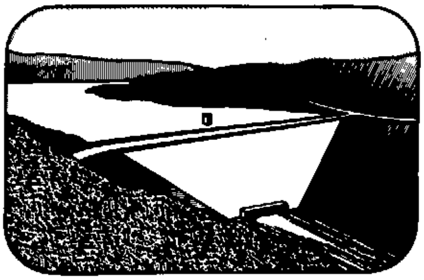

The Quaternary and Civil Engineering

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It has been estimated that at least 72 per cent of the area of the globe, excluding only those parts covered by ice or fresh water or underlain by permafrost, is covered with soil (Goldberg *et al.*, 1965). This is a surprising figure, contrasting strangely with the predominance of papers dealing with solid rock throughout the entire literature of geology. Most of the soil cover of the globe is Quaternary in age, much of it Recent, and so the attention that is now being given to Quaternary studies - typified so well by the life-long work of him in whose honour this symposium was held - is well warranted. Not only are there Quaternary geological problems to be solved, as complex as they are fascinating, but it is in these same deposits that the relics of man's own early history are to be found. This is well recognized by the inter-disciplinary approach that today features all Quaternary research.

If attention be confined to Canada, the same overall picture will be found, with the added feature that 75 per cent of the soil cover of Canada consists of till. Accordingly, there are something like two million square miles of this country, the surface geology of which consists of soil. This is a surprising figure when considered against the popular ideas of the "vast areas" of exposed bedrock in this country. Popular photographs of scenic Canadian terrain support such erroneous ideas but this has to be accepted since it would be difficult to arouse aesthetic enthusiasm for the geological beauty of a flat till plain or even of a prominent moraine.

It is in this same mantle of soil that the civil engineer carries out most of his work. All engineering structures have to be supported by the ground. In almost all cases this involves some excavation, either for reaching ground of adequate bearing capacity or, in the case of building, for providing the necessary underground space for deep basements. Transportation routes require the excavation of large quantities of soil for the cuttings necessary for achieving economical grades, and the corresponding placement of large quantities of fill. Tunnels are excavated preferably in solid rock but the requirements of modern water and sewerage services are necessitating the boring of an increasing number of shallow tunnels, usually in soil.

It is impossible to estimate with any degree of accuracy the quantities of soil thus moved in the course of civil engineering construction work. One of the most valiant attempts at such an estimate known to the writer was that of R.L. Sherlock (1931) who ventured the suggestion that the *total* volume of excavation in Great Britain, to the end of the year 1913, for the main branches of construction is as shown in Table I.

Table I - *Total Volume of Excavation in Great Britain to 1913.*

Railways	3,030,456,000 yds^3
Canals	200,000,000 yds^3
Manchester Ship Canal	53,500,000 yds^3
Roads	624,000,000 yds^3
Marine Works	100,000,000 yds^3
Foundations	500,000,000 yds^3
TOTAL	4,507,956,000 yds^3

Four and a half billion cubic yards is a quantity impossible to appreciate directly. As an aid, it may be noted that the volume of the great Pyramid of Giza in Egypt, well known through photographs as one of the "wonders of the world", has a volume of about three and a half million cubic yards. (It measures about 776 feet square at its base and 481 feet high.) Excavation for civil engineering construction in Great Britain was therefore of the order of about 1,200 Giza pyramids, but this was only up to the end of 1913. Any estimate of the corresponding volume of excavation in Canada up to the present day would lead to astronomical figures that would have little meaning. On one recent job alone, 51 million cubic yards of material (mostly soil) had to be excavated - 15 pyramids - this being the St. Lawrence Seaway and Power Project, to which Prof. Dreimanis alluded. Excavation of varved clay from the bed of Steep Rock Lake in northwestern Ontario, merely to give access to the valuable iron ore beneath the Lake, amounted to about 300 million cubic yards for the initial stage alone - 85 pyramids.

The relevance of these vast quantities of excavated soil to Quaternary studies will be obvious, despite the general neglect on the part of both engineers and geologists of the significant inter-relation of the two. Steep Rock Lake was selected as an example from the many available in the records of recent Canadian construction because here the geological significance of the soil exposure was recognized from the outset of the work. A leading expert on varves was invited to the mine when the varving was best exposed. He published an account of his observations although (strangely) with no reference to the companion geotechnical studies of which he was fully advised (Antevs, 1951).

The fact that the works of the civil engineer can provide the geologist, and especially the student of the Quaternary, with new exposures of value, although so infrequently recognized today, is not new. It has been recognized by some from the very earliest days of geological field work (and of civil engineering construction), in North America as elsewhere. After Charles Lyell had visited North America in 1841-2, he wrote a two-volume account of his travels and observations. On page 6 of the first volume, this comment will be found (Lyell, 1845):

> "Several excavations made for railways in the neighbourhood of Boston, through mounds of stratified and unstratified gravel and sand, and also through rock, enabled me to recognize the exact resemblance of this part of New England to the less elevated regions of Norway and Sweden . . . ."

