The History and Future of the Permafrost Tunnel near Fox, Alaska

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ABSTRACT
The Fox Permafrost Tunnel, now almost 50 years old, will be expanded in the next few years to stimulate research in key permafrost areas. More than 70 technical papers have been written about the tunnel, including topics on mining and geotechnical engineering, surface geophysics, geocryology, geology, biology, paleontology, paleoclimatology, and Mars permafrost studies. The expanded tunnel will more than double the current tunnel's length, and is designed to incorporate research needs. Laboratories, offices, cold rooms, and a learning center will also be built on site. Combined, these will form the Alaska Permafrost Research Center (APRC).

RÉSUMÉ
La Fox Permafrost Tunnel, maintenant presque 50 ans, sera élargi dans les prochaines années pour stimuler la recherche dans des domaines clés du pergélisol. Plus de 70 documents techniques ont été écrits sur le tunnel, y compris des sujets sur l'exploitation minière et géotechnique, géophysique de surface, géocryologie, la géologie, la biologie, la paléontologie, paléoclimatologie, et des etudes du pergélisol Mars. Le tunnel élargi va plus que doubler la longueur du tunnel en cours, et vise à intégrer les besoins de recherche. Laboratoires, bureaux, chambres froides, et un centre d'apprentissage seront également construits sur le site. Ensemble, ces feront l'Alaska Permafrost Research Center (APRC).

1 INTRODUCTION

The Permafrost Tunnel is located 17 kilometers from Fairbanks, shown in Figure 1. Currently, it is jointly operated by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the Institute of Northern Engineering (INE) of the University of Alaska Fairbanks (UAF). The original tunnel was constructed to research excavation methods in permafrost, not as a natural laboratory for permafrost and paleoclimatology research. Nor was the tunnel built for education and outreach on permafrost-related issues in a changing world. The motivation behind expanding the tunnel is to stimulate permafrost research related to climate change, and to address long standing issues related to building on permafrost and to improve the outreach and education experience of people visiting the tunnel.

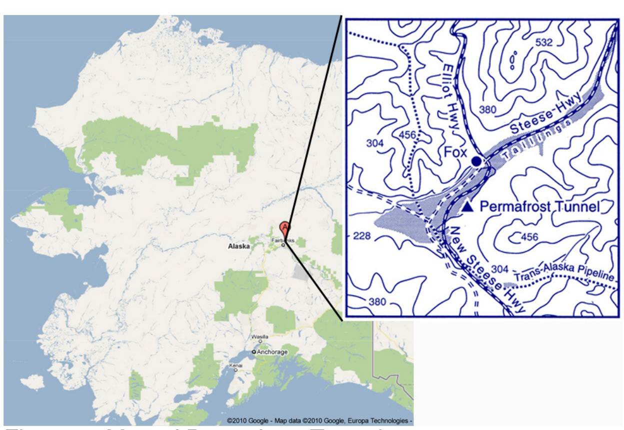

Figure 1. Map of Permafrost Tunnel

The Permafrost Tunnel has two sections called the adit and the winze, seen below in Figure 2. The adit is the 110-meter horizontal section that passes through frozen silt. The winze is the 45-meter inclined section that splits off from the adit and passes down through a gravel layer and reaches bedrock (Sellmann 1972).

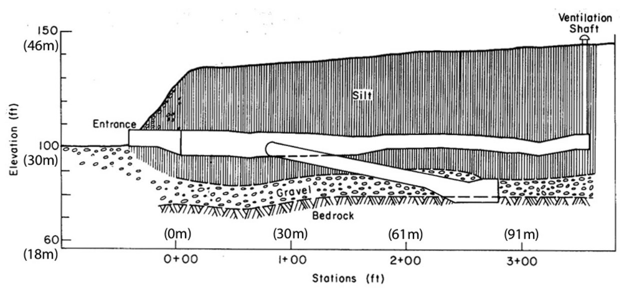

Figure 2. Profile of Permafrost Tunnel (adapted from U.S. Army 1981).

