very short distances. Some difficulties arrived by old wooden piles or un-

Fig. 6a →
Geological documentation today: (Wachberg tunnel, Melk): Drawing of a tunnel face, combined with input data for the dataset. Nevertheless, the drawing by hand is still the original document, the processing in a CAD System is an interpretation, already.

HL-AG

UMFAHRUNG MELK
Wachbergtunnel - Melker Tunnel

BAUGEOLOGISCHE DOKUMENTATION
Ortsbrustaufnahme Maßstab 1 : 50
Tunnelvortrieb: Melk

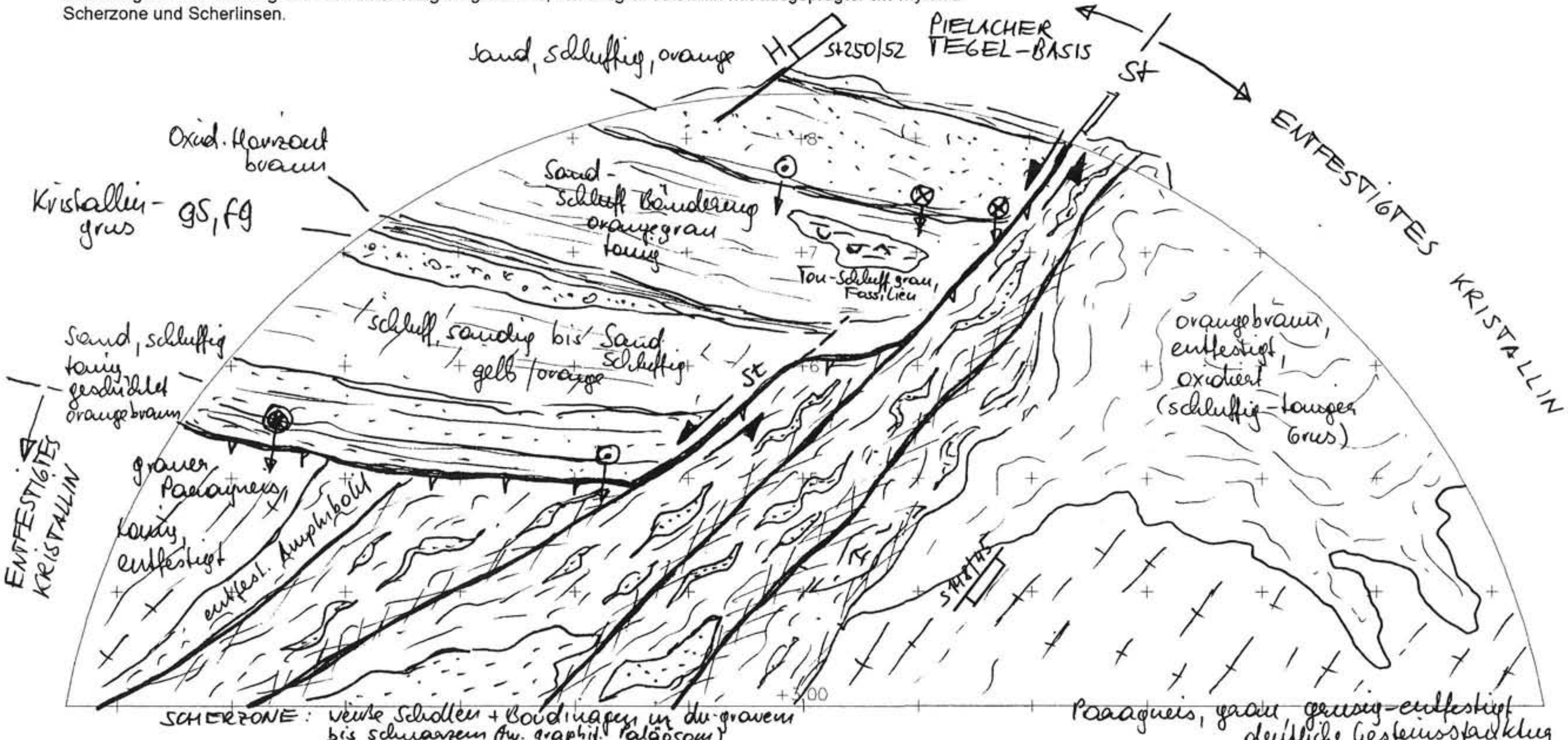
Datum: 07. Mai. 97 13:30 Uhr   Geologe: Stadlmann   BlattNr: 249   ProjKm: 84,852   **Kalotte** Station: **1143,20 m**

