Soils in Canada—A Brief Review

Les Sols du Canada—Une brève causerie

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Soils in Canada is the title of a volume first published by the University of Toronto Press in 1961. It contains seventeen papers presented as a symposium to the annual meeting of the Royal Society of Canada held in Kingston, Ontario, in June, 1960. Out of print for some time now, the volume has been reprinted by the publishers; copies of the second printing were available at the time of the Conference in Montreal.

The symposium brought together papers describing the soils of Canada from the geological, pedological, and soil mechanics points of view. Since the Introduction to the volume gave some of the background to this co-operative approach to soil studies in Canada, and as the last paper presented a broad review of the leading soil problems with which Canadian workers have to deal, abridged versions of these two sections of the book were reprinted in the form of this paper for the information of those attending the Conference, by special permission of the Royal Society of Canada, and of the University of Toronto Press. The volume itself is commended by the Organizing Committee to all who wish to have a reasonably complete over-all view of the soils of Canada.

Soils in Canada est le titre d'un ouvrage publié par l'University of Toronto Press en 1961 et qui contient dix-sept articles présentés comme symposium à l'assemblée annuelle de la Société Royale du Canada tenue à Kingston, Ontario, en juin 1960. L'édition étant épuisée, une seconde impression a été exécutée au temps du Congrès de Montréal.

Le symposium a réuni plusieurs articles décrivant les sols du Canada sous les aspects géologiques, pédologiques et géotechniques. Comme l'introduction de cet ouvrage fait l'historique de ce traitement coopératif des études de sols au Canada et que le dernier article présente une revue générale des principaux problèmes que doivent traiter les Canadiens, des versions abrégées de ces deux sections du livre ont été reproduites sous la forme du présent article pour l'information des participants au Congrès et avec la permission de la Société Royale du Canada et de l'University of Toronto Press. Cet ouvrage est fortement recommandé par le Comité d'Organisation à tous ceux qui désirent avoir à leur disposition une vue générale suffisamment complète des sols du Canada.

FROM THE INTRODUCTION: R. F. LEGGET

THE TERRAIN OF CANADA, the world's third largest country, is unique in that it contains the largest single area of glacial soils found in any country, and correspondingly the largest area of enclosed fresh water. In addition, it is distinguished by at least 500,000 square miles of muskeg. Some of the earlier Canadian geologists, including Sir William Logan and Sir William Dawson, made notable studies of Pleistocene phenomena; there is therefore a long tradition of soil study in geological circles in Canada. Soil mapping for agricultural purposes was started about forty years ago and has made steady progress, greatly accelerated in recent years. Attention to the engineering properties of soils has been a feature of individual Canadian engineering projects for many decades. Some Canadians have been pioneers in this field, notably Samuel Fortier, a graduate of McGill, who did much notable engineering work in the western United States at the end of the last century. Instruction in the new discipline of soil mechanics was first given in a Canadian university as early as 1932, several years before it was officially recognized as an independent branch of study.

In the years since World War II, the Geological Survey of Canada has established a Pleistocene Section and has carried out Pleistocene field investigations in all parts of the country. Soil surveys for agricultural purposes have progressed in all provinces by the co-operative efforts of the provincial and the federal governments and the colleges of agriculture. Soil mechanics has achieved further recognition, not only in educational services but in application on almost all major civil engineering work now carried on in Canada.

With these concurrent developments the liaison between workers in the three disciplines has progressed fruitfully. As an example of this trend, it may be noted that the Associate Committee on Soil and Snow Mechanics of the National Research Council (the function of which is to stimulate and co-ordinate research into the terrain of Canada, with special reference to engineering problems) has for long included in its membership an agricultural soil scientist and at least one geologist.

