CENTENAIRE DE LA SOCIÉTÉ GÉOLOGIQUE DE BELGIQUE
COLLOQUE *GÉOLOGIE DE L'INGÉNIEUR*, LIÈGE, 1974, 259-272

IMPORTANCE OF QUATERNARY EVENTS FOR THE GEOLOGICAL CONDITIONS OF BUILDING SITES

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ABSTRACT

The forms of the present relief and surficial deposits are to a great extent the product and relict of Quaternary conditions, when climatic events of high intensity repeatedly affect the natural environment. This interference can be appreciated only when the extent of ice-covered areas and indirect effects of glaciation on neighbouring regions are realized. Their knowledge is particularly important for engineering geologists whose interest, owing to the character of their work, is mainly centered on the features of the ground surface and on the surface layer of rocks, deposited, weathered, or redeposited during the Pleistocene.

The engineering geologist is faced with different problems in areas once glaciated and in periglacial areas which were situated in front of the continental ice sheets. In the mountain regions he has to consider whether or not mountain glaciers filled the valley. In the positive case, overdeepened valley may have developed and steep valley slopes may have suffered from sliding after the glaciers had melted away.

Fluctuation of sea-level and vertical movements of continental blocks, i.e. subsidence due to loading by ice and rising after ice retreat, resulted in Canadian and Scandinavian coastal areas in the uplift of young marine sediments and development of unstable quick-clays. Vertical movements have also promoted the alternation of erosion and accumulation cycles in the history of watercourses. These, in turn, gave rise to a flight of stream terraces.

The denudation relics of upper terraces are often burried by slope deposits of great thickness. Sands and gravels were supplied to streams by torrents which carried material from extensive fans rimming the bases of mountain slopes.

Quaternary sediments differ appreciably from older rocks, as they are mostly unconsolidated and their physical and technical properties are controlled by their fabric, chemical composition, and genesis. Whether they will be used as building material or will serve as foundation soil, the environment of their provenance must be kept in mind. The character of sands transported by and deposited in water differs from that of wind-blown sands and from sands originated by weathering *in situ*.

The relationship between Quaternary geology and engineering structures will be shown using several actual examples.

In constructing whatever engineering work we encounter on the land surface rocks which were deposited or redeposited in the youngest geological epoch—the Quaternary. Most of the present forms of the landscape are also the product of geodynamical processes provoked by great climatic changes in the Pleistocene.

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Quaternary geological phenomena and events have attracted much attention since the first geological studies and were the subject of comprehensive volumes, beginning with the classical work *Great Ice Age* of James Geikie, published in 1874, up to the most recent book of R. F. Flint *Glacial and Quaternary Geology* which appeared in 1971. In the present lecture it will be possible to outline only several problems which are encountered in engineering works, in order to demonstrate how important it is to be acquainted with Quaternary geology if engineering tasks should be accomplished successfully.

The basic factors which controlled geological processes in the Pleistocene to a great extent were extreme climatic changes. Alternation of cold and warm periods, several times repeated, resulted in recurrent glaciation and deglaciation of extensive areas in Europe, North America, and Asia. The change of large masses of water into ice sheets caused a considerable world-wide lowering of sea level, which rose again on retreat or melting of the ice. The eustatic sea-level changes were combined in glaciated areas with depression of the landmass under the ice load and with isostatic postglacial rebound.

1. Areas Covered with Continental Ice-Sheet

All these processes imprinted to the areas covered by continental ice sheet a peculiar character and provide specific conditions for construction works. The motion of large ice masses smoothed down ridges and elevations so that firm sound rock occurs on the ground surface. The greater part of the glaciated areas, however, is covered with glacial or glaciofluvial sediments. The deposits of glacial drift are mostly unstratified and are called moraines when they show definite topographic forms. They are composed of material transported directly by the ice; in this they differ from glaciofluvial deposits which were laid down by waters discharging from the ice. A special type of moraines that should be differentiated is a push moraine, which is essentially the subsoil deformed and shoved by the advancing ice; in places crumpling and folding of near-surface beds may have occurred.

The development of glacial deposits is responsible for their unfavourable technical properties. The advance of the ice sheet resulted in the deposition of *boulder clay*, the surface layers of which were exposed to weathering and erosion during ice retreat. Every re-advance of ice and re-glaciation promoted the same events. Consequently, the bedrock was overlaid by one or several sheets of glacial material, which differ widely in mineral composition, hardness, and engineering characteristics. In some places sandy material with pebbles and boulders predominates, with occasional pockets of gravel in clay matrix, while clays prevails elsewhere. Locally, even large blocks of firm rocks are embedded. In this material many engineering problems are obviously encountered. Excavations are very difficult since the rock blocks often require the use of blasting. The varying thickness of the deposits may also prepare unpleasant surprise. The inhomogeneity of glacial material must be taken into consideration if this is intended for fills, as well as in designing the foundations where unequal compressibility may endanger the stability of the structure (G. W. White, 1972).