Schichtkomplex: E´,F", F´   Vortriebsart: Tunnelbagger   Abschlagslänge: 1,00 m

PIELACHER TEGEL-BASIS: Wechsel von sandigen Schluffen mit schwach schluffigen Sandlagen (cm bis mehrere dm). KRISTALLIN: entfestigter, bindiger Paragneis mit Felsstruktur, Qu/Fsp-Boudinagen, Amphibolfelsschollen, tw. graphitisch.

Scherzonen mit über 1m Versatz. Flach nach NE geneigte Schichtungen in der Pielacher Tegel Basis, durchsetzt mit Kristallingrus bis Feinkiesgröße. Darunter tonig umgesetztes, entfestigtes Kristallin mit ausgeprägter tw. mylonit. Scherzone und Scherlinsen.

Gebirgsverhalten beim Vortrieb:
Nachbrüche aus Firste und Kämpfern, tw. aus oberem Teil der OB. Festigkeitsminderung aufgrund von rinnend/fließenden Wasserzutritten. Festigkeitsunterschiede im Kristallin, großteils wasserempfindliches Material.



Bemerkungen: Abnehmende Bergwasserzutritte aus der Ortsbrust. Mehrere Meter breite Scherzone im entfestigten Kristallin, streicht annähernd vortriebsparallel.

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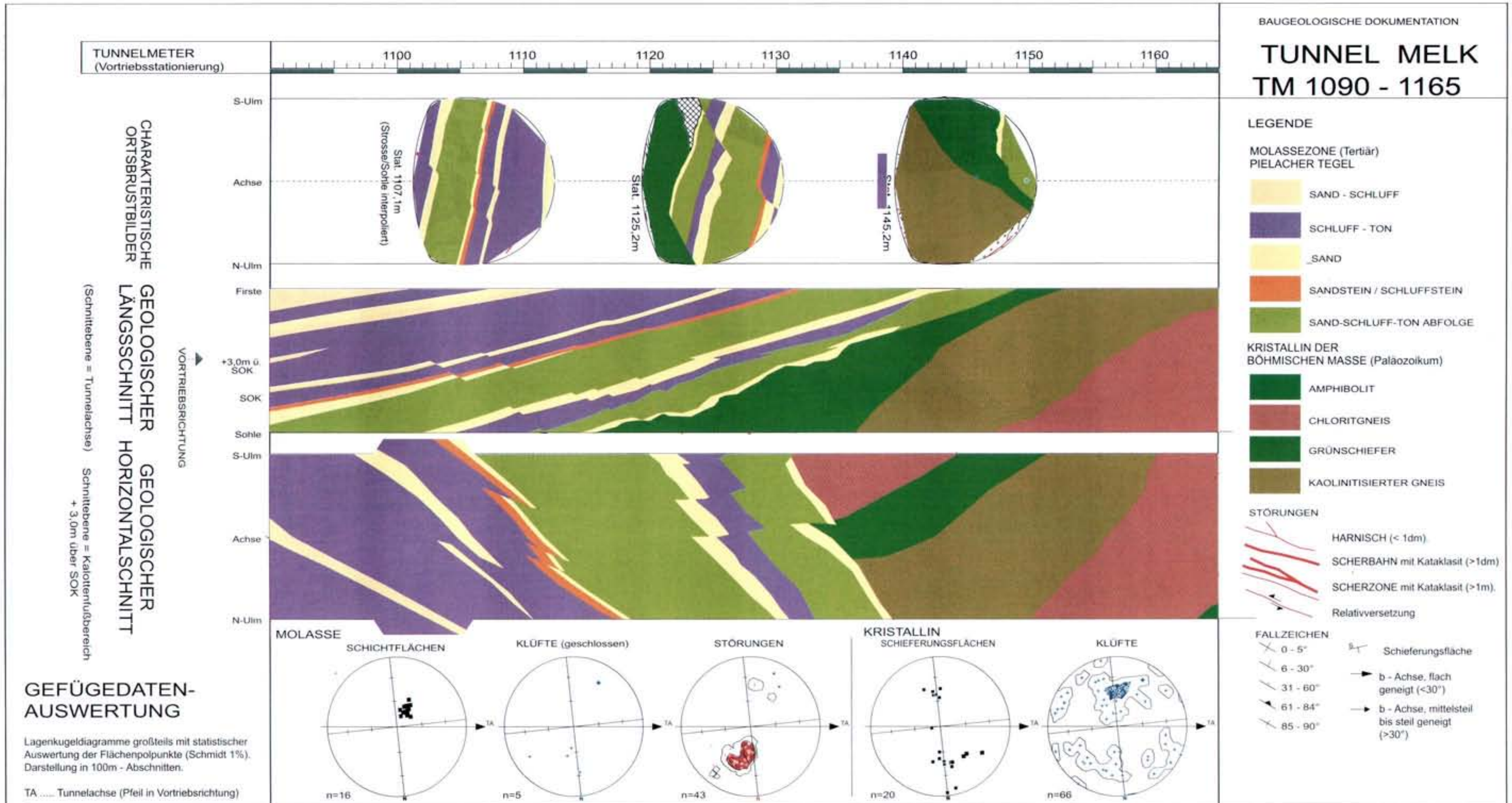
BAUGEOLOGISCHE DOKUMENTATION

