The Subsoil of Switzerland

Le sous-sol de la Suisse

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Sommaire

Le développement des Alpes et de leur avant-pays a engendré des alternances notables dans la composition des sols de la Suisse. En conséquence nous trouvons rarement des sols de fondations homogènes étendus et, dans notre pays, rien n'est plus constant que le changement.

Le relief accusé du sol, conjointement avec l'érosion glaciaire, ont entraîné la prédominance des sols à gros grains, transportés par la glace et l'eau, qui sont exempts d'éléments organiques. En conséquence les moraines, le gravier, le sable, les éboulis et les débris de pentes prédominent et constituent des sols de fondations bien consolidés et stables. Les dépôts sédimentaires à grains fins, formés par les fleuves et charriés dans les lacs au fond des vallées, contiennent parfois des matériaux organiques, cependant il n'occupent que le second rang. Ces limons de crue, limons et craies lacustres et couches de tourbe sont souvent peu consolidés et, de ce fait, soulèvent des problèmes de tassement et de gel; la solution des questions de stabilité s'avère difficile. En troisième rang nous trouvons des dépôts à grains fins formés sur les pentes, tels que les limons de pentes, les dépôts limoneux de glissement, d'éboulement et des massifs désagrégés qui révèlent une tendance aux glissements et des phénomènes de fluage étendus. Par contre, les sols de la Suisse ne comportent pas de couches détritiques marines ou volcaniques et les couches éoliennes et les couches décomposées profondes sont rares.

La présence de ces sols de fondations que l'on pourrait dénommer «une province glacio-alpine» implique certaines conséquences géotechniques. Premièrement, en raison de la fréquence des alternances, tous les travaux de fondations requière l'investigation des conditions géologiques locales au moyen de sondages et d'essais in situ aux fins d'élucider les divers problèmes de géotechnique. En Suisse ces recherches sont faites dans la majorité par des géologues ou des ingénieurs versés en géologie. Les fréquentes superpositions et les alternances de sols à grains fins formant des couches de faible dureté avec des couches compactes à gros grains mentionnées plus haut ont suscité – grâce aux travaux du Prof. *Hæfeli* – le développement de plus en plus répandu des essais de pénétration dynamiques et ont ainsi doté les géotechniciens d'un instrument de travail précieux pour l'analyse qualitative des sols de fondations.

Les recherches de laboratoires poursuivies dans notre pays sont consacrées d'une part aux problèmes pratiques (barrages en terre, problèmes de gel), et, de l'autre, aux recherches scientifiques de base; c'est sur ces dernières que sont fondés les essais in situ qui indiquent la voie aux recherches pratiques.

Les travaux des ingénieurs civils et des géologues suisses les mettent fréquemment en contact avec les Alpes. Les dangers et les catastrophes imminents à la montagne exigent un renforcement d'observation, et l'observation, conjointement avec l'expérience, forment les bases des travaux géotechniques. La structure compliquée du sol, avec prédominance de gros grains, n'offre pas souvent l'occasion d'appliquer les théories de la mécanique des terres. Cependant des solutions typiquement suisses sont nées de la synthèse de ces deux points de vue. Je me bornerai à mentionner les recherches sur la neige et les avalanches qui constituent une zone limitrophe de la mécanique des sols. La tâche du géotechnicien suisse consiste à synchroniser les observations diverses et variées et les rapides développements enregistrés dans le domaine de la mécanique des sols.

Introduction

When visiting a new country the traveller wishes to know something of its culture and its natural science. I therefore intend to give the Conference Members in this lecture a brief outline of the geology of Switzerland. As I am speaking to civil engineers and geologists specializing in engineering geology, the lecture will emphasize especially the geotechnical aspects. To begin with, I shall speak of the geology of the different parts of our country (Fig. 1). The main part of the lecture will be devoted to the geotechnical problems of the soil. In conclusion I shall deal with some general aspects of geotechnical science in Switzerland.

The Geology of the Three Parts of the Country

Alps

The Alps form the "backbone" of Switzerland and actually cover two-thirds of the country (Fig. 2). The core of the Alps is formed by elongated crystalline zones of the central massifs, built up of gneiss and mica schists in a fan-shaped form. In the Carboniferous Age granites intruded into those stratified rocks and later, younger sediments were deposited over both.

During the Tertiary Age different masses of rock were overthrusted. Those masses consist of sediments of Permian up to Tertiary Age, especially of limestones, marbles, dolomites,

Fig. 1 Relief of Switzerland by *C. Perron*
Relief de la Suisse par *C. Perron*

argillaceous schists, sandstones, conglomerates, which are more or less metamorphised according to their position and strain. In addition we find crystalline rocks such as gneiss, mica schists, amphibolites and younger intrusive rocks.

Due to the repeated change of sedimentation conditions and the complex tectonic history of the Alps, we meet over a very short distance rocks of the most varied nature. North of the crystalline central massifs limestones, calcareous and argillaceous schists, sandstones and conglomerates are predominant and we speak generally of the Northern Calcareous Alps. South of the Central massifs gneisses, mica schists, greenstones and marbles are preponderant.

Central Plain

North of the Alps lies the most densely populated part of our country, the Central Plain (Figs. 2 and 3). It is a hilly country, 500–700 m (1500–2100 ft.) above sea level and 40–50 km (25–30 miles) wide. The bedrock of the Central Plain consists of the cemented detritus of the emerging Alps, which was washed into the sinking foreland during the Tertiary Age. This detritus, then consolidated into marls, sandstones and conglomerates, lies flat in the Central part of the plain, whereas in the border zone those deposits are folded, near the Alps even upthrusted.

Jura

North-West of the Central Plain follow elongated mountain chains 800–1680 m (2400–5000 ft.) above sea level, separated by valleys; in other parts we find plateaus. This is our Jura. Limestones, marls, less often sandstones and gypsum from Permian up to Cretaceous Time occur, and in addition sandstones, marls and clay-shales of Tertiary origin. These rocks are partly folded and partly belong to faulted zones.

The physical properties of Alpine rocks—with a few exceptions in the tectonically stressed zones—are not within the special interest of this Conference. On the other hand some clay-shales and marls from the Central Plain and the Jura mountains must be classed between rock and soil. In tunnels it has been noticed that the marls swell and cause destruction. Fig. 4 shows the heaving in a tunnel in Zurich 15 m (45 ft.) wide and 4 m (12 ft.) high. The tunnel was constructed in horizontally stratified sandstones and marls, about 35 m (140 ft.) below the surface. The maximum swelling within 4¼ years (1554 days) was 74.8 mm ($\sim$3 in.) in the middle of the floor of the tunnel, whereas at the sides the swelling was zero, as a result of the restraint of the tunnel walls.

The Soils of Switzerland

Deposits of the Glacial Period

The most important time for soil formation in our country was the Glacial Period. Due to a lowering of temperature and probably an increase of precipitation, together with an upward movement of the Alps, large masses of ice were formed, repeatedly filling up the Alpine valleys (Fig. 5). From the Alps they flowed down into the Central Plain and even on to and over the Jura. Whereas in earlier Glacial Periods the glaciers existed as more or less continuous masses, in the last they formed valley glaciers.

