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THE ALCAN PIONEER ROAD AND DISCOVERY OF PERMAFROST

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Abstract: During the 1930s several American and Canadian commissions examined the feasibility of constructing a continuous highway from the population centers of western and central Canada as far as Dawson for the Canadians and to Fairbanks as the desired terminus of the Americans. The scheme lacked political will and sponsorship until Germany attacked the Soviet Union in June 1941 and quickly advanced to the outskirts of Moscow. Soviet emissaries began lobbying their new North American allies to construct a series of airfields across northwestern Canada and the Alaskan Territory to shuttle American aircraft on Lend-Lease to the Soviets. Canadian planners located 12 airfield sites in their western provinces. The Americans were obliged to observe their declared neutrality prior to the Japanese attack on Pearl Harbor and Germany's declaration of war in December 1941.

The Pacific was the largest theater of military conflict in history stretching >4,500 miles (>7200 km) between San Francisco and Yokohama. American military planners realized how vulnerable Alaska was to airborne attack and seaborne invasion. With America's entry into the war against Japan and Germany in December 1941, 28 air bases were constructed during a 20-month period beginning in the spring of 1942, which connected Great Falls, Montana with Krasnoyarsk in Siberia, Russia. Known as the ASLIB (Alaska-Siberian Air Ferry Route), the Great Circle distance between Montana and central Siberia was 5,145 miles (8285 km). The actual flight path was more than 6,000 miles (9,600 km), making it the longest air bridge of the Second World War. The Alcan Highway was the umbilical cord of Canadian and American presence, authority, and defense of the near-pristine frontier, which accommodated the transfer of ~8000 Lend-Lease combat aircraft, 56% of those that reached the Soviets during the war.

1 INTRODUCTION

In January 1941 the Japanese Foreign Office had announced it was "greatly disturbed" over the proposal to construct an Alaskan-Canadian highway, which they viewed as an "air bridge" across the North Pacific to supply the Soviet Union and limit Japanese expansion. With the sudden entry of the United States into the global conflict a year later, Canadian and American leaders agreed that immediate action was needed to defend the Alaskan frontier from Japanese forces who were rolling over every Allied target of consequence in the Pacific Theater. The projection of air power allowed armies to fly over natural barriers like mountains, lakes, and rivers. Naval power projection was also enhanced by the deployment of long-range patrol and reconnaissance aircraft, as well as carrier-based attack aircraft. From the outbreak of the Pacific campaign there was a growing appreciation of the strategic role of husbanding petroleum, oil, and lubricants stockpiles and increasing realization that oil resources and the efficient transport and storage of these resources would play such a dominant role in the conflict.

Some of the first wartime deployments outside of the continental United States were the engineer regiments dispatched to Canada and Alaska, beginning in February 1942. The U.S. Army's Corps of Engineers (USACE) were given responsibility for laying out and constructing a pioneer road at least 12 feet (3.7 m) wide with H15 minimum bridge loading. This path would be followed by finish grading, paving, and drainage improvements performed by civilian contractors to conform with permanent highway standards established by the U.S. Public Roads Administration (USPRA).

USACE dispatched seven engineer regiments, each one responsible for surveying about 350 miles (560 km) of highway right-of-way on aerial photographs (a historic first), employing three 8-hour shifts per day. Using bearings, surveyors would blaze trails and mark the proposed center line by tying red cloths to bushes and trees. A plane table party would then traverse the alignment and record relative elevations. If this preliminary pass along the proposed alignment proved satisfactory, earthmoving equipment would begin excavating selected alignments working 20 hours per day with four hours reserved each day for maintenance of equipment.

2 BLAZING THE PIONEER ROAD

The Corps' initial assignment was to grade a pioneer road suitable for military vehicles. The person in responsible charge was Brigadier General Clarence L. Studevant, who was instructed to build the pioneer road "*as fast as humanly possible"* (Richardson, 1943). Civilian contractors working for the Public Roads Administration (PRA) would then upgrade the road to status of a permanent highway.

The specs for the Pioneer Road were a clearing width of 32 feet (9.8 m), a maximum grade of 10%, minimum 50-foot (15 m) curve radius, a minimum surfacing width (wearing course) of 12 ft (3.7 m), minimum 3 ft (0.9 m) wide shoulders, minimum ditch depth of 2 ft (0.6 m), a minimum crown of 1 inch (2.5 cm) for each foot (30 cm) of width, and single-lane bridges designed for 15 tons (13600 kg) (H15) minimum axle-wheel loads (Nelson, 1949 and Cohen, 1992).

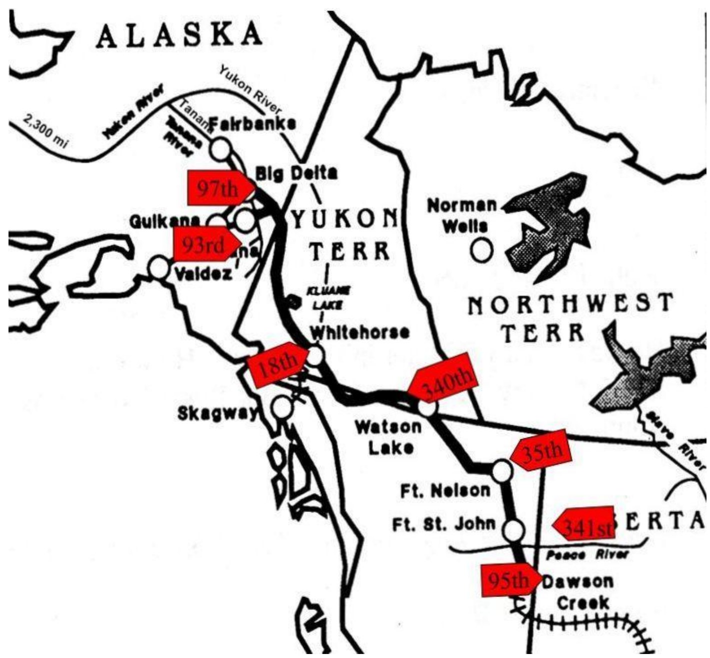


Figure 1: Initial deployment sites for the seven American Army Engineer regiments in early 1942. Regiments were replaced by battalions in a reorganization of the American Army in January 1943 (Source: Rogers, 2019).

