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Excursion 132 C

Engineering Geology in Mountainous Regions

by

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Introduction

The basic idea to this excursion is to take the participants to structures that offered special problems, either to the design or, as in most cases, to construction, last but not least even to the state of exploitation on grounds of long-term security measures and permanent monitoring.

Because of the necessity to fix the final schedule to this excursion quite early the itinerary in the first line had to provide for already completed structures. However, it is expected as well to visit several sites still under construction. As we can not predict the actual state of construction at the time of our excursion, it may happen that the itinerary is to be somewhat adapted to the given situation. As to the different subjects, the itinerary will include highway construction, hydroelectric plants, water works and tunnelling in areas up to 2500 m. above m.s.l., i. e. 8200 ft. (Occasional snowfall may occur even in July!)

In this guidebook G. Horninger has prepared and has been responsible for the stops 1.1, 1.2, 1.3, 1.5, 2.1, 3.1, 3.2, 3.3, 4, 5.2, 6.4, 7.2, 8.2 and 9.1; E. H. Weiss has been responsible for the stops 1.4, 3.4, 5.1, 6.1, 6.2, 6.3, 7.1 and 8.1.

Day 1

Surroundings of Innsbruck

Stop 1.1. The Brenner motor-highway, Europabrücke (Europe's bridge)

Province of Tyrol, to the south of Innsbruck (compiled from papers of A. Fuchs, J. Gruber and J. Malina).

The "Europabrücke" (Europe's bridge) crosses the Sill valley to the south of Innsbruck. The bridge is 190 metres high and 657 metres long. It is the most important and spectacular structure in the course of the Brenner motor-highway. The problems met with the design and foundation of this bridge are striking examples for troubles arising from the present trend, to grant overall priority in highway policy to criteria of traffic without prior consideration of local geotechnical conditions. At the time the location of the bridge was already fixed, only scarce geological results from investigations were at hand.

The geological background to the site area may be briefly outlined. For centuries the pronounced N—S directed valley from Innsbruck to the Brenner pass (1372 m. a.s.l.) and farther on to the south was the given natural traffic line from Germany via Tyrol to Italy. This alpine transverse depression is caused by monoclinal downward flexures from east as well as from west. The valley is an erosion zone along the westward dipping overthrust plane between the penninic and lower-austroalpine rock masses of the "Tauern window" to the east of the valley, and the overriding western complex of the austro-alpine Ötztal gneiss-mass. The rocks bordering the said overthrust plane are heavily solicitated, partly down to loamlike ultramylonites (see stop 1.2, Stefansbrücke, pit for brickloam and gravel pit). Additional solicitations derived from secondary displacements along parts of the overthrust, i. e. "Silltal fault", dipping under medium angles to the SW to W. Just in the site area this fault runs exactly along the morphological valley axis but it is locally covered by recent alluvial deposits of the Sill river. The fault was not hit by excavation works for the foundation of the piers.

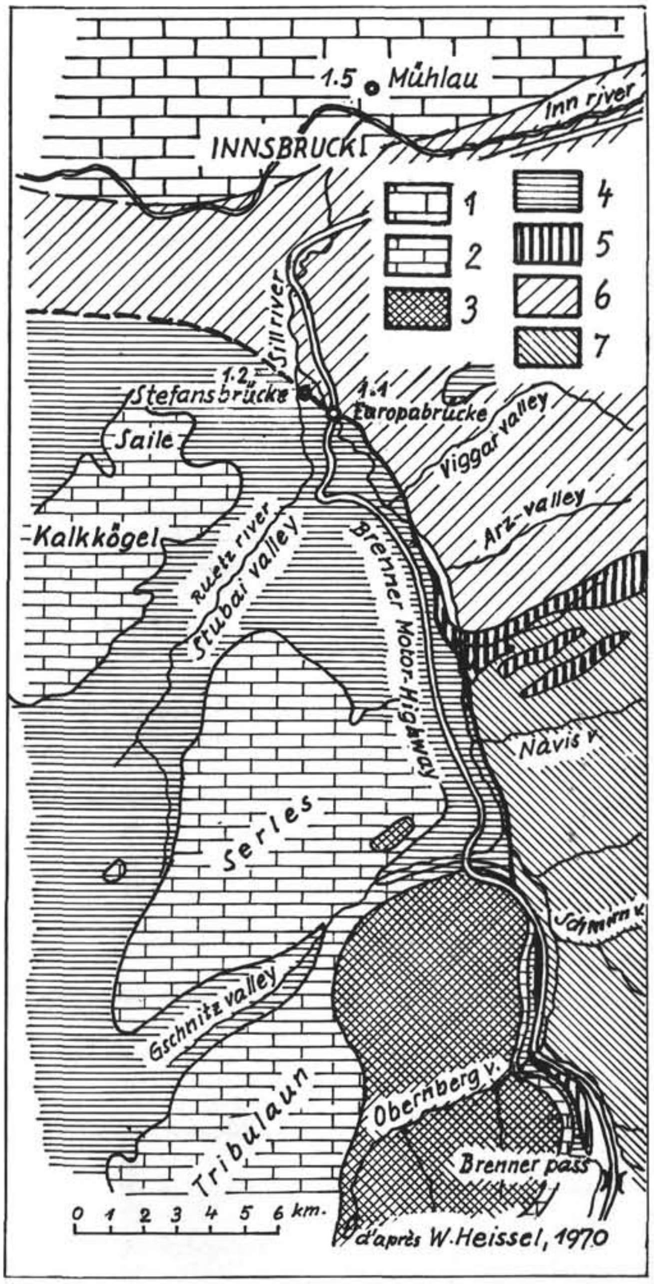
At the site selected for the bridge the right slope, i. e. the NE slope, is built up from the so-called Innsbruck quartzous phyllite, dipping unfavourably to the valley axis. At the opposite flank micaceous gneiss, dipping also valleywards, builds up the lower portion of the slope. For the upper third of the height of the bridge the said rocks are capped by strongly compacted interglacial sand and gravel layers. In those sands and gravels the marginal structures on both ends of the bridge were easily and safely founded.

The foundation of pier I at the right valley slope, with an overall height of 115 m. was a particularly tricky job, partly due to the poor quality of the heavily mylonitized quartzous phyllite. To the other hand, the trouble arose from the pier's location obliquely above the portal of a difficult tunnel in the course of the very important Brenner railway line. Therefore, the railway authorities stipulated for the foundation level of the pier, that a line connecting the valleyside rim of the pier's bedding with the invert of the tunnel must not be steeper than 30°. This prescription enforced a foundation depth of no less than 40 metres at the upper side. The foundation had to be performed by miners' methods instead of open-air excavation.

In order to investigate geotechnical details for the pier an adit plus two crosscuts and two short shafts were made. Their main purpose was an exact location of a fault zone deduced from surface investigation.

In situ shear tests performed upon heavily sheared quartzous phyllite yielded values like $\varphi = 39{,}5°$, whereas $\varphi = 28{,}5°$ was established on loamy mylonites (J. Malina). In situ piston tests led to Young's moduli ranging from 500 (!) up to 4430 MN/cm². A three-dimensional model of the site of pier I, made from acrylic resin, was an excellent means to facilitate mutual understanding.

The foundation of the very high pier II, erected from the valley floor, was successfully performed without important trouble on account of geotechnical reasons. But in the course of excavation for pier III at the left bank, somewhat above the valley floor, a considerable rock slide happened when wheathered and superficially loosened gneiss in dip slope position was undercut. This accident entailed large-scale safety



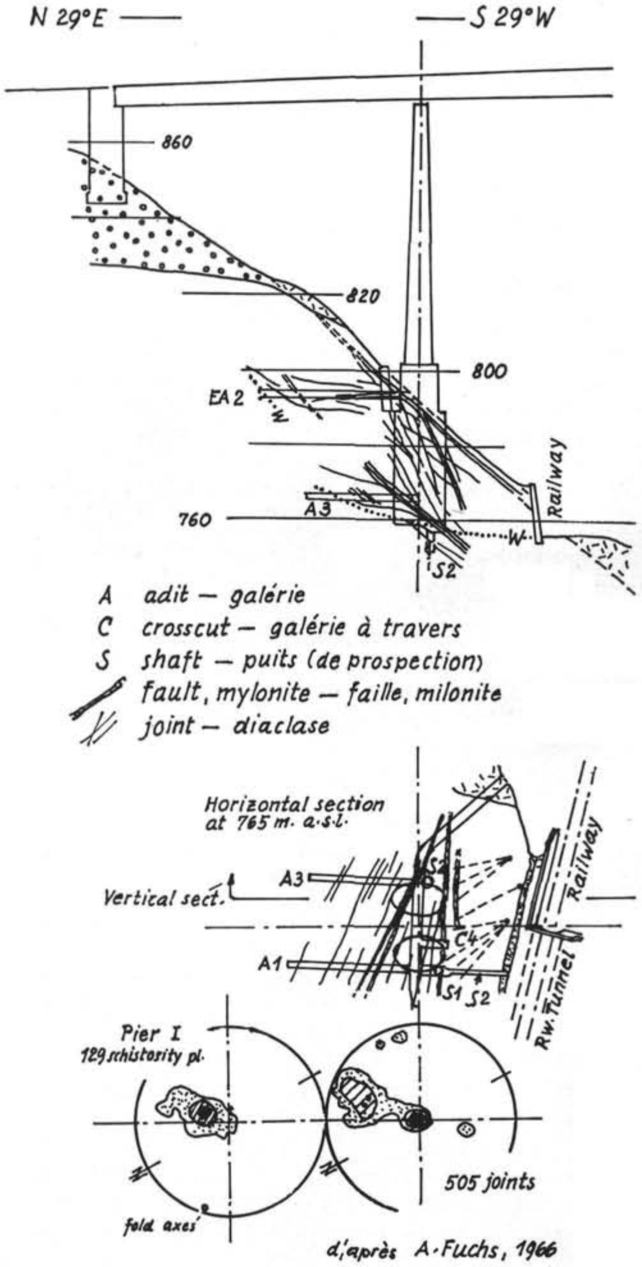


Fig. 1.1:
right side
Europabrücke — Europe's bridge — Longitudinal section and plan of the southeastern third of the bridge.
Geology after A. Fuchs, 1966.

left side
Generalized geological map of the area south of Innsbruck.
Geology after W. Heissel, 1970.
1 Northern Limestone Alps.
2 Brenner-Mesozoic.
3 Steinach nappe.
4 Gneiss of the Ötztal gneiss dome.
5 Tarntal series (lower austro-alpine group).
6 Quartzous phyllite
7 Obere Schieferhülle (upper part of the pennine cover series).

figure à droite:
Pont de l'Europe
Coupe longitudinale de la section NE du pont.
Géologie d'après A. Fuchs, 1966.

figure à gauche:
Carte géologique généralisée de la région au sud d'Innsbruck
d'après W. Heissel, 1970.
1 Alpes Calcaires septentrionales.
2 Mésozoique de la région du Brenner.
3 Nappe de Steinach.
4 Ötztal gneiss.
5 Série du Tarntal (nappe austro-alpine inférieure).
6 Phyllites quartzeuses.
7 Part supérieur de la "Schieferhülle" pennique; prépondérant Schistes lustrés.

measures, temporary ones and permanent ones as well. Deep reaching subhorizontal tendons, each one stressed at 600 kN, tied the retaining walls behind the pier to solid rock. In order to survey possible displacements or tilting of the high piers plumb lines, each one of 20 metres' length, were installed. Even the very high pier II only tilted 4,6 mm. Subsidence of the piers did not exceed 2 mm within 8 months and finally died completely out.

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Topographical maps:

Österr. Karte 1 : 50.000, sheet No. 148, Brenner.

Geological map: see HEISSEL, W. (1972): Geologie der Brennerautobahn. — "Die Brenner-Autobahn", p. 89—92, Innsbruck. (Official geol. map, sheet Innsbruck not yet available in revised edition.)

Stop 1.2. Stefansbrücke Clay Pit

Province of Tyrol. Situated 1,500 ms. NW of Europe's bridge.

Locally very intensely mylonitized quartzphyllite is altered to a sort of clay that is used for the production of tiles. The unusual kind of alteration may be attributed to hydrothermal influence. Possibly it is due to sulfuric acid from the decay of disseminated pyrite. Meteoric water seeping down through a cover of interglacial terrace sediments, more than 100 m thick, surely contributed to the decay of the mylonite.

Reference:

SCHMIDEGG, O. (1953): Die Silltalstörung und das Tonvorkommen bei der Stefansbrücke (südl. Innsbruck). — Verh. Geol. B.-A., 1953, 135—138, Wien.

Stop 1.3. The "Fulpmes-Stollen", tailrace tunnel of a hydroeletric plant.

Province of Tyrol, Ruetz-HE plant of the Austrian Federal Railways, near Fulpmes, Stubai valley.

Probably the excursion will visit the tailrace tunnel of 5 km length, still under construction. Heading in this tunnel met partly very difficult rock conditions in the Ötztal gneiss because of extensive mylonitization and, in the consequence, by rock pressure. With the change from the initial horse-shoe section to a circular one conditions improved markedly. The bad state of the rock results from the vicinity of the penninic — austroalpine thrustplane. Convergences in the tunnel sometimes surpassed 60 cm from roof to invert.

Reference and maps

see 1.1., Europabrücke.

Stop 1.4. The Brenner Base Tunnel Project

Provinces of Tyrol (Austria) and South Tyrol (Italy); Planned and designed by Ingenieurgemeinschaft Lässer-Feizlmayr (ILF), Innsbruck.

In the years 1971 to 1975, a UIC (Union Internationale des Chemins de Fer) mission studied the technical and operational situation on the München — Brenner — Verona railway axis and proposed the construction of a new railway line. This would be a high-capacity high-speed railway line to be designed for speeds of at least 200 km per hour and including as an integral part a base tunnel without uphill sections. The Consulting Engineers prepared a project proposal for the so-called Brenner Flachbahn (base-tunnel railway line), whereas the aspects of regional and engineering geology were discussed in a detailed publication by M. KÖHLER The author of this Report took part in the engineering geological work and tried to minimise the geological risks as are normally involved in projects of this type.

Following extensive preparatory studies in the years 1976 and 1977, two alternative proposals entitled East Line and West Line were submitted.

East Line: Base tunnel 57,7 km long, situated east of the Brenner depression, between Innsbruck and Aicha in the Eisack valley. Three vertical shafts and an approach adit are envisaged as intermediate points of attack. The construction period has been calculated to be 10,5 years.

West Line: Base tunnel 66,6 km long situated west of the Brenner depression, connecting Innsbruck with Meran. As in the East Line project, a tunnel slightly sloping from a central point at the national boundary, with three vertical shafts and an approach adit is planned. The expected construction period would be 11,5 years (Fig. 1.4—2).