TUNNEL MELK
TM 1090 - 1165



GEOLOGISCHE EINHEIT	MOLASSEZONE (Tertiär) — KRISTALLIN
GESTEINE	PIELACHER TEGEL: Schluff-Ton, dunkelgrau, halbfest, mit Fossilbänken und Sandlagen. Im Liegenden PIELACHER TEGEL-BASIS: Sandstein/Schluffstein, Sandlagen und gebänderte Sand-Schluff-Tonabfolge. Ab Stat. 1116m KRISTALLIN: entfestigte Gneise, Scherzone mit Chloritgneis, Grünschiefer und hell-grauen Gneisscherlinsen. Ab Stat. 1165m Übergang der Grünschiefer zu Amphibolit. Großteils stark verwittert und im oberen Teil des Querschnittes entfestigt.
GEBIRGSCHARAKTER	Grabenbruchrand mit vorwiegend SE-NW streichenden Störungen. Überlagerung durch NE-SW streichende Scherzone, die sich vom Kristallin bis in die tertiären Schichten fortsetzt. Kristallin: intensiven tektonisch beansprucht, stark strukturierte Reliefoberfläche, verwittert, großteils alterierter Gesteinsbestand, mechanische Eigenschaften ähnlich wie Pielacher Tegel-Basis. Häufig Harnischflächen mit tonigen Bestegen.
DURCHTRENNUNG / ZERLEGUNGSGRAD (z 1, z 2, z 3, z 4)	
VERWITTERUNGSGRAD (v 1, v 2, v 3, v 4)	
ALTERATION (Kristallin)	
BERGWASSER	

STADLMANN 1998/2000

EISENBAHN-HOCHLEISTUNGS-STRECKEN AG

UMFAHRUNG MELK

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← Fig. 6b
Modern tunnel log: (Wachberg tunnel, Melk): The geological log may be combined with the technical data of the excavation log by the means of graphics or by a database.

known deep fountains or cellars reaching into the tunnel tube (DÖLLERL, 1976). Therefore, only a few sections have been driven by shield machines or roadheaders (MARTAK and PLACHY, 1978, 1985).