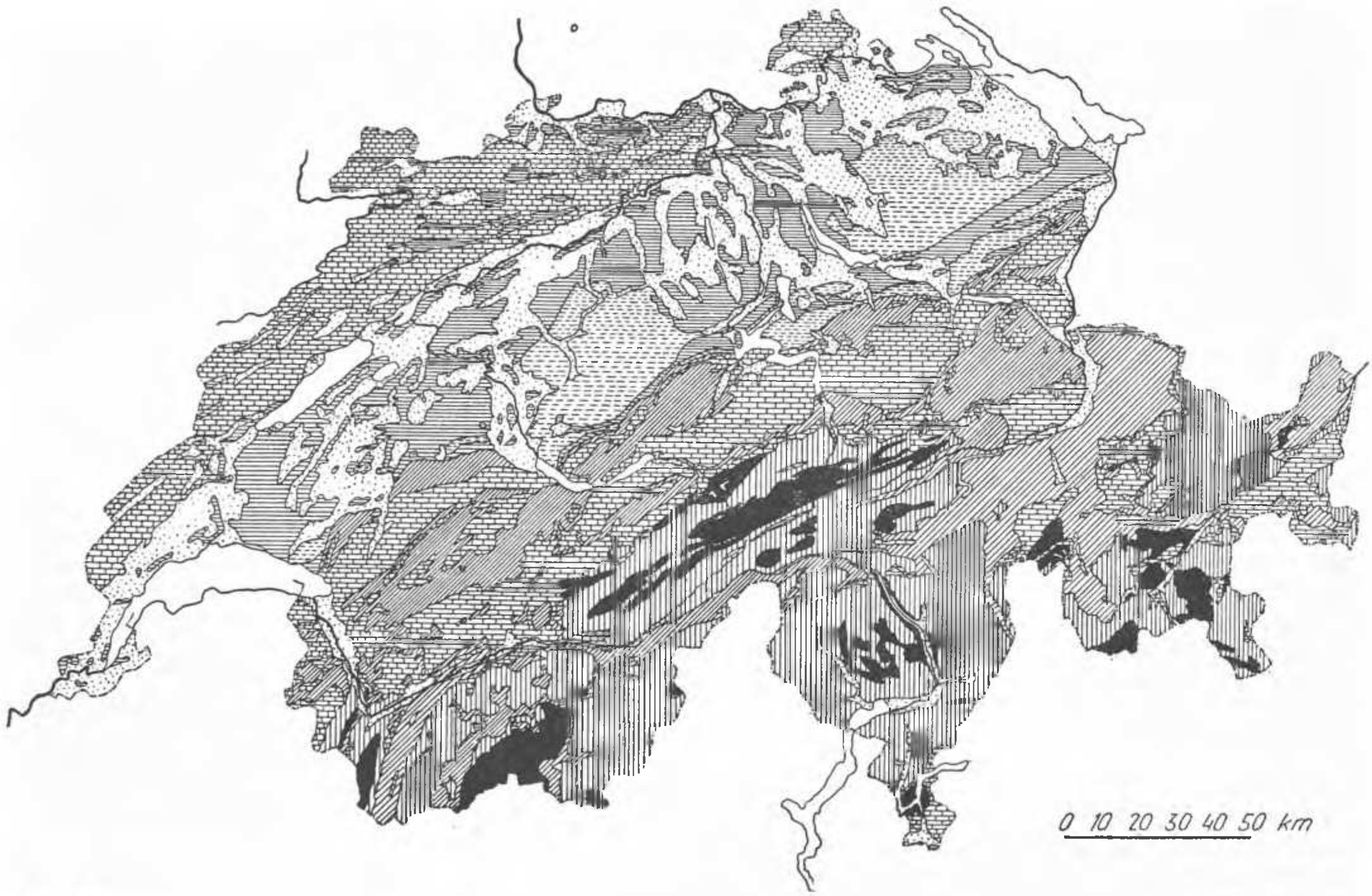
Broad basins and narrow gorges are most characteristic of the parts which have been overrun by the glaciers. These were formed by the grinding action of the ice and the glacial streams. On the whole, they were filled up with morainic material or glacial outwash.

The catastrophe which occurred on 24th July 1908, during the construction of the Loetschberg tunnel, is still in our mind. Almost without warning the head of the advancing tunnel pierced through rock into the sandy and gravelly soil filling of the Gastern valley. A flow of mud, sand and gravel suddenly rushed into the tunnel, killing the workmen and necessitating a change in the direction of the tunnel, 14,600 m (47870 ft.) in length (Fig. 6).

The preliminary work for the Urseren Power Plant during the Second World War showed that the engineers who constructed the St. Gotthard tunnel narrowly escaped a similar catastrophe. In 1941–42 seismic studies revealed a deep basin below Andermatt. In 1944 borings were untertaken in an upward direction from the tunnel near the so-called pressure part (km 2.8). They encountered sand and gravels, only 40 m (130 ft.) above the rails. This proves that below Andermatt, behind the rock gorge of the Urnerloch, there exists a basin 280 m (910 ft.) deep. This basin is filled with silt, some moraine on the bottom and with a top layer of gravel (Figs. 6 and 7).

Such filled glacial gorges and basins may be found not only in the Alps, but also in the Central Plain and in the Jura. The Rhine waterfall owes it origin to the fact that the post-glacial Rhine could not find its old bed which had been formed before the last glaciation. Therefore it eroded a new bed partly in rock and partly in the old soil. The backward erosion of the new Rhine was stopped at the point where the old filling reached the limestone barrier. This is the very point where to-day we admire the famous Rhine waterfall, 20 m (60 ft.) high (Figs. 8 and 9).

The ground moraines are the main deposits of the glaciers. They cover the lower slopes and often, too, the bottom of the Alpine Valleys and wider parts of the Central Plain. The normal type of groundmoraine consists of silt and lean silty loams with some more or less rounded boulders of different sizes. As a result of the preloading of these ground moraines



Mainly crystalline rocks such as granites, syenites, diorites, granite-gneiss, porphyres
Principalement roches massives telles que granits, syénites, diorites, granit-gneiss, porphyres

Mainly schistose crystalline rocks such as gneisses, micaschistes, amphibolites, greenstones, serpentines
Principalement roches cristallines schisteuses, telles que gneiss, micaschistes, amphibolites, schistes verts, serpentines

Limestones, marly limestones, dolomites, marbles
Calcaires, calcaires marneux, roches dolomitiques, marbres

Argillaceous schists, calcareous schists, mica-bearing calcareous schists with inclusion of gritty limestones, sandstones, quartzites, breccias and conglomerates
Schistes argileux, schistes marneux, micaschistes calcaires avec intercalations de calcaires sableux, grès, quartzites, brèches et conglomérats

Marls and slightly consolidated sandstones
Marnes et grès peu cimentés

Coarse, slightly consolidated conglomerates
Conclomérats peu cimentés

Mainly non-cohesive rocks such as gravels, sands, clays, glacial tills
Principalement dépôts non consolidés tels que graviers, sables, limons, moraines

Lakes
Lacs

Fig. 2 Map of the Most Prevalent Rocks in Switzerland, after *F. de Quervain*
Carte des principales roches de la Suisse, d'après *F. de Quervain*

Fig. 3 View of the Central Plain and the Alps Seen from the Jura Mountain, Infra-Red Photograph by *H. Froebel*, Zurich
Vue du plateau central et des Alpes prise de la chaîne du Jura par *H. Frœbel*; Zurich

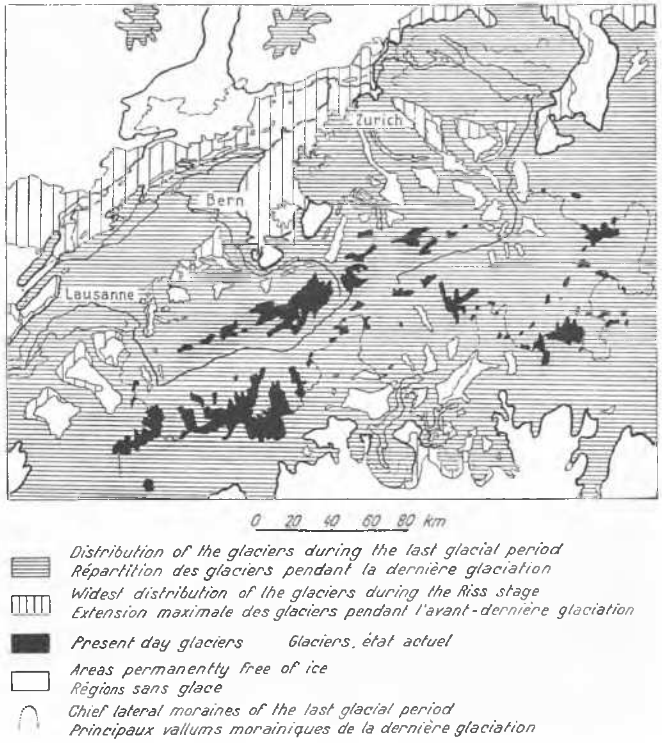


Fig. 5 Area Covered by Glaciers During the Glacial Period
Extension des glaciers pendant la glaciation

by the ice, they are very compact and are excellent for foundations. The core of the Hühnermatt earth dam near Einsiedeln, as well as that at Marmorera, are built of ground moraine material (Fig. 10). As an example of the compact state of those ground moraines, I may mention the earth pillars found in the different parts of the Alps. In each pillar a boulder protects the material below, which lies above the ground water and the capillary fringe, against erosion by rain (Fig. 11).