2 ORIGINAL EXCAVATION

The Permafrost Tunnel's adit was excavated during the winters from 1963 to 1966 by U.S. Army CRREL. The winze was later excavated during the winter of 1968-1969 by the U.S. Bureau of Mines (Sellmann 1972).

2.1 Adit Excavation

The adit was excavated to research underground excavations for possible military installation use. A photograph of the adit is seen in Figure 3. After the excavation, the plan was for the underground tunnel to be assessed for its use as a military shelter or for storage. It was known at the time that permafrost could absorb shocks from explosions without severe shattering (Swinzow 1970). Essentially, the tunnel was excavated out of Cold War fears.

Figure 3. Photo of Permafrost Tunnel's Adit.

The tunnel entrance was placed into a near vertical, man-made slope. The slope was created in 1942 (Holmes 1982) by stripping the overburden silt for the gold dredging of gravels (Sellmann 1967).

The adit was excavated with the Alkirk Continuous Cycle Miner equipped with two 2.1-meter diameter cutting arms, seen in Figure 4. The excavation process started with two pilot holes being drilled into the permafrost, where anchoring packers would be inserted. The packers would grip the sides of the pilot holes' walls and the Alkirk would pull itself into the cutting face (Swinzow 1970).

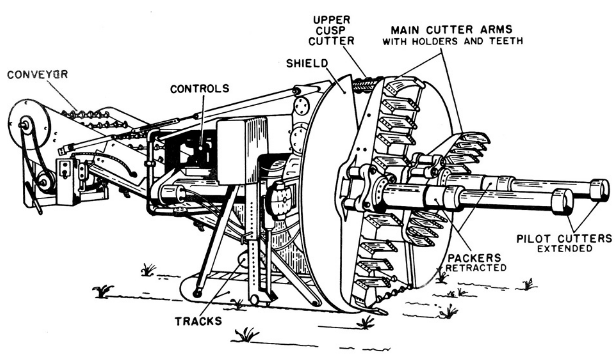

Figure 4. Diagram of Alkirk Miner (from Swinzow 1970).

2.2 Winze Excavation

The winze was excavated by the U.S. Bureau of Mines to test various excavation methods in hopes of increasing the gold mining rate in the area (Chester and Frank 1969). A photo of the winze is seen in Figure 5. At the lower end of the winze, a 2.4-meter tall, 9- by 15-meter room was excavated in the gravel layer just above bedrock. This room was studied for roof stability of the frozen gravels (Pettibone 1973).

Figure 5. Photo of Permafrost Tunnel's Winze.

The winze was excavated using five different drill and blast techniques through the silt layer and into the gravel layer and bedrock. Within the gravel layer, additional unconventional techniques were tried, including thermal relaxation, steam thawing, and hydraulic mining (Chester and Frank 1969).

3 ENGINEERING RESEARCH

Since its construction, the tunnel has been used for additional types of research with mining and geotechnical engineering being the main research foci through the 1980s.

Over this 30-year period, hundreds of samples have been taken from the tunnel and tested for geotechnical research. A few of the experiments include compressive and tensile strength testing and creep testing (Zhu and Carbee 1987a; 1987b). In addition, test strip footings were installed within the tunnel to study creep settlement (Sayles 1985). More recently, intact samples from the tunnel were tested for the long-term strength in relation to the samples' cryostructure features (Bray 2008).

A number of geophysical methods have been tested using the tunnel site as well. These tests have generally fallen into two categories: tests with the placement of underground sensors and tests related to the detection of subsurface permafrost. The former includes cross-borehole radiowave pulse transmissions (Arcone and Delaney 1989) and downhole ground penetrating radar (Hunter et al. 2003). Geophysics experimentation is one of the driving factors for the tunnel expansion.

Sublimation of the ice within the tunnel walls have been a constant problem. It makes cryostructures hard to see and forces researchers to spend hours cleaning just a small section of wall for studying. The fine loose silt falls to the floor and creates a thick carpet of dust that easily gets kicked up when people are working in the tunnel. The desiccated silt layer that remains intact on the walls have been studied and compared to similar desiccated soils on the slopes on Mars (Johnson and Lorenz 2000).

