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Adit Ice Plug Prevention

By William D. Mann

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ADIT ICE PLUG PREVENTION – Non-technical Summary

Many mine tunnels (or adits) in the Yukon have water flowing from them in the winter, which freezes and builds up ice like a road glacier. If ice completely blocks the adit, it can dam water behind it, filling the mine. Eventually the ice dam fails, releasing the water suddenly, as a flood. If a large flood of water is suddenly released from a mine, property can be damaged and public safety can be jeopardized. Water in some mines is contaminated; a sudden release can result in a toxic surge downstream. The majority of Yukon adits do not form ice plug dams.

The Onek and No Cash mines in the Keno Hill area have had adit ice plug floods, or outbursts large enough to wash out the Silver Trail Highway. The Onek portal is located at the edge of Keno City, and produced flooding of some residential property during an outburst in May 1997. The Tom mine near Macmillan Pass experienced an ice plug blowout following an attempt to temporarily seal the mine portals (entrances) with waste rock. Acid rock drainage is produced from the Tom adit, so an ice dam outburst may impact the downstream environment. The largest Yukon adit ice plug outburst occurred at the abandoned Mt. Skukum gold mine in October 1991. A large volume of water was released suddenly producing a torrent, which washed away the portal doors and much of the waste rock at the portal. This outburst continued down Butte Creek, and was powerful enough to lift the ice off the Wheaton River for several kilometres downstream. Ice plug outbursts occur in other parts of the world, but no documentation in scientific or technical literature was found.

Certain factors are important for ice plug formation. Adit ice plugs form in mines that have a gentle uphill slope from the portal, produce water through the winter and are located in moderately cold regions, usually within the discontinuous permafrost zone. In Yukon, these mines tend to occur at higher elevations, and on north-facing slopes. Circulation of cold air through the mine promotes ice formation. Small exploration adits, which have minimal water storage capacity, are of little concern for ice plug outbursts; potential impact increases with an increase in mine size and water pressure.

There are two types of adit ice plugs. Long ice plugs form where cold air circulation freezes long portions of adits. Ice plugs over 200 metres long have been found in the Yukon. Water release from long ice plugs tends to increase gradually. Short ice plugs form where there is little air circulation. They are approximately two to ten metres long, and form at the portal. Failure of short ice plugs can be sudden and can release catastrophic floods where water pressure is high.

Adit ice plug damming can be permanently prevented by construction of a concrete plug in the adit. This solution is expensive, and is an obstacle to future access for mine exploration. Simpler preventive measures include sealing mine openings to reduce air circulation, while allowing adequate drainage from the portal. Heat tracing of drainage pipes may be used where a power supply is available. Use of insulated pipes for mine water drainage may be adequate to maintain flow through the winter. It is important to consider the potential for adit ice plug damming when a mine is abandoned. When planning a mine it may be possible to reduce or eliminate the risk of adit ice plug formation by modifying the design of the mine.

LIST OF TABLES AND FIGURES

1.0 INTRODUCTION

This report, entitled Adit Ice Plug Prevention was funded by the Mining Environment Research Group in the Yukon. Adit ice plug outbursts are common in the Yukon, and have caused environmental and public safety concerns and property damage. The adit ice plug phenomenon has not been previously studied in a Yukon context.

1.1 BACKGROUND

Many adits in the Yukon have water flowing from them in the winter, which freezes and builds up like a road glacier. Ice completely blocks the adit and dams water behind it, filling the mine. Eventually the ice dam fails, releasing the water suddenly. A large volume of water suddenly released from a mine may cause property damage, jeopardize public safety or result in a toxic surge downstream if mine water is contaminated.

1.2 OBJECTIVES

This study has three main purposes: to document case histories of Yukon (and other) adit ice plugs, to determine predictive factors which lead to adit ice plug formation and water outburst, and to present ideas for mitigative measures.

1.3 METHODS AND DATA SOURCES

This project is based on literature research and interviews. There was no field work conducted as part of this study. An extensive search of the available literature, including the Internet did not locate any significant published information on adit ice plugs. One unpublished exploration assessment report was found to contain cross-sections of an adit ice plug with a central drainage tube, mapped along with the geology. Some environmental assessment reports of abandoned mines contained detailed maps and photos of adits indicating substantial drainage channels cutting waste rock dumps at portals. This evidence of very high flow rates suggests adit ice plug floods may have occurred. A Site Characterization report prepared for United Keno Hill Mines provided extensive data on several of the mines studied in this report.