The engineering geological forecast for the two railway line alternatives is based on available documents and the results of site inspections and mapping. Exploratory work such as detailed mapping, drilling, driving exploratory galleries etc. is scheduled for a later date. Both tunnel alignments pass through the mountain at great depth, with overburdens of more than 2000 m posing problems of unprecedented dimensions to the geological forecast. Geotechnical assessment of the deep regions of the rock mass is severely impaired by the lack of informative surface evidence. In addition, in a rock complex of such structural variety, there remain many uncertainties regarding the extents of the structural elements present at the level of the tunnel alignment. The same is true of the occurrence of the individual rock types, the petrographical composition of the structural

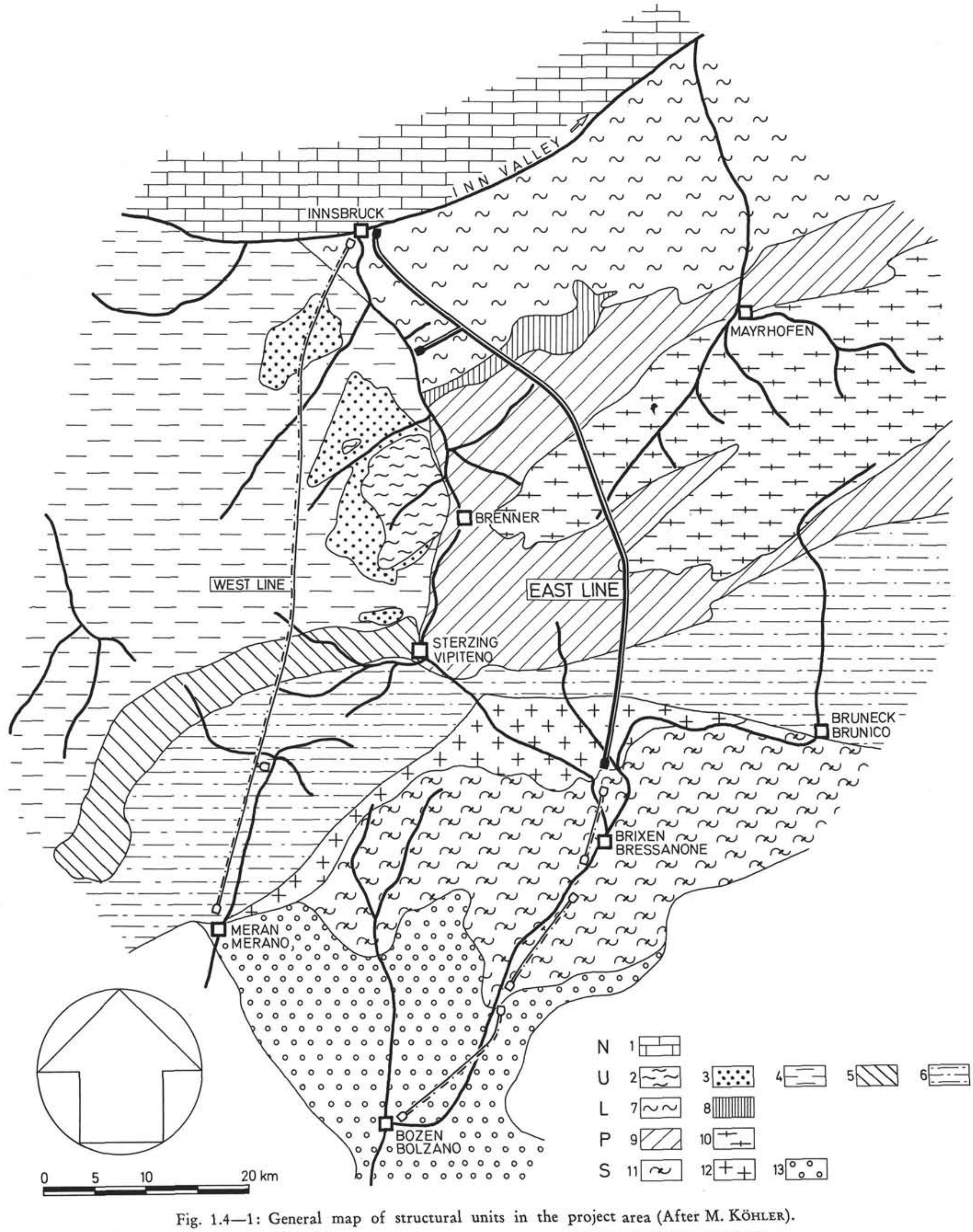

Fig. 1.4—1: General map of structural units in the project area (After M. Köhler).

N NORTHERN CALCAREOUS ALPS
1 Triassic Limestones and dolomites

U UPPER AUSTRO-ALPINE
2 Stainach nappe
3 Brenner Mesozoic
4 Crystalline complex of Ötztal and Stubai Alps
5 Schneeberg belt
6 Zone of Meran — Mauls — Antholz

L LOWER AUSTRO-ALPINE
7 Innsbruck quartzphyllite
8 Tarntal series

P PENNINIC ZONE
9 Upper and lower Schieferhülle
10 Zentralgneis

S SOUTH ALPINE ZONE
11 Brixen quartzphyllite
12 Brixen granite
13 Bozen quartzporphyry

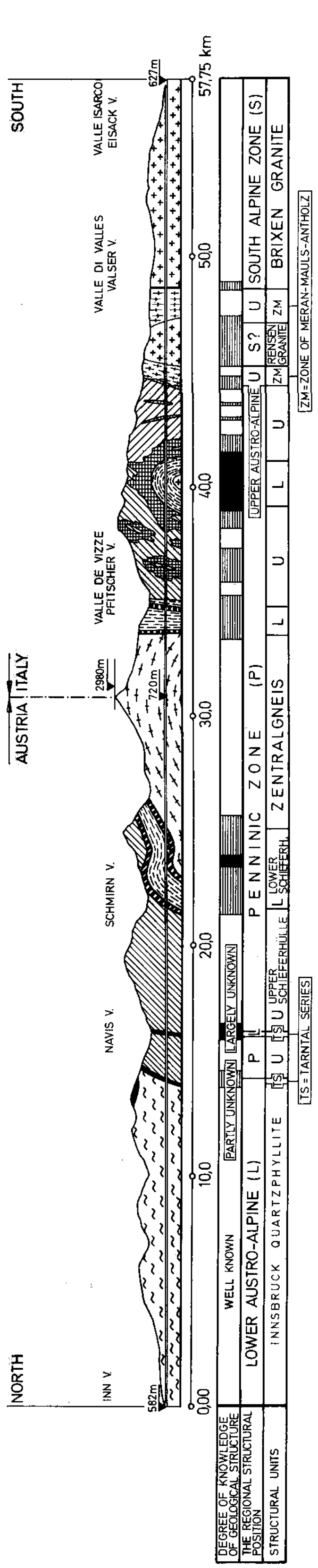

Fig. 1.4—2: Geological Longitudinal Section along East Line (After M. Köhler, 1978).

units, the bedding conditions and the positions in space of important contacts. The greatest uncertainty is experienced with respect to the following geotechnical factors: performance of the rock mass at great depth, stress conditions in units of geological heterogeneity, force vectors, in particular those released by tectonic activities (earthquakes), underground water conditions, and zones where potential ingress of water is anticipated, as well as the localisation of mineralised bodies of water or thermal springs, the assessment of maximum rock temperatures (calculated to range from 50 to 56° C), radioactivity and potential presence of gas.

General summary of the engineering geological properties of the individual rock types:

Zentralgneis (central gneiss complex)

The granitic and eye gneisses are compact and of high stability, forming a homogenous rock mass. Rock bursts are common in underground excavations at great depth.

Lower Schieferhülle (Penninic schist mantle)

This is a series of different rock types where conditions change constantly as heading driving proceeds. The schistose gneisses are for the most part compact, but their strength is affected to variable degrees by tectonic stress, high mica contents, and the presence of underground water. Some of the mica schists and phyllites are very rich in minerals, of low compactness, sensitive to the presence of water, and in places show a tendency to displacement. Similar properties are exhibited by intercalations of serpentine and talk schist. The quartzites show greater hardness, and the thick limestone beds are compact, but karstic and liable to ingress of water. Troublesome residual stresses may extend over large zones. The lower Schieferhülle may prove difficult to control and may in places be pressurised.

Upper Schieferhülle

The phyllonitic rocks show evidence of strong movement. Hence, they are of poor compactness, tend to exfoliate as if affected by weathering processes, and are certainly pressurised at major depth. Poor stability characterises the limestone phyllites, carbonate mica schists and serpentines owing to their tendency to displacement in places, their sensitivity to the presence of water, and in general as a result of tectonic action. These rock types are certainly liable to plastic deformation. Part of the strong-bonded mica schists, the quartzites, carbonate rocks, amphibolites, and greenstones are superior in mechanical properties.

The Lower Austro-Alpine

The Innsbruck quartz phyllite series (quartz phyllites, chlorite schists, quartzite schists and carbonate rocks) has so far shown a satisfactory mechanical behaviour with high strength and compactness in tunnel construction. These properties are less good in tectonic or water-filled zones.

By contrast, the rocks of the so-called Tarntal Series and Matrei Zone show evidence of intense tectonic action (friction breccia, mylonites). The rock mass is believed to the subject to high pressures and deformations. Due to the action of mechanical stresses, the hard quartzites are no longer stable and part of their joints and fissures are water-filled. The rauhwackes will certainly be highly sensitive to water, liable to water ingress, and of poor stability.

The gypsum rocks accompanying the rauhwackes even reduce the performance of the rock mass, and the phyllites may initiate plastic deformations. It is only the carbonate rocks which — apart from their water permeability — are classified as having better mechanical properties.

The Crystalline Complex of the Ötztal and Stubai Alps

This region is chiefly composed of granitic, eye and schistose gneisses as well as mica schists and amphibolites, which in general show satisfactory stability and vary only by their degree of jointing. There may be water ingress along joints and rock bursts in deep tunnels. Unfavourable factors are mica schists rich in minerals and partly also the schistose gneisses because they tend to be substantially weaker in tectonic zones, conducive to spalling, and show undesirable reactions as soon as moisture, even though in small amounts, is present.

The Zone of Meran — Mauls — Antholz

The rock composition is largely similar to the above unit.

The Schneeberg Belt

This series consists of greatly differing rock types, among which the phyllites and the mica schists of high mineral content are noteworthy in terms of tunnel construction because of their poor stability and the presence of increased pressures. The decisive factors for classifying these rocks are the position in space of the schistosity planes relative to the tunnel axis, the depth of overburden and the amount of water contained in joints and fissures. The intercalated limestones and marbles are thick-bedded and strong-bonded, but severely jointed zones are water-filled.

The Brenner Mesozoic

It is only if the West Line, which we classify as unfavourable, were realised that the tunnel would pass through the series of carbonate rocks, argillaceous schists and sandstones over a short distance, where the presence of mylonites and cataclasites as well as substantial ingress of water are anticipated.

The Brixen Quartz Phyllite

These rocks are very much like the Innsbruck quartz phyllite series. They show in general little tendency to spalling and display good excavation conditions in shallow cover. As in any rock, tectonic zones show reduced stability and increased sensitivity to water.

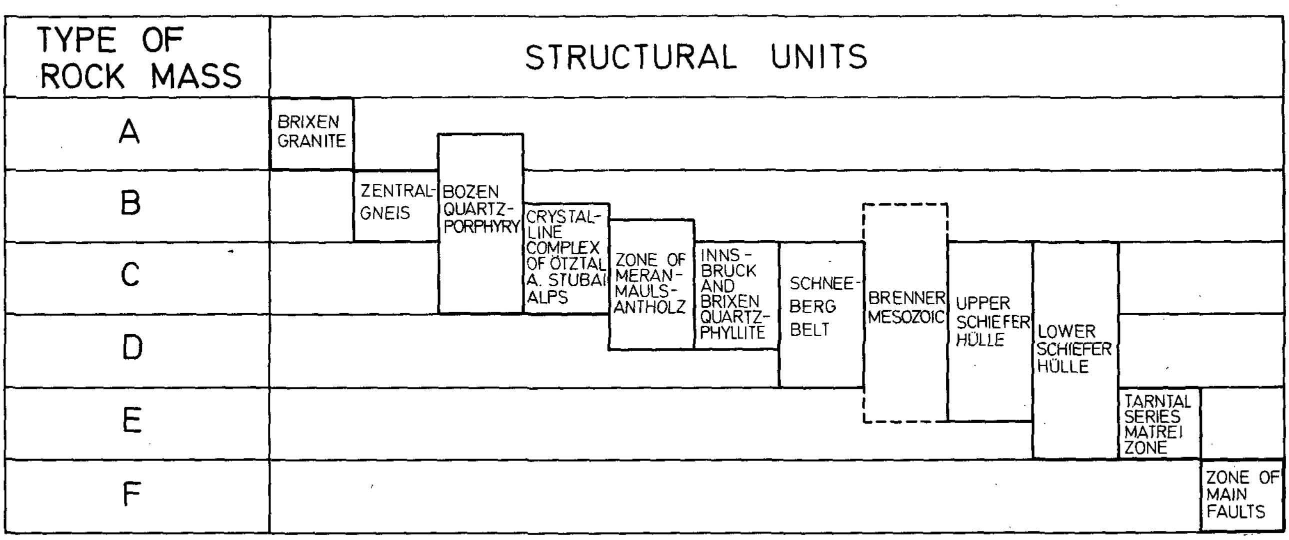

Fig. 1.4—3: Distribution of types of rock mass over the structural units.

The Brixen Granite

The granitic rocks (granite, granodiorite and tonalite) have a high biotite content, they are massive, compact and of satisfactory stability. Near their northern boundary, they show evidence of tectonic action, and high residual stresses are expected to be present in the jointed zones.

The structural units with the above listed rock types between the Inn valley and the Eisack valley can be seen from the map (Fig. 1.4—1). These units have been split up into individual blocks by regional faulting.

A rock mass typology set up by M. KÖHLER assesses the geological factors (rock types, structure, stress conditions, presence of water, etc.) of the respective structural unit. Each of the six types of rock mass stands for an average behaviour, with A denoting the best and F, the worst performance in an underground excavation. The corresponding structural units can be found by consulting Fig. 1.4—3, which is intended to convey an idea of the potential behaviour of the different units.

By a different system, types of rock mass are classified into seven rock classes (Fig. 1.4—4). When translating rock classes into types of rock mass, it should be kept in mind that only an average behaviour can be classified. The figure shows the approximate relationship between rock classes and types of rock mass.

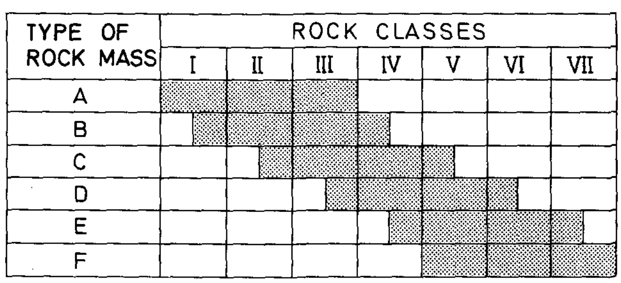

Fig. 1.4—4: Types of rock mass related to rock classes.

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Stop 1.5. Public water supply utilities for Innsbruck. Mühlau Water Works

Province of Tyrol.

During the Second World War and the years afterwards Innsbruck's municipal authorities faced an unusually high increase in population. By that, and by an extraordinary per-capita increase in water consumption a serious shortage in drinking water sprang up. In the year of 1890, the Mühlau karst springs, besides, the only ones of abundant yield in the neighbourhood of the town, were captured for the first time in order to provide the necessary amount of good water for the town. They spring from a ravine of the "Nordkette" range, part of the Northern Limestone Alps, immediately north of Innsbruck. In 1890 Innsbruck's number of inhabitants totalled to nearly 24.000. Up to 1910 the figure increased to 53.000 and 1969 it amounted to 113.944. The Mühlau waterworks at the technical state of 1890 supplied up to 78 litres per second, easily enough up to the year of 1910, but no much longer. By the end of World War II a more effective capture of the Mühlau springs became imperative. Now, the new Mühlau water works, inaugurated in 1952, yield 1.100 to 1.200 l/s the year over, i. e. about 14 times the amount of the former capture facilities! It is expected that the present installations may suffice until 1990. From then on the municipal authorities are to rely upon different supply stocks, ground water from the west of Innsbruck included.