Characteristic of the glaciated areas are low ridges running sinuously, roughly perpendicular to the direction of frontal moraines. These *eskers* or *osar* are interpreted as fillings of subglacial streams. Their relatively well-sorted and pure sand and gravel are exploited as building material, especially as concrete aggregate.

Of another character are glaciolacustrine sediments (sand, silt, banded, or varved clays), which were laid down in lakes originated by the damming of ancient stream valleys by the advancing ice. In northern Europe the continental ice sheet was advancing upstream of rivers and blocked their way to the sea. The rivers were diverted from their courses and followed the borders of the ice. Their broad valleys were filled by a large amount of fluvioglacial sediments. This system of so-called *Urstromtäler*, which run roughly from east to west, parallel to the front of Nordic ice sheet, are today an important source of ground water.

In the areas that were covered with ice in the Pleistocene foundation conditions of two extreme types are encountered:

Either abraded sound bedrock, from which surficial weathered material was removed by the advancing glacier (fig. 1), or little consolidated glacial and glaciofluvial sediments. These comprise morainic deposits, boulder clay, and sandy gravels. Of particular character are silts and clays which were deposited in the sea but after the isostatic uplift of landmass following the melting of ice have appeared on the surface, filling valleys, and depressions.

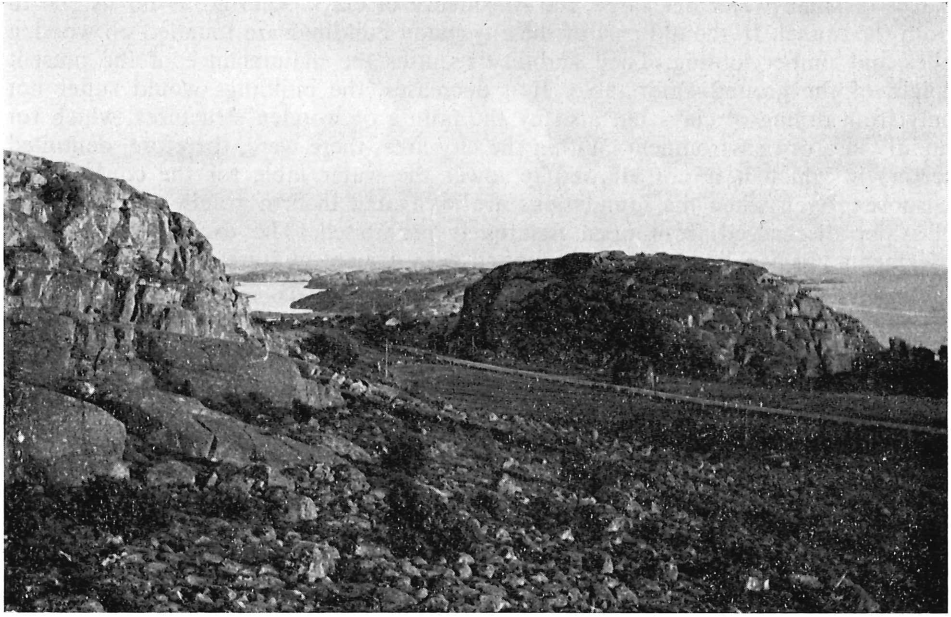

FIG. 1. — *Ice-sculptured surface of granite hillocks of roche moutonnée type on the western coast of Sweden. The intervening valley is filled mainly with clay. Photo by Záruba.*

The foundation soils of the city of Stockholm are of such a double pattern. The topography of the city area is diversified, with rounded hillocks formed of solid bedrock, granite, and crystalline schists which rise 60-70 m above the present sea level. This is the altitude of the ancient peneplain, which is dissected by many deep valleys, eroded by the Pleistocene ice, and subsequently flooded by the sea.

In depressions and on the valley floors there have been preserved glacial and glaciofluvial sands and gravels and clays or silts of marine and lacustrine derivation.

The clay sediments provide fertile agricultural soil but very unfavourable foundation conditions. They were deposited mostly during the Late Glacial and Postglacial transgressions; the youngest of them were still below the sea level at a geologically recent time, as the Stockholm area emerges at a rate of about 45 cm in one hundred years. The clays are little consolidated, and are often of soft consistency under a thin desiccated crust.