Discussions with people who have experience working with frozen adits was essential in gathering data for case histories, assessing the relative importance of various factors contributing to adit ice plugs, and developing ideas for preventing ice plug formation and outbursts. These people are listed in section 8.2, Contacts. Most of the observations of ice plug failure are from the Keno Hill area, where people live and work near numerous abandoned mines.

The author has professional experience with adit ice plug prevention at the Skukum Creek underground exploration project. He has observed adit ice plugs at Mt. Skukum, Webber, and Keno mines, and has visited several of the other mines included in this report. Due to the absence of scientific or engineering studies on the subject of adit ice plugs, most of the analysis presented in this report is a subjective interpretation by the author.

2.0 EXAMPLES OF ADIT ICE PLUGS

The analysis of adit ice plugs presented in this report is based almost entirely on the study of Yukon mines. Ice plugs are reported to occur in mines in other jurisdictions, but no data was collected for specific sites. In the Northwest Territories, there are a few cases of adit ice plugs, but no records of potential problems. The ice plugs are not a problem in this area due to incomplete plugging of the adit by ice, minimal water in permafrost areas or minimal hydrostatic head in relatively flat terrain (Wong, 2000). In southwest Colorado, ice plugs were observed in several mines at higher elevations and in shady canyons (Rehn, 1997).

Yukon has five adits with known, significant adit ice plug problems. There are another seven adits where ice plugs are either suspected or are known to exist. Some of these are small, and are not likely to pose a significant threat. This study did not consider every mine in the territory, due to a lack of a comprehensive mine design and engineering database. All of the mines with known ice plug problems are included in this report. The details of site location and mine layout are summarized in Table 1. Descriptions of each of the mines and case histories of ice plug data are presented in the Appendix. The case histories are listed in approximate order of severity of ice plug outbursts. Plans and vertical longitudinal sections of some mines are included as examples. The Yukon examples cover a range of mine layouts, locations, and types of ice plugs, so that the relative importance of various factors affecting adit ice plugs could be analyzed. The analysis and conclusions based on the Yukon examples can potentially be applicable to other parts of the world.

2.1 ADITS WITH MAJOR ICE PLUG DAMMING

Five adits have experienced significant ice plug outbursts in Yukon, where substantial volumes of water washed away waste rock and portal structures, and in some cases washed out roads downstream. This group includes the Mt. Skukum Gold Mine, which can hold the largest water volume of the mines studied. This mine released a catastrophic torrent in 1991, and has produced less spectacular outbursts subsequently. The Onek mine, at the edge of Keno City produced outbursts in the 1960's and again in 1997. The 1997 outburst washed out the Silver Trail Highway. The No Cash mine near Elsa also washed out the Silver Trail Highway with two outbursts circa 1970, but blocking of air circulation through the mine appears to have prevented subsequent outbursts. Moderate floods from the Keno 700 mine on Keno Hill has recently washed away a substantial volume of the portal waste rock dump, while leaving the portal shed mostly intact. An apparent ice plug outburst at the Tom mine at Macmillan Pass has recently washed away waste rock used to seal the portals.

2.2 ADITS WITH MINOR OR POSSIBLE ICE PLUG DAMMING

Six adits are considered to have minor or possible ice plug damming situations. At these mines outbursts have been small due to low mine volume, or ice plug dams are only suspected based on drainage channels cut into the waste rock dumps in front of the portals. The Skukum Creek mine has a significant potential volume, but a lot of water is diverted into a self-draining internal decline, so ice has not been observed to fill the portal. The Peerless mine has a washout fan in front of the portal, and a long ice plug in the adit was mapped in detail. This mine connects to the Arctic Caribou mine above, which has