This liaison between geological, pedological, and engineering soil studies in Canada has developed despite a rather important difference in terminological practice. The agricultural soil scientists have their own definition for the word "soil"; as is well known this includes what others call "topsoil" and the well-recognized "B" and "C" horizons. Geologists and engineers, on the other hand, following the practice established well over a century ago, use the word "soil" to indicate all the fragmentary material in the earth's crust overlying bedrock, with the possible exclusion of the thin layer of topsoil (generally so described) which is of such importance in agriculture. There has been in Canada mutual acceptance of this variation in the use of the word "soil" and corresponding mutual respect for its varying use by the three disciplines concerned. It may be regretted that two words have not come into general use in the English language to correspond with the two Russian words used to distinguish the soil that is of interest in agriculture from the more general soil considered by the geologist and the engineer. In the absence of this convenience in terminology, the word "soil" is therefore used in Canada in the two distinct ways, but its precise meaning will always be evident from the context in which it is used.

There are other differences in terminology within the practices of the three disciplines represented. As an example, it may be noted that geologists in Canada use the word "compaction" where workers in the field of soil mechanics would use the word "consolidation." It is to be hoped that with time and with steadily increasing liaison between geologists and engineers working together on soil problems, these differences will tend to disappear. Correspondingly, it is to be hoped that eventual uniformity will be reached in the limiting equivalent grain sizes for the subdivision of soil particles into sand, silt, and clay sizes, as slight differences of practice still exist.

Canadian workers in all three fields of soil study appreciate the overlapping of their respective interests and the value to be derived from mutual discussion of soil problems. This is reflected by the contents of this symposium volume which deals with the soils of Canada from the three points of view. The volume may be regarded merely as an introduction to a vast subject but it is thought that, through the arrangement of the papers it contains and with the aid of the associated bibliographies, it presents at least a general picture of the major soil types and soil problems encountered in the Dominion. Its coverage is not any sense complete but it may possibly pave the way for more comprehensive treatments in future years.

FROM THE ENGINEERING SIGNIFICANCE OF SOILS IN CANADA: R. F. LEGGET AND R. M. HARDY

The physical development of a relatively new country such as Canada is to a very large degree dependent upon the work of the civil engineer. On the heels of the pioneer work of the first settlers must come the construction of roads, bridges, and eventually railways; the provision of wharves and other aids to navigation; the installation of municipal services, water supplies, and sewage disposal arrangements, as soon as settlements are large enough to require these; the building of powerhouses, some actuated by falling water, others by the combustion of fuel, and the associated transmission lines; and in more recent days, and particularly in Canada, the construction of airports and necessary aids to aerial navigation.

Engineering works, of which this is but a summary listing, are carried out in all parts of the country, chiefly along its southern border, but today throughout the north as well, even in the islands of the high Arctic. Disturbance of the natural ground surface is almost inevitable in all such work, and in all but exceptional cases this means disturbance of soil. The engineer always hopes to have solid bedrock available for the driving of tunnels and the founding of major structures, but in almost all his work he cannot choose his site, having to accept the natural conditions at sites selected on grounds of convenience and economy. Even when bedrock is available, it is almost invariably covered with some "overburden".

The handling of soil in the carrying out of engineering works has therefore been a continuing feature of importance in the practice of construction. "Dirt moving" has become a term in common use. For all too long a time, soil was regarded by engineers as a necessary nuisance, not worthy of the analysis or study given to other construction materials. Fortunately, from the very earliest years of modern engineering practice, there were always exceptional individuals who did not think in this way. In France, Coulomb (1773) and Collin (1846) were amongst the pioneers. At a later date, Canada had her keen students of the engineering properties of soil, Samuel Fortier (Legget, 1949) being but one member of this distinguished company.

Geology and civil engineering are inextricably associated in relation to all use of soil on construction, as they are correspondingly linked in relation to all engineering use of bedrock. A mere glance at the Glacial Map of Canada (1958) will illustrate the significant aspects of this correlation. The almost complete absence of unglaciated areas with associated residual soils, that can be very troublesome on engineering works, is the first notable feature. The widespread existence of glacial till as the soil mantle is an equally fortunate feature, as is also the common occurrence of such other glacial soil features as moraines, eskers, and kames, providing, as they so often do, supplies of sand and gravel.