At present, more than 80% of the city's drinking water is supplied from the Mühlau springs. Compared to karst springs pouring from pure limestone — e. g. the springs providing water for both "Hochquellen"-conduits of Vienna or to the springs contributing the karst water part to the alimentation of the town of Salzburg — the Mühlau springs derive "only" from dolomitic Wetterstein Limestone; really a big ad-vantage. On the one hand they share an actual catchment area, by far wider than the morphologic one, with genuine limestone areas. And the infiltration rate of the sufficiently karstic, predominantly narrowly jointed Wetterstein limestone is no much less than that of a pure limestone. On the other side the dolomitic limestone avoids the notorious disadvantages of too pure calcitic rock, namely their very wide annual fluctuation of discharge and the insufficient filtration capacity of wide calcareous karst conduits. In detail, the discharge of the Mühlau springs corresponds to a hydrologic catchment area of 30 km² compared to the morphological one, amounting only to a few km², and, moreover, situated on rather steep slopes.

Only by a pronounced, really unusual matter of luck the underground waters from the abundant northern parts of the actual catchment area do not make their way along the west — east running structural axes of the mountains chains. The flow way towards east is cut off by a mighty barrier built up from salt bearing clay at the base of the Inntal nappe. So the water possibly makes its way mainly along one of the few, far reaching transverse fault lines cutting the Karwendel chains from north to south. [1]) Besides, the mentioned salt bearing clay provided the material base of the — now abandoned — rock salt mine of Hall/Tyrol, 6 km NE of the Mühlau springs. Of course, the vicinity of rock salt to the underground waters flowing towards Mühlau involves vital problems for the Mühlau water works and for the salt mine area as well.

The geological exploration of the Karwendel mountain ranges was an essential part of O. Ampferer's lifework. His investigations created the scientific base for the thorough exploitation of the Mühlau springs to the benefit of Innsbruck.

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[1]) In a recently published paper G. Heissel questioned the said established idea of fault conduits in favour of a notion based on water transport along a tectonic scale interface (Bärenklamm-Schuppe).

Topographical maps

Österr. Karte 1 : 50.000, sheet Nr. *118*, Innsbruck.
Alpenvereinskarte 1 : 50.000, sheet Innsbruck-Umgebung (surroundings), No. 31/5.

Geological maps

Geologische Karte, sheet Innsbruck, 1 : 75.000 (ed. 1912).
Geologische Karte, sheet Achensee, 1 : 75.000 (ed. 1912).

Day 2

Surroundings of Innsbruck, Province of Tyrol.

Stop 2.1. The Gepatsch storage basin, Kaunertal, Tyrol

Some difficulties related to the construction of the Gepatsch dam and to the initial impounding steps confirmed the fact, that even in areas seemingly free of trouble on the base of informations from geological maps at a usual scale of 1 : 50.000 or 1 : 75.000, serious problems might arise from the details.

The Gepatsch rockfill dam, 153 m high, with a central moraine core, an overall volume of 7,1 million m³, was constructed from 1961 to 1965. This dam locks the glacially formed, S—N-directed Kaunertal at approx. 1600 m a.s.l. The storage basin and the dam are situated within the so-called Ötztal gneissmass, part of the Austroalpine nappes system. At the valley flanks para- and orthogneisses are partly covered with moraine, either in its original state or redeposited. The through-shaped bedrock is filled up by fluvioglacial sediments ranging from silts to coarse gravels. At the finally adopted dam site, the augengneiss in place was encountered below a 30 metres' sedimentary cover. The sole favourably situated site to quarry the augengneiss for shell fill was a very steep section of the right valley slope, only a few hundred metres downstream from the dam. As a technical consequence of the steepness of the slope the quarry had to be operated at an unusually steep general slope gradient of 1 : 2, i. e. nearby 64°. The whole quarry work came to a good end although it met two heavily jointed slip zones crossing each other somewhere near the central area of the quarry. They were only detected when quarrying was full in operation. (Several years afterwards, this over-steep 1 : 2-gradient at a different site in Austria, of course now "routine", led to a rockfall of 150.000 m³.)

The dam site itself did not cause exceptional trouble for engineering geological reason. But serious problems suddenly arose in the course of the first part-filling of the storage basin in summer 1964 by sagging phenomena at the left valley slope, only a few hundred metres lakeward from the dam's crown. Previous geological investigation work on the flanks of the then future storage basin tracked down, it is true, mile long reaches with definite indications for former slides. But in the area near to the dam the left slope looked good, and even rocky. Exactly this 35° steep slope started to move for 1080 metres' length, as soon as the water level of the basin reached the 40 metres' mark. Investigation drillholes did not promise conclusive evidence in sliding rock masses. Therefore, 4 adits were bored. One of them, bored in a way to pierce finally from the inside of the slope back to the open air, passed now from massive gneiss, against every expectation into moraine and only next into the slide mass. By that it became clear, that the slide caused by impounding affected a wide rock slab, that already had crept down a first time post-glacially over moraine from an area presumably 200 m higher up. By reasons whatsoever this slide mass came to a standstill at a sensitive state of equilibrium — and looked like rock in place. The narrow sliding zone proper was found within the moraine. A careful evaluation of the large amount of geodetic survey data as well as a scrupulous analysis of the displacement measured by wire gauges and makeshift water-tube tiltmeters in the investigation adits yielded convincing evidence, that the slide was a rotational one but no — a much more dangerous — slab slide; a very important result with regard to the concept of remedial measures. Finally, a line of indirect conclusions led to an understanding of the sagging process as initiated and governed by uplift. In the course of time quantitative insight in the mechanism of the sliding process came up to a state that allowed to proceed within three years of stepweise rising the storage level to the designed top level of 1767 m a. s. l. A marginal note: one of the first observations that infallibly indicated the starting phase of a dangerous slide was a continuous perimetral rim along the upper border line of the slide. This perimetral rim reminded awkwardly of an initial phenomenon to Vajont catastrophy which happened only one year ago! To venture the struggle of Gepatsch in view of this oppressive omen was a heavy burden to the engineers responsible for any possible development of facts at Gepatsch site. Finally, the cautiosly balanced stepwise increase of the impoundment became a full success. (After LAUFFER, NEUHAUSER, SCHOBER — 1967).

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Day 3

Stop 3.1. Maria Rast church (village Hainzenberg)

Tyrol. Near the junction of Gerlos valley and Ziller valley.

Notorious slumping area in quartzphyllite at Zillertal right valley flank. The foundation rock proper of Maria Rast church is immediately affected and endangered by periodic rock falls beneath the building. Actually a valleyside quarter of the church's floor does no more rest on solid ground whatsoever, but is only supported by a protruding wooden structure.

Topographical map

Österr. Karte 1 : 50.000, sheet No. 150, Zell am Ziller.

Stop 3.2. and 3.3.

Dams for a hydroelectric scheme in the Gerlos Valley, Tyrol

The upper reaches of the Gerlos valley extend into the Reichenspitz mountain group, part of the Eastern Central Alps. Along its uppermost 10 km from south to north, the valley coming down from the penninic Zillertal—Venediger gneiss core, enters the northward dipping covering nappes comprised unter the term "penninische Schieferhülle". The latter is mainly divided into a lower nappe next to the gneiss core, which is to some extent materially influenced by the tonalitic gneiss, and an upper nappe, built up from low-grade metamorphic rock types. Three km WSW from the Gerlos pass, the valley turns abruptly into an E—W-direction. Apart from a short, steeply graded descent near the junction of the Gerlos creek with the Ziller river the Gerlos valley does not show marked step-like successions of reaches. The small Gmuend arch dam, constructed in 1943/44 and the Durlaßboden earthfill dam, 70 m high, completed in 1967, are situated in series of the Upper schist nappe ("Obere Schieferhülle"). The construction of both dams and the exploration of the storage lakes involved special engineering geological problems deriving from the types of rock, and, in the first line, from secondary structural features by postglacial events.

Stop 3.2. Gmünd

The 37 m high Gmünd dam was the first arch dam ever constructed in Austria. Its abutments are excavated from a greenish muscovite-quartzite. Although hard and solid as a hand-specimen, the behaviour of the rock mass is mainly governed by two sets of joints, both striking along the gorge. The first one, corresponding to the bedding planes, dips under medium angles towards north, the second one in the same way to the south. For both systems the average distances from (open) separation plane to separation plane are of the order of several decimetres. The cutting edges run horizontal. A third set of joints — ac-joints — strikes across the gorge and dips at variable, mostly steep angels. The unit rock blocks form rectangular prisms or stalks of, say, 20 × 20 × 100 to 200 cm³.

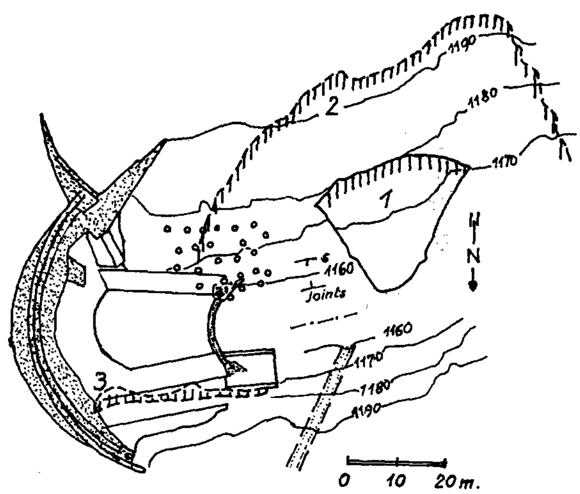
Three considerable rockfalls happened, only twenty years after the completion of the dam, between November 1963 and June 1964 a little downstream of the structure. Two of them fell from the left flank, the third one from the right side. As a result of these events due to unexpectedly rapid loosening of the surficial parts of the rock mass, the dam had to be thoroughly reconstructed. To this purpose a gravity dam, acting as sort of crossbar between the footings of the flanks of the gorge, was constructed immediately downstream of the arch dam. With the reconstruction completed in 1965, the "combine" works now for more than a decade without any further trouble. Gmuend dam is an example for the premature decay of an unfavourably jointed rockmass, induced by technical operations, and coming out within a fraction of the normal life-span of a dam.

Stop 3.3. Durlassboden

As early as 1939 the principal layout to a storage basin on the D u r l a s s b o d e n — in the upper reaches of Gerlos valley —, acting as upper-stage basin to Gmuend stage was designed. Owing to complicated and unfavourable rock conditions, weak graphitic phyllites with intercalated streaks of very hard and brittle carbonaceous and calcareous quartzites, chloritic greenschists of widely differing quality, and because of the lack of a steplike configuration along the course of the valley, the search for a suitable dam site was a protracted and difficult job. In addition, one had to face the fact, that both valley flanks, along the future storage lake as well as over each one of the dam site alternatives showed more or less spectacular evidence for former large-scale slides.

With regard to mere morphology, a site at the narrowest cross section of the valley, approximately 1 km downstream from the dam later on actually constructed, looked promising. But a rough geological examination gave first indications of a post-glacial closing-up of the valley flanks (in German: "Talzuschub"), phenomenon described by the late Prof. J. STINY. Two consecutive sudden water inrushes in an investigation adit on the right slope of this site, each one yielding several thousand of m³, emphasized the bad state of the slope. The enticing alternative had to be abandoned.

No doubt, the finally adopted dam site was not very inviting, because of the locally wide valley floor, but it was not immediately threatened by recently active "Talzuschub". However, this positive statement



1 Rock slide Glissement 1963-11-24
2 Rock slide Glissement 1964-05-09
3 Rock slide Glissement 1964-06-09
Dotted : structures existing prior to reconstruction
En pointillé : ouvrages existant avant la reconstruction
Level lines as prior to rock slides
Courbes de niveau avant les glissements
Rock anchors installed after slide № 1, destructed by slide № 2
Ancrage installé après glissement 1, détruit par glissement 2

Fig. 3.2:

Gmuend dam
Location of the three consecutive rock slides.
Barrage de Gmuend
Plan de situation des trois glissements consécutifs.

had to be backed by the results of two years' drilling campaigns, and from a 217 m long investigation gallery into the more critical right slope. Additionally a shaft was sunk. According to a theoretical concept sponsored by soil mechanics a discrete slide plane as the expected continuation of the well formed upper rim of a 1 km wide subsidence, 600 m higher up, that marked impressively the edge of a conchoidal slide of the past, should be found again in the investigation adit. But against those expectations, no major slide plane could be detected in the adit. Exhaustive core investigation and a detailed geological survey of the adit and the shaft gave good evidence, that the front of a slidden rock mass got stuck in the transition zone from the right slope to the uneven valley floor. This front is now cased into fluvioglacial sands, silts and gravels. It was a tricky job for the geologist to collect reliable

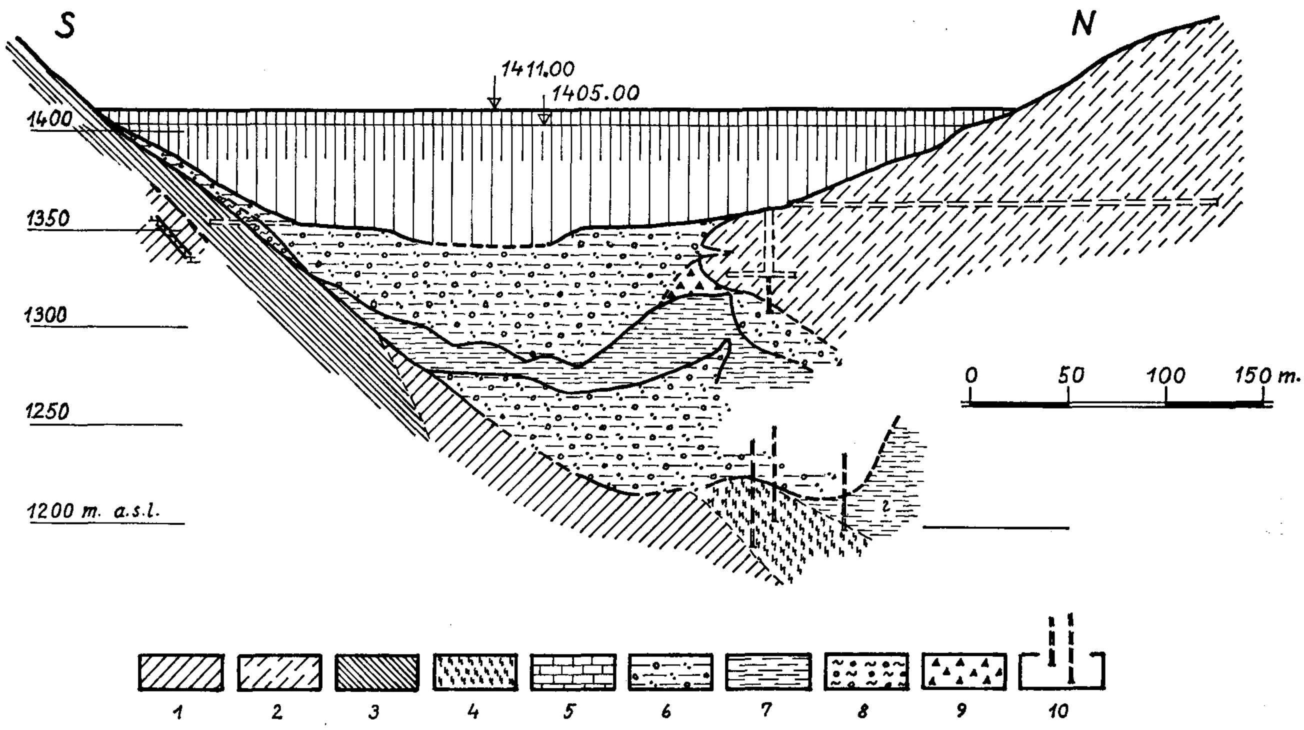


Fig. 3.3:
Durlassboden dam
Geological cross section of the valley at the dam site.