When their water content decreases, they shrink and cause considerable and non-uniform subsidence of the land surface. The lowering of the ground-water table during the construction of the first underground line resulted in the subsidence and great damage on buildings and subsurface services where the tunnels were driven below the depressions filled with clays (C. O. Morfeldt, 1970). Even in places of small water discharge, the subsidence of clays occurred as far as 300 m from the tunnel. In the old part of the city many buildings are founded on wooden piles and timber footing. Their stability requires the maintenance of the present height of the ground-water table. If it decreases, the buildings would suffer not only from drying of clays but also by the failure of wooden structures, which rot rapidly in a dry environment. Within the city area, there were, therefore, delimited sectors in which it is not allowed to lower the water table for the construction purposes. Even when the foundations are excavated in firm granite, the pumping of water discharged from open fissures is prohibited. The excavations for the basements are usually sealed by grounting with cement mixture.

From a geotechnical point of view, very hazardous are *sensitive clays* of marine derivation, which especially in Norway and Canada form plateaus 160-200 m above sea level. As has already been mentioned, these regions experienced a postglacial rebound after the ice melting. The clays are called *quick* or *Leda clays* and show specific properties, which make them liable to sliding. Some disastrous landslides have attracted attention of many scientists (L. Bjerrum, 1965; J. Rosenquist, 1953; C. B. Crawford, 1968) who have systematically studied these soils. It has been found that the strength of marine clays decreases gradually with the rise of the land and that the main cause of this decrease is salt leaching out of the pore water of the clays. The increase in height differences results in the increased rate of ground-water movement, which percolating through more permeable silt layers decreases the salt concentration in soil by osmosis. The atmospheric water infiltrating from the surface contributes to leaching effects. Owing to the reduction of salt concentration in pore water the bonds between clay particles and water are loosened and the strength of clays diminishes. Moreover, the liquid limit is also decreased and the sensitiveness of clays increased. The sensitive clays are characterized by a sudden loss of strength by shocks; under their effect or other disturbances they change into dense viscous liquid. The slides in extrasensitive clays are treacherous in that they may occur in areas sloping at a smaller than 5° angle, and that the movement is very rapid.

Landslides in sensitive clays have many features in common. It suffices when stream erosion or artificial cutting disturbs the stability of the slope within a small area and through the gap large masses of clay flow out with a great velocity. The Vaerdalen landslide in Norway is an often cited example of such "bottleneck slips," which destroyed 22 farms and killed 111 people during a 30 minute interval. The movement involved 55 million m^3 of clay and silt (P. Holmsen, 1953).

Such slope failures may be triggered by very slight impulses even on slopes that were stable for many centuries. The stability of clays uplifted gradually above the sea level depends on their shear strength, particularly in the deeper layers. In result of evaporation and weathering a consolidated firm layer forms at the surface while the strength of clays decreases and their sensitivity rises in the deeper layers owing to the leaching of salt. Stability of many slopes thus depends on which of these processes predominates.

Restoration of slope stability in sensitive clays has not yet been solved satisfactorily, although several research institutes both in Scandinavia and Canada systematically study this problem. They succeeded in identifying and delimiting hazardous areas, threatened by sliding, but no economic corrective measures have so far been developed. The reestablishment of the original salt content in the pore water of sensitive clays, although seemingly a simple procedure, provides great difficulties. It was realized only in very exceptional cases to save structures of extraordinary cultural or economic value. With respect to a small permeability of clays, electroosmosis was used for stabilization, which is a time-consuming and expensive procedure.

2. Areas of Mountain Glaciation

The areas of Pleistocene mountain glaciation offer other serious geotechnical problems. Mountain glaciers had carved deep valleys, which were subsequently filled with glacial and glaciofluvial sediments. The glacial valleys or troughs assumed a characteristic U-shape with steep walls and flat floor. After the glacier had melted, the steep valley sides were preserved only in very firm rocks. Elsewhere, they were disturbed by rock slips or rock falls, the extent of which was controlled by the structure of the rocks involved and their jointing.

In the high mountain ranges, such as the Alps (Zischinsky, 1969) and the Carpathians (Nemčok, 1972), deep-reaching disturbances of slopes have been determined in rocks which are liable to creep deformation, for example in phyllites, gneisses, or micaschists. This process resulted in the narrowing of the valley floor. The slope movements have not always been established at a cursory inspection and the constricted part of the valley appeared suitable for dam construction. When the deformation was ascertained by detailed investigation, it often required a modification of the general project and, invariably, unexpected difficulties during construction. Figure 2 shows the section of the *Durlassboden damsite* in the Austrian Alps. Detailed investigation has shown that a large block of graphitic schists and quartzites had slipped down the right slope and sunk into the valley deposits. These consist of glaciofluvial sands and gravels and lacustrine silts. An earth dam, 70 m high, has been erected in these difficult conditions and sealed by a grout curtain, which extends into silts about 50 m below the valley floor. Since the lacustrine silts fill nearly the whole area to be flooded, the grouting of the alluvium to its whole depth of 130 m was not necessary.