3.1 Tunnel Stability

During the summer after the excavation of the adit, the tunnel operators discovered that the rear of the adit would deform if kept at its natural permafrost temperature of approximately -1°C. Refrigerant coils were installed above the tunnel's entrance for use during the summer and a vent shaft was used to pull cold air through during the winter (U.S. Army 1967). Eventually, a mechanical chilling unit was installed just within the tunnel's entrance to cool the tunnel even further. A mechanical chilling unit is still in use and currently chills the tunnel to approximately -4°C during the summer. During winter months, outside winter air would be pulled to the back of the adit by vent shafts. These vent shafts would fill with water during the summer and freeze, making them inoperable. In total, three vent shafts were constructed and all three were eventually plugged with ice. Currently, the tunnel is cooled during the winter by blowing cold outside air through a flexible duct to the rear of the adit. In 1993, an unfortunate combination of events caused the rear of the adit to slowly deform due to creep and the dislodgement of large pieces. That spring the air chilling unit broke and the tunnel flooded from spring runoff, the combination raised the temperature in the rear of the tunnel to near 0°C. Currently, the last 20 meters of the adit are no longer accessible due to large slabs of fallen silt (Bjella et al. 2008). With upgraded cooling, the rear adit is expected to be reopened during the expansion of the tunnel.

The stability of the underground room within the frozen gravel layer of the tunnel has been studied since its 1968-1969 excavation (Pettibone and Waddell 1969). Shortly after the excavation, unstable pieces of gravel on the ceiling had to be pulled down manually, but after that, the room was considered fairly safe. With artificial cooling of the tunnel, the gravel room was walled off to bring it closer to the natural permafrost temperature. The experiment lasted from August to December of 1969 and room's temperature got up to -2.2°C. During the experiment, sublimation increased and pieces of gravel had to be pulled down more often. The gravel layer also started to pull away from the bottom of the silt layer at a rate of 0.86 millimeters per day. When the wall was taken down, the room temperature dropped, and the parting between the gravel and silt virtually stopped (Pettibone 1973). A second warming study, done in the gravel room in the early 1980s, found that the gravel layer moved as a single block separating from the bottom of the silt layer (Huang 1985). During a 6.2 Richter earthquake in 1995, a large portion of this separated block fell from the ceiling of the room (Bjella et al. 2008). In the expansion of the tunnel, the remaining gravel roof will be excavated in order to make the area safe for research.

4 GEOLOGY, GEOCRYOLOGY, AND BIOLOGY RESEARCH

During the first three decades of tunnel research, only a handful of geological and geocryological studies were done. In the past 15 years, the focus of the research switched from engineering-related studies to studies focused on climate change and paleoclimatology.

In brief, the geologic stratigraphy of the tunnel includes a bedrock layer of weathered schist at approximately 22 meters below the ground surface. Overlaying the bedrock is approximately 5 meters of gravels (Hamilton et al. 1988), more specifically the gold-bearing Fox Gravels (Long and Péwé 1996). Above the gravels is approximately 17 meters of silts (Hamilton et al. 1988) that date back to approximately 43,000 BP (Long and Péwé 1996). The silt is part of two different units, the upper part being the Ready Bullion Formation which dates from 3,500 to 10,000 BP. The lower layer is part of the Goldstream Formation, which dates from 10,000 BP to older than 30,000 BP (Péwé 1975).

The frozen silts are ice-rich syngenetic permafrost that is similar to other unglaciated parts of Interior Alaska, Yukon, and Siberia. The cryostructures seen within the tunnel include layered, lenticular-layered, micro-lenticular (Shur et al. 2004), and reticulate chaotic (Bray et al. 2006). The massive ice features include dozens of ice wedges at different depths and thermokarst-cave ice (Shur et al. 2004).