1 Weak black phyllites intercalated with carbonaceous quartzites.
2 Same as 1, dislocated by ancient slide. Front of the slide.
3 Greenschist.
4 Pale-green phyllite + gypsum.
5 Calcareous schist.
6 Fluvioglacial and fluvial valley deposits; gravels, sands and silt. (partly pervious).
7 Fine sand and silt (impervious).
8 Bottom moraine; impervious.
9 Angular rock fragments. Scree or mud-flow?
10 Final sections of several investigation boreholes.

Digue du Durlassboden
Coupe transversale de la vallée à l'emplacement de la digue.

1 Phyllites noires alternant avec des bancs de calcquartzite.
2 voire 1; déplacée par glissement ancien. Front embourbé dans les alluvions de la vallée.
3 Schistes verts.
4 Phyllite vert-pâle, barrée de gypse.
5 Calcschiste.
6 Dépôts fluvioglaciaires et fluviaux, perméables par parties. Graviers, sables, vases.
7 Sables fins et vases (imperméables).
8 Moraine basale (imperméable).
9 Fragments anguleux. Eboulis ou coulée boueuse?
10 Parties terminales de quelqueunes des sondages de reconnaissance.

indications that the prehistoric (?) slide be dead and might not rejuvenate with impoundment.

By and large, the rock mass traversed by the adit is built up from about 60% of very weak, easily deformable graphitic phyllite and some 40% of intercalated beds from millimetres up to 30 cm of gray, calciferous quartzite. Now, the former investigation adit is incorporated into the large-scale monitoring installations for the dam as well as for slope survey.

Sealing-off of the alluvial masses below the dam was performed by an eight-rows' grout curtain in four different stages of grouting, ranging from Portland-cement to liquid chemicals. The curtain reaches down to a continuous silty layer at 40 metres' depth below the dam. (Bedrock locally only at 130 metres depth!).

Finally, within now 13 years of full exploitation, the geodetic survey yielded, of course, evidence of some creeping, but no more. According to survey data slope creep bears a remote resemblance to a caterpillar's motion or to the wandering of compressions and dilatations in a longitudinal wave.

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Sheet 151, Krimml, publ. by Geol. B.-A., Wien 1979.

Stop 3.4. The Felbertal Scheelite Mine

Province of Salzburg

This scheelite deposit was discovered in the course of a systematic examination in UV light of stream-deposited sediments, proceeding upstream in the River Salzach and the Felberbach. The Felber valley extends between Mittersill in the north and the main rigde of the Tauern mountains. A new road leads through this valley and the Felbertaueren tunnel (5,3 km) to Matrei and Lienz in the south. This road was completed, along with the Transalpine Pipeline (TAL), 13 years ago. The pipeline, too, passes beneath the main ridge of the Tauern mountains in a gallery and this, like the road tunnel, was driven through gneisses in a state of extreme stress (rock bursts!) over its southern part. Over its northern part, however, the rock mass proved severely jointed and water-filled to greath depth. Systematic prospecting work advancing from the north into this zone of rock mass led to the discovery, in 1967, of scheelite on the western flanks of the Brentling peak. The scheelite ore bodies ($CaWO_4$) are confined to a series of metamorphic rocks of Older Paleozoic age from the Penninic Zone, lying in a mica schist and gneiss series with a high content of amphibolites and quartzites. In addition to this, the detrial boulders show workable scheelite deposits. The ore-bearing series proper mainly consist of hornblende schists, hornblende prasinites, chlorite-biotite schists, mica-quartzites and albite gneisses. The whole series has an about east-west strike and dips towards the north at between 30 and 40 degrees. The dominating fold-axis trend is to the north-west and this is also the preferred trend of the ore deposits.

Slightly unstable scree and boulder material overlying the bedrock, as well as increased avalanche activity during the winter months impair the mining procedures.

During the first years, more than 50 drill holes with a total length exceeding 6600 m were sunk and three large ore deposits were discovered. The depth between the individual ore bodies exceeds 1300 m. W. SPROSS estimates the workable deposits at 2.22 million tons with 0,67 percent Wo_3 (surface mining and production from the talus slope, as well as underground mining). Some difficulty is caused to the mining process by the haulage of the ore over 2200 metres of transport road to the flotation plant located at an altitude of 1100 m a. s. l.

In the West Deposit, which is situated at a lower level, in situ stress measurements taken in the near-surface tunnel at the foot of the mountain range to the west of the Felber valley revealed stresses of unexpected severity which F. KOHLBECK, A. E. SCHEIDEGGER and J. R. STURGAL believe not to fit into the supra-regional residual stress pattern. This anomaly is confirmed by he position in space of the joints as results from measurements, and is explined by the assumption that the rock mass is lying on plastic material, so that the rheological state does not show elastic strain in the long term.

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Day 4

Stop 4.1. and 4.2. Kaprun hydroelectric scheme

Province of Salzburg

Because of a series of pronounced consecutive steps along the longitudinal section of the Kaprun valley, it was selected as early as 1914 for the construction of a chain of storage basins. In its uper reaches the valley runs SW—NE, afterwards from south to north. The uppermost trough, suited for large-scale storage begins some 8½ kms. to the north of Grossglockner summit, somewhat below the present end of Karlinger glacier.

From S to N three large basins follow each other from step to step. The valley floor of the uppermost trough, the so-called Mooserboden is developed at approx. 1950 m a. s. l. The next step valley-down is the Wasserfallboden at 1570 m a. s. l. The lowest lying large trough reaches from 1000 m near its upper end down to 850 m a. s. l. at its downstream end near the rocky crossbar of the "Bürgkogel" ("Kogel" means: small mountain). The floor of this lowest basin is still 70 m above the main power station.

Stop 4.2: To start with the uppermost basin, the Mooserboden: the downstream end of this basin is clearly marked by a rocky threshold — as often encountered with glacially shaped alpine valleys. A knoll of more than 150 metres height, the "Höhenburg" is the middle part of the said threshold. To its right and to its left are wide and deep furrows cut across the threshold. Because of that, two separate dams had to be constructed to block off the depressions aside from Höhenburg. West from it a curbed gravity dam, the "Moosersperre" was constructed, east of the Höhenburg an arch dam, called "Drossensperre". Maximum storage level of lake Mooserboden is 2036 m a. s. l.

Stop 4.1: One "step" down, lake Wasserfallboden is dammed up by the "Limbergsperre", an arch-gravity dam, 100 m high. The storage capacity of each one of the two lakes is about 86 million m³.

Fig. 4.1:

Limberg dam, Kaprun
Right abutment. Typical joint set dipping towards the valley axis.
Barrage de Limberg, Kaprun
Situation typique à la zone d'appuy du flanc droit, mise au jour par les travaux d'excavation. Joints plongeant vers l'axe de la vallée.

Halas, in the year of 1938, when the layout of the scheme was finally established, technicians did not yet dare to make use of the lowermost natural trough "Wüstlau" for storage purposes. Prospects to an effective sealing-off of the deep reaching, partly permeable fluvioglacial sediments in the wide, former outlet notch, seemed to be too scanty. Therefore, the planning board contented themselves with closing the actual outlet gap, the narrow, epigenetic gorge "Sigmund-Thun-Klamm" by a small gravity dam. The storage volume of this lake is only 200.000 m³.

As to geology, the two large Kaprun storage lakes are situated in rock of the metamorphic penninic "Schieferhülle" covering the big gneiss cores exposed in the Tauern window. Around the Wasserfallboden basin and its dam, the "Limbergsperre" calcareous micaschists of the Glockner nappe prevail by far other rock types such as prasinites (greenschists i. g.) or non-calcareous graphitic types of micaschists. Much more complicated are rock assemblages at the sites of both Mooserboden dams and around lake Mooserboden, this because of intense imbrications of rock masses belonging to the penninic upper covering nappe with different ones from the lower nappe. Just this intricate interlocking of rock types with widely differing mechanical properties may have led to intense local faulting. Two big faults, each one 3 to 4 m wide, both striking along the valley and dipping eastward, initiated the erosion of the deep notches in the rock barrier, now closed again by dams.

Stop 4.1. Limberg dam

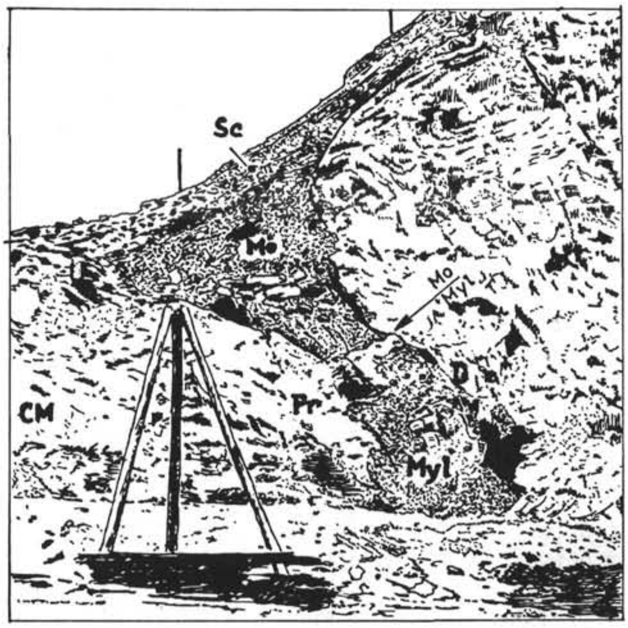
In accordance with the chronological succession in construction and because of simpler geological conditions the following site description begins with the Limberg dam, 120 m high from rock to crown, finished in 1951. The initial design from 1938 provided for a buttress dam. In view of the good calcareous micaschist nobody suspected too much trouble from the excavation; and, if any, only from deep reaching wheathering effects. The latter were induced — erroneously — from intense superficial decay of the schists. But factually this decay did not surpass a few decimetres. Earlier suspected dangerous water losses along possible karst holes, seemingly causing a big spring several hundred metres downstream from the then future dam, could be cleared off as non-existent by J. Stiny.

The buttress dam was designed so as to ride upon the rock threshold, rounded and polished by glacial action. This threshold dips at 40° valley-up under the secondary fluviological filling into the glacigene trough. With the end of 1947, just before the start of concreting, the rock in the upper half of the right abutment displayed more and more of an outspoken dangerous roof-shingle structure, never seen at the natural rock surface. (At that time modern rock-anchoring techniques were not yet at hand.) Of course, nobody was willing to take the obvious risk of rockfall induced by inevitable undercutting for the preparation of footholds to each separate buttress. Finally, the buttress dam design had to be abandoned in favour of a gravity arch dam concept. For reasons of morphology there was no alternative left but to inset the dam abutments at the same spots as already excavated for the buttress dam. In consequence of that, the apex of the now curbed dam lay nearly 20 m upstream from the corresponding part of the buttress alternative. 20 m farther upstream equalled to 18 metres of deeper reaching excavation!

Stop 4.2. Mooserboden

The two dams at M o o s e r b o d e n were completed in 1954. Complicated rock assemblages were expected from the very outset of planning. Excavation started 1949, at first for the western dam "Moosersperre", 107 m high. After clearing the rock from its 15 metres thick fluviatile and fluvioglacial overburden, excavation proceeded from the flat valley floor towards the very steep foot part of the "Höhenburg". Exactly in the sharp indent from the rock of the floor to the Höhenburg wall an east-dipping fault strip — visibly the cause for the indent — 4 m wide, running from the dam's upstream to its downstream side, was uncovered. Up to that day the said fault was completely camouflaged by scree and moraine. Besides, as to permeability the rock contents of the fault behaved neutral compared to the surrounding rock masses. By geological evidence, the vital question, whether the impressive strike-slip fault be "dead for ever" could only be answered to some degree of probability but not to 100% exclusivity. The fault is permanently surveyed by specially designed geodetic methods. It is to say that up to now no displacements at all were observed at the fault, and so for 25 years of full operation. The great variety of different rocks and minerals in itself did not cause any serious technological problem. By the way, in spite of both big longitudinal faults below the dams of Mooserboden storage lake, and of more than 100 m depth of the lake, the impoundment did not induce any perceptible earthquake at all.

More difficulties had to be faced with the construction of Drossen arch dam, 112 m high. They were not so much caused by geology in its narrow meaning but by adverse morphological conditions. The dam was initially designed as a thin double-curvature arch dam. Having the lessons from the unexpected fault in the Mooser dam rock, some suspicion arose from an insignificant longitudinal depression crossing obliquely the future right abutment. Two additional drillholes confirmed the suspicion. They hit the second big Mooserboden fault. It was bound to the boundary zone of an intercalation of prasinite in the calcareous micaschists. The



Sc	*Scree*	*Eboulis*
Mo	*Ground moraine*	*Moraine basale*
Myl	*Mylonite*	*Milonite*
CM	*Calcareous micaschist*	*Micaschiste calcaire*
Pr	*Prasinite*	*Prasinite*
D	*Dolomite*	*Dolomie*

Fig. 4.2:

Moosersperre dam
Strike-slip fault exposed in the downstream excavation wall. The fault previously camouflaged by moraine and scree cover.
Barrage Moosersperre
Etat d'excavation. Vue en direction aval à la faille de décrochement d'abord camouflée par de la moraine basale couverte par des éboulis.

weak, more or less mylonitized rocks in the fault zone, typical conversion products from initial prasinite, had to be excavated down to 15 metres additional depth. As early detected, remedial measures could be planned without undue hurry and without delay to the time schedule. Within the 4 m wide, wildly kneaded dark green to bright green fault mass lay a bright coloured cylindrical rock drum of approx. 1 metre's diameter. Now, after 25 years of complete immobility, proofed by repeated geodetic survey, there is good reason to expect that this "roller bearing" be actualley dead. As already mentioned with regard to the Mooser dam, at Drossen dam the multitude of widely differing rock types — e. g. at one spot no less than 24 different strips for 15 m length — had no deleterious effect to engineering. Unexpected serious troubles came up from a secondary local fault zone at the left abutment. By nature excavation at this flank was tricky because of the acute angle from dam to slope. The concept for excavation was drafted on the assumption of good rock quality. Now, with the faulted rock exposed, the assumption was no more valid and the excavation ran into trouble. The dam had to be redisigned in accordance with the actually encountered rock conditions. The triggering incident for the change of design was a rockfall of a solid mass of 1500 m^3 calcareous limestone. This fatal event — 6 workers died in it — was caused by a slip along a greenish seam of only a few millimetres' width consisting of a greasy mixture of muscovite, chlorite and some actinolithe. This kind of rock, always bound to displacement zones in the otherwise hard and good-natured prasinite, was the only actually dangerous type of rock. When wet, those seams of millimetres' to decimetres' width, irregularly folded, acted like wet soap.

Grout injections into the abutment rock of both dams were mere, although expensive routine. Although locally the water pressure tests could not meet the Lugeon criterion (then sacrosanct!), even in spite of multiple re-injections, the dam sites prooved as satisfactorily watertight; and are so now for 25 years.

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Day 5

Stop 5.1. Großglockner Hochalpenstraße—Edelweißspitze

Provinces of Salzburg and Carinthia;
Planned and owned by Grossglockner Hochalpenstrasse AG.