The *Beauregard Dam* in the Italian Alps provides another example where a damsite was selected in the valley section narrowed by a Pleistocene rock slide. Detailed investigation has revealed that the right slope and the valley floor is made up of firm mica-schists, whereas the mica-schists of the left slope are strongly disturbed and moved onto the alluvium (A. Desio, 1973). The valley floor is covered with glaciofluvial deposits, as much as 40 m thick, which extend deep

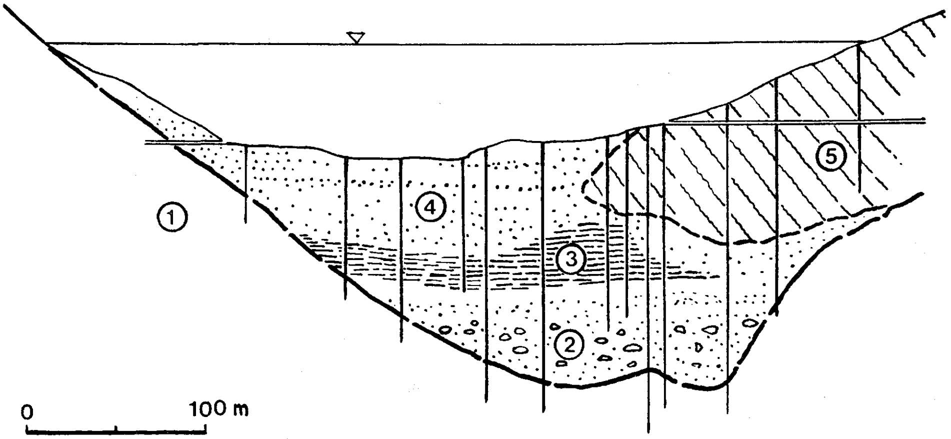

FIG. 2. — *Section of the Durlassboden damsite (after G. Horninger). 1, firm schists; 2, glacial deposits; 3, lacustrine silts; 4, sands and gravels; 5, downslipped graphitic phyllite and quartzite.*

below the foot of the left flank. The construction of an arch dam, 132 m high, demand an adaptation of the project to the geological conditions. Glaciofluvial sediments from a deep pocket below the left flank had to be removed and replaced by concrete. The disturbed rock was consolidated and sealed by grouting. The grout curtain reached to a depth of 150 m and was extended 80 m into the left valley slope (fig. 3).

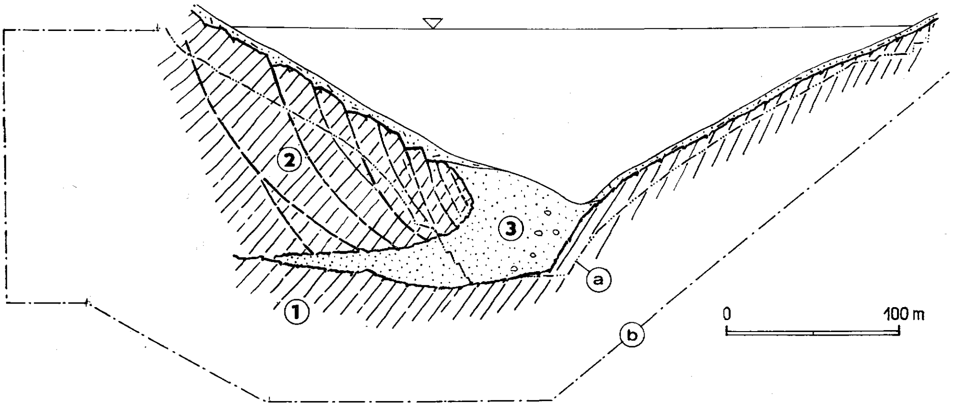

FIG. 3. — *Section of the Beauregard damsite (after A. Desio). 1, firm mica-schists; 2, disturbed downslipped mica-schists; 3, glaciofluvial sandy gravel; a) excavation for arch-dam foundations; b) outline of grout curtain.*

A safe knowledge of the thickness of alluvial deposits in mountain valleys is of particular importance for tunnel construction. Well known is the case of the

Lötschberg Tunnel, constructed in 1908, in the granite massif of the Bernese Alps. The advance gallery struck the waterlogged glaciofluvial deposits of the Kander-river valley. The designers did not presume that these deposits would extend to a depth of 170 m below the ground surface. After a blast the gallery was flooded by water and sand and all tunnel workers were killed. The route of the tunnel had to be relocated so that the tunnel will pass through firm rocks.

