Early Engineering Geology in Canada –

Papers by D.F. VanDine

1. D.F. VanDine, 1987. *Early History of the Geotechnical Profession in Canada.* Proceedings, Canadian Engineering Centennial Convention, Montreal 18-22 May, 1987. R.P. Chapuis and D.W. Devenny, Eds. Publ. by the Canadian Geotechnical Society.

2. D.F. VanDine, 1991. *The emergence of engineering geology in British Columbia.* Proceedings, 'The Earth Before Us – Pioneering Geology in the Canadian Cordillera, Victoria, British Columbia, March 1991. B.C. Geological Survey Branch, Open File 1992-19.

3. D.F. VanDine, 1983. *Drynoch landslide, British Columbia – A history.* Canadian Geotechnical Journal **20**, 82-103.

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Early History of the Geotechnical Profession in Canada

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SUMMARY

The journals and diaries of the early explorers, furtraders and settlers of Canada indicate that some of these pioneers had more than just a little appreciation of the importance of the ground on which they travelled and lived. These early documents include direct references to a number of geotechnical subjects -- field tests on clay, earthquakes, landslides, permafrost, tar sands and an early reference to a St. Lawrence Seaway-like canal system penetrating the continent.

As the colony developed into a country in the 1800's, the rivers, lakes and early trails gave way to canals, railways and engineered roads as the prime transportation routes. Early "military" and "civil" engineering practicians had to deal with a wide variety of geotechnical problems associated with the construction of these "new" transportation routes. Several Canadian universities began to offer engineering courses and programs. Engineering gain some acceptance with the formation of the predecessor of the Engineering Institute of Canada in 1887.

The late 1800's and early 1900's brought a natural demand for larger and more sophistocated buildings, water supplies for the quickly growing urban areas, and dams to generate hydro-electricity. Engineers oblidged and, with just the rudimentary knowledge of geotechnique, were usually successful. Along with the basics of soil mechanics, the importance of geology in the construction of these "civil" works and in the area of natural hazards, gained some acceptance.

This paper follows the early history of the geotechnical profession in Canada up to 1936 -- the year of the 1st International Conference of Soil Mechanics and Foundation Engineering. By the mid-1930's the foundations of Canadian geotechnique had been laid. Upon these foundations, the history of the geotechnical profession in Canada was prepared to be built.

RÉSUMÉ

Les journaux personnels des premiers explorateurs, pelletiers et colons du Canada, indiquent que certains de ces pionniers avaient plus qu'une petite idée de l'importance du sol sur lequel ils circulaient et vivaient. Ces premiers documents font mention d'un bon nombre de sujets geotechniques: essais in situ sur l'argile, tremblements de terre, glissements de terrain, pergélisol, sols bitumineux, et une première référence à un canal pénetrant le continent, semblable à la voie maritime du Saint-Laurent.

Dans les années 1800, alors que la colonie devenait un pays, les rivières, les lacs et les premières pistes cédèrent la place aux canaux, aux chemins de fer et aux routes comme voies principales de transport. Les premiers ingénieurs "militaires" et "civils" devaient traiter une grande variété de problèmes géotechniques liés à la construction de ces nouvelles voies. Plusieurs universités canadiennes commencèrent à offrir des cours et des programmes de génie. Le génie fut accueilli favorablement avec la création, en 1887, de la société qui devint l'Institut des Ingénieurs du Canada.

À la fin du 19^{e} siècle et au début du 20^{e}, il y eût une demande pour des édifices plus complexes et plus imposants, pour l'approvisionnement en eau des zones à urbanisation rapide, et pour des barrages hydro-électriques. Les ingénieurs rendirent ces services, et malgré des connaissances rudimentaires en géotechnique, généralement ils réussirent. On fut sensibilisé aux principes de la mécanique des sols et à l'importance de la géologie pour ces ouvrages "civils", ainsi que pour les risques naturels.

L'article décrit les débuts de la profession géotechnique au Canada jusqu'en 1936, année du premier Congrès international de mécanique des sols et travaux de fondation. Au milieu des années 30, les fondements de la géotechnique canadienne étaient en place. Sur ces fondements pouvait être bâtie l'histoire de la profession géotechnique au Canada.

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This year, 1987, marks the hundredth anniversary of engineering, as an organized body, in Canada. From the viewpoint of the geotechnical profession, however, last year, 1986, was a year of note as well. Fifty years before, in 1936, the 1st International Conference on Soil Mechanics and Foundation Engineering was held at Harvard University in Cambridge, Massachusetts. This conference is considered to be the beginning of what was then called "soil mechanics and foundation engineering" and what is now referred to as "geotechnical engineering". Since 1936, the geotechnical profession has developed into a sophistocated branch of engineering that combines the knowledge of geology with the knowledge and experience of how the ground behaves naturally or how the ground will behave under the influence of changes imposed by Man.

The development of the geotechnical profession in Canada since 1936 will be the topic of several other papers in this collection. This paper traces the early history of the profession and illustrates, with a number of examples, where the fledgling Canadian geotechnical profession was at the time of the 1936 international conference, and how it got there.

The reader will note that no figures accompany this paper, except for a map of Canada that shows the locations of the major localities discussed in the text. During preparation of the text for this collection, it was realized that to properly document the early history pictorially, approximately 25 to 50 additional pages would be required. Instead of presenting a less than proper record, it was decided to forego the figures. It is hoped that at some future date, a pictorial compendium can be published.

EARLY INHABITANTS, EXPLORATIONS AND SETTLEMENTS

The first inhabitants of what is now Canada were Indians and Inuit who, it is believed, arrived from Asia as early as 40,000 years ago. Scanty evidence indicates that the first Africans and Europeans may have visited this land as recently as 1,500 years ago. About 1000 A.D. Viking arrived and settled for a short time at L'Anse aux Meadows, on present day Newfoundland. It is unlikely, however, that these early inhabitants and explorers had anything but an intuitive appreciation for the mechanical behavior of the soil and rock which surrounded them. If they had, there is no written record.

John Cabot landed on the east coast of present day Canada in 1497 and claimed the land for England. Jacques Cartier made a similar visit on behalf of France in 1534. Cabot recorded, "The soile is barren in some places, and yeeldth litle fruit [sic]". Cartier, apparently sighting Labrador, wrote, "I did not see one cartload of earth, I believe that this is the land God gave to Cain". Although inauspicious, these may be the first recorded evaluations of the Canadian terrain.

The first European settlements in Canada (the name "Canada" was alledgedly coined by Cartier from the Indian word "kanata", meaning village or community) met with varying degrees of success. Charlesbourg-Royal, a fort built by Cartier in 1541, twelve kilometres upstream from present day Quebec City, was abandoned in 1543. The settlement on Saint Croix Island, built along the present border of New Brunswick and Maine by Pierre de Monts and Samuel de Champlain, barely lasted the winter of 1604-1605. Port Royal, along the shores of the Annapolis Basin in Nova Scotia, was built by Jean de Poutrincourt and Champlain in 1605 and flourished with mild success until 1614 when it, too, was abandoned.

Geotechnique played a very small part in the location and relative success or failure of these settlements. At Port Royal, however, in 1607, Poutrincourt ordered the building of a water-driven grist mill to grind the wheat which the settlers introduced to the area and grew well nearby. This small mill with its stone foundations, wooden superstructure and undershot wooden water wheel has the distinction of being the first civil engineering structure to be built in Canada. Its construction also initiated the Canadian tradition of harnessing streams and rivers for power.

Ironically it is only a few kilometres from this site where the Tidal Power Corporation of Nova Scotia began operation of its tidal power pilot plant in the Bay of Fundy in 1983. The previous year, the Nova Scotia Power Commission completed a reconstruction of the original 1607 mill (Legget, 1982a).

A year after construction of the original mill, in 1608, Champlain founded "Habitation", which as the present day Quebec City has the distinction of being the oldest continuously occupied settlement in Canada. From Habitation, Champlain explored westward as far as Lake Huron. In 1611, "at a league's distance from Mount Royal" (now Montreal) he exhibited his inquisitive and practical nature and ordered what may be the first test of applied geology to be carried out in Canada.

> "There are also many level stretches of very good rich potter's clay suitable for brickmaking and building, which is a great convenience. I had a portion of it prepared, and built there as a wall, four feet thick, three or four feet high and ten yards long, to see how it would last during the winter when the waters came down" (from Bigger, 1925).

The results of this experiment, which were conducted on material that we now refer to as Champlain Sea marine sediments or Leda clay, are not provided in Champlain's notes.

The 1600's saw a flurry of exploration and settlement in the "New World" or "New France". Prominent among the visitors and inhabitants were the Jesuits. From their records, or "relations", which were conscientiously and painstakingly written in Latin, we find the first references to earthquakes and landslides in Canada.

> "On St. Barnabas Day (June 11, 1638) we had an earthquake in some places [near present day Trois-Rivieres, Quebec] and it was so perceptible that the savages were greatly surprised to see their bark dishes collide with each other, and water spill out from their kettle. This drew from them a loud cry of astonishment" (from Smith, 1962).

On February 5, 1663 another, stronger earthquake was recorded near Murray River (Riviere La Malbaie) northeast of Quebec City. It was accompanied by numerous landslides along the northshore of the St. Lawrence River between the Maurice and Saguenay rivers. The village of Les Eboulement (The Landslides) derives its name from this event. From such humble beginnings come the present day Seismic Zoning Maps of Canada (the most recent of which were prepared for the 1985 National Building Code of Canada) and the extensive studies of slope stability associated with the Champlain Sea marine sediments.

FURTRADERS

The 1600's and 1700's also brought the furtraders -- both English and French -- to Canada. They followed Champlain's early transportation route westward along the St. Lawrence, Ottawa, Mattawa and French rivers to Lake Huron, Lake Superior and beyond. They followed Frobisher, Davis, Hudson and Baffin northward and into Hudson Bay, James Bay and the high Arctic. The early furtrading posts were built as centres for trade with the Indians. Rivalry between the English and French and hostilities with the Indians, however, required that they also be constructed for defence from attack. Two of the largest furtrading centres were Fort Prince of Wales and the Fortress of Louisbourg.

Fort Prince of Wales is located on a peninsula at the mouth of the Churchill River on the shore of Hudson Bay. Construction of this Hudson's Bay Company fort began in 1688. Between 1731 and 1771 the English enlarged and fortified the fort with stone walls that were 9 to 12 m thick at the base and 6 m high. During these periods of construction the English encountered permanently frozen ground -- or permafrost -- for the first time. Despite the military fortifications, the English surrendered the fort to the French without a fight, when attacked in 1782.

The Fortress of Louisbourg was built by the French on Cape Breton Island (now a part of Nova Scotia) to defend the Atlantic approach to "New France". Construction of the 3 m thick, 10 m high stone walls began in 1720 and continued until 1745 when the fortress was captured by the English. It was returned to the French by treaty in 1748 and construction continued until 1758 when it was recaptured by the English and this time completely and systematically demolished.

Today Louisbourg would cost approximately $200 million to build. Part of the reason for the high cost was due to the fact that, even though the fortress was built on rock, the stone for the massive walls was shipped from France. It is also interesting to note that some of these same stones, after the fort was razed, were transported by ship to the "new" town of Halifax where they were used to construct a number of that city's original stone structures.

During the reconstruction of the Fortress of Louisbourg in the 1960's and 1970's, evidence was found to support the geological theory that sea level is rising relative to the Maritimes by approximately 30 cm per century (Grant, 1975). Among other features, the sewage and storm-water sluices which empty through a seawall are nearly one metre below present high tide. Grant (1975) dryly commented that, "If high tide had been as high during occupation of the fortress, disagreeable reversals of flow would have occurred daily".

Both Fort Prince of Wales and the Fortress of Louisbourg are now National Historic Sites, and are being preserved by Parks Canada.

To a large extent, the early furtraders were also the early explorers of the country. They were keen observers and, while being propelled by a troop of canoeists along the waterways, had time to reflect on what they saw and had time to record their thoughts and observations. Alexander Mackenzie is an excellent example of a furtrader-explorer-racounter. In 1789, at age 26, he discovered the river which today bears his name to the western Arctic. Four years later he became the first European to cross North America by land and reach the Pacific Ocean.

On his way to Fort Chipewyan, on the shores of Lake Athabasca in northern present day Alberta and from where he began both his epic "voyages", he descended the Athabasca River. Although not the first European to see the Athabasca tar sands, he was the first to record their presence.

> "At about twenty-four miles from the Fork [downstream from present day Fort McMurray, Alberta], are some bitumenous fountains, into which a pole of twenty feet long may be inserted without the least resistance. The bitumen is in a fluid state, and when mixed with gum, or the resinous substance collected from the spruce fir, serves to gum the canoes. In its heated state it emits a smell like that of sea coal. The banks of the river, which are there very elevated, discover veins of the same bitumenous quality [sic]" (from Lamb, 1970).

During his 1789 trip down the Mackenzie River he noted burning coal seams (which are still smouldering today) just upstream of Fort Norman. "In other places the bank of the river is high of black earth and sand continually tumbling, in some part shews [sic] a face of solid ice, to within a foot of the surface" (from Lamb, 1970). The coal and permafrost to which Mackenzie briefly referred, have become major fields of geotechnical study and research in Canada, especially in the past two decades. The recent development of the Athabasca Tar Sands was just this year selected as one of Canada's ten outstanding engineering achievements of the past 100 years.

Mackenzie was also farsighted. In 1801 he penned a letter to Lord Hobart, Secretary of the Colonies in the British Government entitled "Memorandum concerning a canal projected by the American States from Albany to Lake Ontario; and a Canal between Lake Ontario and Montreal, by which the former would be rendered fruitless." (Lamb, 1970). In short, he was advocating a forerunner to the St. Lawrence Seaway -- a project that would give Canada a trading advantage over the Americans and their soon-to-be-built Erie Canal. From a geotechnical viewpoint Mackenzie noted that along his proposed route "the ground is well adapted to cutting of such passage and water can never be wanting as long as there is any in the lakes of Canada". At that time, his proposal was developed no further, however, during the middle of the present century the St. Lawrence Seaway was constructed jointly by Canada and the United States, and it too has recently been selected as one of the ten outstanding engineering achievements of the past century.

AGE OF CANALS

In Canada up to the early 1800's, the primary transportation routes were the rivers and lakes. Any roads at that time were essentially simple horse trails and/or portages. It is not surprising, therefore, that the early men of commerce proposed canals to improve the water ways.

The earliest excavation for a canal began in 1680. The Lachine Canal was created to bypass the Lachine Rapids on the St. Lawrence River, but this initial, hand dug canal was only large enough to handle canoes. So important was this route, that the canal was enlarged and/or modified in the 1700's, 1800's and 1900's. It served as a most important transportation route until 1959 when the St. Lawrence Seaway was opened (Legget, 1968, 1974).

The first dredging operation in Canada took place in 1747. It was associated with deepening the Richelieu River near St. Ours, Quebec, thereby improving the water transportation link between Lake Champlain and the St. Lawrence River. In 1797 the North West Company, rival of the Hudson's Bay Company, built the first lock in Canada at Sault Ste. Marie, Ontario. This small wooden lock greatly assisted the "York" boats in travelling from Lake Huron to Lake Superior.

Numerous other canals were proposed for the Maritimes, and Upper and Lower Canada, but it was not until after the War of 1812-1814, between British North America and the United States, that other canals were constructed. For purposes of defence. a water route, alternate to that of the St. Lawrence River between Montreal and the east end of Lake Ontario, was proposed. It would follow the Ottawa River up to present day Ottawa, then head cross-country by means of a canal that would generally follow the Rideau River, Rideau Lakes and the Cataraqui River to Kingston on Lake Ontario. This route required a series of locks and canals on both portions of the route.

The Grenville Canal on the Ottawa River was first surveyed in 1816 and constructed between 1819 and 1831 by the Royal Staff Corps. It was the first public work of any size to be constructed in Canada and involved the excavation of 400,000 m of solid Precambrian bedrock (Legget, 1980a). The rock was hand-excavated after blast holes were hand-drilled into the rock. This may possibly be the first drilling operation undertaken in Canada. Lieutenant Colonel Henry du Vernet, the commander of the Royal Staff Corps construction unit, knew enough about geology to leave us some of the earliest records of rock formations in eastern Canada. Du Vernet used his knowledge of "engineering geology" to locate an associated second canal on the Ottawa River at Carillon. "In order to minimize rock excavation ...he followed the lie of the land around the Carillon Rapids even though this involved locking boats up to the main part of the canal on their downstream journey" (Legget, 1976).

The Rideau Canal, which connects Ottawa and Kingston, was located and constructed between 1826 and 1832 by the Corps of Royal Engineers under the direction of Lieutenant Colonel John By. This canal, approximately 200 km in length, includes 47 masonry locks and 50 dams. It has been called one of the greatest construction achievements in North America. Besides the cunning use of the terrain, which By used to his advantage to reduce the length of artificial channels required, there are three locations that are particularly interesting from a geotechnical viewpoint.

The dam at Jones Falls is 106 m long between abutments and 19 m high, and when completed in the 1830's was the highest dam in North America and the third highest dam in the world! It was constructed by John Redpath (who later became a successful businessman in the sugar industry) as a keywork stone arch dam. Founded on bedrock, the stonework is 8.5 m thick at its base and 6.5 m at the top. A "clay and earth" apron was placed on the upstream face of the stonework at a 2.5:1 slope. A 1.5 m thick clay core was placed between the apron and stonework (Passfield, 1982). The dam was built in stages so that the earth apron with temporary spillways could act as cofferdam while the stonework was being constructed.