An ideal road connection between the Salzach valley in the north and the Möll valley in the south is afforded by 48,7 kilometres of mountain road crossing the main ridge of the Alps. The Grossglockner road was completed 45 years ago by Hofrat Dipl.-Ing. F. Wallack. Starting from Fusch (820 m a. s. l.), the north ramp rises to the Fuscher Törl pass (2404 m a. s. l.), where a 1,6-km long road branches off to the Edelweisspitze (2580 m a. s. l.); then follows the summit reach between the Fuscher Törl and Guttal, leading past a lake and through two tunnels (Mittertörl, 2383 m a.s.l. and Hochtor 2506 m a. s. l.); the south ramp finally descends from Guttal to Heiligenblut in the Möll valley. Branching off at Guttal is a road to the Franz-Josefs-Höhe (2329 m a. s. l.).

During the construction period, E. Clar and H. P. Cornelius made a geological survey of the Grossglockner region, and their excellent map is still used by many geologists as a basic document. W. Frank and G. Frasl should be mentioned among the researchers of more recent times. They prepared a geological panorama for the Edelweisspitze in 1969.

Starting in the Salzach valley, the road leads through the valley of the Fuscher Ache, to Ferlach, and then rises steadily, at 10 percent, to the Fuscher Törl. There are only two sections where the slope is so steep that F. Wallack had to provide a series of serpentines. One of these, the so-called Hexenküche, or witch's kitchen, represented a particularly difficult task of mountain road construction. The schist rocks and the Permotriassic series have undergone severe weathering so that the rock face in question has been disintegrated into towers, huge blocks and a thick cover of scree material. The summit reach traverses an Alpine landscape of glacial origin characterised by calc. mica schists, carbonate rocks in general and phyllites. After leaving the Hochtor tunnel to the south of the main ridge of the Alps, and approaching Heiligenblut, the road passes through the same rocks from the Penninic Zone. These shows severe disintegration along the south ramp. The overburden of moraine and scree material exhibits major creep phenomena. Near the point where the road branches off to Franz-Josefs-Höhe lies a very thick sackung-type slide mass, which continues to move towards the Guttal stream. At the foot of the Freiwandeck rock face, it was necessary to provide a covered gallery in order to protect visitors to the Franz-Josefs-Höhe from rockfalls.

From the observation tower on the Edelweisspitze, a peak made up of Upper Triassic schists, the visitor enjoys a magnificent all-round view of the Northern Calcareous Alps and the Central Alps to Austria's highest peak, the Grossglockner (3798 m a. s. l.). At the same time, he obtains an idea of the geological make-up of the Penninic Zone, which is divided into several nappes within a major radius of this vantage point. In the close vicinity, yellowish dolomites and rauhwackes — or cellular dolomites — (Middle Triassic of the Seidenwinkel nappe) are exposed. To the north of the peak, these rocks contain gypsum. They alternate with thick-bedded limestone marbles, quartzites and dark phyllites. At greater distance from the Fuscher Törl, light-coloured chloritoid schists are found in alternation with very light-coloured and much disintegrated quartzites. Towards the east, the rock series with a predominance of carbonates passes into the prasinites, calc. mica schists and phyllites from the Bündner schist series. In the west, the huge calc. mica schist beds form the impressive ridge between the Wiesbachhorn and Fuscherkarkopf peaks. To the southwest follow the dark phyllites poor in carbonate of the Spielmann peak and the dark serpentines of the Brennkogel.

The road as well as the magnificent vantage points on the Edelweisspitze and the Franz-Josefs-Höhe are among Austria's prominent tourist attractions. F. WALLACK succeeded in creating a happy symbiosis between nature and engineering by adapting his project excellently to the topographical and geological conditions and providing engineering structures only where absolutely necessary. His basic idea was to locate long uphill sections in solid rock flanks and to carry his road upwards in serpentines in front of disintegrated scarps. In the Hexenküche on the north ramp he fitted the serpentines into a zone of large blocks with much sense of beauty. Where extremely disintegrated slope sections had to be crossed, he proceeded very carefully, taking the shortest route, so as to guarantee the stability of the slope. The engineering structures necessary south of the Hochtor tunnel, where the road cuts very unstable slopes, also blend ideally with the landscape owing to the use of local materials. Thanks to the circumspection exercised in the construction activities, most of the slopes have reached a state of rest. With a few exceptions, i. e. where constant correction and retaining measures are necessitated by the nature of the terrain, the Grossglockner Road is a traffic route of solid construction harmoniously fitted into the landscape. In this respect, this project contrasts favourably with certain examples of modern traffic route construction in the Eastern Alps, where extremely rigid structures of almost straight alignment, partly even delicate in design, brutally impress their stamp on the landscape.

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Stop 5.2. Storage lake Margaritze

Province of Carinthia

In the year of 1952 a small storage lake went into operation in the immediate foreland of the Pasterze glacier, 5 1/2 kms to the east of Grossglockner summit. This basin works as a remote storage to the Kaprun hydroelectric scheme. The lake fills a natural trough, whose long axis runs perpendicular to the axis of the main valley. The trough is traced out by a large, steeply inclined fault. The natural basin had two outlets to the downstream foreland. The remaining hill between the two furrows is called "Margaritzen Kopf", hence the name of the storage basin. Both furrows are now blocked off by concrete dams. The southern — inactive — furrow — was no much deeper than 30 metres, and the construction of a gravity dam across it offered no trouble. The northern, active furrow showed two stages of erosion: the upper half smoothly rounded, the lower half a deep and narrow gorge reaching some 50 metres deeper than the upper part; the given site for an arch dam. Both dams are situated in mostly marble-like calcareous micaschists of the penninic "Obere Schieferhülle" (upper stage of the covering nappes casing the penninic gneiss cores), recently named „Glockner Decke" according to A. TOLLMANN, 1977. It should be mentioned, that nearly everywhere on both dam sites rock in place was exposed, and the rock was completely scraped off by ice action from traces of wheatered schist. Obviously, the fresh rock would not offer any serious foundation problem. Therefore, the managing board decided for both dam sites to dispens with costly investigation borings or even with pits. A small, inconspicuous concave meadow, only some 50 m long and 15 m wide, in the area earmarked for the right abutment of the arch dam, escaped the engineers' notice. The meadow camouflaged a mylonitic zone. In this bad strip the otherwise competent, gray calcareous micaschist was so intensely squeezed and altered (not: wheatered) that interfingering strips of decimetres' width were really a black, kneadable paste.

Much remedial work was necessary to cope with these adversities. From a geological point of view, the said fault on the site was only a minor parallel to the

"Stockerscharte" main fault. On the contrary, along the gorge — where everybody should rather expect a longitudinal fault — there was not the slightest trace of a fault.

Special problems were, and are still, related to the unknown future attitude of the glacier. At the time of the initial technical planning for the scheme, about 1935 to 1938, all alpine glaciers were still in full "retreat" since decades. Apart from a negligible advance about 1920, the climax of the last advance of glaciers in the Glockner area was 1856. The traces of this last bygone advance are still conspicuously marked on the rocks. At that maximum the tongue of the glacier reached several decades of metres downstream from the two dam sites. The engineering geologist, Prof. STINY, acting 1938, considered three possible alternatives as to the development of climate:

Supposed, the glacier would not melt back any longer, but it would not much advance. In this case a position of both dams immediately aside from the Margaritze knoll — as actually constructed — with the abutments excavated into the upstream slope of the hill, would be alright. A considerable drawback of this dam site is its maximum storage level of only 2000 m a. s. l., whereas the top water level of Mooserboden storage lake was at that time already fixed to 2.036 m a. s. l. Margaritze waters are fed to Mooserboden. Therefore, every year costly pumping energy was necessary whenever Mooserboden storage level surpassed the 2.000 m mark.

Let continue the rapid melting down of the glaciers even many years after 1938 at the same high rate as during the decades before. For this, then possible, development STINY proposed to provide for a new storage basin 1 or 1½ km valley up from Margaritze, at a storage level somewhat above 2.036 m, in order to save pumping energy. In fact, the glacier melted rapidly back until the late sixties of our century. In the year of 1970 the glacier's front had reached a position, which exposed the naked bedrock at 2.100 m a.s.l. Factually, the ice released a wide, flat basin but no practicable dam site. Engineers had to content themselves with creating a simple settling basin. Even this new flat basin has its good merits. Since 1965 silting-up of this basin goes on at a rate of some 35.000 m^3/a, much to the profit of Margaritze storage lake, whose silting rate decreased by that to a mere 2.000 m^3/a. Besides, since the late sixties a trend to cooler climate, and an increase of the glaciers makes itself more and more felt. This fact will, of course, influence the future policies about alpine hydroelectric schemes.

As a third alternative, STINY already in 1938 considered a possible, rapid growth of the glaciers, as experienced in the years after 1830 a. D. For this event a site, approximately 800 m downstream from the actual Margaritze basin was kept in mind, requiring a dam of 200 metres' height.

References

See chapter about Kaprun scheme, 4.1 + 4.2.

Day 6

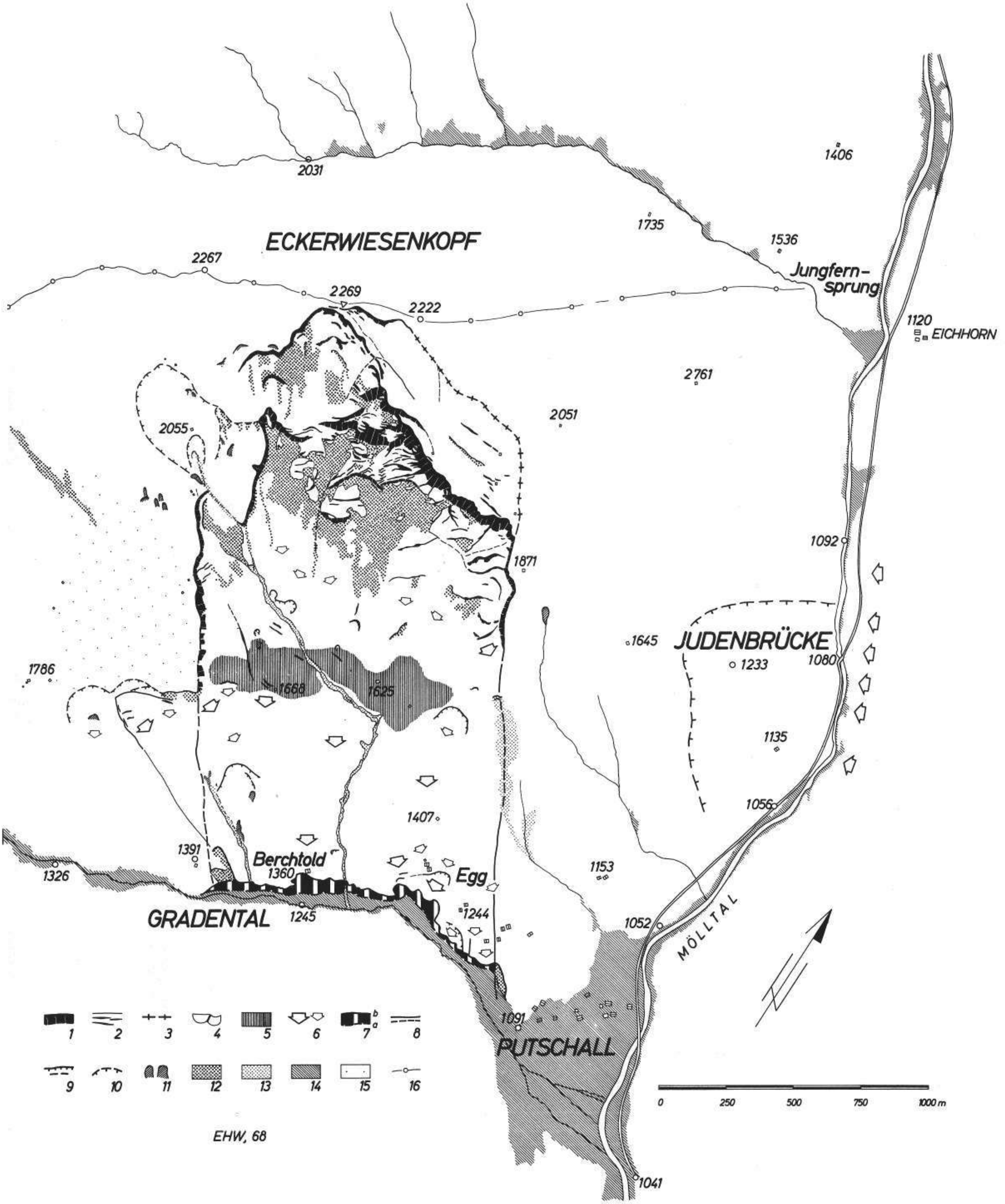
Stop 6.1. The Gradental Landslide

Province of Carinthia.

Some 7 km south of the village of Heiligenblut, near Putschall, the Gradenbach joins the Möll river from the west. On the left-hand side of the Graden valley extend the completely disturbed schists of the Matrei Zone (see 1.4 Lower Austro-Alpine Region). The lower part of the slope rising to the Eckerwiesenkopf is formed of very closely jointed and disintegrated sericitic and chloritic phyllites and diaphthorites striking around WWNW with a dip ranging from nearly parallel to the slope surface to medium steep towards the southwest. In the middle of the upper slope portion, these rocks are completely disintegrated and form no safe bond. Load relief through melting processes following the last but one and last glacial ages led to the first large changes in the state of stress of this steep flank. Geological checks made since 1962 and mapping completed in 1968 showed progressive moving tendency in the toe area of the slope so that already in 1962 the Berchtold Farm and a farm near Egg had to be evacuated for safety reasons. Prior to the floods of 1965 and 1966, displacements of between 1,5 and 4,5 m occurred in the eastern part of the slope, below an altitude of 1407 m. In the middle section (around an altitude of 1600 m),

Fig. 6.1—1: Plan of the Gradental slide (After E. H. WEISS, 1968).

1 Upper edges of failure surface and wide fissures in the tension zone.
2 Fissures and tension cracks.
3 Future line of separation.
4 Slide bodies in motion.
5 Bulge from an earlier slide.
6 Traceable creep movements prior to 1966: very rapid / rapid to moderate.
7 Front of slide mass and upper edge of failure surface
 a in the year 1964
 b in the year 1968.
8 Lateral boundary of the slide: seen/assumed.
9 New muschel cracks and fissures.
10 Older muschel cracks and sackung-type slide bodies (Judenbrücke).
11 Minor popouts (1965 and 1966).
12 Young debris in motion.
13 Ravines in the debris, carrying water-periodic movement of the debris.
14 Flood zone — banks undercut by the floods — mudflow cones from the years 1965 and 1966.
15 Older accumulation of rock fall material — old debris.
16 Ridge line.



ECKERWIESENKOPF
2031
2267
2269
2222
1406
1735
1536
Jungfern-
sprung
1120
EICHHORN
2761
2051
2055
1871
1092
1645
JUDENBRÜCKE
1233
1080
1786
1668
1625
1135
1407
1056
1391
Berchtold
1360
Egg
1326
1153
GRADENTAL
1245
1244
1052
MÖLLTAL
1091
PUTSCHALL
1041
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1000 m
1
2
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4
5
6
7
b
a
8
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EHW, 68

too, major movements were recorded, and cracks several metres in width developed near the line of separation of the slope so that already in 1962 the Berchtold and 1966 the whole slope, 2,5 million m² in area and descending from the Eckerwiesenkopf peak (2269 m) to the Graden valley (1245 m), reached a dangerous degree of mobility. Ever since 1965, a body of sliding material some 250 million m³ in volume — assuming an average depth of 100 m — has moved downhill over a front line of more than 1000 m. The geological investigations have revealed that there are two separate displacement processes (see cross section) and a pile-up of the creeping masses in deeper zones. Due to the sliding process, the front moved downhill towards the Graden valley, and the successive flood waves of the stream carried away material from the toe area. The solids so carried along formed mudflows devastating settlements between Putschall and the village of Döllach in the Möll valley. The undercutting of the foot of the slide repeatedly reactivated the sliding process so as to launch continuous movements.