It is not without interest that a similar disaster may have threatened the construction of the *Gothard Tunnel* in the seventies of the last century. When recently boreholes were drilled upwards from the tunnel in places of great pressures, it was found out that the bedrock is there only 40 m thick and overlain by 280 m of water-logged glacial drift of the Andermatt basin.

Moraines of mountain glaciers and glaciofluvial sediments are a valuable source of construction material for each dams and concrete structures. The material, however, requires adequate treatment. Material for concrete structures should not contain humic and clay admixtures; weathered grains and pebbles are not admissible either, because they would decrease the strength of concrete. In order to obtain the necessary fractions for concrete aggregate, the natural mixture of sand and gravel must usually be washed and screened.

In choosing material for earth dams a sufficient perviousness of sand and gravel should be ensured. The contamination by fine particles of weathered rocks would decrease it and thus impair the stability of the dam slope. In some cases it was necessary to change the design during construction for this reason.

In high-mountain areas it is often difficult to find fine material for impervious cores. For the *Durlassboden Dam*, for example, fines sorted from slope detritus and weathered phyllites were used, but since the water content of the material was too high for compaction, it had to be dried at a high cost.

3. Periglacial Areas

From the technical point of view, Pleistocene features in the foreland of the continental ice-sheet, in the so-called periglacial area, deserve our attention. Periglacial phenomena are well observable in Central Europe, especially on Czechoslovak territory. This was not covered by ice but the Nordic ice-sheet advanced up to the boundary mountains and produced important climatic effects. Moreover, the Alpine glaciation, which was more extensive than it is today, also influenced the conditions of Central Europe.

In the course of glacial periods, very cold and relatively dry climate promoted in the nonglaciated part of Central Europe intensive mechanical weathering and deep freezing of the ground. Only the near-surface layers were thawing in a few summer months. The melt and atmospheric water was prevented from soaking into *permafrost* (permanently frozen ground) and accumulated in the surface layer of nearly liquid consistency. This resulted in solifluction, a slow flow of waterlogged material downslope over frozen ground, even on very gentle slopes. Owing to soil creep, the surfaces of dragged-out beds, smoothed by ancient movements, are potential slide planes after being exposed in road cuttings (fig. 4).

Intensive Pleistocene mechanical, especially frost weathering, is evidenced by bouldery slope debris derived from firm well jointed rocks. Extensive boulder streams occur, for example, in young volcanic mountains, where basalt or andesite sheets were exposed to periglacial weathering. In case they overlie soft rocks, these

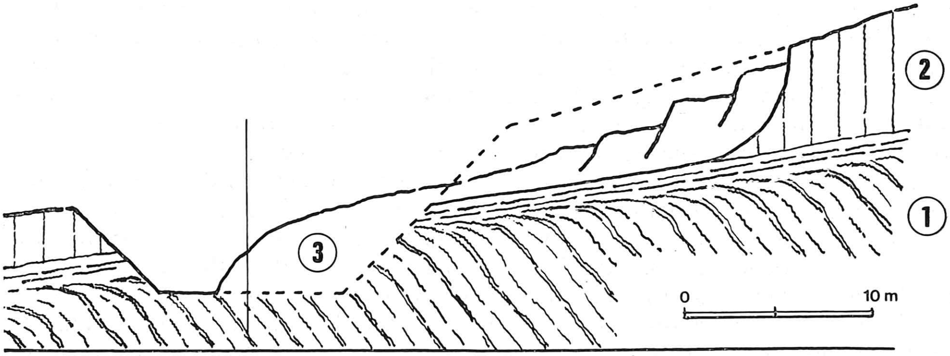

FIG. 4. — *Shales dragged out by Pleistocene solifluction. 1, potential slide surfaces, along which slopes of the cutting may slip down; 2, slope debris; 3, landslide mass.*

may be squeezed out by the load of heavy debris and move downslope. Many failures of clay slopes have originated in this way.

The characteristic disturbance of the ground caused by repeated freeze-and-thaw is known as *congeliturbation*; it involves creep of surface soil, diapiric squeezing of clay deposits toward the surface and contortion of rocks (fig. 5). The ground