The surface moraines are as a rule less homogeneous and coarser. From masses of boulders down to gravels and even silts, all transitions may be found. Such material was used for aggregates in the construction of the Cleuson dam and is now being quarried at the Grande Dixence (Fig. 12). This was only possible because the surface moraines of these glaciers consist of solid, unweathered crystalline material.

The glacial streams separated the morainic material into different fractions. Outwash gravels are very abundant in this country. As they were formed at different times during the Glacial Period, they are found at different heights, even intersecting each other. They obviously form an excellent foundation material and are at the same time a first rate raw material for concrete and road construction.

The water-filled basins left after the retreat of the glaciers

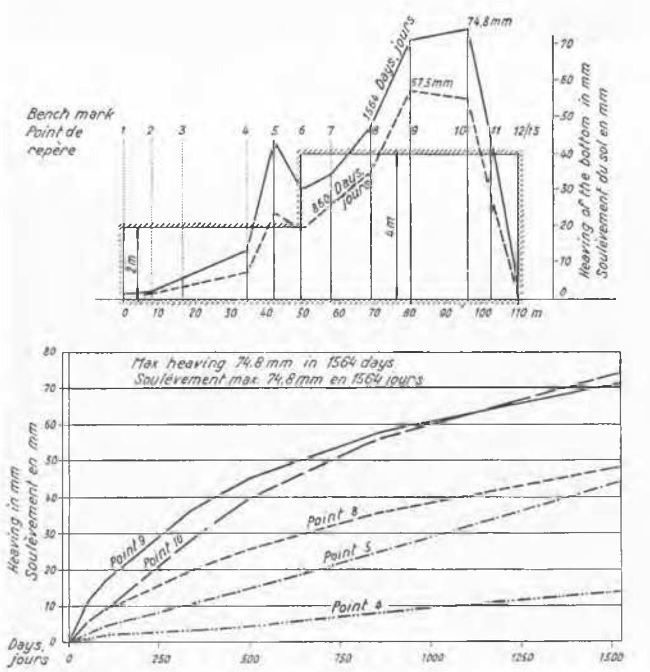


Fig. 4 Heaving at the Bottom of the Leonhardsplatz Shelter Tunnel, Zurich, by *A. von Moos*, 1949
Soulèvement du sol du tunnel du Leonhardsplatz, Zurich, par *A. von Moos*, 1949

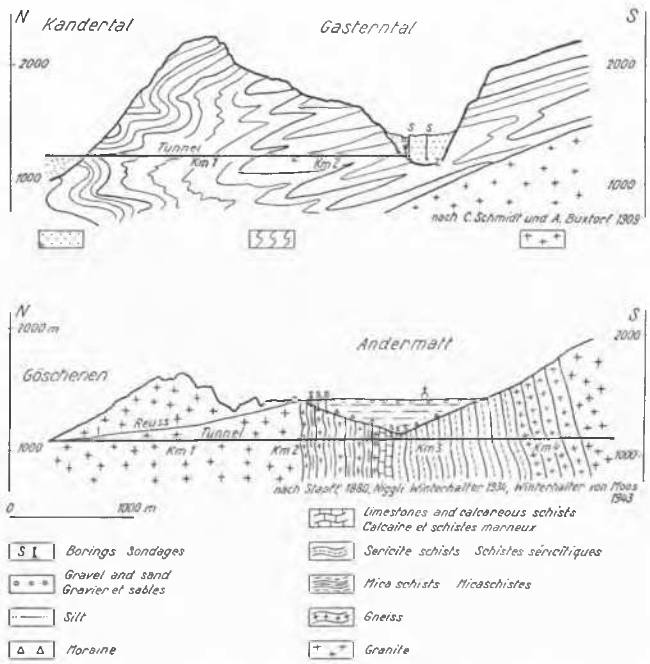


Fig. 6 Schematic Cross Section Through the North Section of the Loetschberg Tunnel (above) and the St. Gotthard Tunnel (below)
Coupe schématique du tronçon nord des tunnels du Lœtschberg (en haut) et du Gothard (en bas)

Fig. 7 Aerial View of the Andermatt Basin Filled up With 280 m of Alluvial Deposits
Vue du bassin d'Andermatt comblé par 280 m d'alluvions

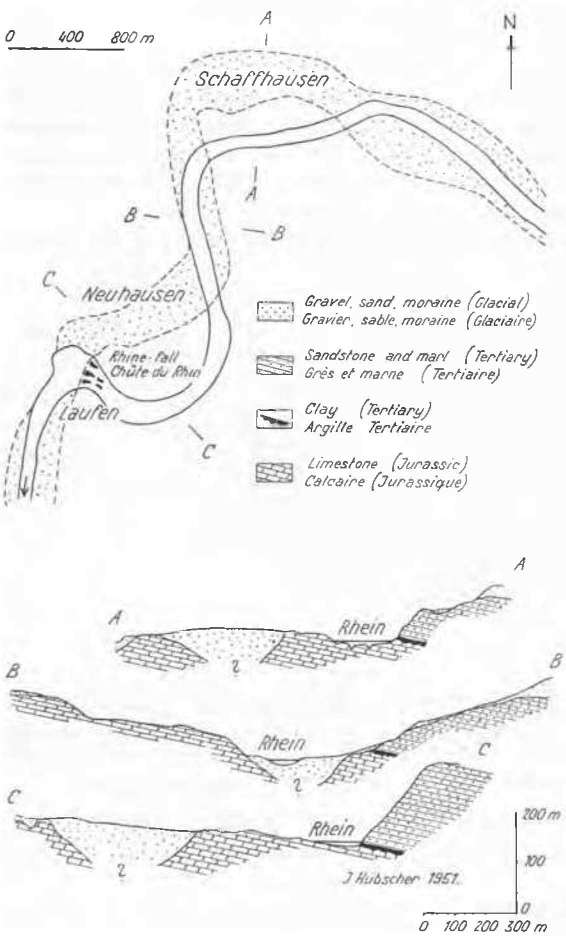


Fig. 8 Map and Cross Sections of the Area Covered by the Interglacial and Recent Valleys of the Rhine—Vicinity of Schaffhausen
Carte et coupes de la région des vallées interglaciaires et récentes du Rhin – Vicinité de Schaffhouse

were partly filled with silt and loams by rivers. Some of those loams are fissured. The airport at Kloten near Zurich, built during 1943–1948, is located on one of those filled basins. The subsoil of that place, which was a marshy plain before, shows the following structure: In the south-eastern part gravels are dominant. They are a remnant of the delta which was formed by the glacial stream in that basin. Those gravels thin in a north-western direction and in their place we find sand and loam, with a top layer of silt. In addition peat and lake marl appear in former depressions and in old channels of the river Glatt, which runs through this valley. As a result of preliminary studies, particularly soundings, borings and loading tests, part of the soil was excavated and replaced by gravels for the projected runway (Fig. 13). The base of the compacted gravel which supports the concrete slab [0.27–0.30 m (11–12 in.) thick] is generally 0.50 m (2 ft.) thick. This minimum thickness of $0.30 + 0.50 = 0.80$ m (total 32 in.) between surface and subsoil was chosen so as to prevent frost heaving. Although the airport allows the landing of planes with a wheel load of 65 tons, the maximum loads so far have been about 30 tons. The

Fig. 9 Aerial Photograph of the Rhine Waterfall
Vue aérienne de la chute du Rhin

Fig. 10 Ground-moraine Quarried for the Core of the Earth Dam at Marmorera
Moraine de fond en exploitation pour le noyau du barrage en terre de Marmorera