In view of the substantial damage caused, the Forstliche Bundesversuchsanstalt (Federal Institute of Forestry Research) in Vienna included these deep slope movements in its research programme. G. Kronfellner-Kraus reported on them in 1974. Three surveying profiles were passed through the large, almost rectangular, area of the slide. Until 1973, most of the targets indicated persistent movement with annual values of between 15 and 120 cm. The directions of movement vary in the upper part of the slope, but are clearly vertical to the axis of the Graden valley over the whole front of the slide. 23 debris dams were constructed in echelon in the years following the disasters to protect the gorge-like valley from further erosion and to stabilise that part of the ravine where the slide mass moves in. Since, however, the front zone continues to move to major depth, some of these debris dams were damaged already in 1973 and, in the following years, were affected so much by the pressure acting from the failure slope towards the stable right-hand flank that eight out of the thirteen upper dams were severely damaged (E. H. Weiss, 1980). As a result of the pressure processes, the dams burst on the right side and crack open on the left due to the push from the foot of the front zone. A 60-cm wide crack was observed on the last but one dam upstream (no. 22) in the October of 1979.

From his 18 years' knowledge of the slide, the author concludes by way of summary that the mountain slope has been in motion ever since he started his observation, that additional disturbance of the equilibrium of the slope came from the catastrophic floods, and that the displacement process is expected to continue.

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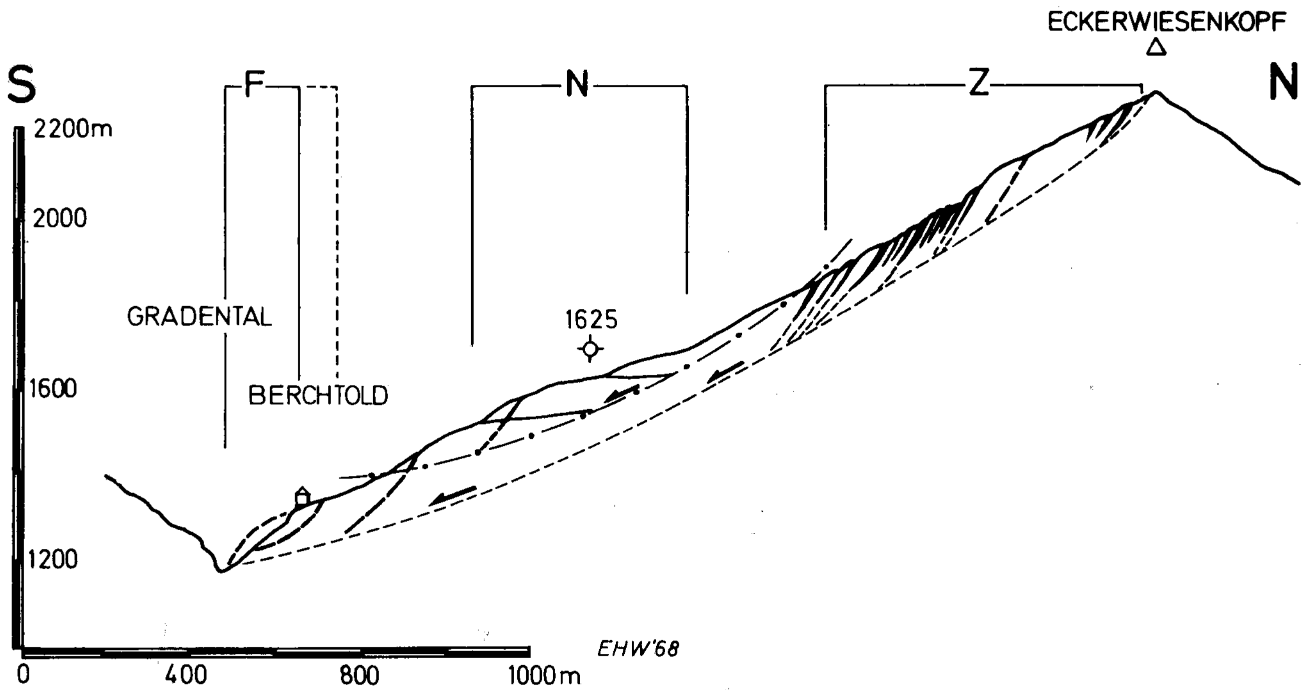

Fig. 6.1—2: Section through the Gradental slide with front of slide mass (F), bulge from an earlier slide (N), and tension zone (Z).

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Stop 6.2. The Fragant Power Station Group

Province of Carinthia;

Planned and owned by Kärntner Elektrizitäts-AG.

The Fragant power station group develops the runoff from the Fragant basin situated to the southeast of the Sonnblick-Goldberg massif. The cirque basin and cirque lakes present at different altitudes have been closed by rockfill dams to form reservoirs. Penstocks, pressure shafts and tunnel systems convey the water to the power stations for peak-load generation.

Extensive mapping work and engineering geological investigations supported by exploratory drilling and seismic measurements were conducted for the purpose of making geological forecasts for underground structures, penstock alignments, dam bases and power station foundations. Valuable information was obtained also during construction (E. H. Weiss, 1969).

The area developed by this power scheme lies in the 27-km long gneiss complex of the Sonnblick mountain (Ch. Exner). This is made up of different types of gneiss and forms a northwest-southeast trending anticline (area around Lake Oschenik), the southwestern limb of which has a gentle to medium-steep dip towards the Fragant valley. Further to the southwest, in the lower portion of the right-hand valley flank, follow the rocks from the Schieferhülle with its varied rock composition. The penstock towards the Ausserfragant power station traverses the latter series, whereas all the remaining structures are situated in the Zentralgneiss.

The rock mass is traversed by pronounced fault lines, many of which had been unknown until disclosed by exploration drillings and galleries and thus made definable. These have been recognised as the continuation of the Möll-Drau Line, a fault zone of great regional

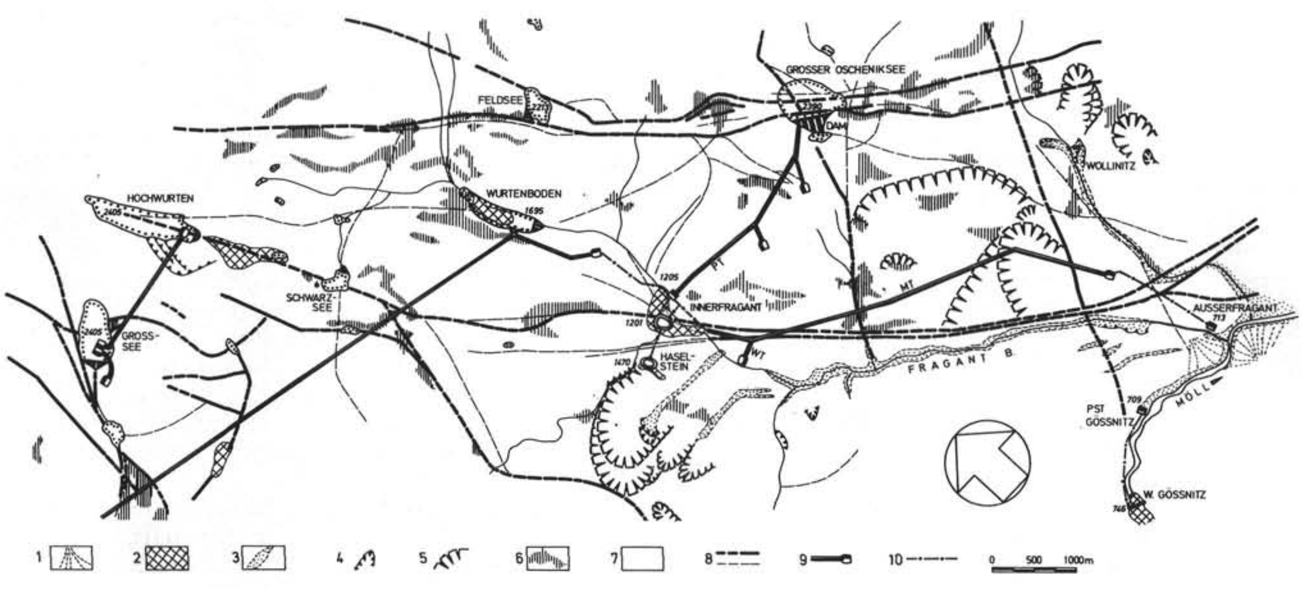

Fig. 6.2—1: General Geological Map of the Fragant group of power stations (After E. H. Weiss, 1969).

1 Alluvial cone.
2 Older lake deposits (lacustrine clay, mud, silt, partly peat),
3 Mudflow deposits from the catastrophic landslides (1965, 1966).
4 Young landslides (1965, 1966).
5 Old major landslides (including sackung-type slides) — talzuschub after Stiny.
6 Zentralgneis, showing a high degree of disintegration.
7 Zentralgneis complex (Hohe Tauern mountains), partly overlain by moraine, talus material and boulders.
8 Main fault, seen and inferred, faults in general.
9 Tunnels (headrace, tailrace)
10 penstocks
WT side drift, MT main tunnel, PT pressure tunnel.

importance. Following the trend of the anticline, the Oschenik Fault passes right through the core of the Sonnblick mountain. The Fragant Fault, a very troublesome discontinuity from the tunnelling point of view situated near the boundary of the Schieferhülle, was encountered only underground. These faults as well as slope displacement processes aided by the downslope dipping schistosity planes caused huge rock slides, sackung-type slides (talzuschub processes as defined by J. STINY) and severe disintegration processes affecting large flank areas. During the 1965 and 1966 catastrophic floods, many flanks were set in motion, huge mudflows were released, and several farmhouses were destroyed. The Wollinitz mudflow temporarily blocked up the Möll valley in the vicinity of the Ausserfragant power station and pushed the river 60 metres towards the south.

During construction, a great number of additional exploratory drillings were carried out, the soil conditions were analysed and the appropriate constructional measures derived. The geological factors having an unfavourable impact on construction work are marked clearly on Figure 6.2—1. Informative details can be read off the map by E. H. WEISS, 1969.

Old mudflows had obstructed the River Möll near the Gössnitz weir as well as the Fraganter Bach above Innerfragant. In the small ponds so formed very fine-grained material, organic matter and boulders and gravels were deposited. The fill of the Möll valley was found to reach a depth to bedrock of 70 m. Apart from fine sands, silt and mud, drill holes encountered old driftwood and provided evidence of the presence of ground water horizons under high pressure (artesian water). Foundation of the weir involved substantial problems (see Sonderheft ÖZE, 1969). Similar conditions were found in the Innerfragant basin, where large settlements occurred in the reservoir area for a long time after completion of the project. For embedding the Gössnitz power station 7 m deep into sands and gravels of medium density ($K_m = 2{,}33 \cdot 10^{-3}$ m/sec), pump capacity of 680 l/sec was operated for four months to lower the water table. In spite of this, uplift phenomena remained and caused problems.

Already at the stage of preliminary design, the main tunnel between Innerfragant and Ausserfragant was set very deep into the mountain so as to be sure to pass beneath the track of a large landslide, although this involved difficulties in heading driving due to the presence of sets of shear planes and abundant ingress of water.

Incomparably greater difficulties were encountered during heading driving from the point of intersection of the Fragant side drift and the main tunnel towards the southeast. With slide and rockfall material as well as moraines covering up the slope, prediction of the presence of a more than 200-m wide tectonic zone, the Fragant Fault, in the midst of a compact gneiss complex would have been impossible without deep exploratory drillings and drifts. Due to the very acute angle the tunnel axis makes with the fault, the tunnel remains within a zone of mylonites and cataclasites for a length of more than 0,5 km. During construction water flowed into the tunnel at a rate of 120 l/sec and expensive supports had to be provided to control the rock mass.

Although it was possible to provide a safe foundation for the penstock to the Ausserfragant power station, many of the thrust blocks needed rock anchors because of the weak bond displayed by the schist rock. At one point, a small rock slide was even caused during the excavation of a trench in a compact looking rock prominence.

Excavation and lining works were easy in the case of the inclined shaft between Innerfragant and Lake Oschenik, in spite of the presence of artesian joint water and variable moduli of elasticity. The 116-m deep Lake Oschenik was not tapped, but the water surface was drawn down to the level of the planned tunnel outlet. The geological problem was the deep moraine-boulder fill of the lake basin. The rockfill dam is founded on solid Zentralgneis. At the Wurten dam site, foundation conditions were similar, except that a lateral moraine had to be removed on the right-hand side and the grout curtain was extended to the gneiss bedrock.

The Haselstein reservoir and penstock can be regarded as a piece of engineering finesse. In a sackung process that occurred during the last Interglacial Age, a very large body of material from the upper portion of the slope came to rest on the Haselstein rock prominence. The narrow terrace that remained between this mass and the steep flank of the Haselstein was adopted as a reservoir site. Silty and peaty sediment fills had to be replaced in the foundation.

A difficult task was the design of the penstock alignment down a rock face showing a high degree of disintegration. The eleven thrust blocks stick to the rock face, as it were, and had to be fastened by rock anchors between 15 and 18 m in length (20 to 50 tons). Determination of the anchor lengths was based on the results of the rock mechanics analysis and the respective amount of grout absorption. The gneiss, although qualified as being intact by the engineers, turned out to be intersected by joints, fissures and even by a small karst pipe to such a degree that the thick waste mantle had to be artificially strengthened by grouting under controlled pressure. In the middle part of the scarp, three thrust-block foundations required solid matter in the amounts of 320 tons, 2147 tons and 973 tons, respectively. Grout was seen to emerge at several points over the lower part of the slope, which is an indication of the great depth to which the rock face is disintegrated. Geologists had been very doubtful about this penstock alignment and had suggested that an inclined shaft be envisaged instead.

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Stop 6.3. The Dabaklamm Dam Project

Province of Tyrol (East Tyrol).
Planned by Studiengesellschaft Osttirol.

The development of East Tyrol's hydro potential has been the subject of several project studies starting in 1938. Over the last few years, an arch dam closing the Daba gorge has been adopted as a central element of the overall project. The dam site is situated in the north-south trending Dorfer valley not very far from the village of Kals am Grossglockner, and is reached by a road branching off from the Felbertauern Road near Huben. South of the Granatspitz and Grossglockner massifs is an about 5-km long basin carved by glacial erosion, which is followed at its southern end by an about 1-km long gorge, the so-called Dabaklamm. The entrance to this gorge is planned to be closed by an arch dam more than 220 m high and 330 m long at the crest. The future top water level is indicated as 1793 m a.s.l. and the level of utilisation, as 940 m a.s.l. (Matrei powerhouse). By impounding the Dorfer stream, and adding the runoff of a great number of streams through diversion tunnels, a storage of 235 million m³ will be provided.

Investigations were started before the Second World War (J. STINY) and, after some interruption, were resumed in 1949. Whereas the site topography lends itself very well to the construction of a dam, the geological conditions are difficult, so that even a rockfill alternative was included in the first project considerations. However, favourable as a rockfill structure may be from the geological point of view, great problems would be involved in the provision of the materials for the fill (in the amount of 9 million m³) and for the impervious elements, as well as in the differential settlements resulting from the dam resting on solid rock over its downstream part and on valley fill upstream.