On the other side of the balance sheet, however, is the vast extent of clays deposited in the great glacial lakes of Canada, and in the encroachment of the sea up the St. Lawrence and Ottawa valleys, and around the coasts of Hudson Bay and the eastern Arctic, and, to a lesser extent, the Pacific Ocean. Mainly because of their geological history, these clays include some of the most troublesome of all "normal" soils. Reference need be made merely to such disasters as the failure of the Transcona Elevator in 1913 (Baracos, 1957), the tragic filling of the Beattie Mine with "mud" in 1944, and a similar accident at the Josephine Mine in 1946 (Legget and Eden, 1960) to demonstrate that Canada does have soils that can have disastrous effects upon engineering works if they are not properly understood.

Canada's unusual climate makes its own contribution to engineering soil problems. Climatic factors are at least partially responsible for the vast expanse of fossilized vegetation (muskeg) that forms a surface cover over so much of northern Canada and which, although not strictly a soil, constitutes an important part of the terrain. Associated frequently with muskeg, but far more widespread and more significant, is the phenomenon of permafrost, the perennially frozen condition of the ground. When the ground consists of saturated silt or clay, permafrost can prove to be perhaps the most difficult of all soil conditions with which the engineer has to deal (Pihlainen and Johnston, 1954).

Glacial and Marine Clays

Crawford (1961) has described the results of extensive engineering tests upon the Leda clay of the Ottawa and St. Lawrence valleys which is typical of the marine clays that are described as "sensitive". This peculiar but extremely important physical property of these soils, found also with similar marine clays in Scandinavia, is directly related to the process of deposition of the soil particles that constitute these clays. That sedimentation took place in salt water is confirmed by the residual salt content in the pore water of these clays today. Variability of this salt content, through leaching, affects some of the clay's physical properties to a marked degree.

The intermolecular attraction at the time of deposition has been established as the factor responsible for the loose, brittle structure of the soil. This structure is sensitive to disturbance, and strains as low as 3 to 5 per cent may result in destruction of the internal bonds. If this occurs the soil loses its shear strength, and soils which have previously been quite "solid" in appearance and behaviour suddenly become quite fluid (Rosenqvist, 1959).

Similar soil instability is found with some fresh-water glacial clays. Dramatic evidence of this was provided by the slides which filled first the "glory hole" and eventually the underground workings of the Beattie gold mine near Duparquet, Quebec, in 1944 and again, and finally, in 1946. Recent studies suggest that the process of excavation followed in excavating in the "glory hole," with a large dragline, eventually resulted in slopes which exceeded the critical safe limit for the local glacial clay (a deposit in Lake Warren?); slope failures resulted which triggered the immense flow slides which had such tragic results (Tuttle, 1939).

A similar disaster overtook the Josephine iron ore mine, north of Sault Ste. Marie in 1946 (Gallie, 1947). Here the underground workings were located beneath Parks Lake which was drained of water, but not of the soil deposits in its bed, before underground mining commenced. Stoping that could not be controlled eventually broke through the lake bottom: this disturbed the unstable glacial clay that formed the lake bed which thereupon started to flow into the workings, completely filling them in the course of three hours. The mine has not been operated since the disaster.

Innumerable minor troubles with these potentially unstable glacial lake clays illustrate the same phenomena that occurred in these major disasters, all of them dependent upon the geological origin of the soils in question. The typically high natural moisture content of these soils affects their strength and compressibility, and so their load-carrying capacity and settlement characteristics. Today this is understood; laboratory tests upon soil samples can determine safe bearing capacities and compressibility properties in advance of design. Before these techniques were available, however, experience had to be the guide, and the solid superficial appearance of these clays led to serious differential settlements as well as to many foundation failures, of which the most notable was the tilting, to an angle of 26°, of the large concrete grain elevator at Transcona, Manitoba, in 1913 when first filled with grain (Baracos, 1957). Recent studies have demonstrated the cause of the failure, which was clearly related to the physical property of the local clay, here a deposit in glacial Lake Agassiz.