The proposed dam at Hog's Back, on the outskirts of present day Ottawa, was to be 52 m long and 14 m high, and of a masonry arch design. Construction began in July 1827 but when the final gap was filled in February 1828, a sudden flood washed away a good portion of the earthfill. It took a year to rebuild the washed out section, just in time for a March 1829 flood to wash away much of the dam as well as material from the west abutment. Colonel By abandoned plans for a masonry dam and, after perservering for two more years, completed a 75 m long timber crib dam (Passfield, 1982). Associated with the initial 1827 dam construction, a short railway was built to transport stone to the dam site from a nearby quarry. Although temporary, this may have been the first rail line built in Canada (Legget, 1955).

The Lower Brewers lock, near the Kingston end of the canal was built, by necessity of alignment, on a thick stratum of soil instead of bedrock, as was the accepted practice (Anon., 1978). Although construction of the heavy lock was no more difficult than normal, the stone structure underwent considerable differential settlement. The resulting problems were not fully resolved until the lock was completely reconstructed in 1976. This is possibly Canada's first and longest settlement case history.

As a tribute to Colonel By and the Corps of Royal Engineers, the Rideau Canal celebrated its 150th anniversary in 1982, is still in full operation and is recognized as a National Historic Site.

At the same time as the Ottawa-Rideau route was being constructed, the Welland Canal was being excavated to bypass Niagara Falls and thus provide a continuous water transportation route between Lake Ontario and Lake Erie. Unlike the former public work, however, the Welland Canal was built and owned by private interests. Forty locks were originally required to connect the two lakes and a one way trip usually took two days. The initial design called for a tunnel to be driven through a height of land between Lake Erie and the Niagara escarpment. This design was subsequently changed to a "deep cut". During excavation of the deep cut, geological problems were encountered which were described as "landslides". However, recent work in this area indicates that ground failure was probably due to the fact that the excavation was advanced through a thick stratum of clay and glacial till overlying more permeable sediments within which the groundwater is under sub-artesian pressure (Legget, 1980). The depth of the deep cut was reduced accordingly and two locks were constructed to lock up boats on their way down to Lake Ontario (Legget, 1976).

The Welland Canal remained private until 1841. In that year, during the first session of the Legislature of the United Province of Canada (today's Ontario and Quebec), the government assumed control of the canal under the newly created Board of Commissioners of Public Works. This Board was the forerunner of the present day Canada Department of Public Works, of which more will be said later.

AGE OF RAILWAYS

As the Ottawa, Rideau and Welland canals were being completed, the advantages of land transportation by means of railways were being studied. As we shall see, the age of canals did not die, but for the moment, Canada entered the age of railways.

The first permanent railway in Canada, the Champlain and St. Lawrence Railroad, was completed in 1836. It connected Laprairie, on the south shore of the St. Lawrence River across from Montreal, with St. John's, Quebec, on the Richelieu River. This 25 km long route shortened by 150 km the water route between Montreal and the United States via the Richelieu River, Lake Champlain and the Hudson River. It also bypassed a required portage -- and later canal and locks -- on the Richelieu River at Chambly, Quebec (Legget, 1973). Geotechnically the construction was relatively simple. Only one low but long embankment and four short and one 122 m long bridge were required.

Several other short railways, also in Quebec (or Lower Canada as it was then called) followed in the 1840's and 1850's. Upper Canada, not to be outdone, also began to "think railways". One of the first railways in Ontario was built in the early 1850's and ran between Toronto, on Lake Ontario, and Aurora, south of Lake Simcoe. Although from a geotechnical viewpoint there is little of interest connected with this route, it is significant in that a young engineer, Thomas Roy, was in charge of and carried out the first survey for this railway in the 1830's (Legget, 1980a).

Little is known of Thomas Roy. From what we do know, however, he appears, by having an understanding of the geological implications of all his engineering work, to be the first Canadian civil engineering geologist. Besides the railway, he carried out a study on the improvement of Toronto's harbour, studied navigation on the upper Ottawa River, postulated a theory for the raised beaches around Lake Ontario, prepared a geological stratigraphic section for a portion of southern Ontario, and wrote a pamphlet on "the Principles and Practice of Road-building as applicable to Canada". Published in 1841, this pamphlet predicted that railways would one day be rivalled by the "steam-carriage upon common roads". He also wrote:

> "Drainage is an affair of primary importance in roadmaking, and requires much skill to execute in a proper manner...it may even be necessary to carry the process of draining far beyond the area of the road" (from Legget, 1980a).

These same words should be heeded by today's engineers.

As the small railways proved their worth, schemes for longer railways were dreamed up, and a few were actually financed and built. The first major railway to be completed was the Grand Trunk. Built between 1845 and 1861, in sections between Sarnia, Ontario in the west and Riviere de Loup, Quebec in the east, it was -- and still is -- the main railway line for Canada. The short tunnel near Brockville, Ontario and the Victoria Bridge over the St. Lawrence are two structures that have interesting geotechnical features.

To provide rail access to the St. Lawrence River from the main Grand Trunk Railway near Brockville, a short branch line was constructed. To overcome a steep bluff, a 500 m long tunnel was excavated. Completed in 1854 this tunnel, which was used up until recently, has the distinction of being the first tunnel constructed in Canada, and the first railway tunnel in North America (Legget, 1973 and 1980a).

The St. Lawrence River was a major obstacle in linking Grand Trunk's eastern and western lines. This was solved by the construction of the 2,800 m long Victoria Jubilee Bridge at Montreal. It was constructed on masonry piers spaced approximately 75 m apart. The piers, constructed within wooden cofferdams, were founded on solid rock on the river bottom. Rock for the piers was transported to the site from Pointe Claire, to the north (using the Lachine Canal), and from Lake Champlain, to the south (using the Champlain and St. Lawrence Railroad). Construction began in 1854 and was completed in 1859, in time for the Prince of Wales to open it officially during the first Royal visit to Canada in 1860. Although the superstructure has been replaced, the original piers are still performing well (Legget, 1975).

One reason for the success of the bridge foundations is possibly the assistance provided to the design engineer, Robert Stephenson, by William Logan, geologist with the Geological Survey of Canada. In his report Stephenson related:

"I have read and studied with great pleasure an admirable and most graphic description by Mr. Logan of the whole of the varied conditions of the river..." (Legget, 1982b).

Although not usually noted for its impact on engineering, the Geological Survey of Canada has, as this example shows and as we shall see later, contributed a great deal to geotechnique in Canada.

The Intercolonial Railway was proposed to connect the Grand Trunk Railway at Riviere du Loup, Quebec with Halifax, Nova Scotia. It was completed in stages between 1858 and 1876. Of the major civil engineering works along the route, the bridges over the Miramichi River, in New Brunswick, are most interesting from a geotechnical viewpoint.

The engineer in charge was Sandford Fleming. He requested borings along the centrelines of the two proposed bridges and designed the foundations for the bridge piers accordingly -- timber caissons to be filled with tremie concrete. At one bridge site, when construction began in 1869, what was thought to be bedrock turned out to be sand and gravel underlain by silt and clay. Fleming halted construction, ordered additional, more sophistocated borings and even carried out static penetration tests to determine the bearing capacity of the underlining strata. These are likely the first penetration tests ever performed in Canada, and perhaps anywhere in the world (Legget and Peckover, 1973). He then increased the number of bridge piers from five to six and increased the loading area of the open timber caissons. During construction, Fleming noted settlement and halted construction once more so that each pier could be preloaded to encourage settlement to occur before the superstructure was constructed. Both bridges, completed in 1875, are functioning well today (Peckover and Legget, 1973).

During his tenure with the Intercolonial Railway, Fleming was asked to carry out the preliminary location survey for the Canadian Pacific Railway to the Pacific Coast of Canada. Between July 1 and October 11, 1872, Fleming, his 16-year-old son and five others travelled 8,500 km between Halifax, Nova Scotia and Victoria, British Columbia. The epic journey consisted of 1,530 km by rail, 3,495 by horse, 2,700 by steamer and 775 by canoe. Detailed records were kept by the secretary of the party, George M. Grant (Grant, 1873).

Because of political and financial reasons construction of the CPR was delayed until the early 1880's. Geologically and geotechnically the legacy of the CPR included: finding the wealth of mineralization at what is now Sudbury, Ontario; finding coal in Alberta and British Columbia; learning in a primitive way how to deal with muskeg in Northern Ontario; and learning about rock slope stability along the Fraser Canyon, landslides in glaciolacustine silt along the Thompson River and snow avalanches in Rogers Pass, all in British Columbia. Many engineers and thousands of labourers rose to the challenges, and by 1885 the Canadian Pacific Railway was complete and one could travel from coast to coast by rail. Although the right-of-way had been cleared and the tracks had been laid, geotechnical problems continued to cause the CPR to be an ongoing challange to future generations of engineers.

SOME ENGINEERED ROADS

Before the railways had a chance to open-up some of the less accessible parts of Canada, land transportation was required to assist in the development, settlement and defence of the country. Surveying and construction of early roads was the answer. Because of their primitive nature, little conscientious geotechnical foresight was applied to these roads, however, two examples will show what the early engineers were up against.

The Cariboo Wagon Road connected Yale, the upstream point of navigation on the Fraser River, British Columbia, with Barkerville, the famous British Columbia gold mining town. The building of this road was commissioned, in 1861, to simplify travel to the goldfields and open-up the undeveloped interior of the "colony" of British Columbia. The road was surveyed and constructed between 1862 and 1865 under the supervision of Colonel R.C. Moody and a Corps of Royal Engineers. The road, which is almost 800 km in length, was built to a standard 18 foot width and cost an average of $1,250/km. Approximately two-fifths of the route followed the treacherous Fraser and Thompson river canyons where in many places it had to be literally notched into the side of, or in part suspended over, the canyons. The construction of the original Trutch Bridge, the first bridge over the Fraser River, and the continual problem with Drynoch Landslide are only two items of engineering interest associated with this early road (Sanderson, 1976; and VanDine, 1983). Two railways and the Trans-Canada Highway follow portions of the original route today, and today's engineers still are faced with geological, geotechnical and engineering challenges similar to those of their predecessors.

The Department of Public Works saw the need of a transportation route between Lake Superior in northwestern Ontario and Selkirk on the Red River in Manitoba. The route was first surveyed by Simon Dawson in 1859, but it was not until 1868 that he was awarded the contract to begin construction. The route was just under 700 km in length and consisted of an 80 km stretch of road between Fort William (present day Thunder Bay) and Lake Shebandowan, a 170 km stretch of road between Lake of the Woods and Selkirk (near present day Winnipeg) and approximately 450 km of water travel, with up to 70 portages, inbetween (Legget, 1974). It was completed in 1870. To think of the difficulties the CPR had in crossing similar terrain immediately to the north, ten years later, the construction of the early engineered road segments and portages is a credit to Dawson and Canadian engineering at that time. It is interesting to note that it took Fleming's 1872 CPR survey party 10 days to cross the Dawson Road whereas previously it might have taken a traveller 3 to 4 weeks to traverse the same route (Grant, 1873).

EDUCATION AND ORGANIZATION

The second half of the 1800's was a period of expansion and development for the fledgling country of Canada, and this was reflected in the growth of engineering. One of the ways in which engineering progressed was the introduction of civil engineering into university programs: at the University of New Brunswick in 1854; Toronto in 1859; McGill in 1871; Ecole Polytechnique in 1873; Royal Military College in 1876; and Queen's in 1893. The early thrust of these civil engineering programs was, not surprisingly, surveying and construction -- especially related to transportation in the form of canals, railways and roads (Richardson, 1976b).

In 1887, the forerunner to the Engineering Institute of Canada -- the Canadian Society of Civil Engineers -- was formed. The first President, Thomas C. Keefer had worked on the Welland Canal, oversaw construction of a portion of the Grand Trunk Railway and later became one of the few Canadians to be President of the American Society of Civil Engineers (Richardson, 1976a).

Samuel Fortier, an 1885 civil engineering graduate of McGill University, and a member of the newly formed Canadian Society of Civil Engineers, made his mark on geotechnique, however, in the United States as opposed to Canada. He worked for the U.S. Department of Agriculture, eventually rising to the head of the irrigation section. In 1896 he presented a paper to the Canadian Society of Civil Engineers which dealt with the design and construction of earth dams. He stressed the importance of knowing the properties of the soils with which an earth dam was to be built, and described the process of soil compaction. Ahead of his time, Fortier stated:

> "For twenty years and over men have been testing the physical qualities of iron, steel, cements...Reservoir embankments on the other hand have been built in most instances without the requisite knowledge, upon mere guess work, brawn and not brain predominating" (from Legget, 1980a).

MORE CANALS AND RAILWAYS

Towards the end of the 1800's and into the beginning of the 1900's, civil engineering was becoming more sophisticated and engineers were developing more of an appreciation for proper investigation of the ground conditions prior to construction. In this regard, several engineering projects of that era, which were associated with canals and railways, provide excellent examples.

The Murray Canal, which provides Trenton, Ontario and the Trent Canal system easy access to Lake Ontario, was first suggested in 1796. The 8 km canal, which has no locks, was finally constructed between 1882 and 1889. Over the intervening years, two proposed routes were suggested and studied: the present route and a much shorter route. During 1880 and 1881, 13 test pits and 500 test borings were made along the proposed routes, and based upon the finding of this subsurface investigation the longer route was finally selected. Along the shorter route, most of the excavation would have had to be in rock, while there was no rock excavation along the longer route (Legget, 1980b).

To connect the Grand Trunk Railway, which served Quebec and Ontario, with Chicago and the mid-western United States, a railway tunnel was proposed under the St. Clair River at Sarnia. Construction of the tunnel began in 1889 and was completed in 1891. It was the first underwater railway tunnel to be built in North America! Of interest to the heritage of geotechnique, however, is the fact that prior to final location and construction, test borings were advanced on 6 m centres across the St. Clair River and along the approach cut locations. Glacial clay with pockets of wet sand and some boulders were encountered, and the engineer-in-charge, Joseph Hobson, designed the tunnel and the tunnelling procedures accordingly. Two steel "hydraulic travelling shields", one starting at each end of the tunnel, were used along with compressed air to complete the 1.8 km long tunnel. The tunnel is still in service today (Legget, 1979).

In 1615, Champlain used the Ottawa River, Mattawa River, Lake Nipissing and the French River to gain access to Lake Huron. This route, known as the Ottawa Waterway, remained the major furtrade route for the next two hundred years. In 1827, Colonel By, obviously enthusiastic about canal building, suggested the construction of a canal along the entire Ottawa Waterway. This route was approximately 500 km shorter than the Lake Ontario, Lake Erie, Lake St. Clair route -- its rival. During the 1800's the idea was revived several times and between 1856 and 1859 two surveys were carried out, but nothing was done. In the late 1800's and early 1900's, the idea of what was renamed the Georgian Bay Ship Canal was raised again. Geologists from the Geological Survey of Canada mapped the geology of route and the Department of Public Works spent almost one-half million dollars on a thorough site investigation. This extensive subsurface investigation included 2,990 test boring advanced with a churn drill at the proposed dams, locks and along the route. The final report estimated construction costs would be $100 million, annual maintenance costs would be $900,000 (both in 1909 dollars) and that it would take 10 years to build (Legget 1976 and 1980a). The canal has yet to be built although as recently as the 1960's the idea once again became popular.

In the early 1900's railway engineers were once again challenging nature. A second railway, the present Canadian National Railways, was completed across the continent and many shorter but more difficult rail lines were located, surveyed and built.

In 1909 the CPR reduced the grade on its mainline by completing the two spiral tunnels through the Kicking Horse Pass in British Columbia. Between 1913 and 1916 they constructed the 8 km long Connaught Tunnel through Rogers Pass. This tunnel will have been the longest railway tunnel in North America until the completion of the 15 km long new Rogers Pass tunnel which is presently under construction in the same area. (This new tunnel will be used for CPR westbound trains, while the Connaught Tunnel will be kept in service for the eastbound trains.) The Connaught Tunnel not only reduced the grade of CPR's track to 2.2%, but also bypassed the worst snow avalanche area in Canada. Very little geotechnical work was carried out in association with these early 1900 railway tunnels, but they must be included to show the sophistication of civil engineering works being carried out at that time (Dennis, 1917).

Between 1910 and 1929 the Hudson Bay Railway, one of the Canadian National Railways, was built between La Pas, and Churchill, Manitoba (very close to the site of Fort Prince of Wales). This 800 km long railway is important for two geotechnical reasons. This may be the first Canadian civil engineering work of any size to be constructed on discontinuous and continuous permafrost. Observations as to the distribution of the permanently frozen ground, its effect on the construction and maintenance of the railway, and how the construction problems were solved, were duly noted by the location and construction engineers (Charles, 1959).

The Hudson Bay Railway may also be the first major transportation project for which air photographs were used for route alignment and used to predict geological and engineering purposes -- a forerunner to engineering terrain analysis:

> "Unable to decide whether Nelson or Churchill would make the best port on Hudson Bay, the federal government in the summer of 1925 ordered that the whole route to Port Nelson and the region surrounding it be photographed from the air to augment a study of the terrain by engineers" (Thomson, 1975).