The initial deployment sites for the seven regiments are shown in Figure 1. Survey parties were supplied with aerial photos to serve as their base maps, and to provide general location and bearings (a historic first). Using magnetic bearings, the survey parties blazed trails and marked the proposed center line by tying red cloths to bushes and trees. They were followed by a plane table party who would then traverse the alignment and record relative elevations. If this preliminary pass along the proposed alignment proved satisfactory, construction units could begin dozing. In the 1943 construction season civilian contractors were brought in to improve the pioneer road and bring it up to USPRA standards.

When the first surveyors of Company D, 29th Engineer Topographic Battalion and Company A of the 648th Engineer Topographic Battalion hit the ground in February of 1942, the base maps were simply aerial photographs. Only one map was provided of the area from Dawson Creek to Fort Nelson. The paucity of maps and snow up to 18 inches (0.46 m) deep posed the biggest challenges for the surveyors. Other problems were mosquitoes, gnats, and yellow jaundice. The surveyors also had to comply with orders to have the pioneer road service the proposed airfield sites in the Yukon Territory and Alaska, as well as avoiding steep terrain and muskegs as much as possible.

Figure 3: Dozer drifting loose soil into a 1940 Chevrolet 4x4 1-1/2 ton (1360 kg) capacity dump truck. It is hauling fill for an airport access road in May 1942 (Source: US NARA).

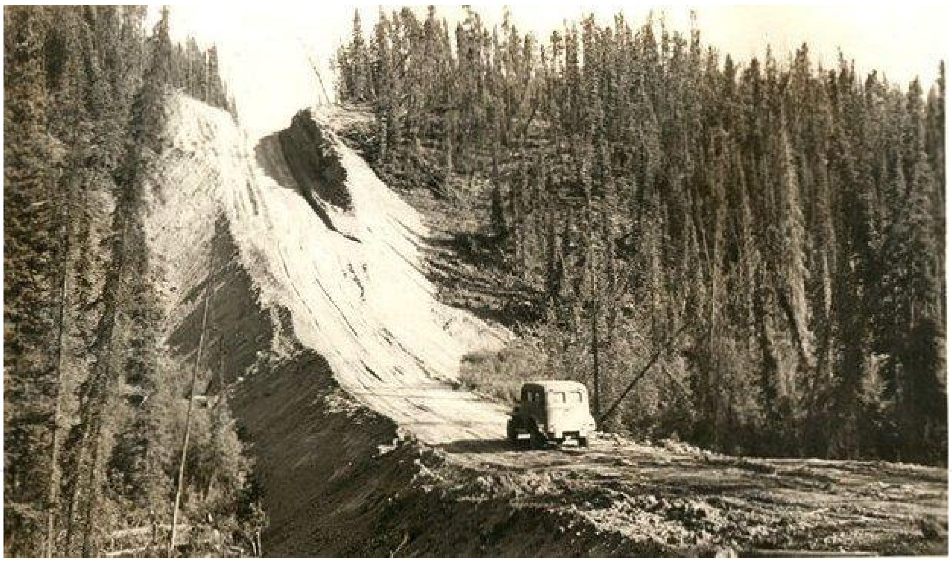
Survey parties were normally comprised of 1 officer and 9 surveyors. The first group to enter the forest would split up into teams and venture out for a mile or two to see which alignments held the greatest potential. The teams would then back track and reunite. This separating and coming back together, along with updated aerial photos, was the only practical way for the surveyors to blaze the best path. Another survey team would follow behind, running a level survey and taping the centerline. Shortly behind them came the transit team that would record the centerline and elevations of the proposed road. The teams would average about 2 to 4 miles (3 to 6 km) per day. They soon found it advantageous to hire native Inuit people as designated guides.

The 341st Engineer Construction Regiment (Figure 2) was the first to arrive in the Yukon, reaching Dawson Creek on March 10, 1942. They started moving north to St. John. Their initial goal was to get across the Peace River just north of St. John before the spring thaw. Otherwise, they had no means of transporting their equipment any farther.

By June of 1942 seven engineer regiments were on the ground constructing the pioneer road. These included the 18th and 35th Engineer Combat Regiments and five engineer general service regiments, which included the 93rd, 95th and 97th African American regiments and the 340th and 341st Engineer

General Service Regiments (the American Army was re-organized in January 1943 and regiments of 1000 to 2000 men were replaced by battalions of four or more companies with 400 to 1000 men). In early 1942 each engineer regiment was assigned a strip of land approximately 350 miles (560 km) long. Their goal was to reach the next regiment's pioneer road before winter set in.

Within each regiment the companies constructed a portion of the road using a leap-frog method. One company would grade their assigned section, another just ahead of them about 30 miles (48 km) distant. When a company worked up to the next company's road, then they would "leap ahead" and start again. During the spring and summer months, daylight could last up to 20 hours with twilight for the remaining 4 hours. This allowed the construction crews to work 3 shifts of 8 hours each, round-the-clock.



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The USACE units began their work with light pre-war equipment, such as Caterpillar (Cat) D-4 tracked dozers until the arrival of heavier equipment, like Cat D-7's, which began arriving in the late summer of 1942. For the pioneer road the Army Engineers were obliged to make do using hand saws, hand axes, small dozers and 2-axle 1-1/2 ton (1360 kg) dump trucks (Figure 3). Building the road required brute force and considerable creativity, often using the natural materials that were readily available.

The biggest surprise on the project was the ability of modern earth moving equipment to make short work of excavating the pioneer road across mountains (Figures 4 and 5). A few years previous would have required time-consuming blasting and tunneling.