TABLE 1. SUMMARY OF ADIT ICE PLUG TECHNICAL DATA

MINE SITE	PORTAL			ADIT			MINE VOLUME M3	NATURAL VENTILATION	WATER FLOW L/SEC	YUKON MINFILE #	PERMAFROST
	LATITUDE	ELEVATION	ORIENTATION	INCLINATION	WIDTH	HEIGHT					
Major Ice Plug Damming											
Mt. Skukum	60 12 26	1635m	N	1%	1.8m	2.1m	85,000	Yes	4 - 23 L/s	105D 158	Probable
Onek 400	63 54 42	1065m	W	1%	1.8m	2.1m	16,000	Yes	0 - 0.7 L/s (av. 0.3)	105M 001	Probable
No Cash 500	63 55 08	1060m	NW	1%	1.8m	2.1m	30,000	Yes	0 - 9 L/s (av. 4)	105M 001	Yes
Tom	63 09 54	1440m	W	1%	2.4m	2.4m	11,000	No	9 - 17 L/s (av. 14)	105O 001	Yes
Keno 700	63º56'30"	1550m	SE	1%	1.8m	2.1m	12,000+	Yes	0 - 6.5 L/s (av. 3)	105M 001	Yes
Minor Ice Plug Damming											
Skukum Creek	60 10 47	1300m	NE	1%	4m	3m	7,000+	Yes	1 - 5 L/s	105D 022	Probable
Peerless	60 04 35	1545m	NW	1%	1.8m	2.1m	2,700+	Yes	<0.75 L/s	105D 009	Yes
Possible Ice Plug Damming											
Vera	64 18 25	1287m	N	~3%	3.0m	2.7m	5,800	No	0.25 L/s	106C 083	Probable
Tintina	61 08 31	1638m	NNE	1%	1.8m?	2.1m?	~2,000	No?	0.1 L/s	105G 006	Probable
Burnick 1200	60 33 00	1200m	NE	1%	4m	4m	4,000+	Yes	~ 1 - 3 L/s	105A 013	Yes
Ruby 400	63º54' 35"	1260m	NW	1%	1.8m	2.1m	5,000+	Yes	0 - 2.5 L/s (av. 1.5)	105M 001	Probable
No Ice Plug Damming?											
Sadie-Ladue 600	63 57 00	1150m	NW	1%	1.8m	2.1m	75,000+	Yes	2 - 19 L/s (av. 10)	105M 001	Yes
Webber	62 03 18	1305m	NW	1%	1.8m	2.1m	2,500	Yes	0 - ? (very low)	115I 065	Yes
Galkeno 900	63 55 08	900m	E	1%	1.8m	2.1m	6,900	No	10 L/s	105M 001	Yes
Venus 2600	60 01 00	790m	SE	1%	1.8m	2.1m	4,300+	Yes	5 L/s	105D 005	No?

substantial volume but is mostly full of permanent ice. The Vera and Tintina mines are both relatively small exploration adits that have obvious drainage channels in front of their portals, though presence of adit ice plugs has not been confirmed. The Ruby mine near Elsa forms an ice plug at its portal, however water flow may not have been totally blocked, or has drained in a gradual manner to date. The Burnick adit at the Sa Dena Hes mine forms ice flows near the portal that have not formed a plug since project suspension in 1992.

2.3 ADITS WITHOUT ICE PLUG DAMMING

Four adits are described that have some of the characteristics common to the adits that have ice plug problems, but have not formed ice plug dams. Comparison of these mines to the problem mines is useful in evaluating the causes of ice plug dams. The Sadie Ladue 600 adit has been through about 70 winters without an ice plug outburst. This mine has substantial water flow and a large mine volume, is located at high elevation on a north-facing slope, and permafrost is present in the immediate area (Tupper, personal communication). The Galkeno 900 portal is driven in permafrost, but has not produced an ice plug dam. The high water flow rate, high water pressure and lack of air circulation may have prevented damming. The Webber mine at Mt. Nansen is plugged with ice, but has very little water flow and has not produced an outburst. The mine may drain internally. The Venus mine near Carcross is presented as an example of a gently sloping adit that produces water and has free air circulation, but is not subject to ice plug damming. The portal is at low elevation, near a large body of water, and is on a southeast-facing slope, and may be generally warmer than the other mines studied.