The government's decision to use air photographs was made shortly after the first paper on airphoto interpretation was published in the Journal of the Engineering Institute of Canada, "The Use of the Aeroplane in Surveying and Engineering" (Vol. VII, No. 1, 1924 - Wilson, 1924). Today airphotos are taken for granted on all large engineering projects, and Canadians are noted as leaders in the field of airphoto interpretation for engineering purposes.

With Canada's extensive legacy of railway location and construction, it is not surprising that Canada's railway network was selected as one of Canada's ten outstanding engineering achievements over the past 100 years.

FOUNDATIONS

The early settlers of Canada constructed buildings on all types of foundations and on all types of foundation conditions. Many of the buildings were small, the foundations were suitable and the foundation conditions, fortunately, were adequate. Undoubtedly there were some failures, but the record of these, for the most part, is missing. One case history, however, of a mid-1800's partial foundation failure has been documented.

Christ Church, the Cathedral Church of the Anglican Diocese of Montreal, was constructed under two contracts between 1856 and 1859. The first contract was for the foundations; the second for the superstructure. Before the second contractor finished the stone building with its 70 m high spire, he noticed that the foundation was settling differentially. When completed, the tilt of the steeple was 12 cm off vertical and the church stopped all further payments. In what may be the first piece of geotechnical litigation in Canada, the contractor took his claim for payment to court. He lost his case in the Canadian court and appealed it to the Privy Council in London. That body dismissed his case as well. The findings in this landmark case were:

> "If the builder thinks fit to trust to the vigilance or skill of the architect, without the independent exercise of his own judgement, he acts on his own risk. He cannot escape from liability..." (from Legget, 1977).

By 1927, settlement of the church reached 16.5 cm and since the steeple was precariously 60 cm out of plump, it was removed. A recent reconstruction of the foundations, this time after a soils investigation, has allowed the steeple to be replaced.

In the early 1900's, the knowledge of how soils behave under loading conditions was still in its infancy. The size (and therefore the weight) of the structures and buildings, however, were increasing. This situation led to numerous difficulties with foundations. Three of Canada's best documented foundation problems in the early 1900's are the Empress Hotel in Victoria, B.C., the National Museum Building in Ottawa, Ontario and the Transcona grain elevator near Winnipeg, Manitoba (Crawford and Sutherland, 1971; Crawford, 1953; Baracos, 1957).

The Empress Hotel evidenced differential settlement due to the combined load of a fill and the structure over a varying thickness of soft marine clay over bedrock. This building has the distinction of having the longest continuous settlement record in the country. The National Museum was constructed on 30 m of sensitive Champlain Sea marine clay and the differential settlement was caused by differential loading in areas of the building. Maximum settlement was 30 cm. The Transcona grain elevators is a very large grain holding structure. When it was initially filled, a classic bearing capacity failure of the clay soil occurred that left the elevators at an angle of 27 degrees off plump. In all three cases, remedial measures were undertaken and all three structures are still in active service today.

In 1918, the Canadian Society of Civil Engineers changed its name to the more appropriate Engineering Institute of Canada. At the same time the Engineering Journal, the journal of the new institute commenced publication. The first paper in that journal to be concerned with foundations and geotechnique appeared in Volume IV, 1921 and was contributed by D.S. Ellis. In that paper he reviewed an early 18th century textbook by Belidor, a French professor of mathematics. Belidor's text, based to a great extent on the work of de Vauban, the great engineer of Louis XIV, was published in 1739 and entitled "La Science des Ingenieurs dans la Conduite des Travaux de Fortification et d'Architecture Civile". Among other items, Ellis described theories of retaining walls, earth pressures against retaining walls, and foundations. Just slightly ahead of their time, Belidor and de Vauban were quite knowledgeable about foundations on rock, competent soil, and soft soil; pile foundations; consolidation; the importance of groundwater; and the use of cofferdams for underwater foundations. And this in 1739, and described in 1921!

The first bona fide geotechnical paper in the Engineering Journal appeared in Volume IX, 1926. A. W. Fosness, a design engineer with Carter-Halls Aldinger Co. of Winnipeg, Manitoba described the foundation conditions in the Winnipeg District. He discussed floating and pile foundations; allowable bearing; causes of settlement; foundations on clay at different elevation along river banks; the influence of frost and the relative cost of various foundations.

WATER RESOURCES

Water supply in Canada, up to the early 1900's, was usually fairly straight forward because of the large number of fresh water lakes close to the urban areas. After 1900, however, the exceptional growth of some of the larger centres required city engineers to look for new water supplies. One of the earliest and most ambitious projects was to carry water by means of a 160 km long aqueduct from northwestern Ontario to the City of Winnipeg, Manitoba. The foundations for the closed horseshoe shaped concrete aqueduct, constructed between 1913 and 1919, varied depending upon the grade and foundation conditions encountered over its length (Fuertes, 1920 and Chase, 1920). The engineers accepted the challenge with the result that there were no major foundation problems during construction and there have been none since. It is interesting to note, however, that just after construction was complete, degradation of the concrete footings and buried sections of the aqueduct was noticed. The resulting investigation found that the degradation was due to the sulphate in the ground. A successful research program by Dr. T. Thorvaldson of the University of Saskatchewan led to the development of the first sulphate resistant cements, later commercially promoted by the Canada Cement Company (Bubbis and Sommerville, 1960).

Besides water supply, water power was becoming more important to Canada in the late 1800's and early 1900's. The first electric dynamo was installed at Chandiere Falls on the Ottawa River in 1882. In 1893, two 1,000 hp units were installed at Niagara Falls (Richardson, 1976a). The Canadian tradition of hydro-electricity, in which Canadian engineers would become the accepted world leaders in the 20th century, had begun.

All across Canada in the early 1900's hydro-electric dams were being planned, designed and constructed. In 1926 the first paper in the Engineering Journal dealing with a hydro-electric dam site was published. E.E. Carpenter, a consulting engineer for the British Columbia Electric Railway Company, described the in-progress construction of the ambitious Bridge River Project in the Coast Mountains of British Columbia, northeast of Vancouver (Carpenter, 1926). In his paper he described what we would now call the geotechnical subsurface investigation to find suitable locations for the diversion and storage dams. Test boring were advanced, permeability tests were conducted and estimates of the bearing capacity were made. Subsequently two diversion dams were constructed and a 4,000 m long, 3.5 m diameter tunnel was advanced through Mission Mountain to the power station on Seton Lake.

Several other early hydro-electric developments are worthy of note from a geotechnical viewpoint. In 1929, a 25-year old civil engineer from Liverpool, England, arrived in Canada and took up the position of Resident Engineer for the Power Corporation at the proposed Upper Notch hydro-electric plant on the Montreal River in Northern Ontario. This was Robert F. Legget's first job in Canada.

In 1930, Calgary Power completed its Ghost Power hydro-electric development on the Bow River, 50 km west of Calgary, Alberta. The dam is 1,500 m long and has a maximum head of 33 m. The dam was designed and constructed as two earth fills on either side of a central concrete section. Of interest geotechnically is the fact that the earth fills, one 225 m long and the other 620 m long, were constructed as hydraulic fills. Their design and construction are described fully in a 1930 Engineering Journal paper by W.H. Abbott of the Foundation Company of Canada.

The Beauharnois, Quebec hydro-electric development, just west of Montreal, was constructed between 1929 and 1932. It was a significant geotechnical undertaking because so much of the site was underlain by sensitive Champlain Sea marine sediments (Leda clay). Detailed subsurface investigations were carried out to delineating the location of clay, till and bedrock. Clay samples were tested in the laboratory for unit weight and water content. D.W. McLaughlin, an experienced railway and canal engineer employed by the Department of Public Works, suggested "insitu" shear tests be conducted on the clay and he devised a primitive test apparatus:

> "The device was a four-finned tool (diameter about 6" and length maybe a foot) pushed down into the Leda clay, and used to determine shear strength by measuring the twisting torque" (from Burpee, pers. comm.).

McLaughlin had discovered the "vane shear test"! Fifteen years later, during a visit to the Beauharnois site in 1944 Terzaghi demonstrated his new idea -- that of taking "undisturbed" Leda clay samples for laboratory testing.

GEOLOGY AND GEOTECHNIQUE

The Geological Survey of Canada (GSC) was founded in 1842 and William Logan (later Sir William) was appointed the first Director. It is perhaps ironic that the first paper that he published after he arrived in Canada presented the results of some of his early research on landslides in the Champlain Sea marine sediments along the St. Lawrence River valley (Legget, 1980a). As mentioned previously, Logan went on to contribute significantly to a number of engineering projects in the country, for example, the Grand Trunk Railway's Victoria Jubilee Bridge near Montreal.

During the latter half of the 1800's, only minor progress was made to include more geology into the design and construction of engineering work. In 1873, the GSC purchased the first steam-driven diamond drill in Canada. This was used in the 1870's and 1880's to locate various construction materials for the construction of the CPR and, as Selwyn, then Director of the Geological Survey, stated to "extend and hasten the exploration and survey in the North West Territory" (Scott, 1979).

In 1900 Henri Ami, a geologist and palaenontologist with the GSC published a Royal Society of Canada paper entitled "On the geology of the principal cities in Eastern Ontario". This paper summarized the geological formations underlying Saint John, Quebec, Montreal, Ottawa and Toronto (Ami, 1900). In 1902, Ami undertook, on behalf of the Department of Railways and Canals, a geological examination of the materials encountered in borings for the abutments and piers for the, now famous, Quebec Bridge (Ami, 1903).

Landslides continued to interest geologists. R.S. Ells, in 1904, published the results of his investigation of recent landslides in the Ottawa Valley-St.Lawrence Lowlands (Ells, 1904). The large rockslide at Frank, Alberta in 1903 was studied by R.G. McConnell and R.W. Brock, and until the 1970's their report of 1904 was used as the classic example of a joint plane failure in rock (McConnell and Brock, 1904).

Geologists also became involved with Canada's early 1900's transportation network. As the automobile became more prominent, GSC staff were employed to find better road building materials in Ontario and Quebec (Blais et al, 1971). When the Department of Public Works wanted to improve navigation on the Fraser River delta south of Vancouver, in 1919, they requested W.A. Johnson, another geologist with the GSC, to carry out a geological investigation and engineering assessment of the area. In 1926, the Department of Railways and Canals began improvements on the historic Lachine Canal. The Geological Survey was asked to interpret the results of borings associated with the engineering investigations for lock construction (Scott, 1979).

At the University of Alberta in Edmonton, in 1925, Professor John Allen of the Department of Geology began a geology course specifically designed for civil engineering students. This is possibly the first engineering geology course to be offered in Canada. Allan was not only an academic, but a practicing engineering geologist as well. In 1927 he published a paper in the Engineering Journal entitled, "Geological Aspects of the Spray Lake Water Power Project". This is the first engineering geology paper to appear in the journal (Allen, 1927).

In 1921 Professor H. Ries of Cornell University and T.L. Watson of the University of Virginia published the first engineering geology text (Ries and Watson, 1921). Eight years later, in 1929, Ries published a paper in the Journal of the Engineering Institute of Canada entitled, "The Importance of Geology to Civil Engineering" (Ries, 1929). In a discussion of Professor Ries' paper Professor Allan foresightedly commented:

> "The day was coming...when the practicing civil engineer would invariably have the geological problems associated with the particular project on hand investigated by one qualified in that profession"(Allen,1929).

This was the theme to be taken up by that young civil engineer, Robert Legget. By the early 1930's Legget was convinced of the importance of geology in civil engineering and with the encouragement of Professor O'Neill of the Department of Geology at McGill he wrote his first paper for the Engineering Journal, "Geology and Civil Engineer: Their Relationship, with Reference to Canada" (Legget, 1934). From this 12 page article grew Legget's first textbook entitled "Geology and Engineering" published in 1939. In 1983, what is essentially the third updated edition of this same text, was published under the title "Handbook of Geology in Civil Engineering" (Legget and Karrow, 1983).

...AND ON TO 1936

This was the state of geotechnical affairs as Canada entered the depression years of the 1930's. The early explorers, settlers and furtraders had come and left their mark. Canals and railways had, in turn, had their day and now roads were becoming more popular. Development of northern Canada was beginning. Buildings were increasing in size and weight and required more sophistocated foundation engineering. Canada was in the forefront of developing its water resources into water reservoirs and hydro-electricity. Geology was recognized as being of some importance to civil engineering.

In the spring of 1936, a small item appeared in an issue of the United States engineering publication, "Engineering News Record", about a proposed conference on soils and soil mechanics to be held at Harvard University, June 22 to June 26 of that year. The President of the conference was to be Dr. Karl Terzaghi, author of the 1925 textbook entitled "Erdbaumechanick (Soil Mechanics)", and a visiting professor at Harvard University from the Technische Hochschule in Vienna, Austria. The conference attracted the attention of approximately 200 engineers from all over the world including eight from Canada: from the Department of Public Works, H.M. Davy and Jack Lucas of the test-drilling and testing laboratories branches respectively; C.R. Young from the University of Toronto, I.F. Morrison from the University of Alberta and G.M. Williams from the University of Saskatchewan; and from industry R.J. Mattson of Foundation Company of Canada, J.M.R. Fairbairn, Chief Engineer of the CPR and R.F. Legget at that time employed by the Canada Steel Piling Company (Legget, 1936).

This conference marked the birth of geotechnique under the name of soil mechanics and foundation engineering. Not only was Canada well represented at the birth, but as we hope this review of the early history of the geotechnical profession in Canada shows, Canadians were also active in the gestation period.

ACKNOWLEDGEMENTS

As a glance through the references might indicate, the author must first thank Dr. Legget for recording many of the little known facts about engineering history in Canada. Not only have his references been a treasure house of information, but over the years they have

acted as a catalyst to the author to delve into Canadian history searching for others unknown references to early engineering in this country. In addition, Dr. Legget has spent many hours reviewing and improving various drafts of this manuscript. The author would also like to thank all others who assisted in the research and preparation of this paper. As you might imagine the list is very long. Dr. J.I. Clark, Mr. D. Townsend and Dr. D.Devenny deserve the credit for instigating its preparation.

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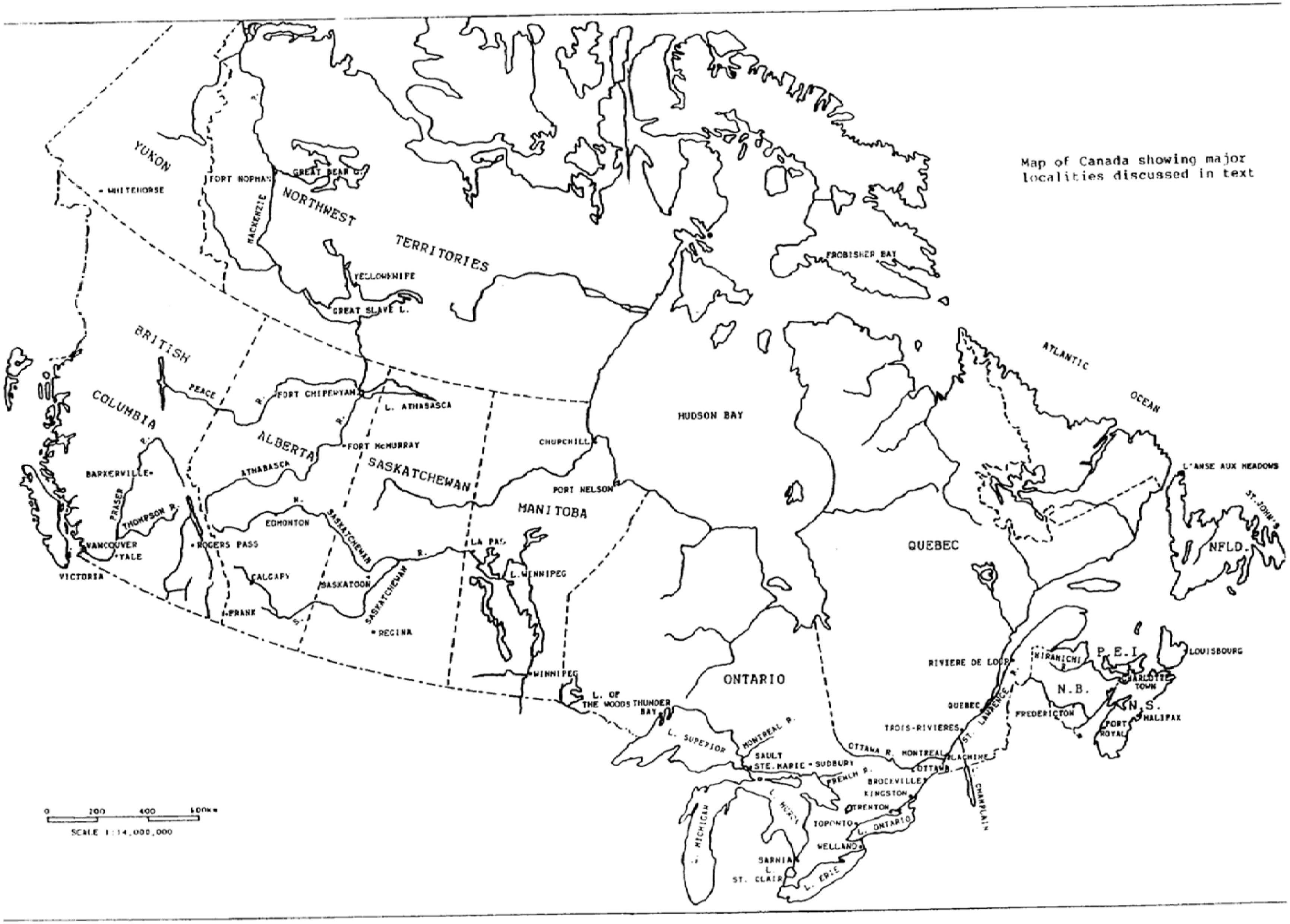

Map of Canada showing major localities discussed in text

THE EMERGENCE OF ENGINEERING GEOLOGY IN BRITISH COLUMBIA

AN ENGINEERING GEOLOGIST KNOWS A DAM SITE BETTER!