Fig. 11 Earth Pillars
Pyramides en terre

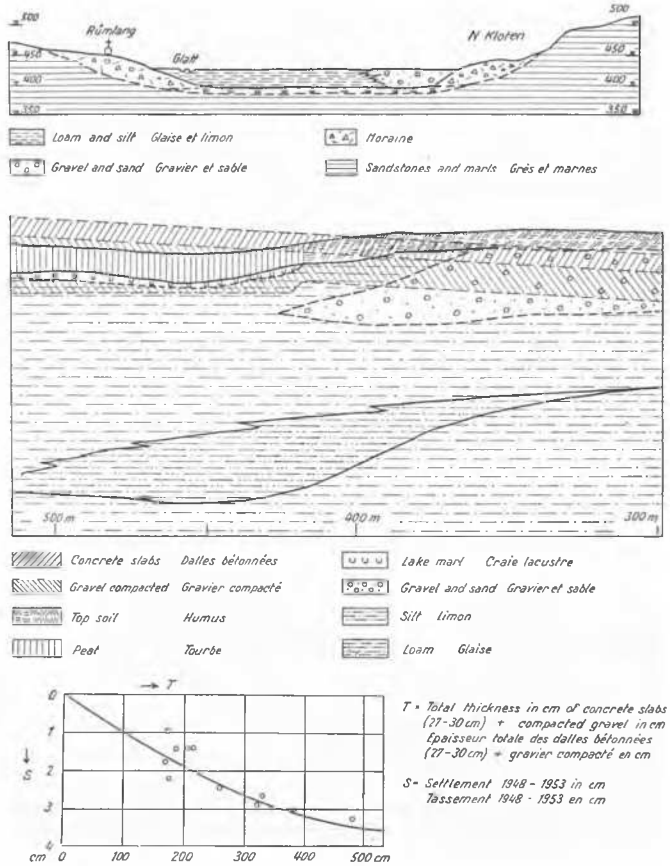


Fig. 13 General Geological Cross Section (*a*), Local Cross Section (*b*), and Settlement Records 1948–1953 (*c*), Kloten Airport, Zurich
Coupe géologique générale (*a*), coupe détaillée (*b*) et tassements 1948–1953 (*c*), Aéroport de Zurich-Kloten

levelling survey in 1953 showed that the settlement since 1948 had been only 0.5–1.7 cm ($\frac{1}{4}$–$\frac{3}{4}$ in.) depending to the thickness of the compacted gravels. The settlements [0.5–4.5 cm (20 in. to 15 ft.)] are proportional to the thickness of the base, the latter values occurring in some particularly unfavourable locations.

Post-Glacial Time

The present-day glaciers are a poor remnant of the Glacial Period, during which the huge valley glaciers had created steep slopes in many places, either in rock or in soil. Since the melting of the ice, those slopes have been subjected to weathering

Fig. 12 Frontal Moraine Quarried for the Concrete Dam at Grande Dixence
Moraine frontale exploitée pour le barrage de Grande Dixence

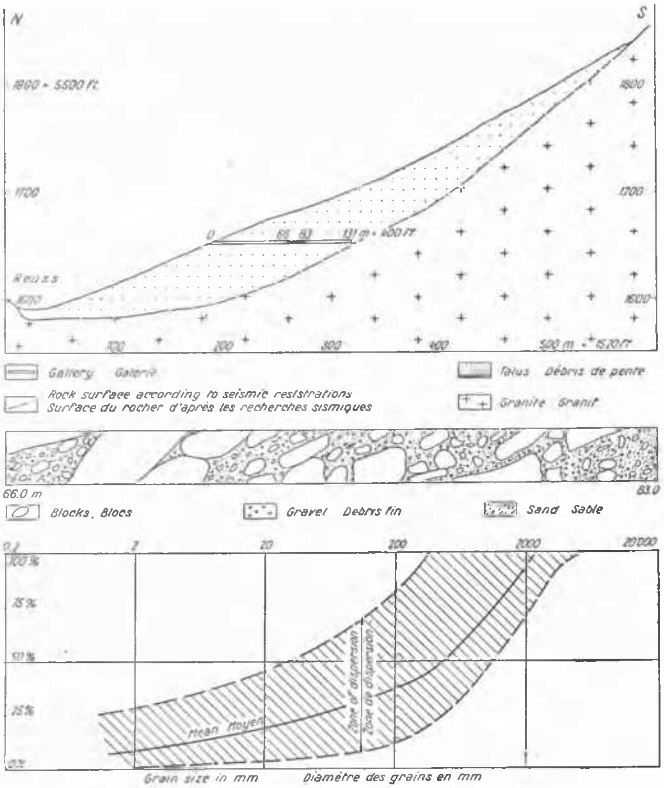


Fig. 14 Geological Cross Section, Geology of the Gallery and Grain Size Distribution of a Talus, Goeschenenalp, after Elektrowatt, Zurich
Coupe géologique générale, profil géologique de la galerie et granulométrie du matériau dans un cône de débris de pente, Gœschenenalp, d'après Elektrowatt, Zurich

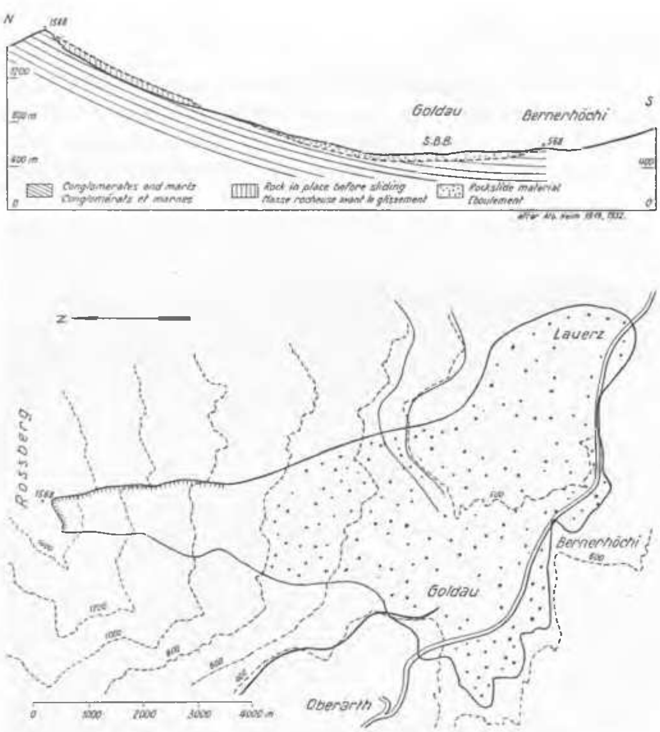


Fig. 15 Geological Cross Section and Map of the Rock Slide at Goldau, 1806
Coupe géologique et carte du glissement de Goldau, 1806

Fig. 16 Aerial View of the Rockslide of Goldau
Vue aérienne du glissement de Goldau

and erosion, and moreover have lost their "ice abutment" or lateral support.

In the Alps, at the foot of the mountains, physical weathering, together with avalanches and earth flows, have produced extensive débris cones with even slopes. Such débris is being used as borrow material in the construction of the earth dam at Marmorera (parent rock: greenstones, serpentine) and will also be used for the projected dam at Goeschenenalp (parent rock: granite). Here test drifts have shown the uniform and in some parts slightly stratified character of the débris cones (Fig. 14).

In Switzerland and especially in the Alps, the remnants of rockfall, or what may be called mountain slides, are common. The most recent extensive deposits of this kind are to be found at Goldau. There, on 2nd September 1806, after a number of rainy years and some particularly rainy weeks, a large mass (over 100 m thick and over 10 million m^3 in volume) consisting of Tertiary conglomerate, slipped down into the valley on a plane of weakness. The latter was caused by bituminous marls, at a slope inclined 20%. The mountain slide was probably caused by the underlying marls as the water could easily reach them through the many cracks in the conglomerate. At the bottom of the valley, thousands of blocks of all sizes, some as big as a house, were scattered erratically all over an area of 6.3 km^2 (2.4 sq.miles). This considerably impeded traffic. Observations in tunnels nearby have shown that these marls have a tendency to swell. The swelling causes the bottom of the galleries to rise and brings about cracks in the concrete lining of the tunnel (Figs. 15 and 16).