The hydrogeological conditions have been very complicated. The shales and mudstones are often interbedded by sand lenses with distinct water pressure.

As the Vienna Basin is of very young tectonic origin, fault zones appear even in young Tertiary sediments. Some difficulties had to be mastered by crossing such zones (MARTAK and PLACHY, 1989).

Highways

Crossing of the Alps required the construction of several long highway tunnels and many shorter tunnels. The very first road tunnel was the 130 m long Neutor tunnel in the city of Salzburg in 1765. The first Austrian road tunnels of the new generation (Finstermünz at the Reschenpass route, 1852) have been driven at the same time as the first rail tunnel. Due to the financial problems after World War II, the construction of the highway-net started comparatively late in the late 1960's.

In the very first planning stage the evaluation of the location lines often led to the necessity to change the line for for geological reasons, such as rockfall or landslide phenomena, as well as foreseeable problems by tectonic fault zones. Nevertheless, during construction the miners and the engineers had to master heavily crushed tectonic fault zones, which occur very often within the repeating tectonic levels (SCHUBERT and MARINKO, 1989) or between different Austroalpine nappes (WEISS, 1975, 1978, 1981).

Some of the highway tunnels have been located near to an existing railway tunnel (Arlberg, Karawanken, Bosruck). Nevertheless, the engineers and geologists had to meet some surprises. In the Karawanken tunnel, tectonic uplift of some carbonatic blocks led to unexpected water inflow of up to 500 l/sec, because these zones are located under the axis of the railway tunnel and have not been met there.

In the Bosruck tunnel, the gypsum and salt formations stayed dry, but at the border to the limestones a water inrush of 300-400 l/sec occurred. Despite all expectations that the water inrush would diminish due to the long-term drainage effect from the railway tunnel, no relief occurred afterall (NOWY and LEIN, 1984).

Large deformations of the tunnel tubes had to be mastered at the Karawanken, Tauern, Katschberg and Arlberg tunnels, in which the deformations sometimes exceeded the value of one meter! (DEMMER, 1976; WEISS, 1975). Some tests with measuring the rock temperature by infrared measurements showed the appearance of open joints with circulating cold air or water (HEISSEL et al., 1989).

The deep clefts of the glacially eroded alpine valleys have been crossed by large bridges, such as the "Europe-Bridge" in Tyrol, 191 m above the valley floor. The foundation of the piles was very complicated, due to intensely crushed rock, slope movements near the surface and especially in the close neighbourhood of existing roads and railway tracks (FUCHS, 1966).

Applied Petrology

Geology in quarry engineering and the use of rocks both in architecture and civil engineering is a special branch of

Table 4
The longest road tunnels in Austria. For locations see Fig. 2.

Tunnel	Constructed	Length (m)	Rock spectrum	Geology by: *
Felbertauern	1964-67	5,183	gneiss, schist	HERBECK, (1966); SINGER, (1966)
Katschberg	1971-74	5,439	phyllite, schist	WEISS, (1975); KUNZ, KAISER
Tauern	1971-75	6,401	phyllite, schist	DEMMER, (1970); BRANDECKER, (1976)
Arlberg	1974-78	13,972	micaschist, phyllite, gneiss	KAISER and KUNZ, (1974); WEISS, (1978); KUNZ, (1981)
Gleinalm	1975-77	8,100	gneiss, schist	NOWY, (1977)
Pfänder	1977-80	6,718	conglomerate, marlstone	CZURDA and GINTHER, (1983); JOHN and WOGRIN, (1979)
Bosruck	1980-83	5,500	gypsum, carbonate rocks	NOWY and LEIN, (1984)
Plabutsch 1st tube	1984-87	9,755	carbonate rocks	BROSCH et al., (1984)
Karawanken	1986-91	7,865	carbonate rocks, marlstone	ANONYMUS [BÄK], (1991)
Roppen	1987-91	5,090	limestone, marl	HEISSEL et al., (1989)
Schmitten	1991-96	5,109	phyllite, metabasite	HACKL, (1996)
Landeck Süd	1996-99	6,900	phyllite, carbonate rocks	KÖHLER
Plabutsch 2nd tube	1999-	ca. 9,700	carbonate rocks	