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ABSTRACT

Engineering geology is a subdiscipline of geology. Engineering geologists apply geological principles of rock, soil and groundwater to the appropriate location, design and construction of a wide variety of engineering structures, and to the assessment and design of mitigative measures for a wide variety of natural and man-made hazards. The types of projects with which engineering geologists are involved are quite different from those carried out by traditional geologists. It follows, therefore, that the aptitudes of engineering geologists and the approaches used in their investigations also differ from those of traditional geologists.

Based on this thesis, the development of engineering geology in British Columbia can be divided roughly into three phases. Up to 1920, geology was not consciously considered in the engineering projects in the province. Between 1920 and 1945, when geological input was required or requested for an engineering project, it was usually supplied by traditional geologists. After 1945, trained and experienced engineering geologists began to practice in the province and began their involvement with the engineering projects of the day. By the 1960s, engineering geology was well established and a recognized subdiscipline of geology in British Columbia.

INTRODUCTION

This paper deals with the *emergence* of engineering geology, and hence emphasizes developments prior to 1960. What is the significance of the sub-title? We'll let you be the judge.

What is engineering geology? There are many definitions and the following is a hybrid of a number of these:

> *Engineering geology is a branch of geology that applies geological principles of rock, soil and groundwater to the appropriate location, design and construction of a wide variety of engineering structures, and to the assessment of, and design of mitigative measures for, a wide variety of natural and man-made hazards.*

Some disagree that engineering geology is a branch of geology; rather it is the application of all branches of geology to the practical problems of engineering. Usually an engineering geologist is a generalist as opposed to a specialist, uses existing geological maps as opposed to creating new ones, predicts how things will behave in the future as opposed to how they were formed in the past, tends to be a pessimist as opposed to an optimist, is a bearer of bad news as opposed to a bearer of good news, and is paid accordingly!

ORIGINS OF GEOLOGY AND ENGINEERING GEOLOGY

Modern geology had its beginnings in the late 1700s and early 1800s, for example, in the works of Hutton, Werner and Lyell. The first geological map of England was prepared by William Smith in 1813, who is now known as the father of British geology (Sheppard, 1920 as referred to by Legget and Karrow, 1983). Smith was also the first engineering geologist. With reference to the location and construction of canals in England, he wrote:

The natural order of the various strata will enable the engineer to find the most appropriate materials, choose his location, avoid slippery ground or remedy the evil.

Meanwhile, during the same era, the Spanish, Captain James Cook, Alexander Mackenzie and Simon Fraser were just discovering and exploring the area that is now British Columbia. Of course, native peoples had lived in the area for many thousands of years.

In the late 1800s and early 1900s, engineering geology was developing as a recognized discipline in Europe and the United States. In 1881, Penning's British textbook entitled *Engineering Geology* was published as the first text in the field. In the early 1900s Charles Berkey, an American, was a trained geologist who worked on the water supply for New York City, then later on the Hoover dam and a multitude of other engineering projects. Berkey is considered the first American engineering geologist. In 1914, Ries and Watson published the first edition of their American text entitled *Engineering Geology* and in 1925, Karl Terzaghi, a trained Austrian engineer, published the first text in *Soil Mechanics* (in German). Terzaghi is known as the father of soil mechanics, but also had great interest in geology. In 1929, Redlich, Kampe and Terzaghi, published their text *Engineering Geology* (in German). Later, Terzaghi was to have a very close association with British Columbia.

An event occurred in 1928 that raised the level of awareness of geology in engineering around the world. In the failure of the St. Francis dam in California, 426 lives were lost. From Ransome's 1928 paper in *Economic Geology*:

So far as can be ascertained, no geological examination was made of the dam-site before construction began...The plain lesson of the disaster is that engineers, no matter how extensive their experience in building of dams...cannot safely dispense with the knowledge of the character and structure of the adjacent rocks, such as only an expert and thorough geological examination can provide. (Ransome, 1928)

ORIGINS OF ENGINEERING GEOLOGY IN CANADA

Thomas Roy is considered the first Canadian engineering geologist. In the 1830s and early 1840s, as a civil engineer in Upper Canada (now Ontario), he had a keen interest in, and appreciation of, geology (Legget, 1980). Projects and studies carried out by Roy include: a survey for one of the first railways in Ontario, a proposed theory for the raised beaches around Lake Ontario, a stratigraphic section for a portion of southern Ontario, a study for the improvement of Toronto's harbour, a similar study for improved navigation on the upper Ottawa River and a pamphlet on the principles and practices of road building in Canada. Today the Engineering Geology Division of the Canadian Geotechnical Society presents an annual award named after him.

The year 1842 was the beginning of the Geological Survey of Canada (GSC), but for many years its work was restricted to bedrock mapping in eastern Canada. In late 1800s and early 1900s, geologists from the GSC started to take an interest in engineering (Scott, 1979). In 1873, the GSC bought a steam-driven diamond drill to locate various construction materials to *extend and hasten the exploration and survey in the North West Territory.* In 1900, H. Ami reported on the geology of the cities of Saint John, Quebec City, Montreal, Ottawa and Toronto. In 1903 he worked on the geology for the foundations of the bridge over the St. Lawrence River at Quebec. In 1904, R.W. Ells wrote about the landslides in the Ottawa Valley–St. Lawrence Lowlands. McConnell and Brock, in 1904, investigated the Frank slide in Alberta, and in 1914 Brock became first Dean of Applied Science at the recently founded University of British Columbia. All this work was done by classical hardrock geologists.

Between the 1850s and 1890s civil engineering began to be taught at a number of eastern Canadian universities including New Brunswick, Toronto, McGill, Ecole Polytechnique, Royal Military College and Queen's. Beginning in the 1870s,

Figure 17. The only known photograph of the Cariboo Wagon Road under construction, probably taken in 1862 along the Thompson or Fraser River. The exact location and date of the photo are unknown (British Columbia Archives photo 74225).

McGill, Toronto, Royal Military College, cole Poly technique, Laval and Queen's began teaching geology but it would be more than 50 years before the two disciplines began to integrate.

In 1925, John Allen at the University of Alberta taught the first geology course in Canada specifically designed for civil engineers. In 1927, he wrote the first engineering geology paper to appear in the (Canadian) Engineering Journal, entitled *Geological Aspects of the Spray Lake Water Power Project.* In 1929, he also wrote a discussion in the Engineering Journal entitled, *Importance of Geology in Civil Engineering.* From that discussion:

> *The day was coming...when the practicing civil engineer would invariably have the geological problems associated with the particular project on hand investigated by one qualified in that profession. (Allen, 1929 as referred to by VanDine, 1987)*

In the late 1920s, Robert Legget, a young, energetic British civil engineer, emigrated to Canada to work on a hydro development in northern Ontario. In the early 1930s, he took up Allen's cause, and wrote his first paper for the Engineering Journal entitled, *Geology and Civil Engineering: their Relationship with Reference to Canada.* This 12-page paper was expanded by 1939 to become the first Canadian text on the subject, *Geology and Engineering*. It is presently in its 3rd edition entitled *Handbook of Geology in Civil Engineering* (Legget and Karrow, 1983). Legget went on to head the National Research Council, Division of Building Research and become President of the Geological Society of America.

DEVELOPMENT OF ENGINEERING GEOLOGY IN BRITISH COLUMBIA

In 1843, Fort Victoria was established on lower Vancouver Island by the Hudson's Bay Company. It was the first European settlement on the west coast of what was to become British Columbia. The first geological observations in the province were made by Dr. James Hector, a doctor, naturalist and geologist on the Palliser Expedition of 1857-60. In 1871, Selwyn and Richardson conducted the first GSC mapping in the province followed by numerous others.

Early Engineering in British Columbia

Examples of early engineering in British Columbia include several road and railway construction projects. In the 1860s the British Columbia gold rush led to the construction of the Cariboo Road from Yale to Barkerville under the direction of the Royal Engineers (Figure 17). The location and construction of the Canadian Pacific Railway (CPR) through the province took place in the 1870s and 1880s. In the early 1900s the spiral tunnels and the Connaught tunnel were constructed to reduce the grade on the CPR line and the Grand Trunk Pacific and Canadian Northern (now the Canadian National) railways were constructed through British Columbia (Figure 18).

If you examine the records for these, and most engineering works in Canada in the 1800s and early 1900s, there was very little attention paid to geology in the location, design and construction. For the most part these works were ***bulled*** through by civil engineers who were trained, both in school and on the job, to be resourceful and innovative and most of all ***to get the job done*** in spite of the geology. In addition, there were few geologists at that time and fewer who were interested in engineering projects.

Figure 18. A Canadian Northern Railway survey party, surveying along the rugged west bank of the Thompson River in 1911 (British Columbia Archives photo 30150).

Early Observations of Landslides in British Columbia

Possibly the first description of a landslide in the province was of the Drynoch landslide, south of Spences Bridge, along the Thompson River. Matthew Begbie, Chief Justice of British Columbia (also known as the *Hanging Judge*), presented a paper to the Royal Geographic Society in 1871 entitled *On the Benches or Terraces of British Columbia*. He writes:

> *In some [areas], the displaced surface seems to have moved painfully and grindingly over the subjacent bed-rock [sic], and the surface is broken into a thousand irregularities ...the mass [Drynoch landslide] looks not unlike an earthen 'glacier du Rhin' (Begbie, 1871 as referred to by VanDine, 1983).*

In 1877, John Macoun, a naturalist with the GSC, also described Drynoch landslide. H.J. Cambie, a civil engineer, during a survey for the CPR in 1878, was the first engineer to briefly describe the slide and postulate a cause and possible solution. Cambie's report is possibly the first engineering geology report on a natural hazard in the province.

In 1897 Robert Stanton, a British civil engineer, wrote a thorough 18-page paper (plus 3 drawings) entitled ***The Great Land-slides on the Canadian Pacific Railway in British Columbia*** which was presented to, and published by, the (British) Institution of Civil Engineers. This paper on landslides in glaciolacustrine silts along the Thompson River is the first major paper related to engineering geology in the province. Stanton described the slides, the bedrock and surficial geology, climatic conditions and postulated probable causes. For example:

> *In considering the real nature and causes of the slides, the solid geology does not have so important a bearing on the matter as the present position and condition of the superficial or drift deposits due to the glaciers, which now partially cover, and at one time largely covered, the interior country (Stanton, 1897).*

Engineering Geology in British Columbia 1920 to 1945

In 1921, Geological Engineering began at the University of British Columbia (UBC), but only geology related to mining and petroleum geology, not civil engineering, was taught. Between 1920 and 1945, British Columbia was beginning to develop and a few larger engineering projects were under construction. In 1919, when the Department of Public Works wanted to improve navigation in the Fraser River delta, W.A. Johnson of the GSC carried out a geological investigation ***to determine by what engineering methods the navigable part of the river might be improved*** (Johnson, 1921). This is possibly the first geological investigation for an engineering project in the province.

Victor Dolmage, a hardrock mining geologist with the GSC, was Chief of the British Columbia division from 1922-1929, and mapped the bedrock geology of many parts of the province. In 1927, he started his involvement in engineering geology by carrying out geological mapping of the tunnel on Mission Mountain as part of the first Bridge River Project for British Columbia Electric Railway Company. In 1929, he began private consulting as a mining geologist and taught on a part time basis at UBC in the Geological Engineering program. One of his students was Dr. Jack Armstrong (referred to later). In 1930, Dolmage provided geological input for the Cleveland dam site on the Capilano River and for the First Narrows pressure tunnel for the Greater Vancouver Water and Sewage Board (Dolmage, unpublished). Although not trained as such, Victor Dolmage can be considered the first engineering geologist in British Columbia.

Other geologists who also contributed to some engineering projects during this period were D.F. (Cap) Kidd and H.C. Gunning, also both originally with the GSC. Kidd left the survey to form his own practice, while Gunning went to teach at UBC and later become Department Head of Geological Sciences and Dean of Applied Science. The volume of their work in engineering and geology is minor compared with Dolmage.

1945 to 1960

The early post-World War II years were a boom period in British Columbia. A host of dams, pulp and paper mills, tunnels and large plants were conceived, designed and constructed. While still consulting as a mining geologist (until 1955), Dolmage was involved in many of these major projects including a number for British Columbia Electric (later British Columbia Hydro) such as the Bridge River Powerhouse, Wahleach power project, Cheakamus power project, Jordan River project and the W.A.C. Bennett dam (Figure 19). He also worked on most of the water tunnels in the Vancouver area for the Greater Vancouver Water and Sewage Board and assessed the geology of most proposed dam sites along the coast for Alcan, including the 14.5-kilometre Kemano tunnel.

Figure 19. Victor Dolmage inspecting dinosaur tracks near Portage Mountain dam (now W.A.C. Bennett dam).

By 1955, Dolmage was doing engineering geology work almost exclusively under the company name of Dolmage, Mason and Stewart. This included the demolition of Ripple Rock in Seymour Narrows for Canada Public Works in 1957, at the time the largest ever non-nuclear blast. A paper on that project, published in the Bulletin of the Canadian Institute of Mining and Metallurgy, won the Leonard Gold Medal. It is interesting to note that of all the hydro-related work that Dolmage did, he did none in the Strathcona Park area (John Hart and Strathcona dams) out of principle, feeling that the park should not be developed. In 1950, in the first volume of the British Columbia Professional Engineer, Dolmage contributed a paper entitled *Geological Examination of a Dam Site*.

In the 1930s and 1940s, Karl Terzaghi was a *Professor of the Practice of Civil Engineering* at Harvard. The only course he taught was Engineering Geology. In 1945, Terzaghi was brought to the west coast, initially in Washington but later in British Columbia, by H.A. Simons as a review consultant for soil mechanics in relation to pulp and paper mills at Port Alberni, Campbell River, Nanaimo, Crofton and Castlegar. Later, for British Columbia Electric and Alcan, Terzaghi worked closely with Dolmage on numerous sites: Mission dam, Daisy Lake dam and Cheakamus power project (located on landslide debris). He also carried out assignments for Pacific Great Eastern Railway (now British Columbia Rail), Greater Vancouver Water District and for

Alaska Pine and Cellulose at Woodfibre (on a submarine landslide). These are all classic, one-of-a-kind projects (Figure 20).

Although trained as a mechanical engineer, Terzaghi had a very strong leaning towards geology.

> *He never gave a lecture in soil mechanics. They were always lectures in geology, geomorphology, and how they related to a problem, to which...some...soil mechanics had an application. He was a geologist at heart although he was an engineer's engineer at the same time. But he always regarded soil mechanics as a branch of engineering geology which in turn was a branch of geology. (Peck as referred to by Legget, 1979)*

> *Every civil engineer is engaged in experimental geology... (Terzaghi, 1953 as referred to by Legget, 1979)*

In Terzaghi's lectures and writings he often referred to his projects and experience in British Columbia. He had a great influence on engineering geology in the province and upon his death in 1963, British Columbia Hydro renamed Mission dam, Terzaghi dam.

In 1951, Charlie Ripley, a relatively young soil mechanics engineer, with an undergraduate degree from the University of Alberta and a graduate degree from Harvard (under Terzaghi), moved to British Columbia from the prairies and started one of the first soil mechanics consulting firms in the province, Ripley and Associates, now known as Klohn Leonoff. Over the next few years Ripley worked closely with both Dolmage and Terzaghi on numerous large engineering projects. Under that tutelage he learned the value of geology in engineering projects, a lesson remembered throughout his career and passed along to his colleagues.

In the early 1950s, the British Columbia Department of Mines was the only provincial department to have any geologists on staff but they were all hardrock geologists working on mining-related projects. There was a need to provide advice on civil engineering and groundwater problems to other departments including Highways, Agriculture, Water Resources and Public Works. Consequently, Hugh Nasmith, a University of British Columbia graduate in Geological Engineering, with post graduate training in Engineering Geology from the University of Washington, was hired. He was the first trained engineering geologist to work in the province and for the province. Nasmith was involved in numerous projects from the early 1950s to 1958 when he left the department and joined R.C. Thurber and Associates, now Thurber Engineering Limited, where he continued that involvement.

Figure 20. Karl Terzaghi (centre) inspecting construction of Deas Island Tunnel (now George Massey Tunnel).

In this same time period other geologists and engineering geologists came on the scene. In the late 1940s

Jack Armstrong, trained as a hardrock geologist, began mapping the surficial geology of Vancouver and the Fraser Lowland which led to the publication of a GSC Paper entitled *Environmental and Engineering Applications of the Surficial Geology of the Fraser Lowland, British Columbia* (Armstrong, 1983).