Whereas at Goldau we are concerned with the sliding of entire layers and large blocks of rock, in other parts of the country, especially in limestone regions, the falling, rolling rock was broken up into fine breccia. The best example of this is found in the mountain slide area of Flims, in the Vorderrhine-Valley.

The rock slide at Mitholz in the Kander Valley illustrates what further developments can ensue from such fine breccia (Figs. 17 and 18). There, in August 1945, a mountain slide occurred in a relatively stable part, on the left side of the valley, opposite the track of the Loetschberg railway. Three days before, the slide had been preceded by the sudden appearance of springs. In a few seconds a fine grained, soft and wet mass of débris flowed downhill, followed by blocks of rock and moraine.

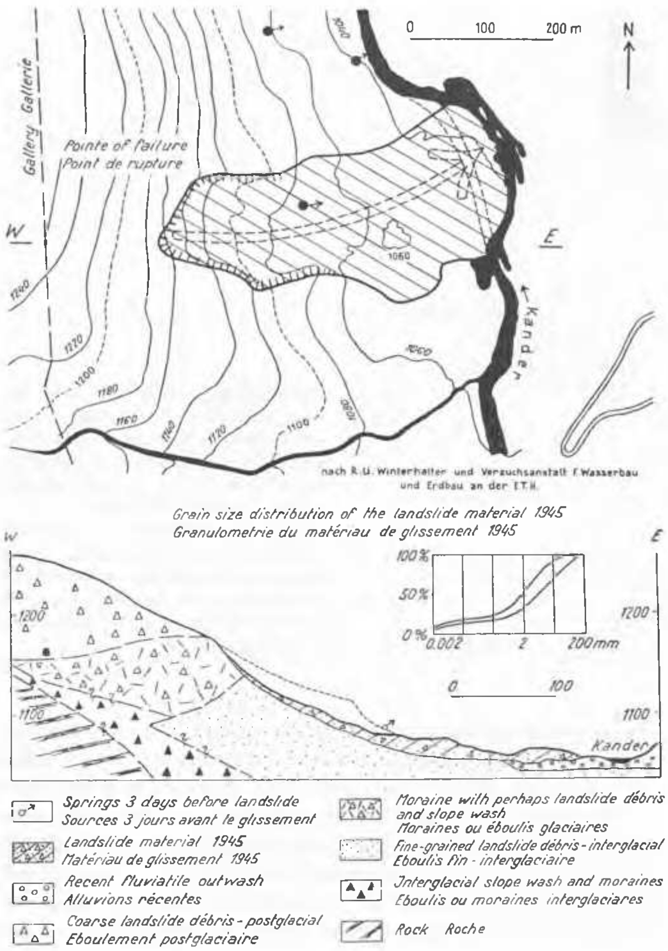


Fig. 17 Situation and Geological Cross Section of the Mitholz Landslide, Kander Valley
Situation et coupe géologique du glissement de Mitholz, vallée de la Kander

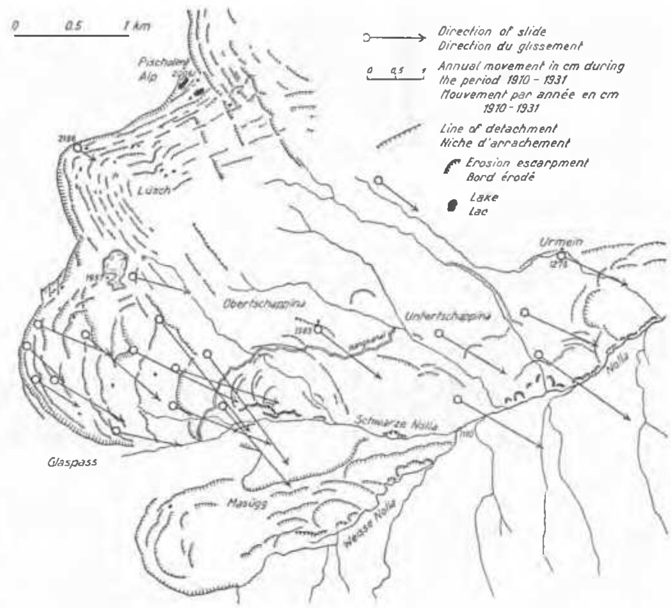


Fig. 19 Slide at Heinzenberg, Grisons, after *J. Jäckli*, 1951
Glissement du Heinzenberg, canton des Grisons, d'après *J. Jäckli*, 1951

The deposited masses blocked and shifted the river and caused heavy damage. The slope of the mountain consists of old, dense and impermeable masses of marly limestones, so-called "Rieseten", which were deposited during some Interglacial Period. Between the western rock slope and the ridge of the slide-mass, a pocket was formed at the line, which later on was filled with previous moraines and particularly by slope débris and recent mountain slide material. Similar material was also deposited on the slopes. It must be assumed that the mountain slide material had already been soaked from the west during many decades and thereby the marly limestone possibly underwent some swelling. These factors caused instability. The slide was most probably finally caused by additional water which suddenly flowed out through cracks that had appeared in a pressure gallery, running through the above-mentioned pocket. Large quantities of water were lost into the débris. In this way the fine-grained old mountain slide mass, like an earth dam, was overflowed, percolated and finally flowed out.

In addition to the rapid and therefore more apparent earth movements, we find extensive zones characterized by slow creep-phenomena in the Alps, but also in the Jura mountains and in the Central Plain. These occurrences often involve a heavy economic burden for the inhabitants. For instance an

Fig. 18 Aerial View of the Landslide at Mitholz
Vue aérienne du glissement de Mitholz

Fig. 20 Aerial View of the Heinzenberg Slide
Vue aérienne du glissement de Heinzenberg

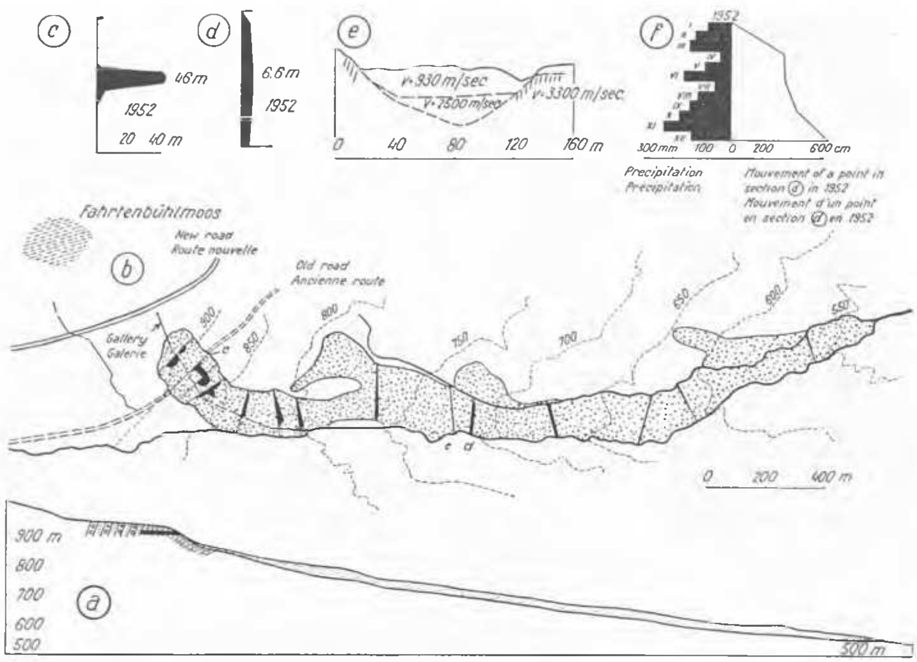


Fig. 21 Longitudinal Profile (*a*), Map (*b*), Distribution of Movement (*c*, *d*), Cross Section (*e*) and Relation between Rainfall and Movements (*f*)—Stoss-Slide in the Vicinity of Altstätten, Canton of St.Gall
Coupe longitudinale (*a*), carte (*b*), distribution du mouvement (*c*, *d*), coupe transversale (*e*) et relation entre précipitations et mouvements (*f*) – Glissement du Stoss près d'Altstætten, canton de St-Gall

area of 40 km² (15.4 sq.miles) with 10 villages on the Heinzenberg (west of Thusis) is slowly moving downhill. The rock, consisting of calcareous and argillaceous schists, is sloping more or less parallel to the surface towards the Hinterrhein Valley. According to the surveys of the Swiss Topography Office the downhill movements amount to 0.9–6.5 cm ($\frac{1}{2}$–$2\frac{1}{2}$ in.) a year, in some parts even up to 10–26 cm (4–10 in.) a year (Figs. 19, 20). The tunnel construction at the Julia-Tiefenkastel Power Station, in a tectonically similar region, has shown that such zones which are sliding and subsiding, partially due to tectonic reasons, may be many hundred metres deep.