* Names without year: only internal reports, not published

engineering geology, as is the search for materials for dam construction, concrete or asphalt additives (EPPENSTEINER, 1976) or other anorganic raw materials (LACHMAYER, 1999). The preservation and restauration of the innumerable historical monuments from more than 10 centuries against destruction and weathering is the other end of accomplishments in this broad field (WIEDEN, 1979).

The field of technical petrography is providing civil engineers, architects, those invoved with monument preservation and stone masonry with petrophysical values, such as specific weight, porosity, water content, hardness etc. The resistance against weathering and destruction by salt has been the research topic of several authors (KIESLINGER, 1951; ROHATSCH and THINSCHMIDT, 1997). The old principles of petrophysical research (grinding, compressing, smashing) remain the same over the centuries, though the methods have been improved and are sometimes carried out by a teamwork of geologists, rock mechanic engineers and physicists (WIDHALM et al., 1995).

Special topics

Engineering geology does involve only spectacular projects. Many colleagues earn their money from smaller projects, e.g. site investigation for foundations, water supply, cutoffs, waste disposal or similar topics.

Some Austrian tunnels are neither traffic not hydro-tunnels but, tunnels for pipelines. Two large international oil pipelines cross the Alps and are partly conducted in special pipeline tunnels (PÖLSLER, 1967).

Underground parking facilities for the city of Salzburg were excavated in the Mönchsberg "Nagelfluh" in 1974, treating the conglomerates by roadheaders. Some difficulties arose, however, upon meeting ancient galleries, formerly used as air raid shelters during the numerous wars (HORNINGER, 1975). Underground caverns for cultural purposes are under construction such as in the city of Graz, within Devonian dolomites or in the planning stage, as in the city of Linz within gneiss.

In 1978, the first nuclear power plant was already finished. Nevertheless, the population of Austria voted against the site in a referendum. Even without heavily contaminated nuclear waste some research for medium contaminated waste is necessary. Some areas with ductile behavior and minimum water inflow were evaluated (NOWY, 1993).

Teaching and Research

Special institutes for Applied (or Engineering) Geology are located at the Technical Universities of Graz and Vienna, at the University of Agriculture in Vienna and at the Mining University of Leoben. The civil and mining engineering students, respectively, can attend graduate and undergraduate courses there. In Vienna and Graz, a special branch of Technical Geology has been installed, in which students of Geology finish the first stage of their studies at the general geological institutes of the universities, after which they proceed to the Technical Universities to specialize their knowledge.

Of great importance is the geological education of the students in the field of civil engineering; they have to take undergraduate and some graduate courses in engineering geology.

As for research, a great deal of effort is being made for collecting databases to clear the interconnection of geological and geotechnical parameters (KLIMA, 2000). The combination of geology, geodesy, hydrogeology and geotechnics is used for evaluation of slope stability (BROSCH and RIEDMÜLLER, 1987; SCHWINGENSCHLÖGL and ROCKENSCHAUB, 1990).

Austrian Engineering Geologists in foreign countries

Austrian engineering geologist are involved in a great number of projects world-wide. Especially the greater engineering consulting companies, such as ILF (Innsbruck) or Geoconsult (Salzburg), employ qualified geological groups within their engineering staff. They deal with dams, irrigation, road and rail tunnels, as well as pipelines and other fields.

Yet even smaller consulting groups sometimes do their job overseas, often as a joint venture with an Austian civil engineer, with a geotechnical consultant or with a contracting company.

"Glück Auf"

In the spirit of this familiar greeting among miners, we are proud to confirm its foundation on and enthusiasm for tunnelling and geotechnical sciences.

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