Doug Campbell, another classically trained geologist, was introduced to engineering geology by Dolmage. In the late 1950s he became involved in geological investigations for the W.A.C. Bennett dam. Jack Mollard, a Regina-based engineering geologist, introduced air-photo interpretation to geology and engineering in the province in the late 1950s, while on a project for British Columbia Electric.

At UBC in 1959, an engineering geology program was initiated within the Geological Engineering Program, partially at the insistence of Henry Gunning, then Dean of Applied Science. Bill Mathews recounting the beginning of engineering geology at UBC:

> *...a demand has arisen for geologists trained in interpreting the rocks and soil in the vicinity of major construction projects in terms of (1) potential hazards, (2) problems of construction, and (3) sources of raw materials. The geological engineer, soundly trained in both geology and engineering fundamentals, is the man, we believe, best qualified to work closely with the civil engineer responsible for the execution of this work (Mathews, 1967).*

1960 to PRESENT

Continued growth of the province has generated numerous, large, challenging engineering projects in recent years. There is a continued acceptance of engineering geology.The number of well trained and experienced engineering geologists, including some of the best in the world, has grown. Today engineering geology is practiced in a number of provincial government ministries, Crown corporations, federal government agencies, railways and consulting firms. Although engineering geology has had little impact on bedrock mapping in British Columbia, it has stimulated research in surficial geology, geomorphology, geologic processes, groundwater and environmental work. Today, engineering geologists are involved in a wide spectrum of projects, of which dams are a major area because *engineering geologists know a dam site better!*

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Drynoch landslide, British Columbia — a history

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Drynoch landslide, located along the Thompson River, British Columbia, is a large volume, slow-moving earthflow. Geotechnically, it is classified as a zonal, infinite slope soil failure. Geological evidence indicates that it began to move approximately 3000–6000 years ago. Until the early 1800's, movement of the slide only affected the lifestyle of the early Interior Salish Indians, the inhabitants of the area. Since that time the landslide has had a direct influence upon the Cariboo Road built in the 1860's (which later became British Columbia Highway 1 and more recently the Trans-Canada Highway) and the Canadian Pacific and Canadian National railway lines. The history of Drynoch landslide is entwined with the geographic and geologic exploration of British Columbia and the development of the interior of the province. Over the past hundred years many geologists and engineers, some quite eminent, have recorded a number of theories on the possible cause and failure mechanism of this notable slide. Suggested and attempted methods of controlling the movement of Drynoch landslide have been numerous, and have met with various degrees of acceptance and success.

Le glissement de terrain de Drynoch, situé le long de la rivière Thompson en Colombie-Britannique, est une coulée de terre de grand volume et à déplacement lent. Géotechniquement il est classé comme rupture locale d'une pente infinie. Géologiquement, certaines preuves suggèrent qu'il a débuté il y a environ 3000–6000 ans. Jusqu'au début des années 1800, le mouvement du glissement affectait simplement le mode de vie des habitants de la région, les Indiens "Interior Salish". Depuis cette époque, le glissement a une influence directe sur la route Cariboo construite dans les années 1860 (devenue ensuite route n° 1 de la Colombie-Britannique, puis route Trans-canadienne), les voies ferrées du Canadien Pacifique et du Canadien National. L'histoire du glissement de Drynoch est étroitement liée à l'exploration géologique et géographique de la Colombie-Britannique et au développement de l'intérieur de cette province. Dans les derniers 100 ans, de nombreux géologues et ingénieurs, dont certains éminents, ont développé une série de théories sur la cause possible et le mécanisme de rupture de ce glissement célèbre. Les méthodes suggérées ou mises en œuvre pour contrôler les mouvements du glissement de Drynoch ont été nombreuses et ont eu un accueil ou un succès variable.

[Traduit par la revue]

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Introduction and geotechnical background

As you travel by either road or railway along the Thompson and Fraser river valleys in the interior of British Columbia, you cannot help but be awed by the spectacular scenery. The fact that man has been able to engineer any sort of transportation route in that rugged terrain is a wonder in itself. One particular landform that has had an influence on man and his transportation routes from the time of the early Interior Salish Indians to the present day is Drynoch landslide.

Drynoch landslide is located on the east side of the Thompson River, 8 km south of Spences Bridge and approximately 180 km northeast of Vancouver (Fig. 1). From the Trans-Canada Highway (B.C. Highway 1) or the Canadian Pacific Rail right-of-way (both cross the toe of the slide, Fig. 2), it is difficult to appreciate the size of the landform. It is 5.3 km long from its headscarp to its toe at the Thompson River (Figs. 3 and 4). In that distance it drops 710 m in elevation. The slide, which closely resembles a valley glacier in surface appearance, is only 670 m wide at its widest point and 120 m at its narrowest point. The gradient of the slide surface varies from 25:1 to 3:1 and averages 6.5:1 (8.7°), with gradients steeper in the lower section (Fig. 5). Drilling results indicate that movement occurs along a failure zone that varies in depth from 7.5 to 18 m (Brawner and Readshaw 1963) and varies in thickness from 4.5 to 6.0 m (VanDine 1980).

The volume of material involved is approximately 17 $\times 10^6$ m^3. For comparison it is estimated that the Hope slide (1965) contained 47 $\times 10^6$ m^3 and the Frank slide (1903) contained 32 $\times 10^6$ m^3 (Mathews and McTaggart 1969; Cruden and Krahn 1973). However, unlike these catastrophic rock slides, Drynoch landslide is classified geologically as a slow-moving earthflow.

A study of air photographs taken between 1951 and 1972 indicates that portions of the slide have been moving at a rate of 3 m per year (Fig. 6). This figure is substantiated by a compilation (VanDine 1980) of B.C. Department of Highways data between 1957 and 1960 (Fig. 7). There is a reasonable correlation among peak spring runoff, high groundwater levels, and maximum rate of movement. The amount of precipitation does not appear to affect the rate of movement, possibly because of the great deal of evapotranspiration in the region. Radiocarbon dates (Powers and Wilcox 1964; Arm-

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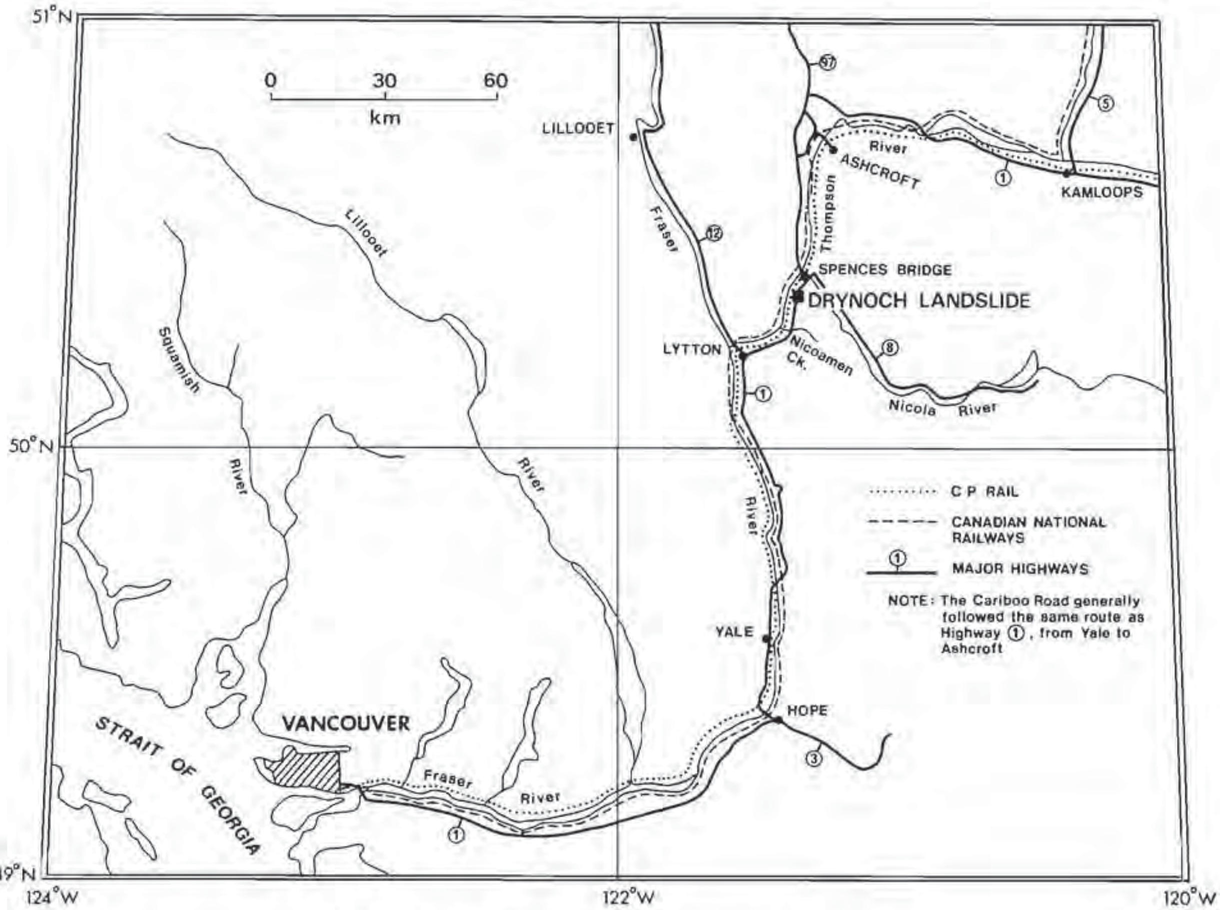


FIG. 1. Location map showing present-day transportation routes.

strong and Fulton 1965; Lowden *et al.* 1969) indicate that the landslide began to move approximately 3000–6000 years ago. From the initial movement, Drynoch landslide probably has moved steadily but at irregular rates throughout various parts of the slide.

Drynoch landslide also differs from the Hope and Frank rock slides in that the material involved is a heterogeneous mixture of pebbles from glacial drift, Tertiary remoulded sediments, Cretaceous rock fragments, and a matrix of sandy clay. An analysis of the clay mineralogy indicates that montmorillonite is predominant; kaolinite, quartz, and feldspar occur in minor amounts. A summary and comparison of the shear strength parameters, determined for the material from the failure zone, is presented in Table 1. From this table, it appears that the slide material is failing in a remoulded state, and has a low coefficient of effective cohesion and a range of effective friction angles from approximately 14 to 17.5°. Geotechnically, Drynoch landslide is classified as a zonal infinite slope soil failure.

However, this article is not intended to be a technical record of Drynoch landslide. That has been recorded elsewhere (VanDine 1974, 1980). The purpose of this paper is to trace the history of the landslide and its effect on man and the surrounding area.

Up to 1800

In the mid-1960's, charcoal, a microblade, and fish vertebrae (presumably salmon) were uncovered in an excavation (archeological site designation EcRi:1) on the south side of the toe of Drynoch landslide (Fig. 4) (Sanger 1967; Fulton 1968). These materials were found in a thin, wind-blown sand layer that overlies ancient Thompson River terrace sand and gravel. But, in turn, this sand is overlain by volcanic ash and debris from Drynoch landslide. From this excavated section (Fig. 8) and the material that was radiocarbon dated an early history of the area can be reconstructed.

The first inhabitants of the interior of British Columbia were the forefathers of the Interior Salish Indians.

FIG. 2. Oblique air photo looking southward down the Thompson River valley and across the toe of Drynoch landslide (to the left). Transportation routes from left to right are: (1) new Trans-Canada Highway (B.C. Highway 1); (2) CP Rail main line; (3) old Trans-Canada Highway (note how central portion has been disrupted); (4) Thompson River (note how the slide has pushed the river against the west bank); (5) Canadian National Railways main line (GSC photo 175698).

They entered the area as the glacial ice melted, approximately 9000 years ago (Borden 1957). The cultural remains found in the excavation suggest that the early inhabitants used the ancient river terraces, which were capped in places by wind-blown sand deposits, for travelling, locating their nomadic dwellings, hunting, and fishing. Charcoal from fire pits in the sand has been dated as being 7500 years old (Lowden *et al.* 1969).

Approximately 6600 years ago volcanic ash fell over much of southwestern British Columbia, including the Drynoch area. In places near the slide the volcanic ash has been found in beds up to 5 cm thick (VanDine 1974). The ash has been traced back to its source, the Mazama volcano, in present-day Oregon State (Powers and Wilcox 1964). It is difficult to know exactly what effect this volcanic ash had on the early Indians. However, after seeing the effect of the recent Mount St. Helens volcano, on a population much less dependent on nature than were the Salish Indians, it is probable that the short-term effect was great.

Overlying the ash is approximately 1 m of alluvial sand and gravel. This material was washed down from the mountains, perhaps as a mudflow, and was deposited on the relatively flat fluvial sand and gravel terrace. It is intriguing to note that the deposition of the alluvial material did not everywhere remove the ash of the Mazama volcano. This alluvial sand and gravel stabilized the wind-blown sand and volcanic ash, making this location even more appealing to the Salish Indians.

From the radiocarbon dates and the relative stratigraphic position of the slide debris in the excavation, it can be assumed that debris from the Drynoch landslide reached the Thompson River terraces more recently than 6600 years ago. In 1961, the British Columbia Department of Highways uncovered tree roots within the slide mass. These have been dated as being 3200 years old (Armstrong and Fulton 1965) and indicate the slide was active about that time. Although the exact date of landslide initiation is not known, it is known that the slide would have buried the Indian trails and campsites in the area and generally created havoc for the natives. It is reported that "Indian legend, which goes back

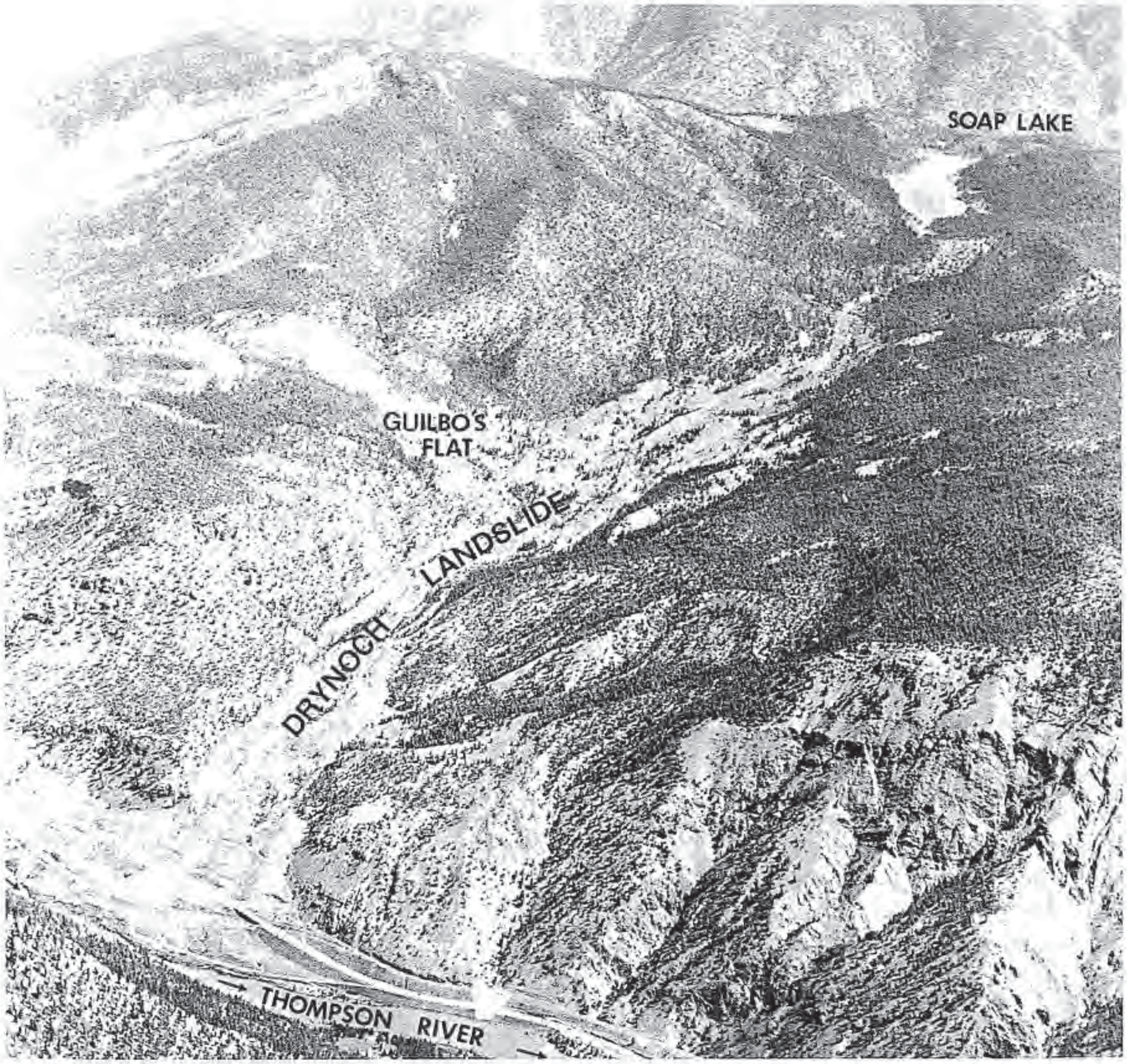


FIG. 3. Oblique air photo of Drynoch landslide, looking northeast. Summit in upper left is 1340 m; Soap Lake is 920 m; Thompson River is 208 m asl. Horizontal distance from Thompson River in the foreground to Soap Lake is 5.3 km (photo by D. A. MacLean).

hundreds of years, describes the landslide but no reference is made of its beginning" (Brawner and Readshaw 1963).