Rominger and Rutledge (1952) have reported an extensive investigation of the engineering properties of the clays of Lake Agassiz and have correlated their results with the geology of this unusually large fresh-water lake. (Their studies were conducted upon soil samples obtained in North Dakota but since the area of Lake Agassiz south of the border is a very small proportion of the total, this pioneer investigation may be considered to be almost a Canadian study.) By carrying out a variety of soil mechanics tests upon almost 450 samples from three locations, the authors were able to correlate lithologic units not easily defined by ordinary geological methods and to locate accurately the depth of an old drying surface, within the clay, that indicated a geological interval not otherwise apparent. This correlation of the results of soil mechanics tests conducted in the laboratory with geological interpretations has placed a significant new tool in the hands of the geologist, as is shown by a number of more recent studies including those of Dreimanis (1961).

Glacial Till

Glacial till is usually a very compact material, its composition as a mixture ranging from boulders to clay-sized particles often giving unusually high densities. It is frequently encountered in so overconsolidated a condition that it has an almost rock-like character, until it comes into contact with water. This can be extremely serious when such material is encountered in excavation work, as recently occurred on the construction of the St. Lawrence international power and seaway project. Knowledge of the glacial history of an area can here prove to be a very useful guide, the relative age of glacial till usually indicating whether it has been consolidated by later ice pressure or not (Wright, 1920).

The familiar character of glacial till makes more remarkable the fact that tills have been encountered in the Ungava-Labrador area that are the reverse of overconsolidated, their solid character disappearing immediately water comes in contact with them. They are found to have an open structure, possibly the result of high ice content when deposited and subsequent thawing; water can therefore quickly fill the open voids, where it is held because of the well-graded mixture of particles. As a result the till, when wet, very quickly becomes "soup", with difficulties for contractors that can readily be imagined (Woods, *et al.*, 1959).

Some Western Soils

In western Canada, all the foregoing soil problems are to be found as well as some that are peculiar to the area. A particularly troublesome soil type occurring widely in western and northwestern Canada is shale. Shales of Cretaceous age occur in a strip several hundred miles wide to the east of the Rocky Mountains and may be interbedded with coal seams, silt, sand, siltstones, and sandstones. These deposits are characterized by a wide variety of cementing media. Many of the shale types are compressed clays in which the major diagenetic process in their formation has been overburden pressure from the weight of overlying glaciers. They now exist at much reduced overburden pressures from the maximum during their geological history, and are therefore in a state of "rebound," in soil mechanics parlance, in which they are tending to revert to clays. The process is accelerated by the availability of subsoil moisture and weathering action, including freezing and thawing. In the field of soil mechanics such shales have been designated "clay shales", and are also known as "preconsolidated" or "overconsolidated" soils (Hardy, 1957).

These shales are rocks from the geological point of view but are on the borderline between rock and soil. They exhibit a very wide variation in properties of significance in engineering practice. Rock excavation techniques may be necessary for their excavation, but what appears to be hard sound rock immediately following blasting reverts to a loose mass of clay within a few hours of exposure to weathering. The rebound process under reduced overburden pressures has resulted in the formation of fractures, fissures, and slickensides in the shale strata at shallow depths, particularly adjacent to the major river valley. The parent material consists of clay-size particles varying widely in plasticity characteristics. Some deposits contain a high percentage of montmorillonite, occasionally pure bentonite, and these shales are capable of exerting high swelling pressures in the process of reverting to highly plastic clays under reduced overburden pressures.

These characteristics result in unusual problems in a wide variety of engineering practice in the areas of occurrence of such soils. In highway work, in particular, conventional methods of roadbed construction may precipitate tremendous, deep-seated slides, in which the change in stability conditions due to the construction appears to be very minor in relation to the huge forces involved in the ultimate soil movement. The collapse of the Peace River bridge at Taylor, B.C., is a spectacular example of the engineering problems arising with these soils. The collapse occurred some fifteen years after the bridge was built and was caused by a large slide which developed in clay shale on the north bank of the river. The slide was 900 feet long and extended to a depth of about 130 feet below the top of the shale bed. The weight of the bridge foundations in the slide area and the loads transferred to them from the bridge were insignificant compared to the forces involved in the moving mass of soil within the slide area; the bridge foundations merely rode along with the moving soil mass. The cause of the slide was a major unloading of the area adjacent to the north of the bridge incidental to the construction of the approach road to the bridge and major alterations to the surface drainage pattern adjacent to the north end of the bridge. The precipitation during the six months before the collapse substantially exceeded the precipitation during any comparable period in the history of the bridge.