Lyell crossed into Canada in the spring of 1842 and was here welcomed by Thomas Roy, a civil engineer and geologist of Toronto, with whom he had been in correspondence. Roy was a remarkable man of whom all too little is yet known (Legget, 1976). His work on the first railway survey north of Toronto had shown him the raised beaches of Lake Iroquois. He recognized them for what they were and described them in 1837 in a paper to the Geological Society of London (Roy, 1837). It was presented to the Society on behalf of the author by Charles Lyell on 22 March and 5 April 1837. One can readily imagine the mutual pleasure that the meeting of the two men must have given. The idea of a civil engineer showing the great British geologist glacial landforms so close to London is singularly opposite to the deliberations of today.

Thomas Roy exchanged letters with James Hall of New York State Geological

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Survey, some of which have been discovered (although not yet published). In these he shows a clear grasp of the draining of the earlier Great Lakes along well defined channels, the only thing missing from his vivid descriptions being an appreciation of the ice age which we now know to have been the cause of so much of local Quaternary geology. But Roy did use the exposures of soil resulting from construction works to further his geological knowledge, as witness this extract from a letter to Hall dated 13 January 1842:

> "In making an excavation not far from the Lake (Ontario) the blue clay was reduced in thickness and the Brown surface clay 12 or 15 feet thick regularly stratified over the blue clay, we found several organic remains deposited in the broken strata of the blue clay,amongst other things a piece of wood cut into shape by a stone hatchet or some other blunt instrument. It had the marks of a wythe twisted round its middle and no doubt was used as a mallet. It was found 23 feet below the present surface of regularly stratified clay. Does not this indicate that the more levated parts of the continent had been inhabited whilst the lower parts were still submerged and even before the present fertile surface was deposited."

It is tempting to wonder what became of that interesting specimen but, after his death in August 1842, all traces of Roy's work disappeared. Nothing is yet known of his life before he came to Toronto in 1836 but the letters he wrote to James Hall indicate that he had travelled widely in eastern Canada and in Ontario. He remains a man of mystery.

There were others in the early days of Canada who had a lively interest in soil, not the least being Sir William Logan. But as mining caught the imagination of the public, geology in Canada become more and more the study of bedrock. Interest in soils continued, although in low key, as shown by the fact that ten per cent of the earlier maps published by the Geological Survey of Canada featured some aspect of Pleistocene geology. At universities there were a few men in Departments of Geology, notably Dr. A.P. Coleman at Toronto, who did outstanding work on the geology of soils, but it was not until the years following the second world war, and more particularly during the last two decades that studies of Quaternary geology have gained the recognition in Canada which they warrant.

Lest it be thought that this is a somewhat jaundiced personal opinion, some figures from a notable review of the "state-of-the-art" of studies of till, published as recently as 1976 may be cited. The list of references accompanying this wide-ranging review numbers 172. Ninety-three, or 54 per cent are publications of the 1970s, 50 come from the 1960s, but only 29, or 17 per cent, for the period before 1960, extending back for almost 100 years. The author of the notable paper was Prof. Aleksis Dreimanis (Dreimanis, 1976).

In civil engineering a similar general pattern is to be found - a general neglect of soil as a material worthy of study, brightened only by the pioneer studies of a few individual workers. The awakening here came well before the second world war, being well indicated by the holding in 1936 of the first International Conference on Soil Mechanics and Foundation Engineering at Cambridge, Massachusetts. This meeting formed part of the tercentenary celebrations of Harvard University. It must be admitted that "Soil Mechanics" was an unfortunate choice of name, adapted as a translation of the German word *Bodenmechanik*. It is gradually but steadily being replaced by the far better word *Geotechnique*, one with the added virtue of being a "bilingual word" (if such an expression can be permitted).

The guiding spirit in the development of Geotechnique was a man of true genius, Karl Terzaghi. In his inaugural address, as in all his own work, Terzaghi stressed the vital importance of study of the geology of soils as a first and essential step in the engineering use of soils. Today, Geotechnique is well recognized and used throughout the world but its important association with Quaternary geology is not always appreciated as well as it should be, and as Terzaghi always urged. Nor do geologists seem to have availed themselves as fully as they might have done of the powerful aid that geotechnical studies can be in Quaternary geology. It has even been suggested that in some mysterious way, engineers "stole" Soil Mechanics from geologists, a concept so ludicrous as to verge on the tragic and yet one which may have indirectly affected adversely the most desirable links between the two disciplines.