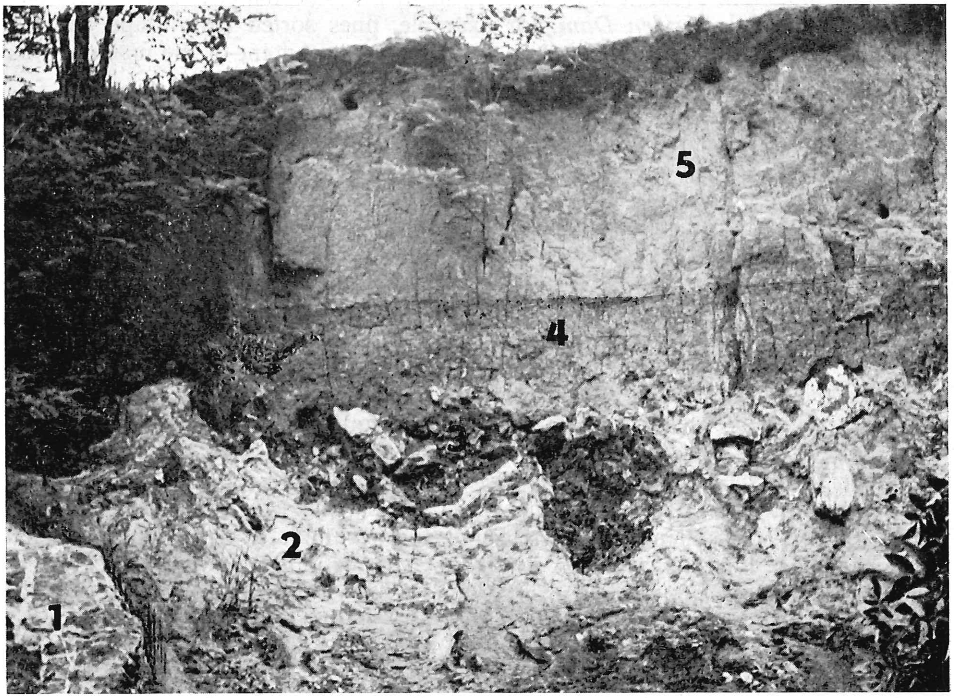

FIG. 5. — *Old surface of Cretaceous marls disturbed by frost action; a lydite quarry northeast of Prague. 1, Algonkian lydite; 2, contorted Cretaceous marls; 3, relic of fossil soil with lydite detritus; 4, older loess; 5, younger loess. Photo by Záruba.*

thus disturbed does not provide good foundation soil, since it is heterogenous and, consequently, of unequal compressibility. Moreover, the fossil features are often buried by younger loess or slope detritus and found only in excavations. In the neighbourhood of Prague, the foundations of an industrial plant had to be additionally deepened because of this reason. A blanket of loess covered an ancient surface of Cretaceous marls, disturbed by frost wedges and solifluction and bearing relics of fossil soil in places (fig. 6). Since the ancient surface was very irregular, the building had to be founded on a deeper layer.

FIG. 6. — *Excavation for the foundation of an industrial plant northeast of Prague. 1, weathered Cretaceous marls; 2, frost wedge filled with fossil soil; 3, marls with soil dragged out by soil creep; 4, loess cover. Photo by Záruba.*

The existence of permafrost is also evidenced by wedge-shaped fissures, which were filled with ice in the Glacials and later by sand or loam. In weathered rocks these ice or *frost wedges* are accompanied by distorsion, crumpling, or even erection of beds. The material has the character of residual detritus grading downwards into sound rock. An example of difficult excavations in frost-disturbed Ordovician shales for a street in Prague is shown in fig. 7. The stability of slopes was threatened by loosening of the rock along fissures filled with sand.

Also interpreted as periglacial phenomena are large-scale deformations of slopes due to squeezing of soft rocks in the valley floors, which have been identified in some opencast mines and excavations for dam foundations. They have been first explained by Hollingworth *et al.* (1944) and called *bulging* and *cambering*.

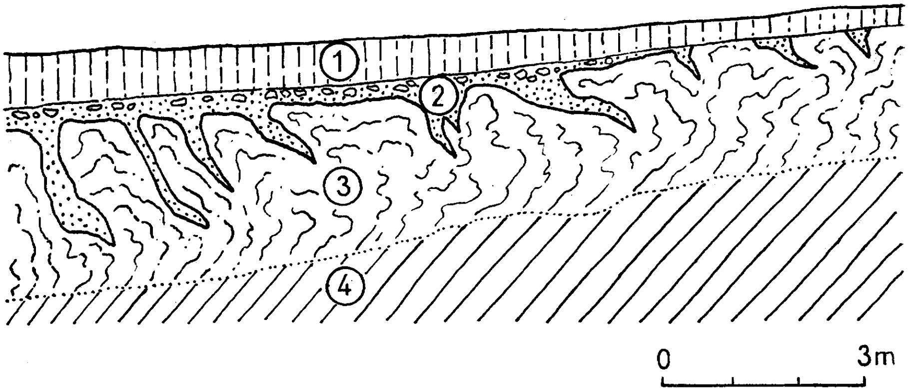

FIG. 7. — *Section showing frost wedges in the wall of excavation for a street in Prague suburb. 1, loess; 2, sand; 3, disturbed shales; 4, firm Ordovician shales.*

G. A. Kellaway (1972) in his recent paper is inclined to the view that the valley bulges developed rather during deglaciation, but he remarks that movements in the valleys affected by bulging and cambering could be renewed by periglacial processes.