Anomalous situations can arise in building construction in the areas of these soils. In engineering practice one usually expects buildings to settle if foundation conditions are poor. With clay shales, however, the movement may be one of heaving rather than settlement. A second anomaly arises in connection with the concept of safe bearing pressure for the soil. Conventionally, structural designers consider that the safety of a foundation is increased by reducing the bearing pressure on the soil. For clay shales which exhibit high swelling characteristics, however, reduction in the bearing pressure may result in a less safe foundation. It is frequently advisable to specify that the bearing pressure shall not be less than a lower limit based on the swelling properties of the soil.

A large portion of Saskatchewan is underlain by the Bearpaw shale; the characteristics of this soil place it within the group of clay shales. Extensive and detailed investigations have been made of the engineering properties of this shale, incidental to the design of the South Saskatchewan irrigation and power project, by the staff of the Prairie Farm Rehabilitation Administration of the Canadian Department of Agriculture. Their work has suggested that some of the slumping along the valley of the South Saskatchewan River is due to the slow expansion of the shale both horizontally and vertically, and that these movements in recent geological time have amounted to hundreds of feet (Peterson, 1958). It has also been shown that the rebounding shale is capable of exerting substantial swelling pressures. This characteristic is of considerable economic importance in the design of tunnels; extraordinarily high pressures build up on the linings, and the horizontal pressure has been found to be considerably greater than the vertical pressure.

The characteristics of these clay shales is a subject of current research. With the present state of engineering knowledge concerning them, it is for practical purposes impossible to predict accurately by subsurface exploration where instability will definitely develop in side hill construction. Further, the presently accepted methods for analysing the stability of slopes do not appear to be adequate to predict accurately the safety of slopes in these materials.

In the Kamloops area of British Columbia, troubles have been experienced with the foundations of buildings and irrigation structures and the performance of roads built on the local loess, a type of soil not generally realized to occur in Canada (Hardy, 1950). The open structure of loessial soils renders them always susceptible to the effect of water, saturation with water being an accepted method of site preparation. In the Kamloops area, a further complication arises from the fact that the loess contains from 5 to 6 per cent of calcium carbonate, giving to the soil some artificial cohesion. Percolating water will dissolve the calcium carbonate, destroying the artificial cohesion, and the soil will thus consolidate under its own weight together with any superimposed load that it may be supporting, with possibly disastrous results. A small colloidal clay content in such loessial soils may also impart an artificial cohesion which is destroyed by contact with water.

Northern Soil Problems

In the north, few new soil features of significance in engineering are encountered, although the relative distribution of southern features changes markedly. Solid rock exposed on the ground surface, for example, with its elimination of all soil problems, although infrequent in southern Canada, is common in the north. Similar also, and indeed often associated with shallow rock cover, is the distribution of muskeg. In the south a minor nuisance in engineering work, except in highway construction, its distribution being so limited and spasmodic that it can usually be avoided in site selection, muskeg in the north is so extensive and can be so troublesome that its existence may make the difference between the success or failure of some engineering enterprises. When it is realized that Canadian oil companies have had to develop over 100,000 miles of trails through the "bush" of northern Alberta and British Columbia, that much of this vast mileage has been over muskeg, and that over these trails unusually heavy drilling and construction equipment has had to be moved, it will be appreciated that muskeg is a very real "soil problem" to the engineer (Keeling, 1958). It was to assist with the very practical problem of trafficability over muskeg that Dr. N. W. Radforth started his fundamental studies of organic terrain; the lecture by Dr. Radforth to this Conference is recognition of the significant place occupied by muskeg in Canadian engineering terrain studies.