A second example of these slow movements is a more uniform glacier-like sliding below the Stoss-Strasse, West of Altstaetten in the Rhine Valley (Fig. 21). There a mass of débris-material 1970 m (6459 ft.) long and 115 m (377 ft.) wide has, since 1931, been slowly moving down into the valley. The speed of the mass, which according to a seismic investigation has a depth of up to 35 m (114 ft.), varies according to the place from 1–15 m (3–50 ft.) a year. The material consists of wet weathered marl débris, containing also some sandstone and glacial till. The inclination of the "stream" which has a volume of approximately 2.5 million m³ (3.2 million cu.yds.), varies between 30% in the upper part and 14% in the lower part. The slide is in the area of steep stratified sub-alpine Tertiary deposits (Molasse). Conglomerates and sandstones are predominant above the breaking-off part of the slide, while below this part, we find mainly marls exposed. The whole zone has been broken up considerably by tectonic stresses (lifting and faulting) and by creeping. The movement of the loamy mass of débris is being increased by the influx of water. It reaches the material partly along the last bank of conglomerates above the marl, but comes also on the surface from a swamp (Fahrtenbühlmoos). An attempt is being made to stop the movement by means of a drainage tunnel and other drainage provisions. The possibilities of a large retaining wall and of stabilization by electro-osmosis in order to protect the settlements below, have not so far developed beyond study of the question.

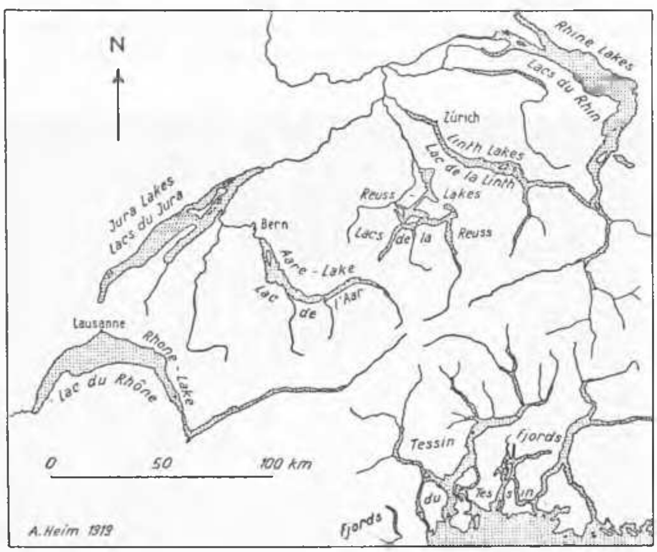


Fig. 22 Map Showing the Lakes of the Interglacial Valleys of Switzerland, after ***Alb. Heim*** 1919
Carte montrant les lacs des vallées interglaciaires de la Suisse d'après ***Alb. Heim*** 1919

During the Pleistocene Period extensive valley systems were created by ice and water, assisted by tectonic movements. In these valleys many lakes were formed after the retreat of the glaciers. These lakes are now increasingly silted up, where they were not already completely filled at the end of the Pleistocene Period (Fig. 22).

The silting or filling up of the wide valley bottoms was continued by the rivers. Where the melt-water rivers had already formed gravel banks at the bottom of the valley, silts and clays were deposited on the top of them during the high water level. We find therefore in most of the Central Plain valleys a fairly thick layer of clay and silt above the base-gravel. They are often decarbonized and organic, or even interpersed with peat layers. These clay layers are not much consolidated, sensitive to loading and in the summer dry out to a considerable depth, shrinking and fissuring (Fig. 23).

However the major part of the material carried by the rivers,

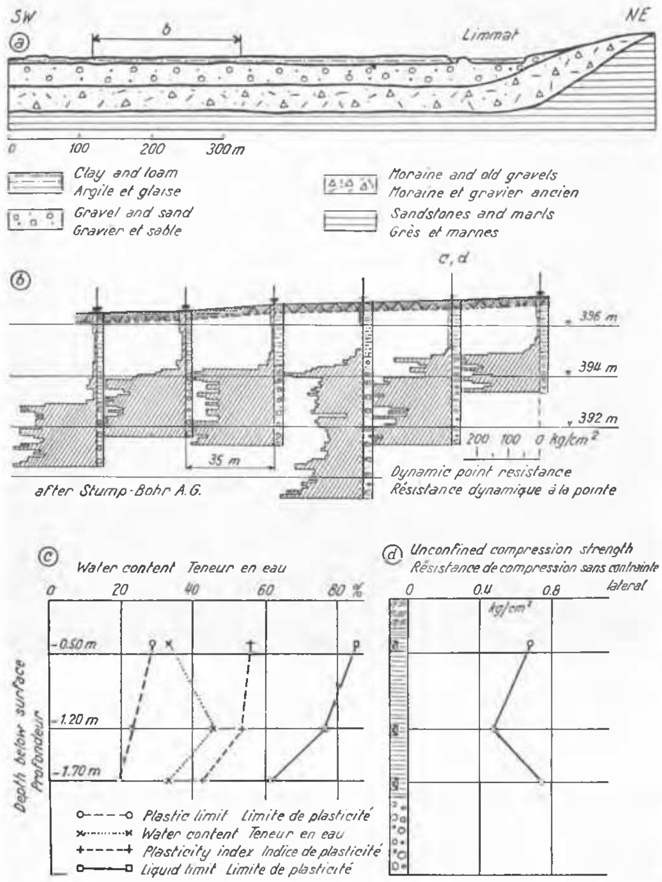


Fig. 23 Geological Cross Section (*a*), Results of Soundings and Borings (*b*), Field and Laboratory Tests (*c*)—Limmat Valley near the Hoenggerbrücke, Zurich
Coupe géologique (*a*), résultats de sondages (*b*) et résultats d'essais sur place et de laboratoire (*c*) – Vallée de la Limmat près de la Hœnggerbrücke, Zurich

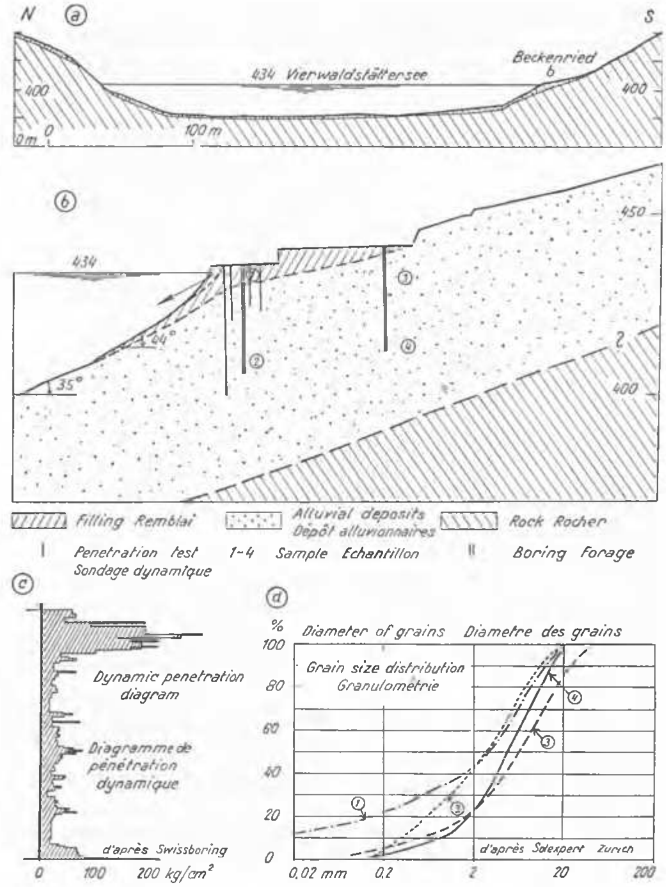


Fig. 25 Geological Cross Section (*a*), Results of Borings and Soundings (*b*), Results of a Dynamic Penetration Test (*c*) and Grain Size Distribution (*d*) of a Delta near Beckenried—Lake of the 4 Cantons
Coupe géologique (*a*), résultats de sondages (*b*), diagramme d'un essai de pénétration dynamique (*c*) et granulométrie (*d*) d'un delta près de Beckenried – Lac des Quatre-Cantons