After the initial movement of Drynoch landslide, movement continued either intermittently in surges or slowly and continuously, or in some combination of the two. A landform, the predecessor of the one we see today, was formed. The Salish Indians probably avoided building their pit houses on the slide material (by this time they were building more permanent structures called Kekuli or Keekivilly (Fig. 9) (Shewchuk 1975; Anonymous 1978)), but it is quite likely that they continued to fish in the Thompson River from the toe of the slide. The toe, projecting into the Thompson River, narrowed the river and forced it against the western bedrock wall of the valley (Figs. 2 and 4). This constriction, and the resulting rapids, would have provided an ideal location for primitive salmon fishing.

The landslide also provided a notch or break along the east side of the Thompson River valley (Fig. 3). The Salish Indians used this notch as access to the uplands. They travelled and lived in the uplands during the hot summers because of the cooler temperatures, more abundant vegetation, and more plentiful game offered

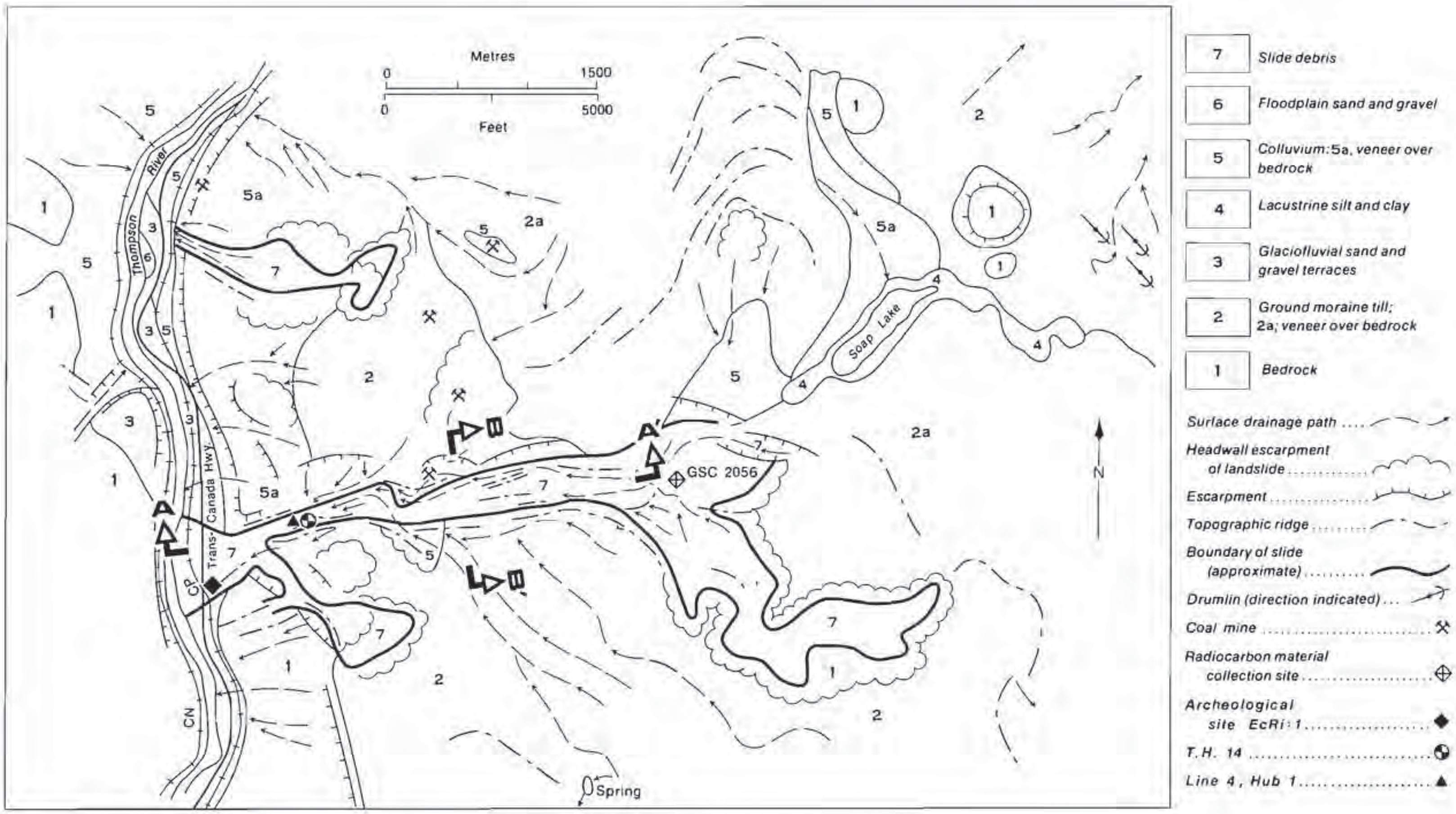


FIG. 4. Surficial materials of Drynoch landslide area based on airphoto interpretation.

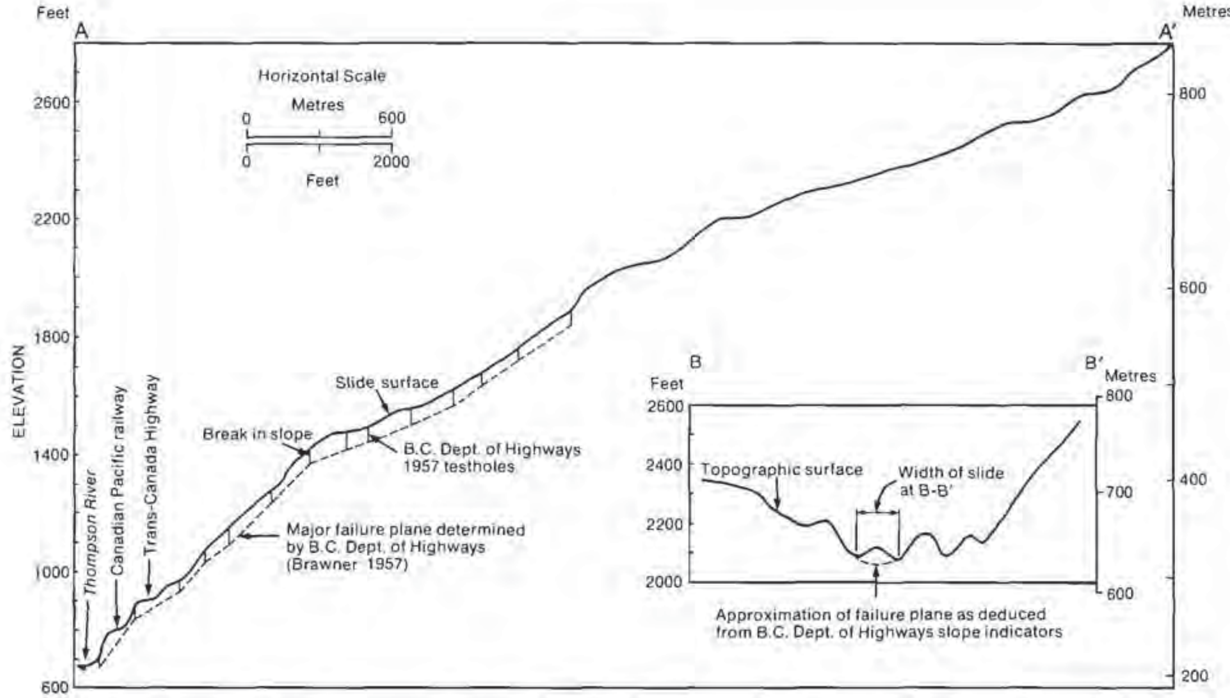


FIG. 5. Longitudinal profile and cross-section of Drynoch landslide (see Fig. 4).

by the higher elevations. Evidence that the slide was used as access to the uplands is provided by a buried fire pit, which was uncovered by the writer on a relatively stable, upper portion of the slide. Charcoal from this pit was radiocarbon dated as being 900 years old (VanDine 1974; Lowden and Blake 1980).

From 1800 to early 1900's

The fur traders

The period between 1800 and 1900 was formative for the exploration and settlement of British Columbia. Fur traders in the early 1800's were the first Europeans to penetrate into the area. They found that the lower Thompson and Fraser rivers made relatively poor fur trade routes in comparison to the Harrison Lake route to the west and the Okanagan Lake route to the east. The fur traders therefore bypassed Drynoch landslide and we have no record of this period.

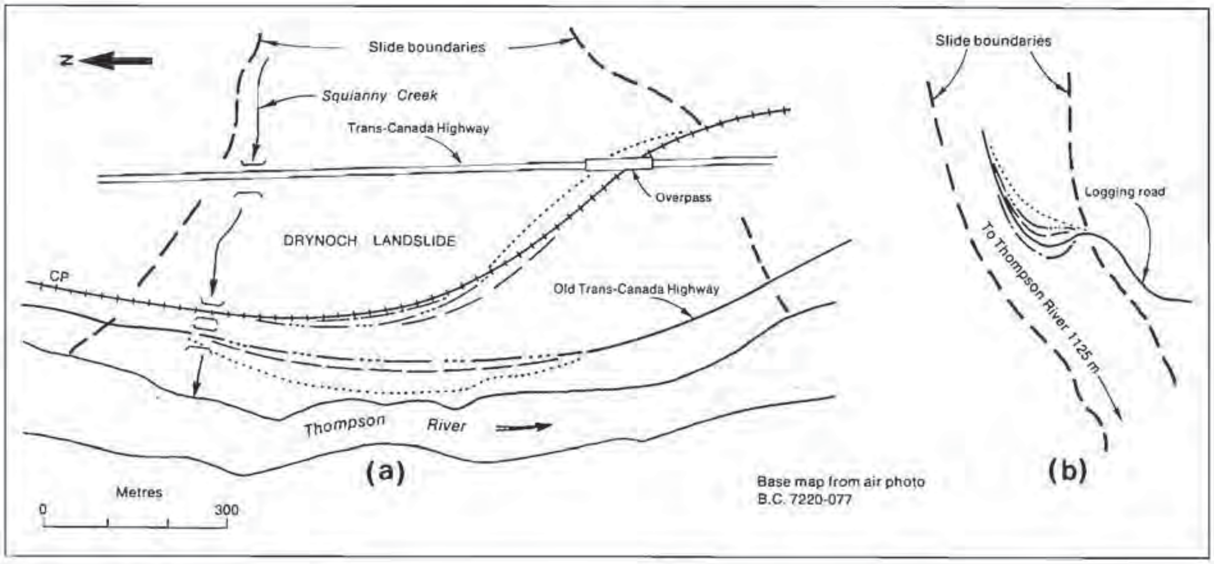
Caribou wagon road

In the second half of the 19th century, however, the lower Thompson River became a popular transportation route.

In 1857, gold was first discovered in British Columbia at Nicoamen Creek (Dawson 1879), where the Thompson River swings abruptly westward approximately 10 km south of Drynoch landslide (Fig. 1). Its discovery led to the eventual Cariboo gold rush further to the north, in 1858. As the rush for gold intensified in the early 1860's, and to simplify travel to the Cariboo and Barkerville, James Douglas, Governor of British Columbia, commissioned the building of a wagon road (Fig. 10). Construction of this road began in 1862 under the direction of Colonel R. C. Moody of the Royal Engineers. It started at Yale, the upstream end of navigable water on the Fraser River, and continued northward up the Fraser and Thompson rivers eventually to the goldfields of the Cariboo. A great part of the road followed the older, established Salish Indian trails.

The contract for the section between Lytton and Cooks Ferry (later called Spence's Bridge and now spelt Spences Bridge) was let in early 1862 to Charles Oppenheimer and Walter Moberly (British Columbia Department of Public Works 1924; Moberly 1908). One thousand men were employed to build the first 20 km north and east of Lytton. Thereafter the lure of the Cariboo gold rush and an outbreak of smallpox reduced the number of workers so that Chinese and Indians had to be pressed into service to build the section from Nicoamen Creek across the Drynoch landslide to Cooks Ferry. In late 1862, the government terminated the contract and had to complete the unfinished portions of the road itself. The entire 800 km of wagon road were completed by 1864 at an average cost of \$1250/km (Williamson 1927).

The records of construction for this section of the Cariboo Road were kept by Robert Howell, R.E. None of his reports to the Colonial Secretary mention the



Year	Symbol	Remarks
Old Trans-Canada Highway		
1951	....	Movement of slide prior to 1951 caused considerable disruption of designed curve, bringing it close to edge of Thompson River.
1960	—...—...—	Between 1951 and 1957 highway was realigned uphill. Further disruption is evident on left side of sketch.
1965	-—-—-—	Movement continued downhill as maintenance of old highway was discontinued on completion of new highway.
1969 & 1972	————	Old highway has been washed out by toe erosion and subsequent toe failure.
New Trans-Canada Highway		
1969	════	Built in 1961, this road has undergone little movement because most of the failure plane was removed during construction.
Canadian Pacific Railway		
1951	....	Movement prior to 1951 created a sharp curve.
1960	—...—...—	CP Rail realigned tracks and removed some of the curve prior to construction of overpass by B.C. Department of Highways.
1965	— — — —	Movement increased sharpness of curve.
1969	+++++++	Realignment in 1967 decreased curve once more.
1972	-·—·—·—	Downhill movement continued between 1969 and 1972.
Logging Road		
1951	....	Continual downhill movement increased sharpness of curve of logging road.
1960	—...—...—	
1965	— — — —	
1969	————	
1972	-·—·—·—	

FIG. 6. Sketch showing movement of Drynoch landslide as interpreted from vertical air photos.

landslide or mention any difficulty in construction over the toe of the slide (Howell, Incoming Colonial Correspondence, unpublished, 1862). However, shortly after construction it became apparent that this area was not as stable as the terrain upstream and downstream. Mathew Begbie mentioned this area of instability in 1871, John Macoun noted it in 1877, and a journalist for the Victoria Daily British Colonist alluded to it again in 1885.

Mathew Begbie was a principal figure in the Cariboo gold rush. In 1858, he was appointed the first judge for the colony of British Columbia. It was his job to maintain order and deal out penalties for injustice

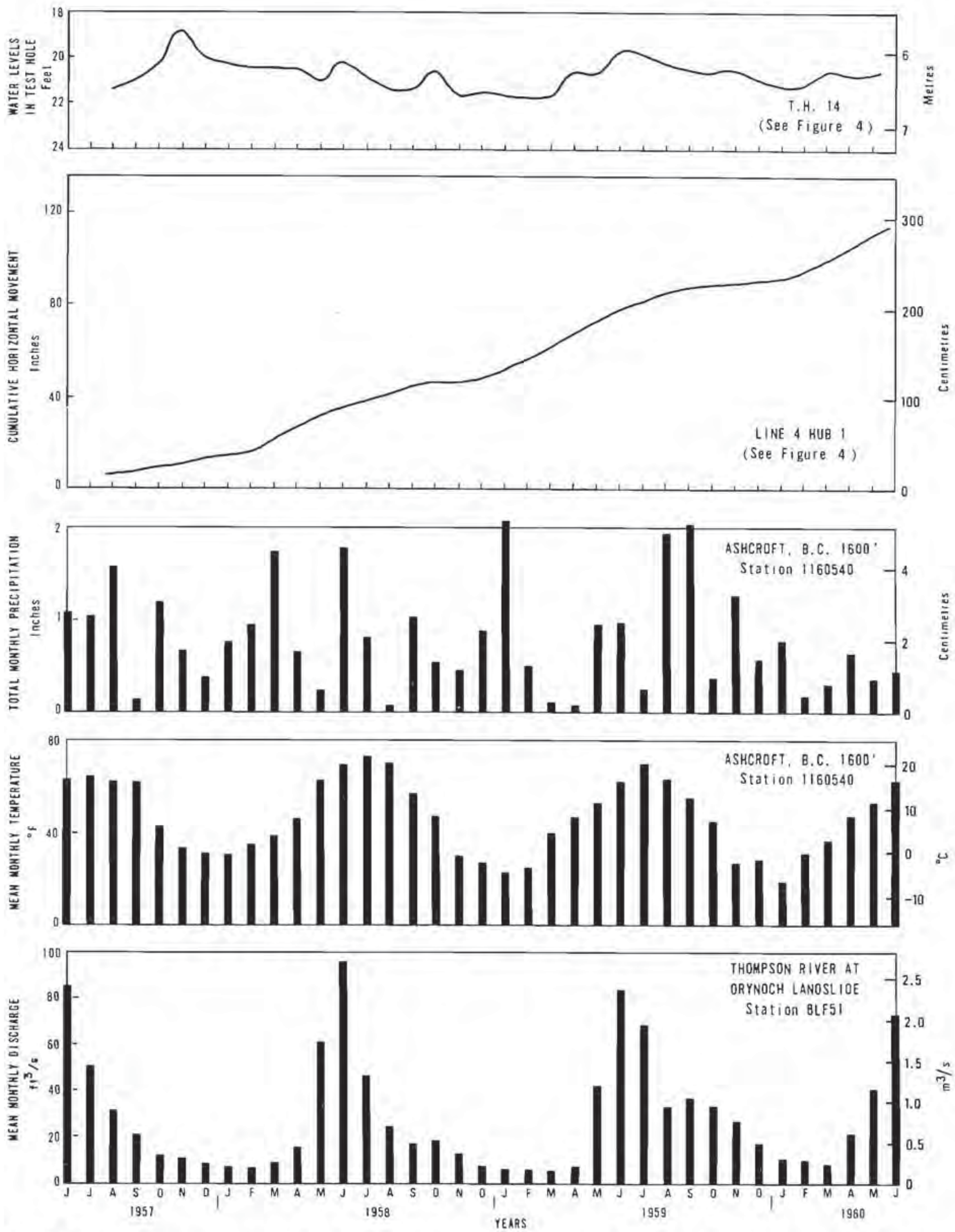


FIG. 7. Movement hubs, groundwater levels, and hydrologic and climatic data for locations indicated for a period from June 1957 to June 1960 (T.H. 14; line 4, hub 1).