In northwestern Canada, the residual soils that are to be found in unglaciated parts of the Yukon, such as badly weathered granite, have caused minor interference with engineering work, but no significant problems. Much older soils were encountered in test drilling work carried out recently on the Lewes River in connection with the development of power from the Whitehorse Rapids. Deep boreholes here encountered sands and silts after penetrating 150 feet of solid basalt, a surprise to some of the engineers engaged on this work, a salutary reminder to all who have heard of the occurrence of the changing geological scene.

At nearby Whitehorse airport, engineers utilized the natural plateau provided above the town by the 200-foot deposit of glacial silt, which is here such a notable physiographic feature, to form one of the most convenient and safe of all northern airfields. Unfortunately, some associated engineering operations had the effect of destroying the stability that natural vegetation had given to the steep slope which separates airport and town. The subsequent erosion of this slope has become a singularly vivid reminder of the vital importance of working with nature in the protection and promotion of vegetation in all work involving soil slope stability.

Permafrost

Permafrost is encountered in the Yukon, just as in Alaska, but in the Northwest Territories it is the almost universal condition of the ground. It must be stressed that the word "permafrost" when used literally applies to a ground condition and not to a special material. Despite the valiant efforts of a geologist (Dr. Kirk Bryan) to introduce the use of semantically accurate words for the description of frozen ground, the terminological inexactitude of "permafrost" persists. Its use is further confounded by the singular semantic sloppiness of engineers who sometimes use the word to describe perennially frozen silt, the major cause of trouble to engineers in areas of permafrost.

At a depth of about twenty feet the temperature of undisturbed ground can be shown to be reasonably constant throughout the year. Between this depth and the surface the temperature of the ground varies. The closer to the surface, the greater is the variation. It is generally seasonal but at shallow depths it is also diurnal. The steady temperature at depth is usually found to be within a few degrees of the mean air temperature for the locality throughout the year. When, therefore, local annual mean air temperature is appreciably below 32 F, the ground will be perennially frozen, thawing occurring only very close to the surface during the later weeks of the short northern summers. At depths below 20 feet, ground temperature is known to increase slowly but steadily, in places at the rate of one degree for every 150 feet. It therefore follows that with perennially frozen ground, the frozen condition will persist downwards to such a depth that the normal increase of temperature with depth eventually raises the sub-freezing ground temperature to 32 F.

Permafrost in Canada may therefore be visualized as an immense wedge-shaped condition of the ground, the thin end of the wedge being a very irregular southern band of discontinuous frozen ground, the wedge thickening towards the Pole. Maximum depth so far observed in Canada is approximately 1,300 feet at Resolute Bay on Cornwallis Island. Although there are scattered isolated references to "frozen ground" in the older literature of the north, some of unusual interest, the significance of permafrost was not generally appreciated until the last two decades. Recent geological interest in geothermal problems has directed the attention of some geologists to the fascinating theoretical questions posed by permafrost and its manifestations, but it has been the work of the engineer in opening up the north, starting with the construction of the Alaska Highway, that has focused attention upon the practical problems created, in some areas, by permafrost. As is so often the case, the search for answers to these problems has led first engineers and then scientists into quite basic studies of the thermal régime of the surface of the ground, with special reference to the north (Legget, *et al.*, 1961).

When the ground consists of solid rock or well-drained dry soils, such as sands and gravels, the frozen condition is generally of theoretical interest only. When, however, permafrost is the condition of saturated silts or clays, it becomes of major practical importance. If the frozen condition is ameliorated, material previously rock-like in character may be quickly converted into the engineering equivalent of soup, with results that can be generally imagined. Thus, when muskeg was scraped off frozen glacial silt in early northern road construction, the hard frozen silt quickly became a quagmire. Heated buildings in contact with frozen soil would start to settle, and not always uniformly, as soon as their heating systems were placed in operation. Even the effect of solar radiation on large buildings in the far north has been found to cause differential settlements, measurable in feet, between the north and south facing walls. These were early engineering problems; solutions to them are now available; study of them continues.

Engineering Excavations

The contributions that may be made to geological knowledge, and particularly to the extension of Pleistocene information in Canada, through careful observation of the soil cross-sections revealed by engineering excavation work, is the natural and welcome reciprocal of the contributions that geological information can make to the satisfactory conduct of soil engineering. Notable in Canadian experience of this kind was the use made of the remarkable exposures of varved glacial clays in the bed of Steep Rock Lake, after draining.