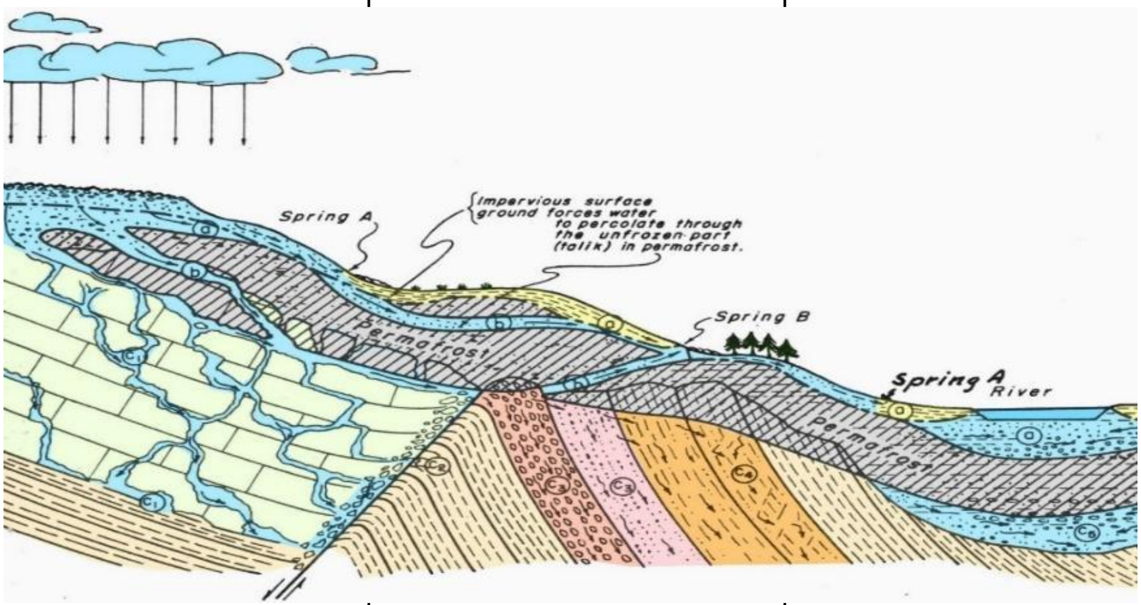
3 SIEMON MULLER DISCOVERS IMPORTANCE OF PERMAFROST

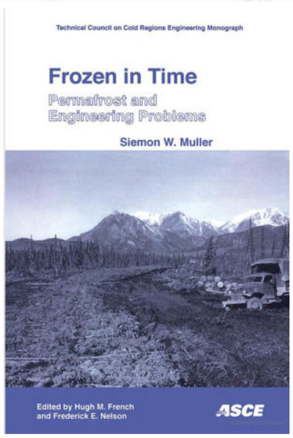
Dr. Siemon ("Si") William Muller (1900-70) was born in Blagoveschchensk in eastern Russia between Siberia and Manchuria in May 1900, where his Danish father was working on the Trans-Siberian Railway's telegraph line. When the Russian Revolution began in October 1917 Si was enrolled in the Imperial Russian Naval Academy at Vladivostok. He later escaped to Shanghai, where he was employed by an American firm and learned to speak English. In 1921 he immigrated to the United States and followed his older brother Bill to the University of Oregon where he received his BS in geology in 1927. He received a graduate assistantship at Stanford working for Prof. James Perrin Smith in paleontology and stratigraphy, receiving his master's in 1929 and PhD in 1930.

Soon after graduation he joined Stanford's faculty as an assistant professor and was promoted to associate in 1936 and full professor in 1941. His career focused on paleontology to interpret the origins and history of stratified deposits of the Mesozoic and Paleozoic Eras in western North America, with particular emphasis on the stratigraphy of the Triassic Period in west central Nevada.

In 1942 Stanford Geology Professor Siemon W. Muller (Figure 6) was selected by the U.S. Geological Survey's Military Geology Unit (USGS-MGU) to develop construction details appropriate for the frozen ground conditions in Alaska. Muller coined the term *"permafrost"* to describe permanently frozen subsoil beneath cover of vegetation and topsoil (known as the "active layer"). The active layer insulates the frozen subsoil.

Figure 6: Dr. Siemon W. Muller (1900-70), the originator of the term permafrost and the author of three books on the subject in 1944, 1947, and 2008 (Sources: ASCE and Branner Library at Stanford University).





SIEMON WILLIAM MULLER
(1900–1970)

Shortly after the war Muller was cited by the Army for his unique contributions to the war effort with the Freedom Medal, the highest award available to civilians (renamed the Presidential Medal of Freedom in 1963). In 1947 Muller self-published the first open-source text in English describing the engineering challenges of building on permafrost (Muller, 1947). His last textbook was published by posthumously in 2008 by the American Society of Civil Engineers (Figure 6).

Figure 7 provides valuable insights on the most common sources of near-surface ground water in arctic areas. Note how permafrost zones tend to create groundwater flow boundaries and selective flow conduits.

Figure 7: Diagram illustrating the most common sources of shallow groundwater in permafrost regions (Source: modified from Mueller, 1947)

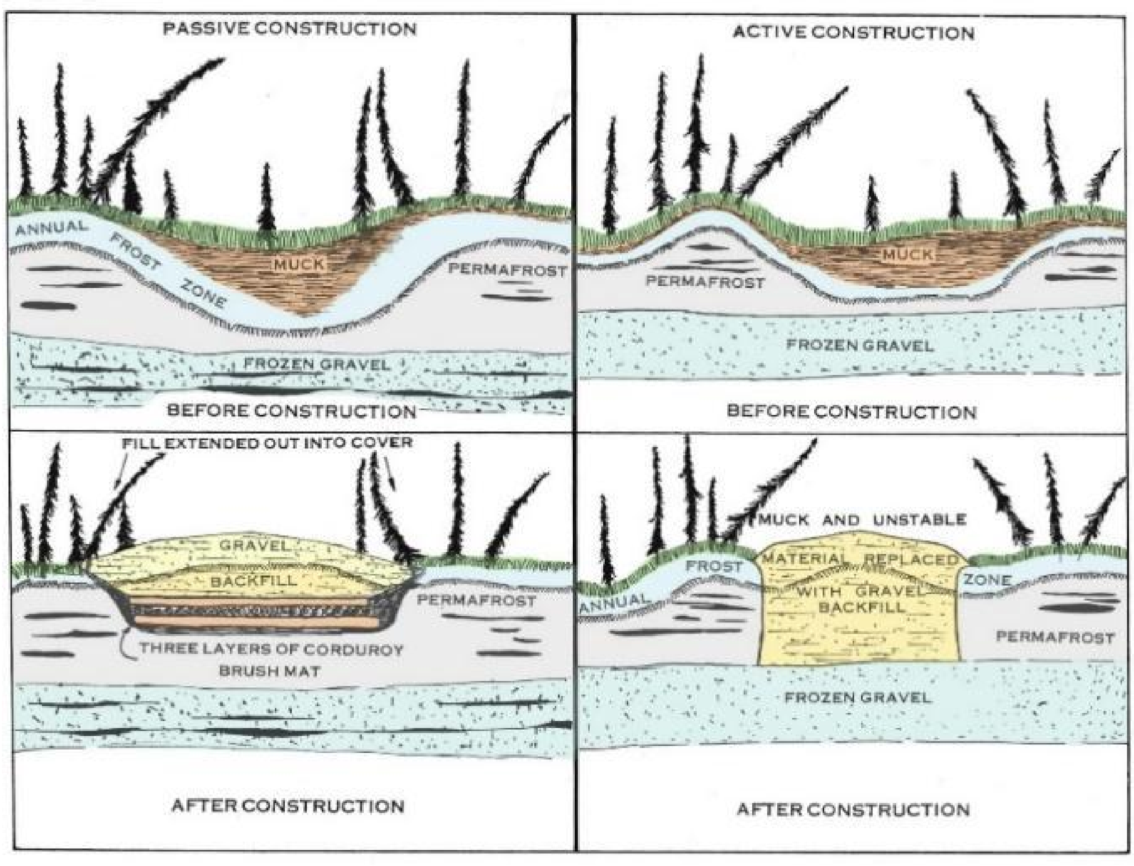


Figure 8 shows some of Muller's sketches for treatment of muskeg pockets. He felt that active drainage zones were best addressed by over-excavation and back-filling of active seeps with free-draining gravel.