Similar phenomena have been described from the Caparthian region, remote from the glaciated areas (Záruba, 1956, 1958). In my opinion, these deformations may have formed either by squeezing of clay rocks towards the area of minimum loading (plastic deformation) or by swelling of clays due to removal of load, upon wetting and freezing. All instances of valley bulging which I had the opportunity to study were fossil features originated under periglacial conditions in the Pleistocene. The interpretations of these plastic deformations, however, are still but working hypotheses. Careful records of them in temporarily accessible excavations will be of great value for their recognition.

The distinctive Pleistocene sediments of periglacial region are *loess* and *loess-like* deposits. They cover large areas in Central Europe, Asia, and North America. Extensive loess blankets originated in several Pleistocene climatic phases; as a result, they are not homogeneous but are composed of a cyclic succession of members. The typical or true loess is an eolian sediment deposited during cold periods. It is calcareous, very porous with vertical jointing and a predominance of silt fraction. The layers of true loess are usually several meters thick and separated from one another by layers of solifluction and hillwash sediments and by relics of fossil soils, which developed during more humid and warmer climatic conditions (Kukla-Ložek, 1961).

From the point of view of the engineer, the loess is a difficult and troublesome soil. On account of their high porosity, loesses are strongly compressible and very sensitive to the differences in loading. Even a small non-uniformity in loading by foundation structures or uneven width of foundations cause considerable differences in the settlement of constructions. The compressibility of loess, moreover, varies vertically, since some layers when forming the fossil ground surface had been altered by weathering, and laterally, depending on structure and chemical composition of the soil. The importance of the knowledge of regional or even local conditions is evident (Záruba-Mencl, 1961).

High permeability of loess, especially in vertical direction, is another unwelcome property in engineering practice. It is because its cohesion decreases rapidly after saturation by water, which promotes an abrupt settlement. The excavation for foundations in this collapsible soil must therefore be protected from the access of water. In the town of Brno, for example, two multistoreyed old buildings collapsed when water from a disused cistern dicharged into the loess subsoil, more than 20 m thick.

It also should be noted that, whereas true calcareous loess is distinguished by the temporary stability of nearly vertical walls in cuttings, the non-calcareous loess loam succumbs rapidly to deformation and sliding. An analysis of the chemical composition of the loessic soils is therefore advisable, especially because these two types are usually not differentiated on the maps.

4. Pleistocene River Terraces

Vertical movements of landmass blocks combined with climatic changes caused an alternation of erosion and accumulation periods in the evolution of streams. As a result of this alternation, a succession of terraces developed in many river valleys. The river terraces are particularly well developed within the area of the *Bohemian Massif.* The gradual uplift of the Massif from the beginning of the Pleistocene led to intensive downcutting of the river beds which was repeatedly interrupted by aggradation during cold climatic phases. Since the rivers were far from the sea, the erosion-accumulation rhythm was not influenced by the fluctuations of the sea level and the sequence of terraces is quite regular, from the oldest at the highest altitude to the youngest forming the floodplain.

The shape and width of valleys were controlled by the hardness of rocks. In the areas formed of hard crystalline and igneous rocks the valleys are narrow, canyon-like and the terraces have been preserved as small denudation relics only. In soft rocks the valleys were widened by lateral erosion; the low terraces are fairly extensive but the higher ones are represented only by isolated relics.

On the basis of information obtained by engineering-geological investigations of potential dam sites, there were distinguished eleven phases of gravel terraces on the Vltava river and other streams of the Bohemian Massif (Záruba, 1961). The terraces have been divided into four groups, which can be correlated with the main glacial phases; Günz, Mindel, Riss, and Würm. The correlation has been based on the topographical position of the terraces, the interrelations of the stages of erosion and accumulation, as well as on palaeontological and palaeomagnetic studies.

Figure 8 shows a section of the Vltava-river valley north of Prague, cut in soft Cretaceous sandstones and marlstones. In this broad valley reach, the old

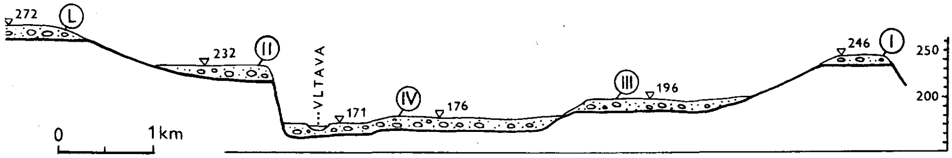

FIG. 8. — *Broad valley of the Vltava river in the Cretaceous sediments near Veltrusy, downstream of Prague. L, I, II, old terraces; III, IV, younger terraces.*

terraces (L, I, II) have been preserved as denudation relics, whereas the younger (III, IV) form thick accumulations of sandy gravel in the valley bottom. As the younger terraces provide suitable material for the concrete aggregate, with pebbles of sound rocks, large sand pits have been opened in them.