Within the syngenetic permafrost deposits in the tunnel, there are numerous organic remains, perfect for the study of paleoclimatology. Thermokarst-cave ice and other past erosion features can be seen in the tunnel's walls. In one section of the winze, there are seven distinct peat layers with corresponding ice layers below, evidence of seven different past active layers (Kanevskiy et al. 2008). Further paleoclimatology research of the site is expected with the expansion, including a trench on the surface to study the near-surface stratigraphy missed within the tunnel.

Numerous vegetation and bones have also been found within the tunnel. One of the more interesting of these paleofauna includes a baby mammoth tooth. Another is an area where 31,000 BP sedge grasses (Wooller et al. 2007) are still green. Recently, living bacteria have been taken from an ice wedge sample dated to 25,000 BP (Katayama et al. 2007). Cold-adapted fungi grow within the tunnel at the ambient -3°C temperature and in the dark. Their origin is yet unknown but likely contamination from the outside of the tunnel (Waldrop et al. 2008).

5 TUNNEL EXPANSION

The Permafrost Tunnel expansion will more than double the current tunnel's length, and is designed to directly incorporate research needs. In addition, supporting facilities will be built on site to aid in research and outreach. Combined, these will form the Alaska Permafrost Research Center (APRC). The expansion will be most likely excavated with a road header, which will allow preservation of large blocks of permafrost samples along with bones and vegetation.

5.1 The Need

The fact that the tunnel was not built to facilitate extensive research or outreach is a limiting factor, especially with the permafrost-related issues in a changing world. The motivation behind expanding the tunnel is to stimulate permafrost research related to climate change, as well as long standing issues related to building on permafrost. The expanded tunnel will be an open facility where U.S. and international researchers can come and study permafrost. The main research foci are expected to be on these four critical areas:

a) Improving standoff detection technology and surface geophysical methods for monitoring permafrost
b) Understanding how permafrost will respond to warming
c) Improve estimates of carbon stocks and release rates
d) Developing models of permafrost heterogeneity for engineering

5.2 Why in Fox, Alaska?

The location of the current tunnel is optimal, being 17 kilometers from Fairbanks, a major Alaskan city, and UAF, a large research university. This provides easy and relatively inexpensive access for researchers and students alike. The current tunnel was luckily constructed in an area containing numerous permafrost features, including ice wedge complexes, varying sizes of segregated ice, thermokarst-cave ice, frozen silt and gravel, and organic materials. The vicinity also provides an unprecedented continuous hundred-meter exposure of permafrost extending in time from the present to approximately 50,000 years in the past. Co-locating the new tunnel adjacent to the old allows for confidence in meeting the research needs in the four main research foci.

5.3 The Expanded Tunnel Design

To facilitate the research, the following will be included in the project:

a) Detailed 3D map of complex permafrost features
b) Extensive baseline mapping and sampling
c) Side rooms to allow for permafrost warming experiments
d) Boardwalks and gantry above the tunnel for test geophysics and remote sensing

The conceptual, though not final, site plan of the expanded tunnel is shown below in Figure 6. Where, the current tunnel (H&I) is on the left side shown in light gray. The new tunnel and connecting side tunnels (A-E) are on right side shown in black. A surface trench (F), on the far right side, will be used to study the recent geology of the site. Boardwalks and stairways (9-11), shown in a checkerboard pattern, will be constructed on the surface to protect vegetation. The new buildings are 1-4, with the refrigeration (6&13) and portal (7&12) at each tunnel entrance.

The tunnel will be designed for a variety of research activities. Non-metal walkways will allow for easy access without interfering with test geophysics. Lights will be placed along the walkway for safety along with plug in for extra lighting and equipment. The electrical wires, data cables, and refrigerant tubing will be located in a subsurface box below the walkway. The tunnel design will allow for periodic cleaning of the sublimated silt.