Once frozen, the gravel reacts more favorably than other materials, and served to broaden the base of the highway. Care was taken to remove excess quantities of fine sand and silt which tended to heave when the fill froze. Habitable structures constructed with conventional interior heating began suffering from differential thawing like that sketched in Figure 9.

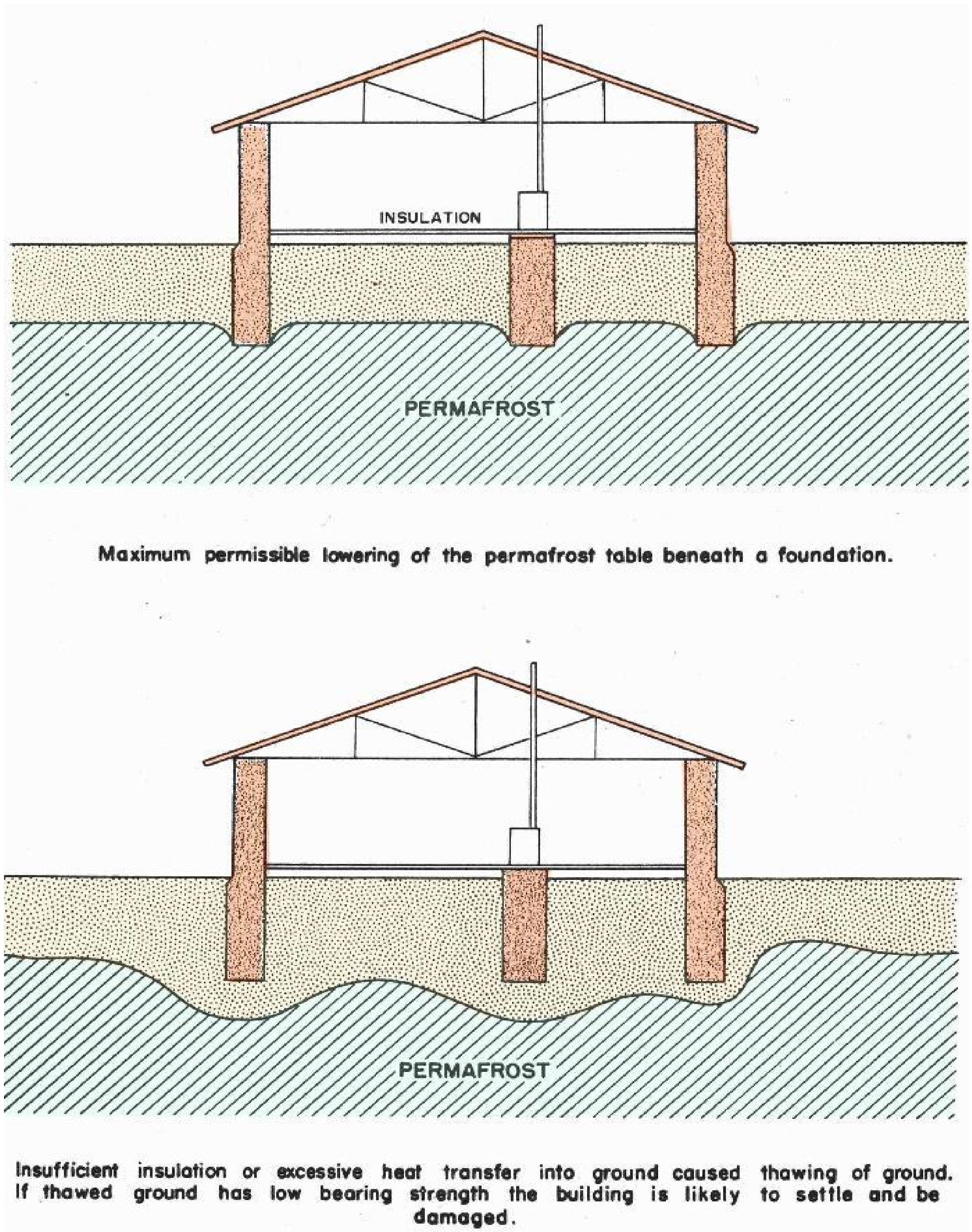


Figure 9: Heat radiated from habitable structures often triggered plastic deformation of thawed ground that often resulted in differential settlement (Source: modified from Muller, 1947).

With America's entry into the Second World War in December 1941, American and Canadian military engineers began considering the establishment of an "aerial bridge" from somewhere near the US-Canada border into central Siberia. This would require a pioneer road through Alaska and western Canada (Alcan) highway, and a new oil field near Norman Wells in the Northwest Territories. This became the Canol Project, which wasn't completed until March 1945 (Sill, 1947; and Finnie, 1945).

It was assumed that civilian contractors would upgrade the pioneer road to USPRA standards, but they soon encountered unforeseen problems with maintaining the highway improvements on partially frozen This was the ground, which lost significant shear strength when it thawed, ruining much of the graded surfaces (Figure 10).

The principal reason Si Muller was dispatched to Alaska in 1943 was so he could study the experiences of the Russians in Siberia and educate the American and Canadian engineering geologists working with construction crews on developing mitigation protocols for operations and maintenance of the paved right-of-ways, which were suffering the ill effects of the active layers at the pavement shoulders thawing out losing strength.

In 1942 the USACE asked the USGS-MGU for any reference materials on construction issues or problems on frozen ground (Mueller, 1944; 1947). The MGU discovered that the only published works on construction in frozen ground had been by the Russians in Siberia, so they searched for an American geologist fluent in Russian, which led to Professor Siemon Muller at Stanford.