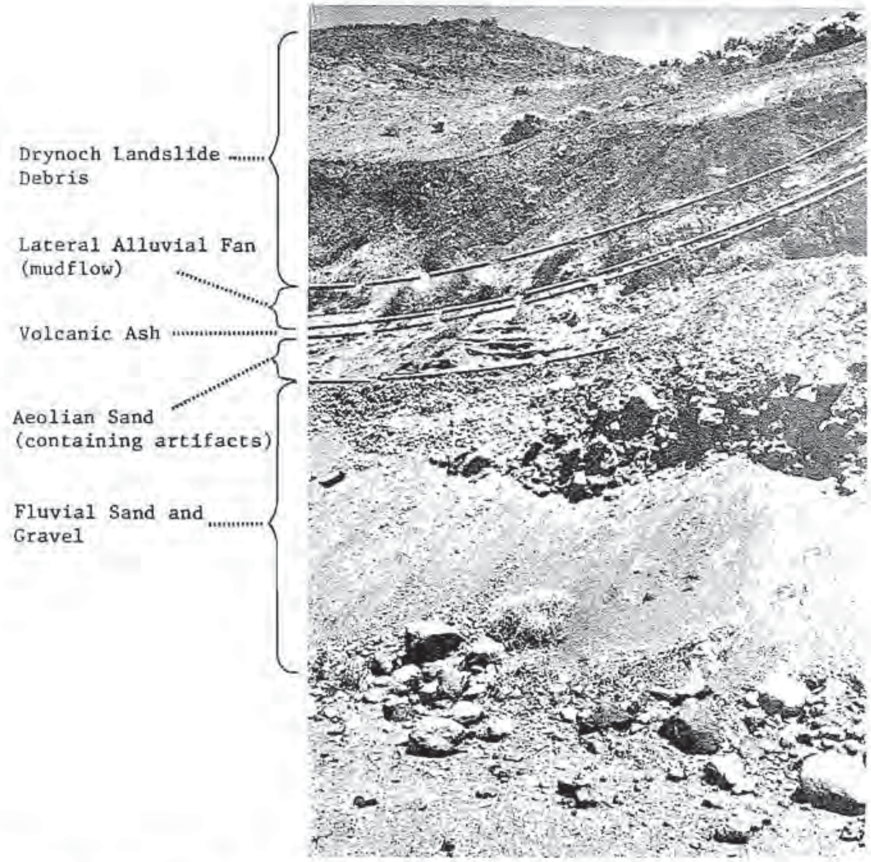


FIG. 8. Excavated section of unconsolidated material in a gravel pit near the toe of Drynoch landslide. Shovel is approximately 1.3 m long (GSC photo 175588).

throughout British Columbia, especially amongst the 10 000 gold seekers of the Cariboo region. He accomplished both by gaining the reputation of ruling with an iron hand, while being fair and just. Begbie, who became Chief Justice in 1870 and was knighted in 1875, travelled the Cariboo Road extensively (Fig. 11) and crossed the toe of Drynoch landslide many times. He was an observant man — observant of the natural landscape through which he often travelled. In 1871 he wrote a report for the Royal Geographical Society in London, *On the "Benches", or Valley Terraces, of British Columbia* (Begbie 1871). In this paper he described several landslides, including the Drynoch landslide:

> In some [areas], the displaced surface seems to have moved painfully and grindingly over the subjacent bed-rock, and the surface is broken into a thousand irregularities; at Pavillion [approximately 70 km northwest of Drynoch landslide and close to the Fraser River] and on Thomson [sic] the mass [Drynoch landslide] looks not unlike an earthen "glacier du Rhin."

This relatively short reference[1] is the first recorded description of the long, narrow appearance and slow-moving character of Drynoch landslide.

In 1877, John Macoun, a botanist with the Geological Survey of Canada, commented on the section of the road that crosses Drynoch landslide (Macoun 1877):

> A short distance below the bridge [Spences Bridge], the mountain is constantly sliding towards the river [Thompson River] and even in the short space of time since the road was built [13 years] it has been rebuilt thrice at a more secure distance from the river.

An unidentified "representative" of the Daily British

[1]It is interesting to note that Dr. Cheadle read Judge Begbie's paper to the Society and commented on it afterwards. Walter Cheadle, an English gentleman, accompanied by Lord Milton, crossed Canada in 1862–1863. They crossed the toe of Drynoch landslide in September 1863. Although he did not refer to it specifically, Cheadle noted that along the Thompson River, "gulches," one of which could have been Drynoch landslide, flowed into the river (Cheadle 1931).

FIG. 9. An abandoned Salish Indian pit house, also called Kekuli or Keekivilly, photographed in 1907, near the confluence of the Nicola and Thompson rivers (B.C. Archives photo 88755).

TABLE 1. Summary of shear strength parameters

Method of estimation	C' (kPa)	ϕ' (°)
Triaxial test	25.5	21.4
Direct shear test		
(*a*) Undisturbed*	0	21.3
(*b*) Remoulded* #4	0	15.0
Back-calculation		
(*a*) Bishop method	0 (assumed)	17.1
(*b*) Skempton and Delory method	0 (assumed)	17.4
Ripley and Associates (1960)	33.3	14–17

*The terms undisturbed and remoulded, when referring to this slide debris, are relative terms only, since all this material has been disrupted from its original location.

Colonist of Victoria, B.C., recorded on March 25, 1885, "In the course of a year it [Drynoch landslide] has been known to slide several feet, the wagon road having to be rebuilt a couple of years ago in consequence of this phenomenon" (Anonymous 1885).

Canadian Pacific Railway

In 1871 British Columbia joined Confederation with Canada. With this confederation came visions of a transcontinental railway connecting all the provinces. However, the promise of completing this railway within 10 years was a little optimistic. Surveys for the railway began in 1872 with the epic journey from "Ocean to ocean" by Sandford Fleming, chief engineer of the newly formed Canadian Pacific Railway Company (CPR) (Grant 1873). During 1877, H. J. Cambie (Fig. 12), engineer in charge of surveying, carried out a location survey along the Fraser and Thompson rivers for the new railway. Cambie has the distinction of first describing Drynoch landslide (then known as the "Mud Slide") from an engineering viewpoint. He postulated a failure mechanism and proposed a method of controlling its movement (Cambie 1878):

> The worst feature on this section [Spences Bridge to Lytton] occurs near the 333rd mile, and is known as the Mud Slide. It commences at a height of 1900 feet above the line and about two miles distant, and extends down the mountain side to the Thompson River when it terminates abruptly in a bank about 1000 feet in length and 40 feet in height. At the point where crossed by the [proposed rail] line, it is 1000 feet wide and the average forward movement per annum is about eight feet at the centre, decreasing gradually towards the sides. It is apparently caused by springs near its source, which disappear into the ground, reappearing, at intervals,

FIG. 10. The only known photograph of the Cariboo Wagon Road under construction. The exact location and date are unknown; however, it was probably taken in 1862 along the Thompson or Fraser River (B.C. Archives photo 74225).

> causing the earth which is strongly impregnated with alkali, to dissolve to the consistency of soap, thus forming a lubricator between the bedrock and the mass of earth above. By careful drainage of these springs near their source, and diverting them elsewhere, the slide can doubtless be so far stopped as to cause but little inconvenience.

In 1879 Andrew Onderdonk, an American contractor, was awarded Contract 62 to construct 45 km of the CPR from Lytton to 9 km north of Spences Bridge (Figs. 13 and 14). Five years and untold hardships and loss of life later, this most difficult contract, which included 265 trestles, was completed.

H. A. F. McLeod, C.E., was construction engineer for this contract. In 1882 he gave the name Drynoch to a semipermanent railway surveying and construction camp located approximately 2 km south of the "Mud Slide" (Fig. 15). McLeod, a true Scotsman, named this camp and future railway station after the seat of the McLeod clan on the Isle of Skye in Scotland (Melvin 1972; Duart MacLean, personal communication 1976). A map of the Isle of Skye exhibits names such as Drynoch River, Glen Drynoch, the Village of Drynoch, and Drynoch Lodge. A post office was active at the Canadian Drynoch from 1882 to 1885, and the postmaster was the same H. A. F. McLeod, C.E. (Melvin 1972). (The name was officially confirmed by the Geographical Board of Canada in 1936. In 1953, a Mr. Shaw requested the name be changed to Shaw Springs, but the request was turned down by the Geographical Board (Pearson, personal communication 1982.))

Although there are no records of any problems arising while building across the toe of Drynoch landslide, it is probable that the railway, which was built to specifications that were much more stringent than those for the Cariboo Road, would have encountered some early construction and maintenance problems. An indication of this is the dispatch filed by an unknown journalist from the Victoria Daily British Colonist. Just prior to the completion of Contract 62, he toured the construction of the CPR from the coast to Kamloops Lake and reported (Anonymous 1885):

> A couple of miles from Drynock [sic] is the famous MUD SLIDE [sic] so named on account of the tendency of the land to move into the river. It is an immense

FIG. 11. An 1867 photograph of a number of B.C. colonial officials, including Judge Begbie (2nd from the left), resting along the Cariboo Wagon Road (B.C. Archives photo 63650).

> deposit half a mile long and three miles deep at the rear of which are lakes. The mud resting on a fonndation [sic] of rock, the water oosef [sic] underneath and this causes the immense body to move.

G. M. Dawson, a federal government geologist, commented on Drynoch landslide or, as he called it, the "Big Slide", and its effect on the railway, in his 1896 summary report (Dawson 1896):

> About a mile and a half above Drynoch station, the railway track is laid across what is known as the Big Slide, a mass of soft debris, which is still in a gradual, if intermittent, state of motion towards the Thompson River. The material of the slide consists of yellowish and brownish soft tuffaceous deposits, completely poached [sic] together and packed with fragments of basaltic and other volcanic rocks. It has descended to its present position from a high level on the edge of the Nicoamen Plateau, where rocks of the same kind are still seen in place, and are supposed to represent a continuation of the Tranquille beds described on the Nicola.
>
> As viewed from high points on the other side of the Thompson, the Big Slide is found to have originated from the edge of a flat meadowlike area with little pools or lakes, which forms part of the edge of the Nicoamen Plateau here. Where crossed by the railway below, it consists of irregular mounds and ridges, with frequent gaping fissures, and is evidently slowly subsiding upon the inclined surface of hard underlying rocks, the evidences of motion being greatest at seasons when the soil is saturated with moisture.

Reports by the CPR noted that "continual annual movements of several feet per year required very frequent and costly rail realignment and occasional repair to telegraph lines" (Brawner and Readshaw 1963) (Fig. 16). This condition is confirmed by a report written in 1909 by C. E. Cartwright, CPR division engineer, 25 years after the initial construction (Anonymous 1909):

> The Drynoch slide is almost 1500 ft. wide where it crosses the track and extends back over the hills for over two miles, the upper end of the slide being 2000 feet above track. This slide resembles closely a glacier in

FIG. 12. A photograph taken in 1875 of a group of CPR engineers on their way from San Francisco to B.C. H. J. Cambie is standing 2nd from the left (B.C. Archives photo 1150).

FIG. 13. CPR construction camp of A. Onderdonk, located along the Thompson River. Photograph taken in 1881 (B.C. Archives photo 75122).

FIG. 14. An 1881 photograph of the construction of the CPR, presumably taken close to the construction camp shown in Fig. 13 (B.C. Archives photo 75116).

FIG. 15. A view up the Thompson River taken in 1885 at the completion of the CPR in B.C. Drynoch station can just be seen at the foot of the cliff. The profile of Drynoch landslide, approximately 2 km to the north, appears just above the station (B.C. Archives photo 74995).

FIG. 16. An 1896 photograph of a CPR work train and steam shovel just north of Drynoch landslide (B.C. Archives photo 61335).

> action, being very slow in movement, averaging about 10 ft. per annum. The movement, however, is not constant and periods of several months occur when none is observed. The cause of the slide is probably water saturating a stratum of clay over a smooth bedrock. The remedy adopted has been to divert a portion of the water before it enters the slide by a ditch filled in with a tile drain, loose rock and cedar poles, crossing the slide about 1000 ft. above the railroad. It was hoped to get this ditch down to bedrock, but this proved impractical. While not completed long enough to show definitely that all movement has ceased, it certainly has been materially reduced.

Essentially this remedial work followed Cambie's suggestion of 32 years earlier. Smith (1954) and Brawner (1957) report that the CPR drilled several shallow holes in 1906 to determine the depth to the failure plane and the approximate volume of material that was moving. It is doubtful if the CPR "borings" ever did intercept the failure plane. It should be noted that Cartwright was the first person to refer to the "Mud Slide" or the "Big Slide" as the Drynoch landslide. The name was obviously derived from the railway siding just south of the slide.

Early 1900's to present

Geological mapping

In 1912, the Geological Survey of Canada began a program of geological mapping of all British Columbia south of the Canadian Pacific Railway (Zaslow 1975). Charles W. Drysdale was assigned to map a 16-km strip of land along the Thompson River between Kamloops Lake and Lytton. Drysdale, an assistant geologist at the time, must have spent a day or two hiking over Drynoch landslide. He described it as (Drysdale 1914):

> A much older landslide [relative to those upstream on the Thompson River which occurred in the last half of the 19th century] composed of older volcanic and sedimentary materials of a reddish brown colour is traversed by the railway a few miles north of Drynock [sic]. A deep cirque-like scar on the upland, with steep bounding walls, may be seen a couple of miles back from the railway and marks the source of the material. The slide material forms exceedingly rough ground containing stagnant pools and simulates in many places a glacial moraine with the thickening of earth flow material down valley. It differs, however, from a moraine in the nature of the materials and the abundant open crevasses on its upper surface.

Canadian Northern Railway

About the same time that Drysdale was mapping this area, a new railway was being constructed through the Thompson and Fraser River valleys. The Canadian Northern Railway began construction in British Columbia in 1911. Because it was the second railway in those valleys, its alignment was often less favourable than that of the CPR. For most of the route the new railway followed along the opposite side of the valley from the older railway, and such was the case in the area of Drynoch landslide.

FIG. 17. A Canadian Northern Railway survey party, surveying along the rugged west bank of the Thompson River near Drynoch landslide. Photograph was taken in 1911 (B.C. Archives photo 30150).

Initially, one would think the Canadian Northern Railway was better off in this instance, since it did not have to deal with "a perpetually" moving slide. However, this was, and still is, not exactly the situation. Drynoch landslide, for the past several thousands of years, has been forcing the Thompson River against the west bank (Fig. 2). In so doing the west bank has become almost a sheer cliff. So, to construct the Canadian Northern Railway, the contractors had to carry out a fair amount of tunnelling and blasting to form a bench on which to set the rails (Fig. 17).

Even to the present, the slide is affecting the "new" railway which is now part of the Canadian National Railways (CNR). The slide is still pushing the Thompson River westward and is presently undercutting the CNR tracks and railbed. The CNR has had to continually place fill along the riverbank to replace material eroded away (Robertson, personal communication 1973).

Upgrading the Cariboo Wagon Road

In Drysdale's report on his 1912 field activities, he mentions that "old trails and wagon roads [the Cariboo

Road] were built at great expense through the Thompson valley and are still used considerably as highways" (Drysdale 1914). With automobiles becoming more popular in the first few decades of the 20th century, the "old trails and wagon roads" of the 19th century had to be upgraded to new specifications. In the Fraser and Thompson River valleys, Hector Whitaker, a surveyor and engineer for the British Columbia Department of Public Works, was in charge of rebuilding the Cariboo Road (Lowe 1966; Hatfield, personal communication 1975). In 1924 Whitaker, along with his new bride, camped with the construction crew along the banks of the Thompson River (Mrs. H. Whitaker, personal communication 1973).

Whitaker would not have had an easy task to upgrade the section from Lytton to Spences Bridge. It seems that during the construction of the CPR in the 1880's the Cariboo Road was all but destroyed. Two reports from the Public Works roads superintendent include the following excerpts (British Columbia Department of Public Works 1924), for 1882:

> From Nicoamin [sic] to Cook's Ferry [Spences Bridge] the Waggon [sic] Road is very much damaged in many places by railway construction, the road at several points is filled in by railway work [railbed] and the railway lands [excavated material] are taken away and leave the waggon road in a very unsatisfactory state. Teamsters are in danger of capsizing their valuable freight into the Thompson River.

and for 1892:

> A trail has been kept open although it is very hard to keep even a trail open over this portion of the old road: the C.P.R. works fill it up and destroy it.