6 ALASKA PERMAFROST RESEARCH CENTER

The Alaska Permafrost Research Center (APRC) will include the expanded tunnel and new supporting facilities on site. The new building will have highly adaptable spaces that function as laboratories, small offices, and a Learning Center. Cold room laboratories and storage will be built into side rooms of the tunnel itself. A meteorological station outside of the tunnel, along with temperature monitoring within the tunnel, will telemeter data to the Learning Center. For test geophysics and remote sensing, non-metal stairs and boardwalks will be set up over the tunnel to protect the vegetation. The surface trench will allow for paleoclimatic study of the past 10,000 years, which is missed through the horizontal entrance of the tunnel.

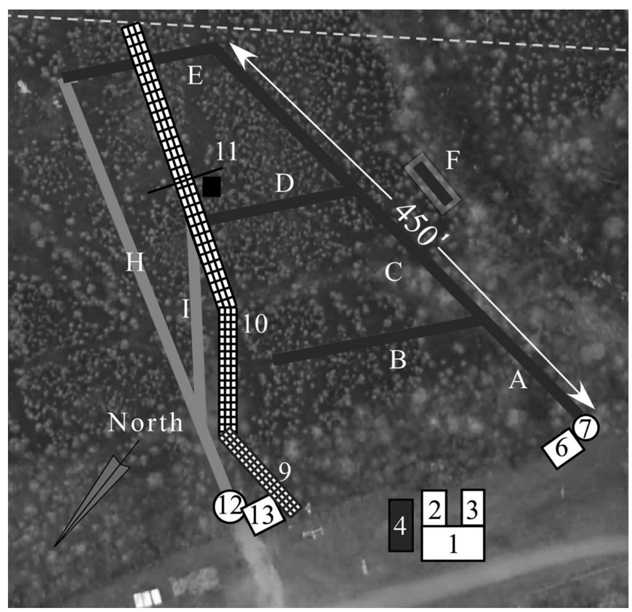

Figure 6. Conceptual Site Plan

6.1 The Learning Center

Thousands of people have toured the tunnel to learn about permafrost firsthand, including high school, undergraduate, and graduate students, Presidents, Cabinet members, Congressmen, and the general public. The future and current leaders have come away with a better appreciation of the challenges related to permafrost facing the U.S. The Learning Center will house creative displays explaining permafrost and the climate history of Alaska, including a freezer for permafrost cores that can be handled by the public. It will have moveable tables and chairs with a projector and a screen, for classes, conferences, or an open space for research set up as needed. Beyond the physical portion of the Learning Center, there will be distance delivery of educational lessons and videos on permafrost, live data, and a virtual tour of the tunnel.

Already, there is introductory permafrost information and a brief history and geology of the Permafrost Tunnel on the CRREL's Permafrost Tunnel website, http://permafrosttunnel.crrel.usace.army.mil/. In addition, there is a link to a virtual tour of the tunnel on the website. The virtual tour is built from 360° panoramic photographs taken every five meters along the tunnel. Eventually, the virtual tour will be made interactive with permafrost explanations built in with pop-up text blocks and videos.

7 TIMELINE

A design charrette with the Alaska District of the U.S. Army Corps of Engineers was held this past February. Pre-construction geophysics started in fall of 2009 with borehole drilling at the end of March 2010. The tunnel excavation is planned to begin in the 2011-2012 winter. The excavation can only be done during the winter, and the excavation is intended to be completed within one season. The construction of the new building will start the summer after the tunnel excavation. The initial baseline research will be conducted during the construction of the new facilities. The expanded tunnel and new facilities are expected to be opened in the fall of 2013.

8 CONCLUSION

The original Permafrost Tunnel has facilitated research from engineering to paleoclimatology and geocryology. This research will hopefully continue in the expanded tunnel along with new research related to permafrost in a changing climate. The Alaska Permafrost Research Center will include a new building and other supporting facilities to allow for easier and more comprehensive sampling and testing. The Learning Center will allow for continued and improved outreach and education. The Permafrost Tunnel has had a great legacy for the past 50 years, and hopefully the expanded tunnel and APRC will continue this legacy for the next 50 years.

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