As early as 1944 A.W. Skempton had presented a review of the theory of consolidation of clays, developed by Terzaghi, to a geological audience (Skempton, 1944). In 1953 he gave a broader review of the geological implications of soil mechanics to another geological audience (Skempton, 1953). Supplementing these two early papers was a significant publication of J.F. Rominger and P.C. Rutledge (1952) on Lake Agassiz sediments. It showed how the relative simple "indicator tests", well developed by that time in soil mechanics laboratory techniques, could prove to be a useful aid in Quaternary studies. Rominger (1954) followed up this notable paper with a more detailed review. Only very rarely does one see references to these papers in geological literature. They were even missed by Professor P.G.H. Boswell when, in the final years of his life, he complied a small book with the unusual title *Muddy Sediments*, explained to a degree by the subtitle - *Some Geotechnical Studies for Geologists, Engineers and Soil Scientists* (Boswell, 1961). Boswell's book was published posthumously and so it is not well known. This is one of the few printed records of the listing of these three disciplines, cooperation between which has so happily always distinguished Canadian geotechnical studies, demonstrated by the symposium of the Royal Society of Canada on *Soils in Canada* (Legget, 1961).

One of the papers in that symposium, dealt with engineering studies of the Leda Clay (Crawford, 1961). These included a summary of the use of laboratory-determined preconsolidation pressures for determining probable elevations of sample locations above sea level. Kenney (1964) approached this same problem from the geological side by assembling records from which a graph of eustatic sea-level records for the last part of the Pleistocene period was prepared. He then correlated this chart with the results of consolidation test results upon soil samples from Boston, Nicolet, Ottawa and Oslo. Yet another use of laboratory-determined preconsolidation pressures has been demonstrated by Harrison (1958).

These three examples indicate the potential, still not fully exploited, that geotechnical laboratory tests and theories provide for use in Quaternary geological studies. Much can be done, however, without the aid of sophisticated laboratory tests. Test boring is the second phase of site investigations for civil engineering purposes, utilized for determining subsurface conditions at the boring site and for procuring samples for laboratory testing. When the number of such exploratory borings put down annually is considered, the vast repository of invaluable subsurface information which they present can readily be visualized. The GEOCRES system of filing such boring records, developed by the Geotechnical group of the Ontario Ministry of Transportation and Communications is an admirable, simple, and economical method of making easily available the information given by test borings carried out all over Ontario. It should be better known, and a pattern for innumerable similar guides to collections of test boring records, for all conveniently sized regions.

John T. Hack of the U.S. Geological Survey showed as early as 1957 what can be done by an informed use of test boring records obtained for essentially engineering purposes (Hack, 1957). He examined the boring records from 14 locations in Chesapeake Bay and was able to show, by careful correlation of this engineering information, the existence of a submerged river system beneath the waters of the famous Bay (25 miles and 175 miles long). A quite different use was made in 1964 of engineering test borings by three other members of the staff of the USGS, through use of samples obtained from borings made in New Haven harbour by the Highway Department of Connecticut at the site of a proposed new bridge (Upson *et al.*, 1964). Carbon-14 and pollen analyses were carried out on organic material in the soil samples by means of which it was possible to determine a post-glacial change in the sea level at New Haven at a rate of 1.8 mm per year. Fisk and McClelland (1959) have similarly used test boring results from the delta of the Mississippi River which revealed, incidentally, a weathered surface of a late Pleistocene deposit now 164 feet below sea level. These are but a few of the published records of the use of engineering test boring results by geologists. They clearly suggest that wider use could well be made of this link between engineering and geology. But, to complete this brief review to full circle, one does not even have to have test boring results in order to ensure that the works of the civil engineer contribute usefully to the advance of Quaternary geology. Examination of exposures revealed by engineering excavations is still an effective means of adding to geological knowledge at no expense other than the expenditure of time and effort.

Dreimanis has fully exploited this source of new information, especially in "his" region of southwestern Ontario. His example has been followed by others, a recent example being the use made by Karrow *et al.* (1978) of the quite mundane excavation for a small bridge job at Guelph. On a much larger scale, construction of the Toronto subway system has shown what can be done when geologists and civil engineers work in harness (Legget and Schriever, 1960). From the start of the planning of the first section of the subway, from Front Street at Union Station, the importance of the geology that would be revealed by the excavations to be made was fully appreciated. A small advisory geological committee was established to ensure that the best possible use was made of the potential that this large project presented. Complete records of all soils exposed were made; access to working faces was arranged; suites of samples were taken at regular intervals; and eventually useful papers were published.

Even larger exposures of Quaternary soils were made during the construction of the St. Lawrence Seaway and Power Project, and especially so along the Wiley-Dondero Canal and its two locks in the United States section of the great waterway. All who were privileged to walk on the exposed limestone bedrock after removal of the overlying two tills and Leda Clay will never forget the experience. And the geological records were greatly enriched by the careful observations of Paul McClintock (1958). It is regretable, however, to have to add here that the other side of the coin was revealed by the neglect by excavation contractors of the mass of geological information available. Claims for extra payments by earth-moving contractors due to the alleged unsuspected tough character of the till ran into the millions of dollars and this despite the fact that the existence and general character of the tills had long been known, and of exactly similar experiences half a century earlier on the Massena power canal, and a quarter of a century before on the Welland Canal (Legget, 1979).