The geology of the dam site and the reservoir area was carefully investigated, a great number of drill holes were sunk and exploratory drifts excavated, and many geotechnical and rock mechanics tests were carried out. Apart from J. STINY, renowned geologists and rock mechanics experts (E. CLAR, W. DEMMER, W. EPPENSTEINER, G. HORNINGER, L. MÜLLER, F. PACHER, P. RUDAN) have studied the area and reported on it (L. MÜLLER & F. PACHER, 1957; L. MÜLLER 1963).

Geologically, the Daba gorge lies in calc. mica schists with limestone marls as well as in prasinites forming part of the upper Schieferhülle (Penninic Zone). Intercalated in both main rocks are seams of limestone phyllites and mica schists. These rocks strike from west to east, across the gorge centreline, and dip at 40 to 60 degrees towards the south. The excavation for the dam foundation would produce high cuts in both abutments. In connection with the downstream dip of the schistosity planes and the presence of main joint sets this would call for extensive precautions. Undercutting of schist beds, in particular on the left-hand side, can cause huge rock bodies to break from the rock face. The problem is less difficult on the right-hand side. L. MÜLLER and F. PACHER have built a model which clearly shows the steepness of the rock faces and the intersection of the schist beds with the toe line of the dam abutment. Cuts to be made in the flanks are expected to be up to 80 m high. In 1957, the above mentioned authors suggested the following rock stabilisation scheme: The uppermost upstream rock portions should be removed from stratification joint to stratification joint (sliding joint) and the remaining portions immediately fixed by rock anchors as work proceeds. As a next step, the rock should be excavated, under the shelter of the anchorage, for the construction of a protective arch on the upstream side, behind the arch dam. The supporting effect of this protection would be enhanced by an anchorage system. It is only under the shelter of this arch and provided careful blasting that the excavation for the dam foundation could be made. Over the last few years, new suggestions have been made relating to the stabilisation of the rock face in the light of the results of detailed geological and rock mechanics investigations. According to these, the problem could be solved by removing the dangerous rock portions in proceeding from above downslope and sinking rock anchors at the same time. On the whole, the stabilisation of the steep rock faces to enable the construction of an arch dam represents the principal problem. Treatment of the flanks and the dam foundation to ensure imperviousness is feasible by conventional methods (grout curtain).

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Stop 6.4. Geotechnical problems met with planning and construction of the final sections of Malta scheme headrace structures

Province of Carinthia.

For the most part the structures of Malta hydroelectric scheme are situated in the so-called Hölltor-Rotgülden gneiss cupola, the easternmost of the penninic gneiss cores of the Tauern window. However, the final 850 m-section of the headrace tunnel, running 21 km from north to south, and the open-air penstock line down to the Möll valley, covering a level difference of 863 m, belong to the penninic schist cover ("Schieferhülle") of the gneiss mass. This schist cover includes metamorphic, initially sedimentary rocks as well as intercalations of originally eruptive rocks. The decisive trouble already met with the planning stage for the headrace installations, and, above all, in the course of construction, and of the initial filling tests, was connected to interglacial or even post-glacial detrimental changes in slope structure and stability. A schematic cross section of the northeastern, i. e. the left flank of the Möll valley, drawn along the Malta headrace, shows a sudden tilt of rock dip, just at the level of the Malta headrace tunnel: the main gneiss mass, and the adjacent parts of the schist cover dip under medium angles to the south, i. e. valleywards. But below 1400 m a.s.l., at least for the outermost several hundred meters of the slope, the schists dip towards the slope. A reasonable assumption derives this structural feature from gravitative effects after the melting down of ice masses filling the Möll and the Drau valley over several consecutive stages. (See FINGER, W. et al. 1979).

At the time of preliminary geological investigations the structural conditions for a zone, say, from 1.400 to 1.500 m a.s.l. could not be cleared up because of a conspicuous local scarcity in natural outcrops. Therefore, an investigation adit of some 300 metres length was bored. It disclosed along its whole length chaotic structures in heavily loosened rock. On grounds of this experience the initial idea to construct an inclined penstock shaft was abandoned in favour of the open-air penstock line. In fact, heading through the outermost section of the headrace tunnel, the Burgstall-Stollen, was very troublesome because of the badly distorted and partly mylonitized micaschists, phyllonites and related rocks. A dangerous cave-in occurred with repeated water inrushes. This cave-in happened in faulted prasinite, very sensitive to soaking. The cave-in was said to have occurred without perceptible warning, only 6 weeks after heading went through, just before the mounting of steel lining.

Heading operations in the Hattelberg gallery, the eastward adjacent section to the Burgstall gallery, and the raising of a vertical shaft for a surge chamber only met gneiss of various kinds. They involved — at first — no extraordinary trouble. All the more there was reason to surprise, when with the first tentative filling operation in the headrace system the considerable water losses were tracked down to the southernmost section of the concrete lined Hattelberg gallery, and to the lower extension of the surge shaft. An immediate inspection of the damaged gallery revealed a series of coaxial cracks along the concrete lining, each one as long as 10 to 20 metres. Visibly, the partly mylonitized, heavily broken gneiss failed to back up the lining to the expected degree. Measuments evidenced for the pressure state during consecutive test fillings that those cracks opened up to more than 5 mm. The cracks were along spots, where previous geological survey recorded low-angle crossings of dense joint sets with the gallery. Injections of the usual kind turned out as completely ineffective. Therefore, additional steel lining for no less than 824 linear metres had to be conceded .

The water losses down into the surrounding loosened rock masses totalled to several hundred l/sec; a rate that induced some suspicion the leakage water would possibly impair the stability of the skin area of the Möll valley slope. Curiously enough, the leakage water did not cause a perceptible increase in the discharge of the springs of the slope area. A tracer dye, uranine, was put into a borehole in the wall of the damaged gallery before refilling. Only at the end of three weeks the first positive traces appeared, nearly at the same time in several ones of the surveyed springs. They were more than 1 km distant from the point of injection. With the final assembly of the additional steel lining troubles whatsoever were definitely overcome.

The excavation for the anchor blocks of the penstock line was not so troublesome as expected, at least for the upper blocks. But it was rather difficult with the lowermost anchor block No. 9, some 80 m above the sharp bend from the slope to the valley floor. Different from usual construction principles this anchor block is not situated in the immediate vicinity of the power

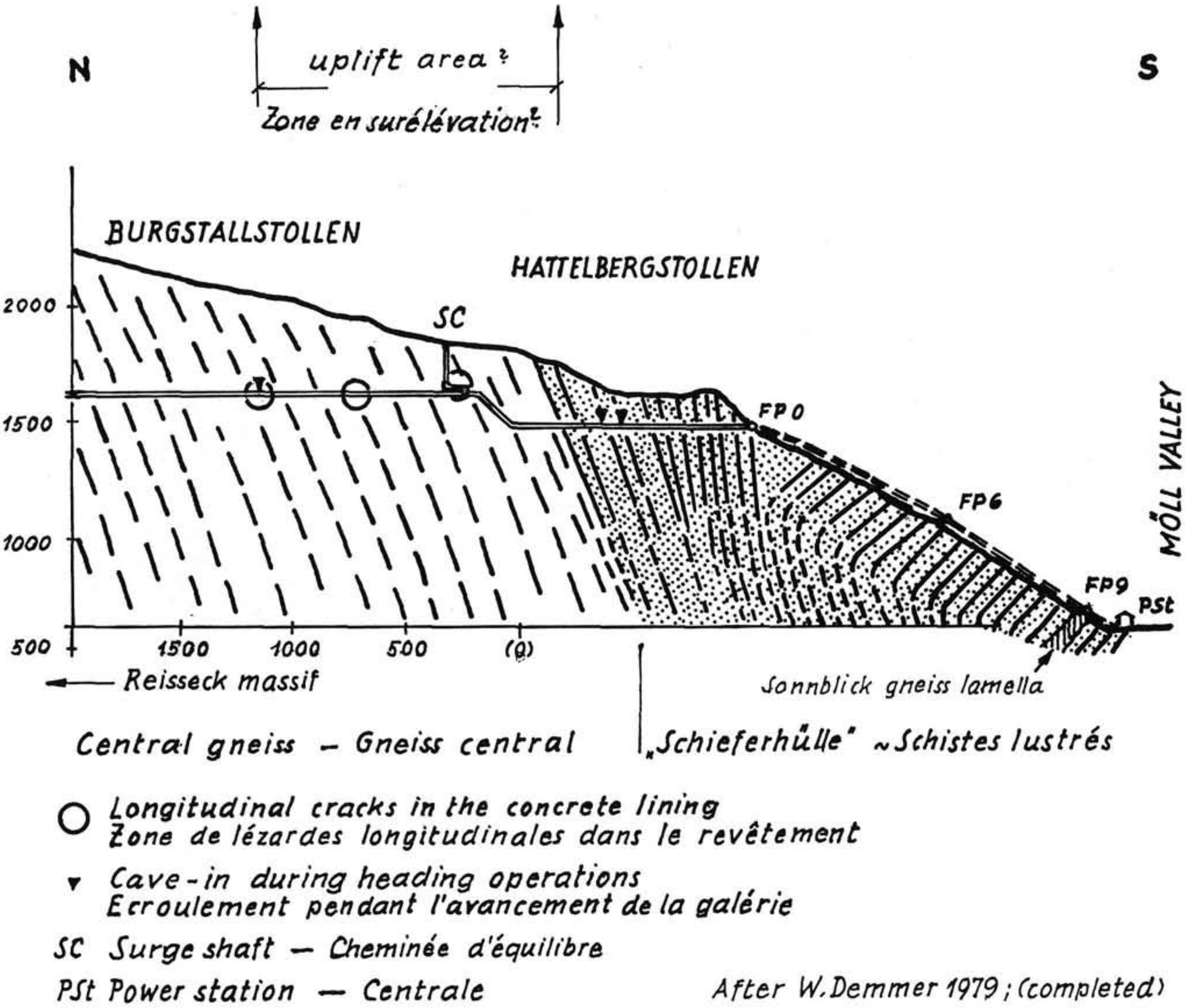

Fig. 6.4:
Schematic section along the terminal reach of the headrace tunnel and the penstock line.

Coupe schématique le long de la section terminale de la galerie d'amenée et de la conduite forcée

house because of unfavourable geological conditions. Just in the footing area of the penstock slope the excavation for the power house revealed a series of steeply inclined, wet, and extremely weak mylonitic mica-schists. Therefore, the anchor block No. 9 had to be shifted slope-up into the so-called "Sonnblick-gneiss lamella", tectonically intercalated within the calcareous phyllonites. But the gneiss rock of this lamella is badly jointed, and deeply wheathered, down to every depth suitable for open-air excavation. The concrete volume for the anchor block grew to a final 6.800 m^3. For a time the open hillward excavation wall was as high as 35 metres. And, only a few hundred metres slope-up the penstock line crossed the road bed of the Tauern railway line! After all, everything came to a good end.

W. Demmer reported about an interesting "by-product" to the construction of the headrace: A periodically repeated geodetic survey in the Hattelberg section of the headrace tunnel yielded indication of a steady buckling-up, at least along this part of the system. Within one year the lift amounted to no less than 8 mm. Verification of the said preliminary findings supposed, this buckling is a remarkable parallel to an uplift of 70 mm within 60 years established by the Federal Geodetic Survey in a neighbouring section of the Tauernbahn.

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Geological maps

No detailed map at present available.

Day 7

Stop 7.1. The Lieser Valley

Province of Carinthia;
Planned and owned by Tauernautobahn A.G.; under construction.

The Tauernautobahn, once complete, will be a motorway connection between Spittal/Millstättersee in the south and Salzburg in the north (147 km). Two tunnels, 5,4 and 6,4 km in length, respectively, had to be driven for traversing the two main mountain ridges lying across the route, i. e. Katschberg and Radstädter Tauern. The most difficult stretch in terms of motorway construction lies between the town of Gmünd and the Rauchenkatsch pass south of the Katschberg tunnel. The itinerary of the Study Tour will touch this 13-km long construction site, and Participants will be able to see the exceedingly steep rock faces on the left bank of the Lieser valley.

In 1962, the Geological Department of the Province of Carinthia investigated both valley slopes thoroughly, studied strength and water conditions in the different areas by driving short exploration galleries, sunk drill holes and took seismic measurements to explore the deeper zones of bridge foundations. Interpretation of the results showed that the left slope of the Lieser valley was to be preferred over the opposite slope, but still presented problems over a large proportion of the 13-km stretch. Many parts of this section had to be spanned by hillside bridges in order to minimise disturbance of unstable slopes by deep foundations (caissons, deep pier foundations with additional anchorage). The total length of bridges in this section is almost 9 km. To the right of the small Rauchenkatsch pass, orographically speaking, a severely disintegrated rock face failed and thus caused a rock fall comprising a mass of several thousands of cubic metres. The Federal road was relocated for safety reasons, which necessitated the construction of a new bridge. This case of damage demonstrated very clearly the sensitivity to mass movements — whether quick or slow — of the steep rock faces in the Lieser valley.

As was done in the design, allowance has to be made for several factors also in the construction of the motorway now under way in the narrow valley. These are:

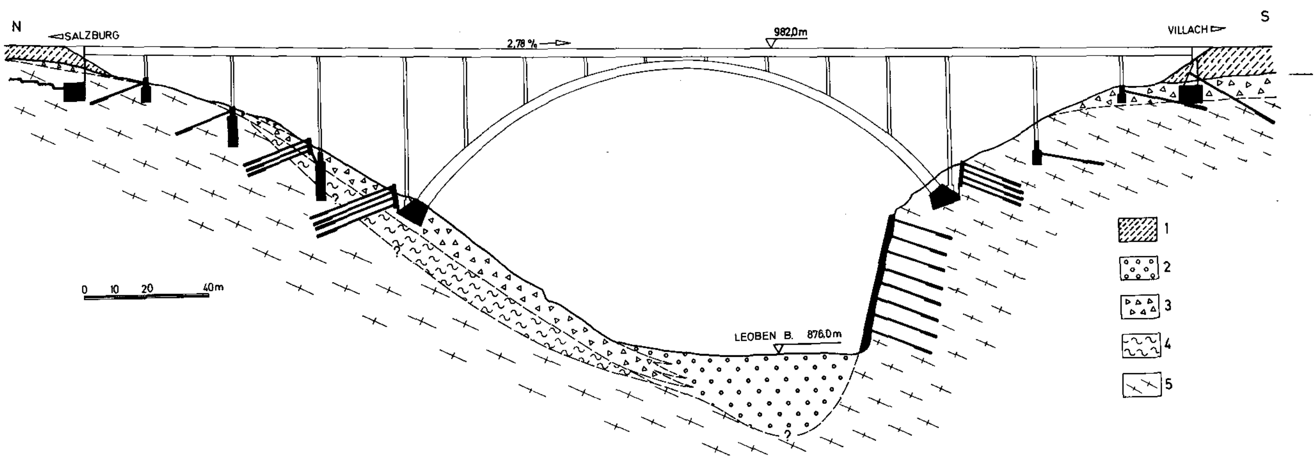

Fig. 7.1—1: Cross section through the Leoben valley (After H. BRANDECKER, 1976).

1 Embankment (motorway), 2 Valley fill consisting of sands, gravels and boulders, 3 Large detrital boulders, stones and regolith, 4 Disintegrated rock mass (gneisses and mica schists and more or less active displacement), 5 Gneisses, biotite schists with quartz lenses, very friable.