Fig. 24 Aerial View of the Rhine and Aach Delta—Lake of Constance
Vue aérienne du delta du Rhin et de l'Aach – Lac de Constance

is deposited in the lakes (Fig. 24). According to the investigations of the Swiss Office of Water Economics, the two rivers Aach and Rhine, carry into the Lake of Constance 4 million m³ of material a year. This corresponds to a removal of 513 m³ (671 cu.yds.) per km² of the watershed area. Nowadays the coarse-grained river bed material can reach the Lake of Constance through the artificially straightened and narrowed bed, whereas before the correction, this material was deposited considerably higher up before reaching the lake. We find therefore in the Rhine Valley, in the area of St. Gall and Vorarlberg, gravel deposits only in the upper parts and there only sparsely. Everywhere else lean clays and silts are predominant, on as well as below the surface, with extensive peat layers.

The lakes are not only filled by the main rivers, but also by the smaller ones forming deltas along the shore. The deltas are generally coarse-grained although intermixed with finer materials. They are, as a rule, stable with the exception of the outer zones where we find steep slopes often accentuated by artificial fills. At Beckenried, for instance, on the Lake of Lucerne, there is a heavy cement factory on the very edge of such a delta; during the last 60 years, slides have only occurred in the extreme outer zone (Fig. 25).

The lower end of the lake at Zurich is an example of the silting up of a lake (Figs. 26, 27, 28). There, inside the terminal moraines of Zurich, the lake is being reduced, mostly by the

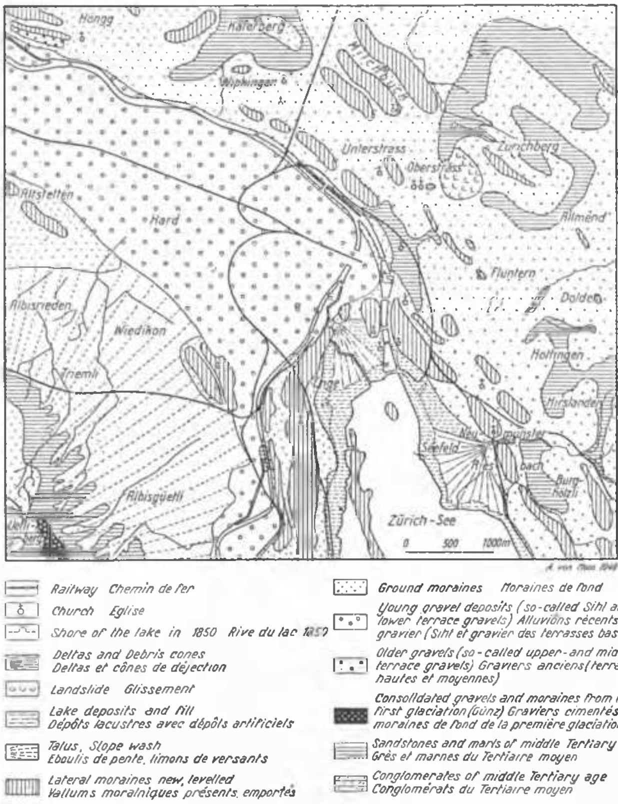


Fig. 26 Geological Map of the Town of Zurich by *A. von Moos*, 1946
Carte géologique de la ville de Zurich par *A. von Moos*, 1946

Fig. 28 Aerial View of the Lower End of the Lake of Zurich
Vue aérienne de la partie inférieure du Lac de Zurich

deposits of the local rivers, but also by mud and lake marls. These last, a mixture of precipitated calcite crystals and organic material, were formed by a biogenetic process. The lake marls are of rather loose structure. In many places artificial fills have been deposited over them within the last hundred years. Boring within the shore of the lake reveals from top to bottom the following succession: firm fills, soft lake marl with mud, lacustrine clays or loam, increasingly firm ground moraine or till (Fig. 29). Buildings on these parts need either pile foundations, such as the Kongresshaus, or raft foundations, such as the National Bank close by. The settlement of the shore is still going on, especially where there are more

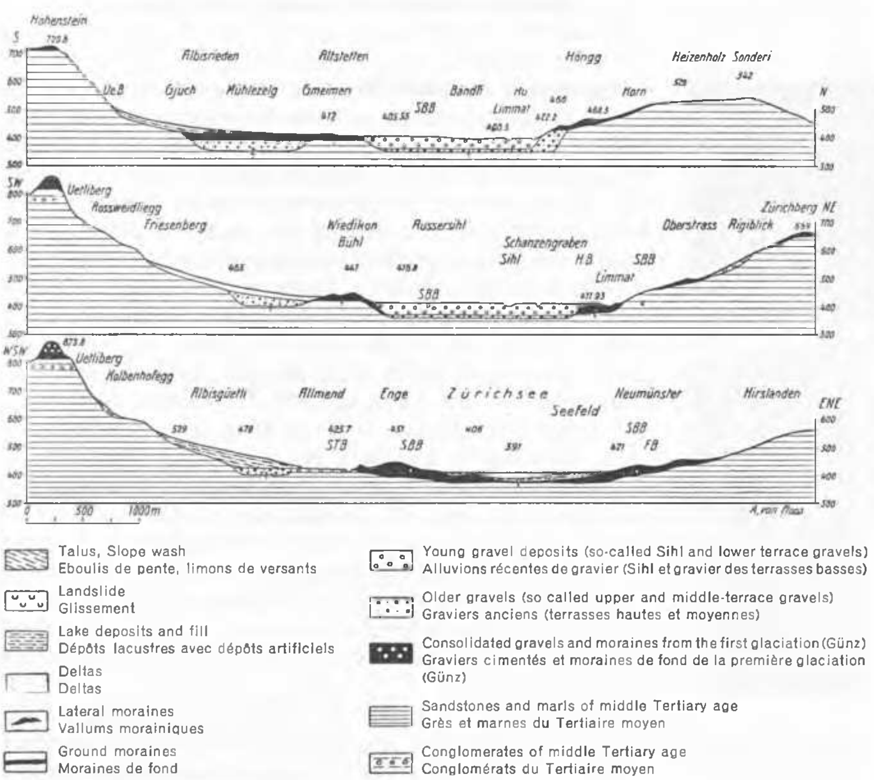


Fig. 27 Geological Cross Sections Through Zurich by *A. von Moos*, 1946
Coupes géologiques à travers la ville de Zurich par *A. von Moos*, 1946