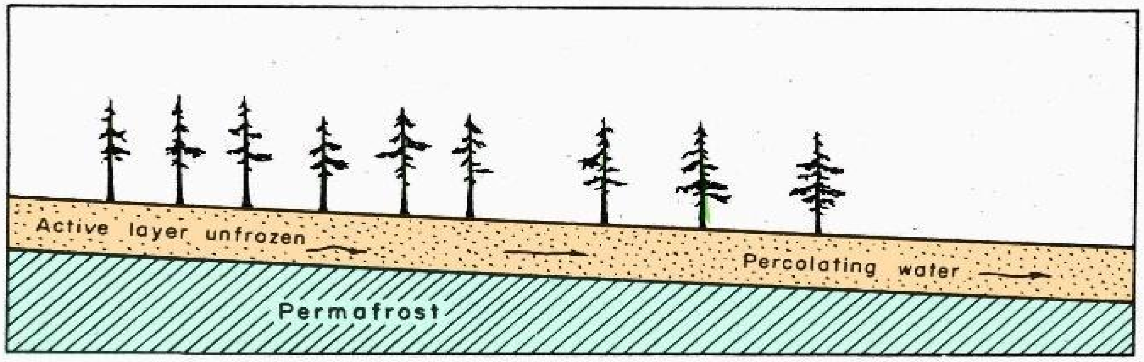
Muller was asked to affiliate with the USGS-MGU for the duration of the war, and soon found himself attached to the Army's Air Installation Division, Headquarters Alaskan Division, U.S. Army Air Forces (USAAF) Air Transport Command (ATC) out of Elmendorf Army Airfield in Anchorage. He was given the pay of a lieutenant colonel but did not display any rank on his uniform (Figure 6-right). Within a year of his arrival in Alaska he produced a training manual for USACE titled "Permafrost or permanently frozen ground, and related problems" (Muller, 1944).

3.1 Roadside Drainage Failures in Permafrost

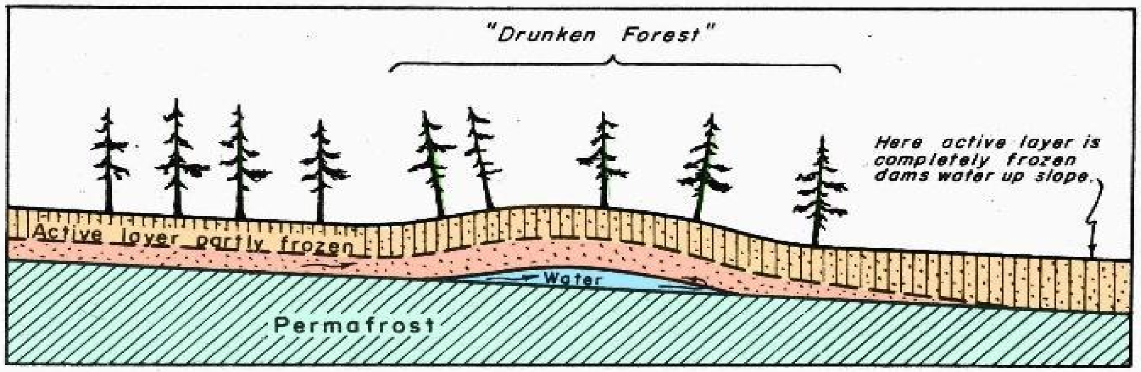
In many cases the pavement subgrade was almost completely undermined by thawing of permafrost, which resulted in extensive sloughing of the saturated soil horizons or pockets of thawed liquid within the active zone. This problem was often caused by narrow shoulders and/or over-excavation of roadside drainage ditches.

Figure 10 Illustrates how seasonal percolation was restricted to the active zone, just beneath the ground surface. The problem was exacerbated by drifting in fill from adjacent to the highway to fill in the collapsing ditch, as shown as "receding permafrost" in the lower pane of Figure 10.

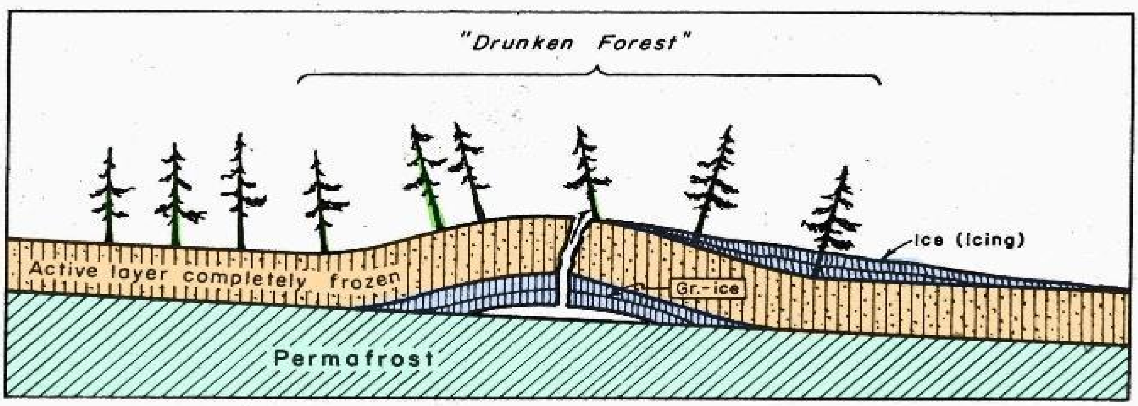
When the ground begins to freeze, flow becomes blocked, leading to the formation of "frost blisters," as shown in Figure 11. Seasonal percolation often led to the formation of frost blisters. These blisters occasionally "erupt," releasing water to the surface which can re-freeze and enlarge the frost blister.



Ground water in active layer percolates freely down slope.



Hydrostatic pressure pushes up surface ground.



Mound is ruptured by hydrostatic pressure (and crystallization of ice?). Water freezes forming icing and ground-ice. Occasionally a hollow space is left in the core of a mound.

DIAGRAMS ILLUSTRATING FORMATION OF FROST-BLISTER

3.2 Engineering Geologic Input for Operation and Maintenance Activities

With the research help of the USGS-MGB, Si Muller compiled an exhaustive summary of the Russian literature on permanently frozen ground. By early 1943 Muller had translated and digested the available literature and developed a briefing for use by the Army and USPRA engineers working on the Alcan Highway (Muller, 1944). Muller then conducted extensive field surveys of the Alcan Highway right-of-way and the various locations proposed for American and Canadian airfields (8 sites in Canada and 6 in Alaska were eventually completed).