This lake in northwestern Ontario had an area of about ten square miles. It formed part of the course of the Seine River but the river was diverted by a major civil engineering operation so that two ends of the lake could be dammed and the entire lake pumped out. This operation was successfully completed. Subsequent excavation of the lake bed deposits revealed what is probably the largest exposure of varved glacial clays ever seen. These were studied by Dr. Antevs (1951) as purely geological phenomena, and also in connection with the engineering development of the two iron ore mining operations that are now in progress in the old lake bed (Eden, 1955). Geological knowledge of varved material was thus advanced almost as a by-product of engineering operations (Legget, 1958).

On a different scale and with entirely different geological conditions, the excavation for Canada's first subway, the Yonge Street line of the Toronto Transit Commission, was similarly used for geological purposes incidental to the major engineering undertaking represented by the construction of this subway line. A complete soil profile along the subway was obtained and a full suite of soil samples was deposited for future use by geologists in the Royal Ontario Museum. Geological studies of the soils thus revealed have added further information to the stock of knowledge regarding the justly famous Toronto interglacial beds (Legget and Schriever, 1960).

CONCLUSION

This general review will at least serve to show the variety of problems related to soil mechanics and foundation engineering with which Canadian engineers have to deal. There are today in all parts of the country well-equipped soil mechanics laboratories, from St. John's, Newfoundland, to Victoria, British Columbia, from southern Ontario to Inuvik in the Northwest Territories, almost on the Arctic Coast. They are to be found in commercial testing laboratories, in the service of provincial and federal governmental agencies, in the buildings of the larger firms of consulting engineers and of major public utilities, and naturally in universities.

There are now twenty-one universities in Canada granting degrees in engineering. In almost all of them, soil mechanics is a regular part of the undergraduate curriculum for students in civil engineering, thus continuing the pioneer practice of over thirty years ago. Today, graduate training is well established at about half of the universities mentioned, with correspondingly active research programmes.

The results of this Canadian work are to be found reported in the regular outlets for reports on such work, such as in the pages of *Géotechnique* and in the *Proceedings* of the international conferences. For almost twenty years, preliminary reports were often presented at the annual Canadian Soil Mechanics Conferences, sponsored from 1947 to 1962 by the Associate Committee on Soil and Snow Mechanics of the National Research Council. Mimeographed *Proceedings* of the first sixteen of these Conferences were published as *Technical Memoranda* of the Associate Committee. Although most of these are now out of print, complete sets are to be found in libraries around the world.

The Seventeenth Conference, in 1963, was the first to be sponsored solely by the Engineering Institute of Canada, to which the Associate Committee has gradually transferred responsibility for these annual meetings, in view of their changing character and increasing size. Concurrently there was established, under the joint auspices of the two bodies mentioned, the *Canadian Geotechnical Journal*, in the pages of which many of the papers given at the annual conference will now be published. This quarterly journal, now well into its third volume, has already established itself as a further international medium for the publication of given papers on soil mechanics and associated subjects. Copies were on view at the Montreal meeting.

The Sixth International Conference is being held just twenty-one years after the establishment by the National Research Council of the Associate Committee on Soil and Snow Mechanics. Although initially charged with an urgent inquiry into a wartime terrain problem, the Committee was envisaged from the outset as a co-ordinating body for assisting with the development of soil mechanics work in Canada by the President of the National Research Council at that time, Dr. C. J. MacKenzie. It was he who suggested the dual title for he saw even then the relevance of modern soil studies to the problems of snow and ice with which Canadian engineers also have to deal. The holding of the Sixth International Conference in Canada is a challenge to all Canadian workers in the geotechnical field to continue and develop the progress so briefly here recorded.

REFERENCES

ANTEVS, E. (1951). Glacial clays in Steep Rock Lake, Ontario. *Bull. Geological Society of America.*, Vol. 62, pp. 1223–62.