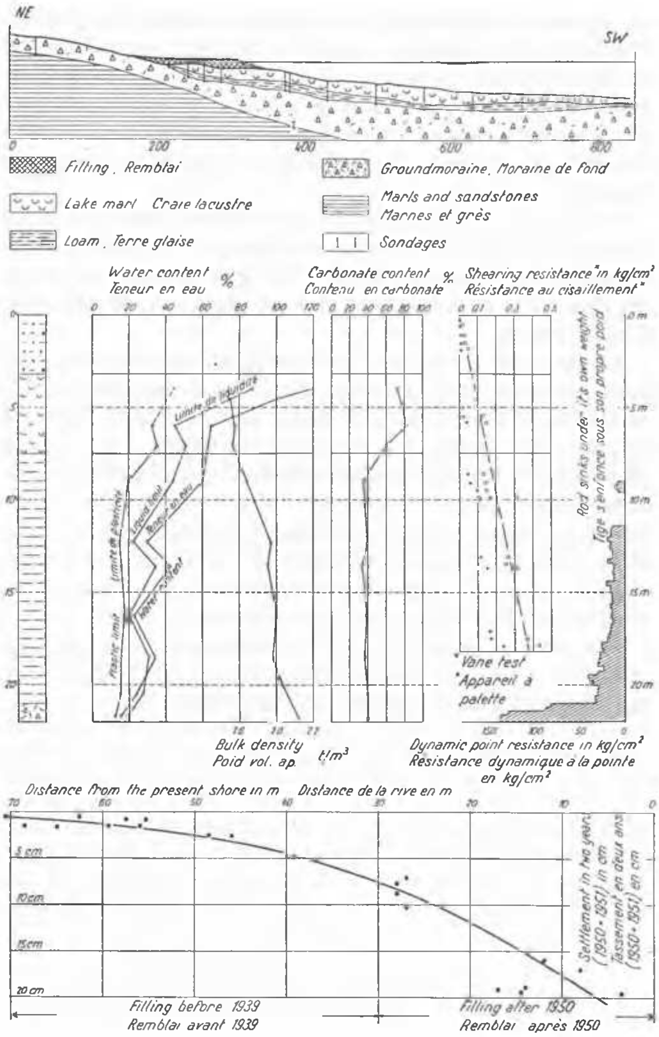


Fig. 29 Geological Cross Section, Results of Boring, Field and Laboratory Tests and Settlement Observations Carried Out on the Shore of the Lake of Zurich near Tiefenbrunnen
Coupe géologique, résultats de recherches en place et au laboratoire et observations de tassement sur la rive du Lac de Zurich, près de Tiefenbrunnen

recent fills. Fig. 29 shows that the settlement varies from centimeters up to decimeters (inches up to a foot) a year.

In conclusion a few words will be said on the plastic properties of some of the Swiss cohesive soils. Fig. 30 shows the usual graphic representation of the liquid limit and plasticity index, together with the A-line, according to *A. Casagrande*. The points representing the Swiss ground moraines and hillside loams lie above the A-line. The variation of the hillside loam is greater than that of the moraines, due to its more variable petrographic composition and grain size distribution. Most of the points belonging to lake marls are very scattered, lying below the A-line, because they contain organic material. The lacustrine loams and clays show an even more pronounced scattering; those with organic material are below, those containing only inorganic material, above the A-line.

Table 1 gives the mean values, together with the maxima and the minima, of some cohesive Swiss soils studied in our laboratory.

The plasticity index of those cohesive Swiss soils is as a rule not very high, because of their small contents of active minerals.

Table 1

Material		*Liquid limit* %	*Plastic limit* %	*Plasticity index* %
Moraines	Max.	32.6	19.2	18.8
	Mean	22.2	13.2	9.0
	Min.	15.4	8.0	3.5
Hillside loam	Max.	101.0	34.6	77.9
	Mean	43.8	18.9	24.9
	Min.	23.8	12.4	6.0
Lacustrine loam	Max.	158.8	90.0	91.8
	Mean	46.0	25.5	20.5
	Min.	21.0	13.9	3.6
Lake marl	Max.	106.1	81.8	69.3
	Mean	66.9	37.1	29.8
	Min.	39.5	22.2	9.3

The higher values for lacustrine loams and clays and lake marls are due—as already mentioned—to their organic material, whereas the higher values of the hillside loams are produced by active minerals.

Conclusion

I hope I have been able to show you that the geological development of the Alps and their Vorland produced a great vertical and horizontal variation in the composition of the soils.

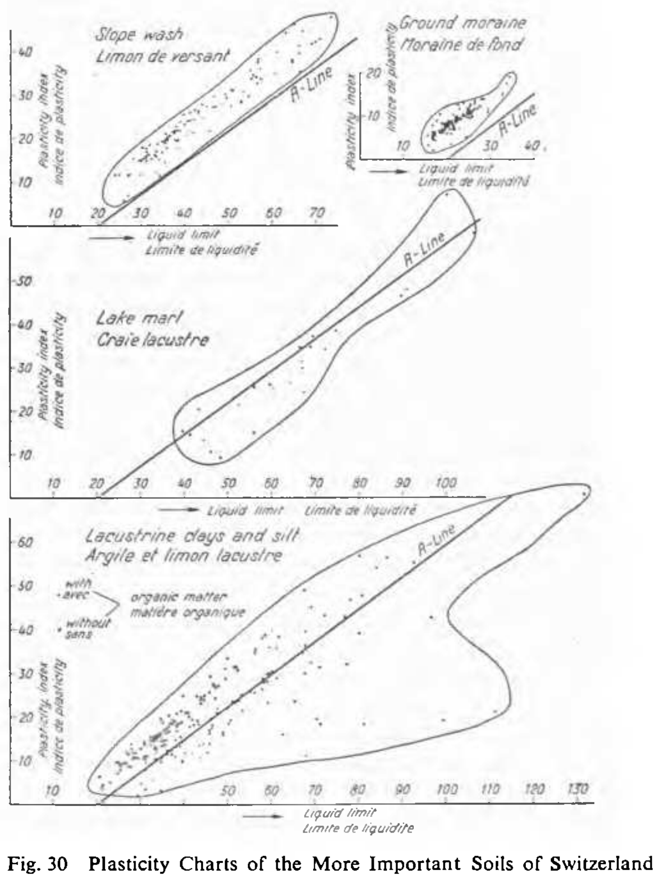


Fig. 30 Plasticity Charts of the More Important Soils of Switzerland by *A. von Moos*, 1950
Diagrammes de plasticité des principaux sols de la Suisse par *A. von Moos*, 1950

Our building soils are seldom homogeneous and there is nothing more constant than change!

Owing to the sharp relief, together with the work of the glaciers, coarse soils predominate which are free from organic material. Moraines, gravel, sand and the débris from slides in hillsides and rock are common. They ensure solid and stable ground for building.

The fine-grained deposits of rivers and of lakes at the bottom of the valleys are of secondary importance. The high water loams, lacustrine loams, lake marls and peat layers are often only slightly consolidated. They imply settlement and frost problems, together with questions of stability.

A third group are the fine-grained soils on the slopes, such as hillside loams, clayey slide materials or weathered materials. Their predominant quality if their tendency to slide and creep. On the other hand marine and volcanic soils are entirely absent from our country, and the eolic deposits and the deeply weathered subsoils are rarely present.

Certain geotechnical consequences ensue from the existence of the above mentioned soils, which speaking geologically, may be called a "glacio-alpine province". The frequent changes of the subsoil demand an intensive investigation of the local geological conditions. In many cases boring and sounding, together with some field tests, are sufficient to solve the geotechnical problems in question. These researches are mainly in the hands of geologists and engineers interested in geology. The geological conditions, already mentioned, have furthered the dynamic penetration test. They were applied, first to snow research and later on to subsoil exploration. In our country the dynamic sounding method is a most valuable means to foundation engineers when used in the qualitative analysis of the subsoil.

Our laboratory investigations are confined either to special practical problems, such as earth dams or frost problems, or to fundamental research work. The latter shows the way to the field tests, which in their turn are decisive in all the practical problems.

The Swiss civil engineers and geologists are, as a rule, very much in contact with the Alps. The dangers and catastrophes of our mountainous country make them specially observant and their observation is one basis of their work. The complicated subsoil with the predominance of coarse-grained soils, does not give many opportunities for the application of theoretical soil mechanics. Notwithstanding, typically Swiss solutions have been found, especially in snow and avalanche studies, as snow is the only Swiss material of homogeneous composition extending over large distances.

The aims of geotechnology in Switzerland is to bring together the many and various observations and the ever more rapidly developing science of soil mechanics.