1. Steep rock faces with water-filled joints and fissures exhibiting variable degrees of disintegration;
2. Talus material, moraines, sandy gravel and old remnants of obstruction-pond deposits overlying the rock relief tend to slides and creep;
3. Traversing old s a c k u n g masses and landslide debris is possible only by means of hillside bridges with caisson foundations extending to a maximum depth of 30 m;
4. Severely jointed rock zones in the immediate vicinity of the motorway site or directly at the locations of engineering structures call for expensive preventive measures by means of anchors;
5. The motorway passes through many areas already affected by t a l z u s c h u b forces;
6. The Lieser valley marks the boundary between the Penninic Zone (Hohe Tauern) and the Upper Austro-Alpine (metamorphites of the Millstatt Crystalline and is at the same time an earthquake line. Therefore, the bridges have been designed to withstand earthquakes.

Figure 7.1—1 is a section through the Leoben valley showing the structure of the foundations and the stabilisation measures for the piers and abutments of the arch bridge. The anchors needed for the abutment zones reach a maximum depth of 25 m.

The Katschberg tunnel passes through the overlying S c h i e f e r h ü l l e (schist cover) over its southern part, where slight tunnel floor heaving and, in places, plastic deformation were experienced. Stream-deposited like-grained sands and redeposited fine-grained glacial moraine material in the area of the south portal were slowly drained and controlled by use of the wellpointing method. The fine-grained gneisses in the middle and northern parts of the tunnel showed high stability.

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Stop 7.2. The "Tauerntunnel" of the Tauern motor-highway (constr. 1971—75)

Province of Salzburg.

The Tauerntunnel, 6401 m long, penetrates for nearly 8/9 of its length phyllitic rock masses of the Upper schists cover nappe ("Obere Schieferhülle") belonging to the penninic nappe system. The final, northern one eighth is best named according to W. DEMMER a "zone of irregular rock lumps". As to tectonics this zone may be described as intensely distorted "frictional carpet" at the base of the thrust plane between the Lower Austroalpine nappe and the underlying penninic nappes system. As predicted by A. TOLLMANN, the spectacular dolomite and limestone rock masses forming the northern slopes do not reach down to the tunnel level. The northernmost 400 metres of the Tauerntunnel penetrate scree and fluvioglacial sediments. Heading through the tectonized and partly mylonitic rocks of the northern one eighth of the whole rock mass was by far the most troublesome job; worst of all, a 50 m long border zone of badly squeezed and jointed, variegated phyllites. As good luck would have it, water inrushes worth mentioning did not occur. In the said bad reach of 50 metres' length the rock overburden in a vertical direction was but only 600 m, compared to the maximum value of 975 m. Nevertheless, just here subsidences of the roof came to their highest values of 1,20 m (!).

Special engineering geological problems were connected with an underground ventilation station to be situated near the middle of the tunnel's length. This machine hall had to be connected to the open air by a vertical shaft of 103 m² cross section. An investigation drilling of 550 metres length — besides, apart from several short boreholes down from the scree near the northern mouth, the only one along the tunnel line — was sunk from the deepest morphological depression above the tunnel. But the actual shaft had to be constructed 233 metres south from the borehole. The necessary installations at the upper end of the ventilation shaft at the drilling site proper might be endangered by snow avalanches. As a consequence of the said dislocation of the shaft site the investigation drillhole lost much of its informative value in view of the big underground ventilation cavern. It is to say, the strata generally dip to the N and NNW under angles of 20 to 40°. Therefore, the drill cores could not yield information about the rocks for the lowermost 100 m of the future shaft, just the site area of the machine hall. After all, this hall was designed to 60 m length, 20 m width and 20 m height. Tunnel heading from the south was at that time still too far away to be of any direct value for a prognosis. At this critical state geological considerations, admittedly somewhat risky and far-fetched ones, helped decisively to come to a good end. W. DEMMER, the responsible geologist, picked up some promising items of A. TOLLMANN's important geological mapping results, conducted years ago for mere scientific purposes. Now, DEMMER supposed the — highly uncertain — admissibility that strike and dip values from surface outcrops high up on the mountain, could be straightforward extrapolated down to the tunnel level. A strip of greenschist, serpentine and quartzite, intercalated into the monotonous Schieferhülle-phyllites might possibly fit just into the site for the planned ventilation cavern. For geological reasons there was some hope to find also, with some good luck, even dolomite. Taken as a whole, the experiences from heading through the phyllites (up to that time earmarked for the cavern) were so discouraging with respect to the stability of a large underground structure, that engineers already considered a change-over towards an open-air machine hall building at the top of the shaft; and this in spite of the serious handicaps, above all in winter times. Good luck added to the ingenious, although risky idea: the sole dolomite mass, just large enough to house the greater part of the planned cavern, was met close by the footing area of the shaft.

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Geological maps

No printed official map available.
For maps and sections see W. DEMMER, H. PÖCHHACKER, A. TOLLMANN.

Day 8

Stop 8. Bosruck Motorway Tunnel

Provinces of Styria and Upper Austria. Planned and owned by Pyhrn Autobahn AG; under construction.

From 1901 to 1906 a railway tunnel of 4765 metres length was bored through the Bosruck mountain massif, part of the Northern Limestone Alps. In the circles of tunnelling professionals Bosruck has its special ill reputation because of its notorious geotechnical conditions. With progressing heading for the railway tunnel trouble went on, be it by heavy water inrushes from triassic karstic limestone and rauhwacke, be it by postponed rock pressure in "Haselgebirge" — local term for natural mixtures from clay, gypsum, anhydrite, rock salt and some limestone —, last but not least by an outburst of methane with grave consequences. One geological reason for the high total amount of inrushing water was the bowl-shaped gross structure of the Bosruck massif, with pervious, mostly triassic carbonates and marls in multiple repetition, underlain by impermeable, clayey rock masses including Werfen shales and fine grained, clayey sandstones as well as the permoscythian "Haselgebirge". Although, of course, the Haselgebirge is highly sensitive to wetting, as a rock mass it may be completely waterproof. The mesozoic series of the Bosruck massif comprise every age from Permoscythian to Karn. Jurassic is scarce, but cretaceous Gosau marls locally cap the triassic and jurassic rocks. As to its tectonic position the Bosruck massif with the dominant central part of karnian Bosruck limestone, is now regarded as a separate unit of the Juvavian nappe system (see A. TOLLMANN, 1976).

Stop 8.1. The Bosruck Auxiliary Tunnel (Ventilation and Drainage Tunnel) — South

An auxiliary tunnel is being driven from the south in advance of the main tunnel. It is situated outside the future main tunnel tube and will later serve as a ventilation tunnel as far as Station 1,367 m (30 m^2 in cross section) and continue to the north as a pure drainage tunnel (10 m^2 in cross section). Excavation for the latter has reached Station 2500 m (November 1979). Sandstones, siltstones, slates and quartzites from the Werfen Series (Lower Triassic) predominate to Station 2023 m. The rauhwacke bed expected to be present between Stations 1200 m and 1300 m was not encountered. Therefore, ingress of water as had taken place in the railway tunnel (800 l/sec and 700 m^3 of overbreakage) did not occur. This sedimentary rock is found in a narrow syncline rising towards the west so as to cross the railway tunnel, which is further east, where it caused the above mentioned problems. The road tunnel passes beneath this syncline. The second rauhwacke bed and the dolomite (Anis formation; Lower Triassic) was encountered north of Station 2023 m. After being worked through a tectonic transition zone with slates showing evidence of plastic and cataclastic deformation, the tunnel reaches closely reticulated dolomites destroyed by physical and chemical processes. These are followed by dolomite with all the karst phenomena, a formation which was not encountered by the railway tunnel. The karstic dolomite is full of hollow spaces filled with loam and blocks of rock, the fill slowly flowing into the underground opening and severely impairing tunnelling operations.

Experience made so far in the excavation of the auxiliary tunnel suggests that there is good agreement between predicted and encountered rock conditions. The Werfen Series even proved of surprisingly high strength where in a dry state. The rock classes encountered were much better than expected, and the speed attained by heading driving ranged around 14 m/day, whereas the mean speed in the dolomite was still as much as 7 m/day. It is only over a section of 250 m from the south portal that slight moisture in the rocks from the Werfen Series called for increased supports in Rock Classes IV and V. As the depth of overburden increased and the moisture content of the rock mass decreased, rock classes soon improved. In his forecast, W. DEMMER took care to classify the many-layered and complex Bosruck Mesozoic with the aid both of experience gathered during the construction of the railway tunnel and W. NOWY's new survey of the structural geology of the area so as to make more information available to the tenderers for a better calculation of their works. This appears not to be the case with the geotechnical information, as the envisaged three test reaches in the tunnels already driven will unfortunately not be realised so that rock mechanics characteristics will not be available for the subsequent excavation of the main tunnel.

Stop 8.2. The Bosruck Auxiliary Tunnel (Ventilation and Drainage Tunnel) — North

The tunnel runs parallel to the old railway tunnel at a distance of only a few hundred metres, and is a little deeper situated than the latter. Heading work in this northern reach will encounter just the same types of rock from good to bad, as met with the railway tunnel. It should be a fascinating task to compare those two neighbouring tunnels in view of rock behaviour and water conditions. Now, at the end of September 1979, the northern section of the ventilation tunnel is 1100 m long. As a rule, water conditions in deep lying tunnels, first of all in karstic areas, escaped — and still escape — every chance to detailed prognosis. The Bosruck tunnel confirms the rule. Whereas water inrushes to the northern heading of the railway tunnel (1901 to 1906) happened without dramatic single maximum — the first considerable inrush only 260 linear meters behind the boundary from clayey Haselgebirge to karstic limestone — two serious inrushes occured in the southern lot. With the present heading operations in the ventilation tunnel only insignificant amounts of methane were met and the Haselgebirge was dry, up to ist boundary towards limestone at chainage 1.070 m. Up to now, no serious rock pressure was noticed. But different from the railway tunnel, exactly with the begin of limestone, the first water inrush of 300 litres per second happened. Against every expectation a noticeable relief as hoped for, because of a long-term drainage effect from the railway tunnel, stayed out. This fact demonstrates once more the independence of karst conduits.

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Geological maps

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Day 9

Stop 9.1. Some engineering geological aspects and problems of Salzburg city and its surroundings

The town is situated exactly at the outer border line of the Northern Limestone Alps towards the Flysch zone. With a view to morphology, Salzburg and its surroundings lie in a funnel-shaped bay of more or less flat land, open towards north. This funnel cuts through the Helvetic zone, the adjacent Flysch zone, and for another 30 km from the town towards the south it cuts into the northern part of the Limestone Alps. The E—W directed trace of the thrust plane between Flysch and the upthrown Limestone Alps passes below the city under a thick cover of fluvioglacial and fluviatile sediments. As to the hills in the town, the Kapuzinerberg at the right bank of the river Salzach and the Festungsberg, i. e. the hill bearing the citadel, at the left bank are outcropping parts of the Tyrolian nappe of the Limestone Alps. Both hills are mainly built up from upper triassic Hauptdolomit and Dachsteinkalk (Kalk = limestone). In the northern foot area of the Kapuzinerberg a small rim of neocomian marls, overlain by traces of gypsum-bearing Haselgebirge, is part of a lamella of the Bajuvarian nappe, nearly completely overridden and squeezed by the Tyrolian nappe. Gosau marls form a defective cover upon the older rocks.

The rock of the Festungsberg, too, may be compared to the Kapuzinerberg. But at the Festungsberg's northern end towards the adjacent Mönchsberg nagelfluh — a Mindel-Riss delta conglomerate — there is a small, steeply inclined, uneven seam of weak uppercretaceous Gosau marls jammed in between the dolomite and the nagelfluh. Exactly this intercalation, hardly marked by natural outcrops, the most comfortable rock for tunnelling with primitive tools, was selected by medieval miners. They bored a first water tunnel through the Mönchsberg about 1130 A.D. in order to take water from the Königsache creek to St. Peter's abbey. Really, at that time an admirable technical deed.

Only in the course of undermining in 1940/41 of the N—S extended Mönchsberg for the construction of air raid shelters, a local flysch core below the conglomerate was discovered in the hill of Mülln.

The greater part of the residential quarters of the town is built upon postglacial sands and gravels of the Salzach river. Those alluvial masses of recent times are only a cover of 5 to 9 m, resting upon 10 to 20 m of sand and soft postglacial silt. These on their part mostly rest upon ground moraine, more or less in its original state. Only below this moraine several investigation drillholes hit marls, sandstone and limestone of the Flysch zone. Large-scale regulating measures to the river Salzach were carried out for the first time during the sixties of the nineteenth century. Upon this, the up to then untamed alpine river reacted sensitively. Since those days deepening of the river bed progressed at a rate of some 36 mm per year. In the vicinity of the river the ground water level sank, of course, at the same rate. Consequently the bearing capacity of the finegrained lake sediments decreased markedly, and this, above all, in the immediate neighbouring area to the river. Thus, serious damage to houses and even to bridge piers occured for decades. A spectacular case of differential settlement for this reason is the St. Marcus church, designed by the famous Fischer von Erlach. Besides, a protracted reconstruction of the church, i. e. support of the foundation by "underpinning" with well dosed cushions of injected cement grout, was now successfully completed. A case of long lasting trouble for erosive deepening of the river bed from the very outset were the unusually broad, wooden pile gratings of the railway bridge over the river Salzach in the course of the Line from Salzburg to Munich, constructed in 1859/60. According to Bistritschan & Fiebinger the average annual deepening increased up to the year of 1947 to 47 mm per years. By 1955/60 the stability conditions of the piers of the railway bridge deteriorated to a state, that the construction of a groundsill (1963) became imperative. A few years ago, in 1959, the Salzach motor-highway bridge, Autobahnbrücke, in the course from Salzburg to Munich collapsed after a very short but intense flood. The foundation of the bridge's piers constructed during World War II, was too shallow. It did not reach down through the pleistocene lake sediments to solid ground. The reconstruction was performed by piers resting on bored piles. They reach 26 m down from the river bed into limestone in situ.

The mentioned St. Marcus church is a substitute for an elder church at the same spot. This elder one was smashed to pieces together with another 13 houses along the Gstättengasse mountain wall by a terrible rockfall in 1669. The death roll amounted to 220 victims. E. von Geyer, the engineer who dared to design and to construct from 1763 to 1765 the 130 m long road tunnel, called "the Neutor" through the Mönchsberg, put down his well based opinion about the said rockfall 100 years ago. He did not blame so much undercutting of the vertical walls, but big open joints on the wall, reacting to freezing and thawing. The construction of the Neutor road tunnel, at the time in strong competition against an open cut of 65 metres' depth — note the big quarry niche above the eastern orifice of the Neutor — had good luck. Only 40 m more to the north, the tunnel would hit a natural cave-in of 20 × 25 m^2 in plan. One of the crosscuts of the air raid shelters constructed during World War II missed the underlying cave unsuspectingly only by a mere 80 cm. Underground parking facilities, constructed 1973 to 1974, could not avoid the collapsed cave. As the cave's dangerously loosened roof could not be underpinned in a safe way, the roof had to be suspended to higher, solid parts of the nagelfluh by a system of prestressed tendons. Besides, locally the construction of the parking facilities was seriously impeded by fully unexpected deleterious effects of weakening corrosion due to groundwater that mixed with chemically different water trickling along steeply dipping joints. To the west of Neutor road tunnel the very soft postglacial lake sediments go up without any gravel cover nearly to the street level. Here, too, damages to houses by differential settlement are rather frequently seen. The Libby-radiocarbon age of a root stock extracted from a thin, undisturbed peat layer near the top of the lake sediments was determined at Vienna University to 9990 years b. P.

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Artikel/Article: Engineering Geology in Mountainous Regions 257-286