Prior to the upgrading there was a great deal of controversy among the Provincial and Federal departments of Public Works and the CPR about who should pay for the upgrading of this section of road across the toe of Drynoch landslide. It is not clear who finally paid the $131 000 that was estimated for the upgrading of this section; however, the "new" road was built and crossed the toe of the slide downslope of the CPR railway tracks (Fig. 18). Harley Hatfield recalls, "I do not remember that there was any great difficulty in the construction [of the road across the toe]...however maintenance in later years was always something else" (H. R. Hatfield, personal communication 1975). The change in the road, from a wagon road to a highway, was poetically summed up (Williamson 1927): "The toot of the motor horn has replaced the crack of the stagecoach whip...; the clatter of hoofs has given way to the purr of the motor..."

The Depression

The stock market crash of 1929 and the subsequent depression of the 1930's had their impact on the Thompson River valley and Drynoch landslide. Adventuresome men with little money, little chance of getting jobs, and lots of time on their hands were drawn to the Thompson River to pan for gold. The gold that was found paid expenses but, for most fortune seekers, that was all (D. G. McLean, personal communication 1973).

Some men began prospecting in the mountains that border the river. In the area of Drynoch landslide coal was found immediately to the north of the slide on a prairie-like plateau called Guibo's Flat (Fig. 3), and gem quality agates were found in the bedrock surrounding the landslide. Several prospect trenches were dug and two adits were driven to determine the extent of the Tertiary coal measures (Duffel and McTaggart 1952; Brawner and Readshaw 1963). A small amount of mining of the 2-m thick coal seam occurred on and off during the 1930's. Although coal mining essentially died out after the depression, rock hounds have continued to visit the Drynoch landslide area to collect the abundant gem quality agates (VanDine 1974).

Also during the depression years, a modest amount of logging began on the Nicoamen plateau above the landslide. At the same time, Drynoch landslide and the surrounding highlands started to be used for summer grazing lands by neighbouring ranches.

All this activity in the 1930's led to the building of a crude access road up the length of the landslide through the same "notch" that the Salish Indians used at least 1000 years before to gain access to the highlands. Ironically, this access road, which is still passable today by a four-wheel drive vehicle, provides access to the Squianny and Enhalt Indian reserves, two relatively small reserves located above the slide on the Nicoamen plateau.

Further geological mapping

The 1940's saw more geologists enter the area of the lower Thompson River valley. In 1944 W. H. Mathews summed up his ideas on the deglaciation of the area during Pleistocene time (Mathews 1944). Between 1945 and 1947 S. Duffell and K. C. McTaggart continued the bedrock geology mapping begun by Dawson and Drysdale. The Geological Survey of Canada Memoir 262 (1951) is still considered the definitive regional bedrock geology report for the area. It is interesting to note that neither the 1944 nor the 1951 publication mentions Drynoch landslide.

CPR studies

The "very frequent and costly rail realignments" (Brawner and Readshaw 1963) that were required by the CPR to keep their trains running across the toe of Drynoch landslide (Fig. 15) reached a critical point in 1954. That year the railway retained two eminent

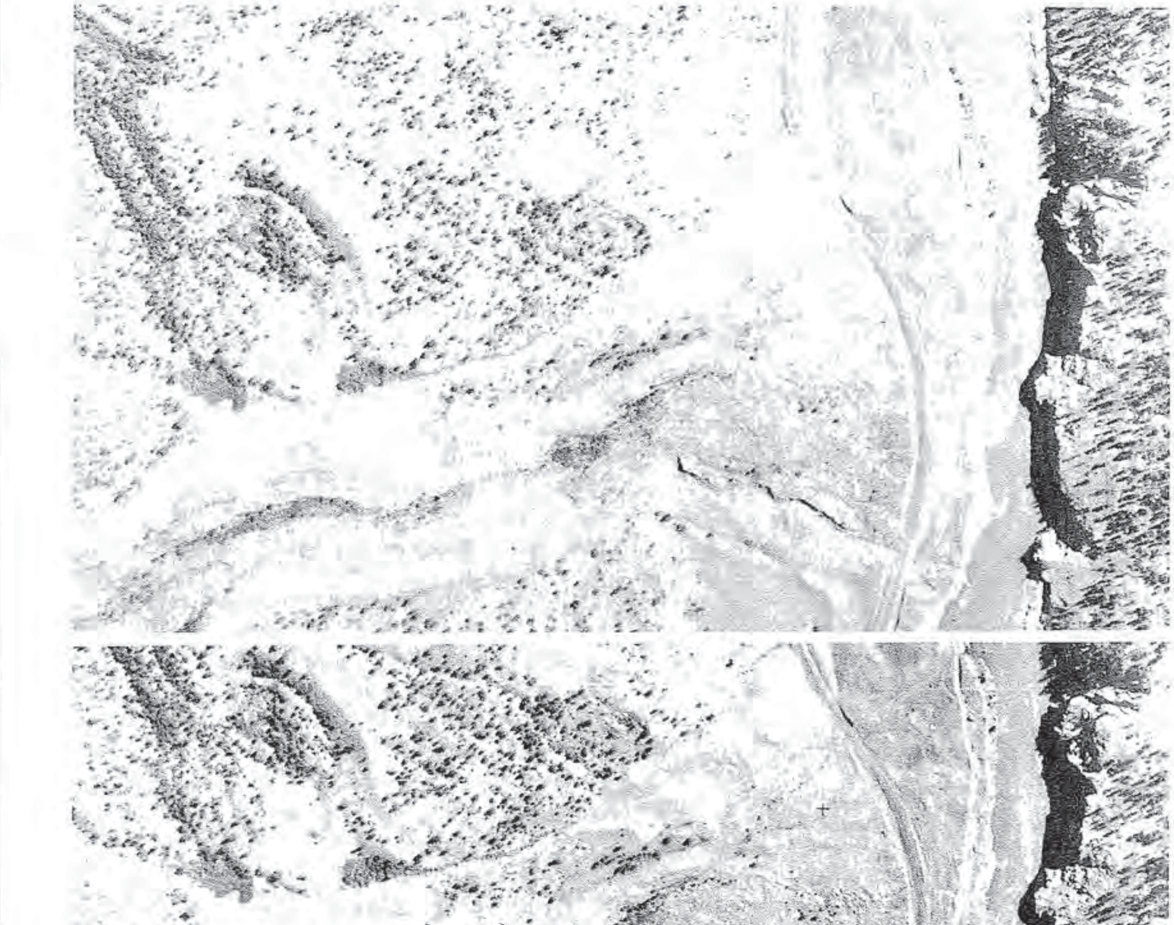


FIG. 18. The first vertical air photo stereo pair taken of the lower portion of Drynoch landslide. Taken in 1928, at 3000 m asl, by the RCAF. Note the 1924 highway located between the CPR and the river. Also note the many realignments of the CPR (National Air Photo Library photos A 290–101, 102).

engineers to study the landslide problem and recommend remedial action. R. Smith, an American railway engineer, and R. B. Peck, professor of geotechnical engineering from the University of Illinois, made independent reports and suggested possible solutions. These studies were based on the CPR's 1906 borings and a site visit (Brawner 1957). It is not surprising that the two engineers recommended similar remedial work. From Smith's (1954) report to the CPR:

> ....Drynoch slide involves a moving mass of plastic material, probably rock disintegration. The section of interest is about 500 feet wide and extends 2–3 miles into the hills. The depth to bedrock is apparently shallow — 30 feet. The movement is classed as a debris flow similar to a glacier. Considerable water is present on the north side of the slide.
>
> By determining the depth of bedrock at the narrow section about 1500 feet east of the river a drainage system could be designed. Keyed into the rock this should intercept considerable water.

From Peck's (1954) report:

> ....Since the depth to bedrock appears comparatively shallow, it appears that the slide could be stopped by excavating a trench across the entire slide and backfilling with gravel. The trench should be located about 1500 feet from the river not less than 20 feet wide at the base. The backfilled trench provided with suitable drainage outlets would cut off seepage through the material in the lower 1500 feet of the slide. Sliding material from above would accumulate on the upper part of this block and reduce the gradient towards the head of the slide until ultimately most of the ground above the trench would also become stable.
>
> It is not necessary to key the trench into the bedrock. However, to get proper gradients for drainage of the gravel it may be necessary to cut a trench in the rock beneath part of the backfill.
>
> The few borings made in 1906 should be supplemented by others to get a satisfactory estimate of the quantity involved along the line of the proposed trench.

The suggested methods to control the movement of the landslide seemed too expensive for the CPR at that time. They therefore continued to keep realigning the rails wherever the slide moved them a critical distance from their original position.

Trans-Canada Highway

In 1957 the Fraser and Thompson River valleys were selected to be the Trans-Canada Highway route through this portion of British Columbia. It fell to the British Columbia Department of Highways to upgrade the "highway," which Hector Whitaker had previously upgraded in 1924, to Trans-Canada Highway standards.

The road across the toe of the Drynoch landslide had been such a maintenance problem for the past century that three alternatives were considered (Brawner and Readshaw 1963).

(i) Building of a new road on the west side of the Thompson river. This would involve building two bridges to cross the river, and finding room to build a highway so as not to interfere with the Canadian National Railways. The cost estimate for this alternative was \$3.5 million.

(ii) Construction of a new road on a bridge-like structure supported on piers founded on the bedrock in the Thompson River bottom. This alternative was estimated to cost \$2 million.

(iii) Construction of a suspension bridge across the slide. This would cost an estimated \$5 million.

At the time, these costs appeared prohibitive. It was therefore decided by the Department of Highways to conduct a geotechnical investigation to see if subsequent remedial construction could halt, or at least reduce, the slide's movement. The Trans-Canada Highway could then be built using conventional methods.

The site investigation, remedial work on the slide, and construction of the new B.C. Highway 1 took place between 1957 and 1963. The investigative work, which included surface and subsurface geotechnical studies, was initiated by R. C. Thurber, then head of the Materials and Testing Branch of the Department of Highways. Other engineers and geologists from the department who contributed to the studies included C. O. Brawner, A. F. Bucham, E. E. Readshaw, S. F. Hillis, J. Horcoff, N. A. Huculak, A. T. Webster, and G. Richardson. H. Q. Golder, C. F. Ripley, and R. B. Peck, geotechnical engineers, were retained at different times during the study to consult for the department; W. C. Jones of the British Columbia Department of Mines was asked to conduct a bedrock study in the vicinity of the slide; and R. E. Grim, professor of geology at the University of Illinois, was asked to study the clay mineralogy of the slide material involved (VanDine 1980).

The investigation indicated that water, both surface and ground, was the major cause of sliding. Huculak and Brawner (1961) presented a very good example of just how temperamental Drynoch landslide was with water.

> At Drynoch Landslide...the rate of movement increased within 24 hours following commencement of drilling [with water] each Monday and decreased within 48 hours after cessation of drilling each Friday.
>
> As excavation [of a drainage trench] continued, the rate of movement during drilling periods became so great that installation [of horizontal water relief drains] had to be temporarily discontinued. The drill water appeared to increase temporarily the pore water pressure at a greater rate than the previously installed drains were reducing it.

The method of stabilization proposed by the Department of Highways was a combination of surface and subsurface drainage (VanDine 1974, 1980). Surface drainage works consisted of draining all swamps and water holes within the slide, providing permanent drainage channels from such areas and diverting a small creek across and out of the slide area.

Several different approaches to reducing the amount of subsurface water were proposed, tested, and, at various times, implemented. Initially, a 1.5-m diameter drainage adit was advanced into the slide. Vertical drainage wells were jacked into the roof of the lined tunnel to increase drainage. Initial results indicated that at least 10 such adits would have to be driven. This proposed method was abandoned for economic reasons and because the initial adit collapsed due to movement of the slide shortly after it was completed (Hillis, personal communication 1974).

The Department of Highways then tested the effectiveness of electro-osmosis to lower the groundwater table. This did not prove feasible because of the soil type and mechanical difficulties with the equipment.

The next approach was to use several methods simultaneously: excavation of a 15-m deep cut-off trench, installation of horizontal drains, removal of a large volume of the sliding material, and the addition of lime to a portion of the slide to reduce surface water percolation to the groundwater table. Initial results indicated a reduction in movement, although movement of the slide prevented the methods from being completed to specification.

During this period of stabilizing the landslide, the highway was relocated and rebuilt across the toe of Drynoch landslide uphill from the CPR tracks (Fig. 2).

Unfortunately photographs of this period of the Drynoch landslide history were destroyed after the British Columbia Department of Highways files were microfilmed in the early 1970's.

In subsequent months and years, the following reports were filed by the Regional Highways Engineers (British Columbia Department of Highways 1957–1973):

June 1962—"large movements noted in the backslope of the cut off trench"

January 1963—"slide pushing highway right-of-way fence downhill"

April 1965—"considerable fresh failure is showing between highway and cut-off trench;" "slide material is encroaching upon highway ditch;" "fence has been pushed down"

April 1966—"movement between 15 December 1965 and 24 March 1966 is approximately 20 in"

July 1970—"there are signs that Drynoch Slide may be starting to move."

Sometime after 1965, the old highway, which was located downhill from the CPR tracks (and after 1963 was not maintained), finally was washed into the Thompson River by further movement of the slide (Fig. 2). From then to the present, minor and some not so minor remedial measures and maintenance have been carried out by the Department of Highways on the Trans-Canada Highway. These measures include placing polyethylene over portions of the slide to further prevent infiltration of surface water, filling in the old creek bed that ran down the length of the slide, and diverting water from a spring above the slide into another watershed. The slide is still moving but, at present, more slowly. All in all, the Department of Highways has constructed and is maintaining a very good stretch of highway considering the problems they have had to tackle and the natural conditions with which they have had to deal.

Further visitors and studies

Since the major remedial work by the British Columbia Department of Highways in the early 1960's, Drynoch landslide has become much better known among geologists, geological engineers, and geotechnical engineers. It has even gained a bit of notoriety. In 1965, J. E. Armstrong and R. J. Fulton of the Geological Survey of Canada included Drynoch landslide as a stop on their field trip for the International Association of Quaternary Research (Armstrong and Fulton 1965). During the 24th International Geological Congress in 1972 the landslide was included as a stop on H. W. Nasmith's field trip on the Engineering Geology of the Southern Cordillera of British Columbia (Nasmith 1972). Drynoch landslide has also been visited by the Japanese Landslide Society in 1979 (Patton, personal communication 1979) and the Cordilleran Slope Hazards Group in 1981 (Clague and Bovis, personal communication 1981). It is included as an example of a colluvial mudflow in J. D. Mollard's air photo manual (Mollard 1980).

The lower Thompson River valley and Drynoch landslide have continued to be studied from several different facets. In 1965, R. E. Goodman, professor of engineering geology at the University of California, Berkeley, visited the slide and postulated a scenario for its initial movement (British Columbia Department of Highways 1957–1973). Two graduate students of his attempted to use subaudible rock noise monitors to hear the slide movement. The results were less than exciting and led Professor Goodman to the conclusion that "slow moving slides are not optimum for the rock noise method" (Cadman *et al.* 1967; R. E. Goodman, personal communication 1974).

In 1966, D. Sanger, an archeologist with the Canadian Museum of Man, uncovered the preslide artifacts in the gravel pit at the toe of Drynoch landslide (EcRi:1; Sanger 1967; Fulton 1968). These contributed greatly to the formulation of the preslide history.

In 1970, L. J. Anderton expanded on previous surficial geology studies of the area (Anderton 1970). In her thesis she postulated how Drynoch landslide fits into the overall glacial and postglacial history of the area. This work was expanded upon by J. M. Ryder and the

Geological Survey of Canada during the summer of 1974 (Ryder 1981).

Drynoch landslide had been examined as a part of other studies as well. In 1971, W. F. Bawden made a reconnaissance study of many landslides in southwestern British Columbia, including Drynoch landslide, for the Geological Survey of Canada (Bawden 1972*a*,*b*). A year later G. Young and A. Bedwany, pedologists for, respectively, the provincial and federal agriculture departments, mapped the landslide along with much of the Thompson River valley as part of a soils and landforms study (Young and Bedwany 1973). In 1973, R. Mamu used Drynoch landslide as an access route to study the metamorphism in the bedrock surrounding the landslide (Mamu 1974). In the past year the Geological Survey of Canada has begun to remap the bedrock geology of the map sheet containing Drynoch landslide (Monger 1981).

The writer was introduced to Drynoch landslide during the summer of 1973. During that summer a detailed engineering geology and geotechnical study of the slide was conducted. The work, which was designed to expand upon the results of the previous investigations, was funded by the Geological Survey of Canada. It was completed as a Master's thesis (VanDine 1974) and culminated in a technical paper for the Geological Survey of Canada (VanDine 1980). Needless to say, the writer became engrossed with the history of the landslide, the result of which is the present paper.

Conclusion

This review of the history of Drynoch landslide covers a lengthy period of time. During these years, activities along the Thompson River changed from primitive salmon fishing, to exploration, to gold panning, to the opening up of a new province in the Dominion of Canada, and to railway and highway building. Although it would be an exaggeration to say that this landslide influenced the history of British Columbia and Canada, it would be no exaggeration to say that Drynoch landslide has touched the lives of many persons from the early Salish Indians to present-day travellers along the lines of the CPR, the CNR, and the Trans-Canada Highway.

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