It was the excavation necessary for the building of the famous "Twin Locks" at Thorold, at the base of the Escarpment, that then caused such trouble. What had been assumed to be "just soil" proved to be unusually compact till, as would be expected at this location in view of the southward direction of earlier ice movements. The sub-contractor for the excavation had to resort to drilling and blasting for excavating this "soil", at what extra cost can be imagined. The extra cost led to failure of the firm and, indirectly, to the failure of the general contractor, one of the most famous construction companies in Canada at that time. It has not yet been possible to piece together the various aspects of this unfortunate experience but, when this can be done, the resulting record will be a cautionary tale indeed for all civil engineers and civil engineering contractors as to the vital necessity of recognizing the importance of Quaternary geology in all their work.

What are the lessons to be learned from even so brief a review as this of the inter-relation between Quaternary Geology and the practice of civil engineering? It is abundantly clear that the training of all civil engineers should include at least an introduction to Quaternary Geology, in association with that general introduction to the science of Geology which is an essential part of all civil engineering undergraduate training. If this introduction to the Quaternary can be associated with the course(s) in Geotechnique which are to be found today in almost every university course in Civil Engineering, much benefit will result and Soil Mechanics will become more meaningful. Not only is such an introduction to Geology essential for the efficient practice of Civil Engineering, but it will also encourage civil engineers to be on the look-out, in all excavation work, for features that may be of geological significance.

Accordingly, and since so many civil engineers now in practice did not have the advantage of taking any undergraduate courses in general Geology, still less in Quaternary Geology, surely this is a gap that could well be filled by suitably arranged Extension Courses. A real challenge appears to exist in arranging, for civil engineers in practice, a combined short course starting with general Geology, explaining Quaternary Geology and concluding with an introduction to Soil Mechanics. Correspondingly, no study of Quaternary Geology should today be regarded as complete if it does not include at least an introduction to the fundamentals of Soil Mechanics, and especially to the basic engineering soil tests (now standard in civil engineering), the results of which can so often be of direct relevance to the progress of Quaternary studies.

Equally necessary on the part of Quaternary geologists is an appreciation of the fact that every engineering excavation is worth examining since it may present information of unique geological importance. Should not every university Department of Geology have at least one member of staff, one of whose special responsibilities it is to maintain and develop liaison with local civil engineers, so that all significant excavations and soil boring programes may be brought to the attention of the Department as a whole? In this way optimum advantage can be taken of the engineers' uncovering of geological strata previously hidden from view, and soon to be covered again, to the great benefit of geological studies when new features are thus displayed. Steady development of this practice would be one of the best of all tributes to Prof. Aleksis Dreimanis who has been an exemplar to all in recognizing and utilizing the interrelation between his "first love", Quaternary Geology, and the practice of Civil Engineering.

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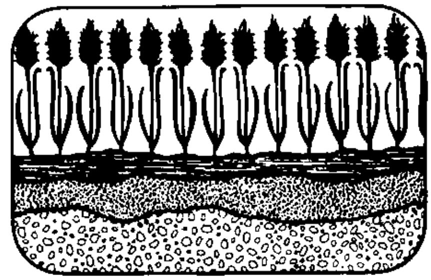

Late Cenozoic Geology and the Second Oldest Profession

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Abstract

All soils that are now farmed have been formed or modified by late Cenozoic events. Where these events have been dramatic with glaciers and plate tectonic processes actively intervening, old soils have been obliterated and replaced by newer, inherently more fertile materials. In more placid regions, soils that originated on Tertiary and even Mesozoic landscapes persist, and continue to evolve towards states of low fertility. The inherent fertility of soil, a renewable resource, is largely ignored in modern mechanised agriculture in favour of chemical fertilizers largely mined from non-renewable deposits. A saner attitude once existed, still exists in at least part of the Third World, and should be re-examined as a possible basis for future strategies.

Introduction

The production of an agricultural surplus frees part of the population from the need to grow food. This has enabled the human race to sustain cities and to invent the cultures we call civilised.[1] It depends directly on two things, climate and soil. About the former we can do little in the way of control or amelioration, but in the interests of large crops and short term profits, we have learned to manipulate the latter to a high degree.

In manipulating the soil, human beings constitute a potent geological force. We are not simply figures in the landscape but shapers of the landscape. Landscapes unmodified by human activities scarcely exist in the old world outside of the high latitudes and the high mountains. Even landscapes once thought to be natural, such as those of moorland Britain, are now seen as resulting from

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