During his periodic inspection trips he was often accompanied by USGS geologists Robert F. Black, Robert E. Wallace, and Max Elias. His principal subordinate was Seward E. Horner, Chief Geologist of the State Highway Commission of Kansas, who became one of the most respected engineering geologists in the United States for his formative work on the importance of subdrainage in pavement design (Nelson, 1949) and the recognition of landslides and solifluction-prone terrain (Eckel, 1958).

It was in 1943-44 that Mueller coined the English term “permafrost” to describe permanently frozen ground, and this nomenclature was promptly accepted. After the war the “permafrost research program” was turned over to the USGS, which they have continued many of the early studies up to the present time.

During the war everything Muller prepared was classified by the USGS-MGU. After the war he sought to get his reports declassified so that other scientists could benefit from the considerable experience and expertise the Americans and Canadians had made during the war.

In 1947 Muller privately published these notes as “Permafrost or Permanently Frozen Ground and Related Engineering Problems” (Muller, 1947). This 231-page tome became most cited text on recognizing and dealing with permafrost, in large part because of Muller’s skillful pen and ink sketches, which included illustrative cross sections (see Figures 7 thru 12), as well as his technical summaries of the Russian literature, which usually included their photos and sketches.

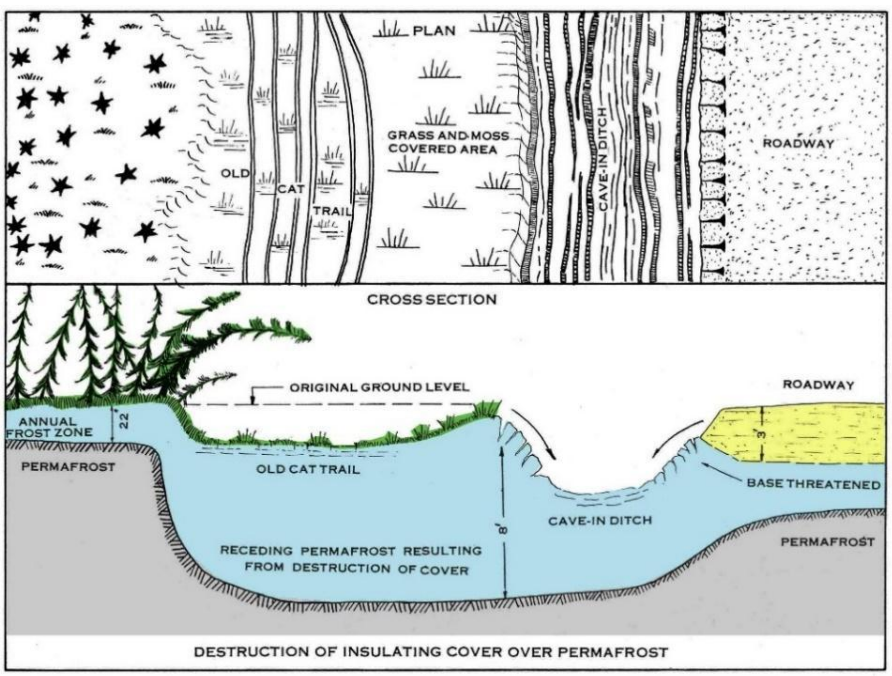


Figure 12: Old tractor trails excavated on permafrost allowed water to pond and infiltrate zones adjacent to the Alcan Highway, undermining the pavement subgrade (modified from Muller, 1947).

3.3 Overcoming muskeg hazards

Figure 13: Tracked dozer swallowed up by a muskeg hole. Muskegs sometimes appeared to “swallow” the heavier equipment, then exhibiting thixotropy, when the silty mud mixture “sets up.” (Unknown date. Source: US NARA).

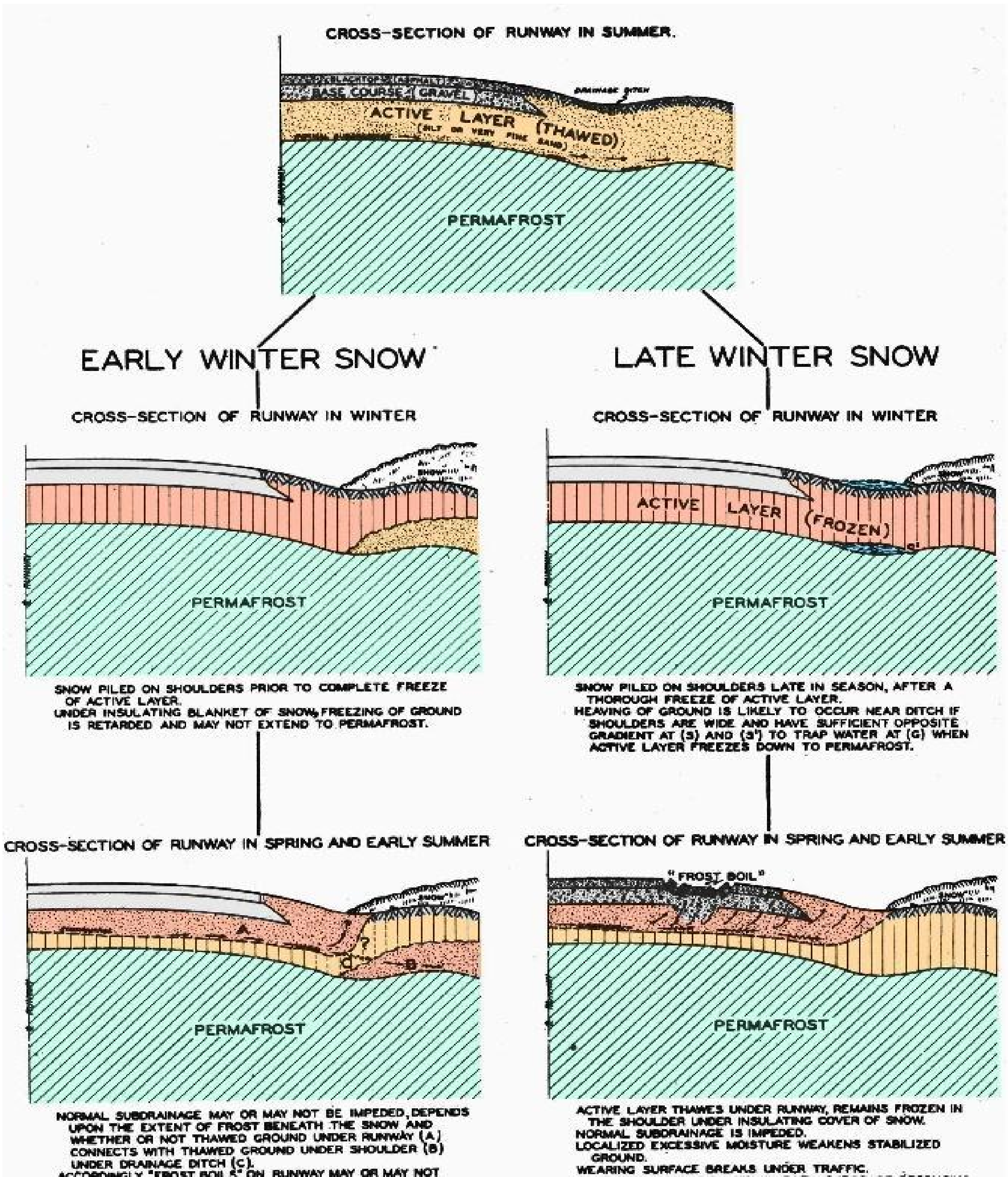
To overcome the liquid mud created by disturbed Muskegs, the Army Engineers laid corduroy, just like the Romans (Figures 13 and 14).