BARACOS, A. (1957). The foundation failure of the Transcona grain elevator. *Engineering Journal.*, Vol. 40, p. 973.

COLLIN, ALEXANDRE (1846). Landslides in clays. Translated by W. R. SCHRIEVER. Toronto: University of Toronto Press, 1956.

COULOMB, C. A. (1773). Essai sur une application des règles de maximis et minimis à quelques problèmes de statique, relatifs à l'architecture. *Mémoires de l'Acadèmie des Sciences* (*Savants Etrang.*) (Paris) Vol. 7, pp. 343–82.

CRAWFORD, C. B. (1961) Engineering studies of Leda Clay. In R. F. LEGGET, ed., *Soils in Canada*, Royal Society of Canada, Special Publication No. 3, pp. 200–17. Toronto, University of Toronto Press.

DREIMANIS, A. (1961). Tills of Southern Ontario. In R. F. LEGGET, ed., *Soils in Canada*, pp. 80–96.

EDEN, W. J. (1955). A laboratory study of varved clays from Steep Rock Lake, Ontario, *American Jour. Science*, Vol. 253, pp. 659–74.

GALLIE, A. E. (1947). Mining methods and costs at the Josephine mine. *Canadian Mining and Metallurgical Bull.*, No. 427, pp. 589–683. Glacial map of Canada (1958) Toronto, Geological Association of Canada.

HARDY, R. M. (1950). Construction problems in silty soils. *Engineering Jour.*, Vol. 33, pp. 775–9.

——— (1957) Engineering problems involving preconsolidated clay shales. *Trans. Engineering Institute of Canada*, Vol. 1, pp. 1–10.

KEELING, L. (1958) Some aspects of the terrain problems in Northwestern Canada. N.R.C., Associate Committee on Soil and Snow Mechanics, Fourth Muskeg Research Conference, Proceedings, *Technical Memorandum 54*, p. 11.

LEGGET, R. F. (1949). Samuel Fortier, pioneer in soil mechanics. Engineering Journal, Vol. 32, p. 68.

——— (1958). Soil engineering at Steep Rock iron mines, Ontario, Canada, *Proc. Institution of Civil Engineers*, Vol. 11, pp. 169–88.

———, H. B. DICKENS, and R. J. E. BROWN (1961). Permafrost investigations in Canada. In G.O. Raasch, ed., *Geology of the Arctic*, Vol. 2, pp. 956–69. Toronto, University of Toronto Press.

——— and W. J. EDEN (1960). Soil problems in mining on the Precambian Shield. *Engineering Jour.*, Vol. 43, pp. 81–7.

——— and W. R. SCHRIEVER (1960). Site investigations for Canada's first underground railway (the Toronto subway). *Civil Engineering and Public Works Rev.*, Vol. 55, p. 73.

PETERSON, R. (1958). Rebound in the Bearpaw shale, Western Canada. *Bull. Geological Society of America*, Vol. 69, pp. 1113–24.

PIHLAINEN, J. A., and G. H. JOHNSTON (1954). *Permafrost investigations at Aklavik (drilling and sampling), 1953*. N.R.C., Division of Building Research, publication NRC 3393.

ROMINGER, J. F., and P. C. RUTLEDGE (1952). Use of soil mechanics data in correlation and interpretation of Lake Agassiz sediments. *Jour. Geology*, Vol. 60, p. 2.

ROSENQVIST, I. TH. (1959). Physico-chemical properties of soil: soil water systems. *Proc. A.S.C.E.*, Vol. 58, SM 2, pp. 31–54.

TUTTLE, J. (1939). The spiral stoping system as applied at the Beattie mine. *Trans. Canadian Institute of Mining and Metallurgy*, Vol. 42, pp. 95–122.

WOODS, K. B., R. W. J. PRYER, and W. J. EDEN (1959). Soil engineering problems on the Quebec North Shore and Labrador Railway. *American Railway Engineering Association Bull.*, Vol. 60, pp. 669–88.

WRIGHT, G. F. (1920). *Ice age in North America and its bearing on the antiquity of man*. 6th ed. Ohio, Oberlin Publishing Company.