In the middle reach of the Vltava, where the steep valley sides are formed of hard crystalline rocks, remnants of sand and gravel accumulations have been found in several places, the altitudes of which correspond to those of the terraces. They provide evidence that during the periods of aggradation even these deep parts of the valley had been filled with thick deposits of sandy gravels, which were, for the most part, removed in the following erosion stage. The sandy terrace deposits have been preserved only under suitable conditions, e.g. in the cores of meanders or buried by alluvial cones (fig. 9).

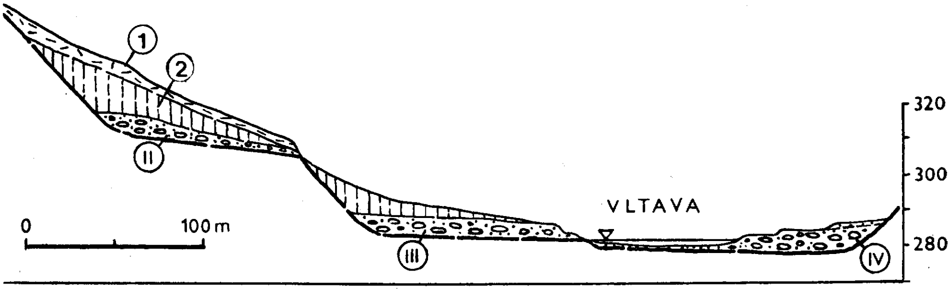

FIG. 9. — *Deep Vltava-river valley in Algonkian crystalline rocks near Zlákovice. Relics of terrace deposits covered by slope debris (1) and loam (2).*

These terrace deposits were regarded as a possible source of materials for the construction of dams of the Vltava Cascade. Engineering-geological investigation, however, has shown that the gravels contain a considerable amount of weathered granite pebbles, pointing to a short transport form their derivation. The terraces could not, therefore, be used for this purpose. The weathered pebbles would impair the quality of concrete and the mechanized exploitation did not permit their sorting. Moreover, the terraces are usually covered with a thick bed of slope debris.

In some areas, Pleistocene gravels of higher terraces make up continuous surfaces or fill ancient channels of abandoned river branches. This is very impropitious for the construction of reservoirs, because the permeable gravels had to be sealed for a considerable distance. Figure 10 shows a site on the *Moravice river* near Slezská Harta, where the construction of a dam 90 m high has been planned. The valley is cut in firm Culm shales and greywackes, but in the right flank an old Pleistocene valley filled with terrace gravels and buried by a basalt flow 800 m broad has been established by boring. Since the very pervious gravels and fractured basalt would form the banks of the future reservoir for a length of about 4 km, their sealing would be so difficult and expensive that the construction of the dam was postponed (O. Horský *et al.*, 1972).

The development of terraces of the Bohemian Massif differs from that of the terraces in the lower courses of the rivers, where the effects of sea-level

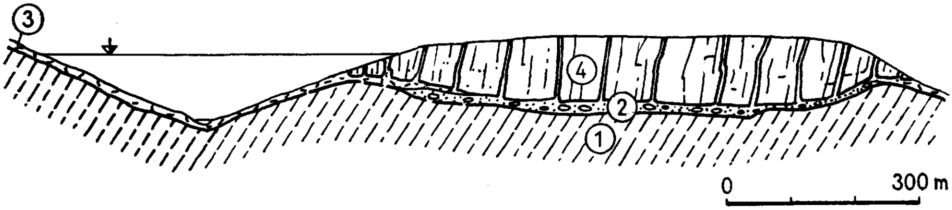

FIG. 10. — *Section of the Slezská Harta damsite on the Moravice river (after Horský). 1, Culm shales and greywackes; 2, Pleistocene terrace gravels; 3, slope debris; 4, fractured basalt flow.*

fluctuations were predominant (Wolstedt, 1952). Irregularities in the sequence of terraces may also be due to young tectonic movements. The terraces of the Danube river within the Great Hungarian Plain, for example, were affected strongly by neotectonic activity.

This short report, based mainly on the results of my experience with Quaternary phenomena in Central Europe, shows what advantage can be gained by the engineers by understanding the Pleistocene history. It remains to add that, on the other hand, excavations for engineering structures have contributed greatly to the knowledge of Quaternary geology.

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