A corduroy road surface is constructed by first laying piles of brush, then logs, then more brush, and more logs, and finally covering the sandwiched mass with a layer of gravel.

In one stretch, two miles (3 km) of corduroy was laid. Overall, over 100 miles (160 km) of muskeg was corduroyed in this manner along the Alcan.

In May and June 1943 about 100 miles (160 km) of the Alcan between Burwash Landing and Koidern, Yukon became nearly impassable, as the permafrost thawed, because it was no longer protected by a layer of delicate vegetation.

Figures 15, 16, and 17 illustrate some of the most common problems with permafrost thawing adjacent to paved surfaces and shoulders. A corduroy road was built to restore the route, and corduroy still underlays old sections of highway in this area. Considerable problems were often triggered by the piling of snow along



EFFECT OF SNOW PILED ON SHOULDERS OF RUNWAY

paved shoulders, which created additional insulation during the winter, but formed “pockets” of seepage perched on depressions of the active zone during the summertime.

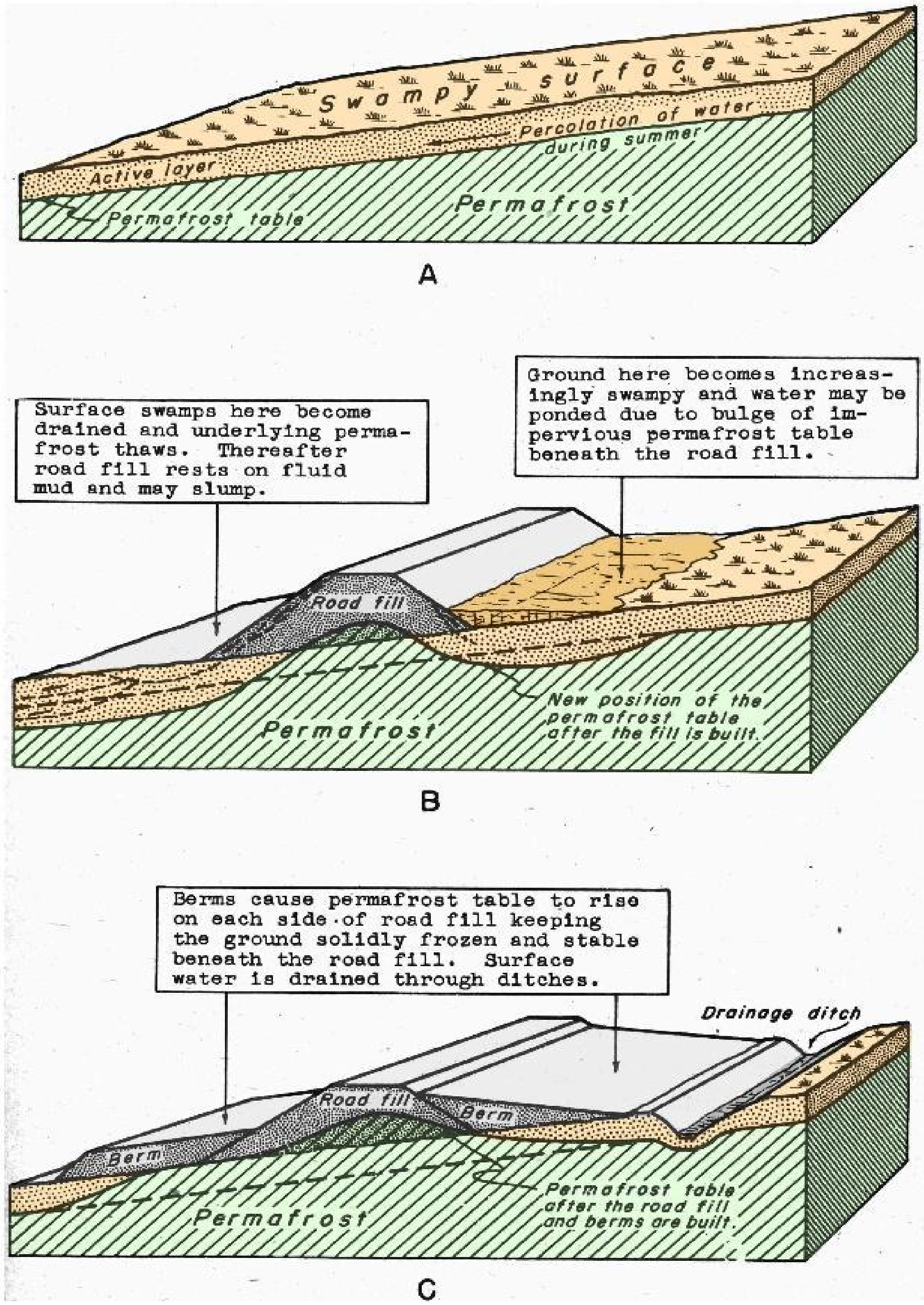


Figure 16: This illustrates the practicality of employing free-draining berms along the flanks of the highway on sloping ground (modified from Muller, 1947).

Thawed permafrost becomes swampy when its thermal insulation is diminished. When constructing a road, it was a common procedure to remove the topsoil. But, when the active layer was excavated, the underlying permafrost thaws out and becomes increasingly plastic, with degraded bearing capacity. Stabilizing berms on either side of the highway fill prism helped to alleviate this problem, as shown in Figure 16.

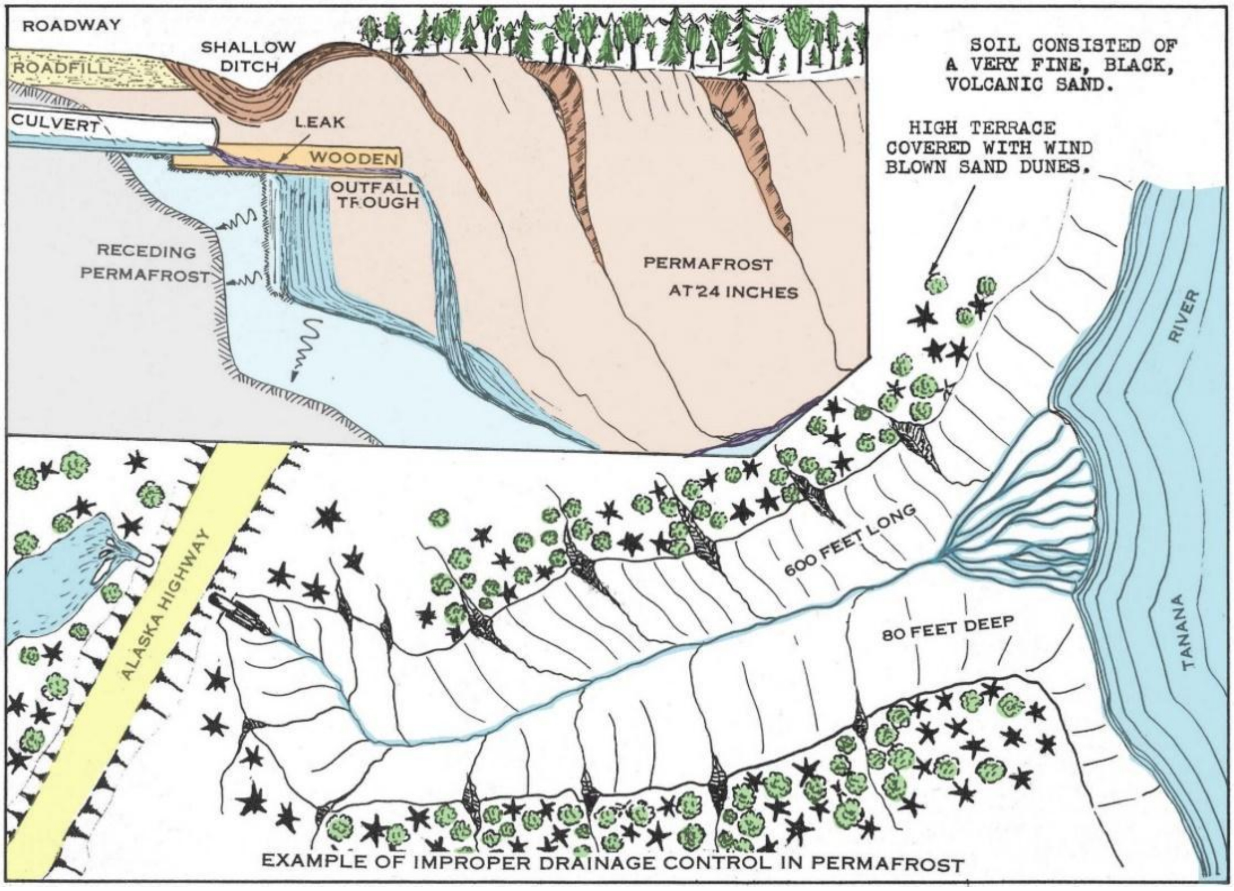


Figure 17: This drainage ditch was cut by a dozer to channel discharge away from a culvert to the Tanana River in 1942. Within a year this seemingly innocent ditch had excavated itself over 80 vertical ft (24.4 m), simply by exposing permafrost to thaw (modified from Muller, 1947).

4 CONCLUSIONS

All the locals thought that a pioneer road through the wilderness would be impossible to sustain. Not only did the USACE construct a road through the Yukon Territory to Alaska, they completed the project in a record time of 8 months and 11 days, completing 1,543 total miles (2483 km) of pioneer road.

10,670 Engineers were used to construct and improve a total of 1,685 miles (2711 km) of highway (Richardson, 1943). 41 American and 13 Canadian contractors assisted in the construction and improvement of the paved public highway. November 20, 1942 marked the official opening of the pioneer road of the Alcan Highway. The ASLIB air bridge was never interdicted by enemy action, and the discovery of permafrost during the construction of so much engineering infrastructure has impacted the design and construction of countless facilities located in artic and subarctic areas throughout the past 75 years. The air bridge was never interdicted by enemy action, and the discovery of permafrost during the construction of infrastructure has impacted the design and construction of countless facilities built in artic and subarctic locations throughout the past 75 years. The completed Alcan Highway was not opened to the public until 1948 and has been in continuous operation since that time.

References

Cohen, S. 1992. *Alcan and Canol*. Pictorial Histories Publishing Co., Inc, Missoula.

Eckel, E. B. Editor. 1958. *Landslides and Engineering Practice.* Highway Research Board Special Report 29, NAS-NRC Publication 544, Washington, DC.

Finnie, R. 1945. *Canol: the Sub-Arctic pipeline and refinery project constructed by Bechtel-Price-Callahan for the Corps of Engineers*. U.S. Army 1942-45, San Francisco.

Muller, S.W. 1944. *Permafrost; studies in connection with engineering projects in Arctic and Subarctic regions.* Headquarters, Alaskan Division, US Army Air Forces Air Transport Command.

Muller, S.W. 1947. *Permafrost or Permanently Frozen Ground and Related Engineering Problems.* J. W. Edwards, Inc., Ann Arbor.

Muller, S.W. 2008. *Frozen in Time: Permafrost and Engineering Problems*, Eds. H.M. French and F.E. Nelson, ASCE Press, Reston.

Nelson, H. E. 1949. *Military Road Construction in Foreign Theaters*. National Research Council, Washington, D.C.

Richardson, H.W.1943. "Alcan: America's Glory Road." *Engineering News-Record*, New York.

Rogers, J. D. 2019. "Construction of the ALCAN Highway in 1942," Powerpoint lecture, Military Geology (GE 5642) Missouri S&T.
https://web.mst.edu/~rogersda/umrcourses/ge342/Alcan%20Highway-revised.pdf

Sill, V. R. 1947. *American Miracle.* Odyssey Press, New York.