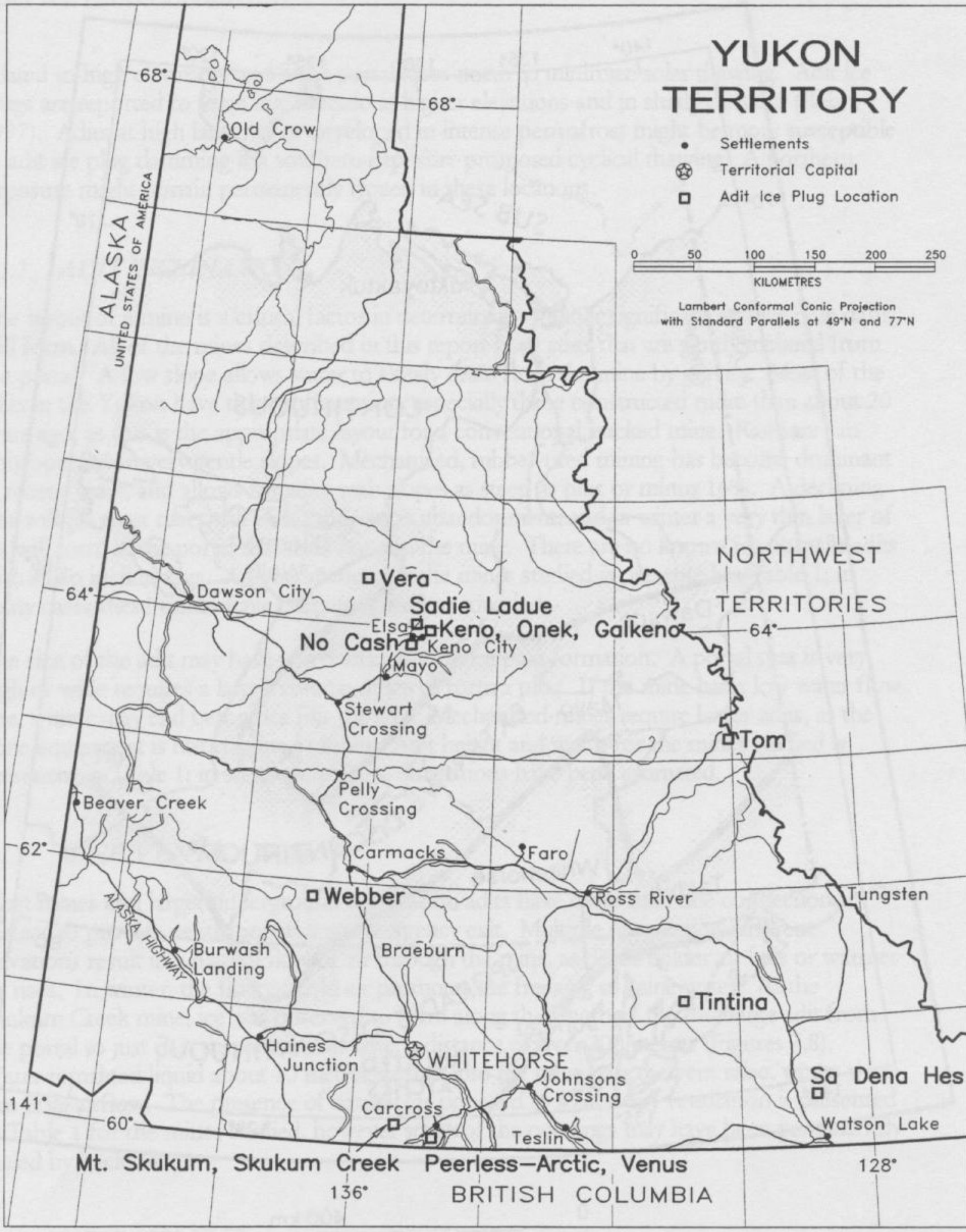
3.0 FACTORS WHICH MAY INFLUENCE ADIT ICE PLUGS

Adit ice plugs form due to a combination of the following factors: the mine design, the flow rate of water from the mine in winter, and freezing temperatures. An analysis of the case histories of adits with ice plugs in comparison to adits that do not form ice plugs suggest the relative importance of the various factors.

3.1 MINE LOCATION AND DESIGN

The mines subject to adit ice plug damming described in this report are all located in southern and central Yukon (Figure 1). This corresponds to an area of extensive discontinuous and sporadic discontinuous permafrost (Figure 2). The specific location parameters of latitude and elevation influence the microclimate at the site related to freezing and thawing. The orientation of the portal is thought to be significant, as north-facing slopes receive less heat from the sun. South- or west-facing portals appear to be less prone to ice plug formation, with important exceptions being the Onek, Keno and Tom mines. (The Tom mine faces west, however it is within a deep north-facing valley that receives relatively little sunlight). Controls other than orientation appear to be dominant at some sites such as the Onek and Keno. The Arctic-Caribou mine faces due south, but remains filled with ice year-round.

Adit ice plugs can form at any latitude cold enough to have a long freezing season, perhaps



ADIT ICE PLUG PREVENTION

YUKON ADIT ICE PLUGS LOCATION MAP

William D. Mann, Geological Consultant

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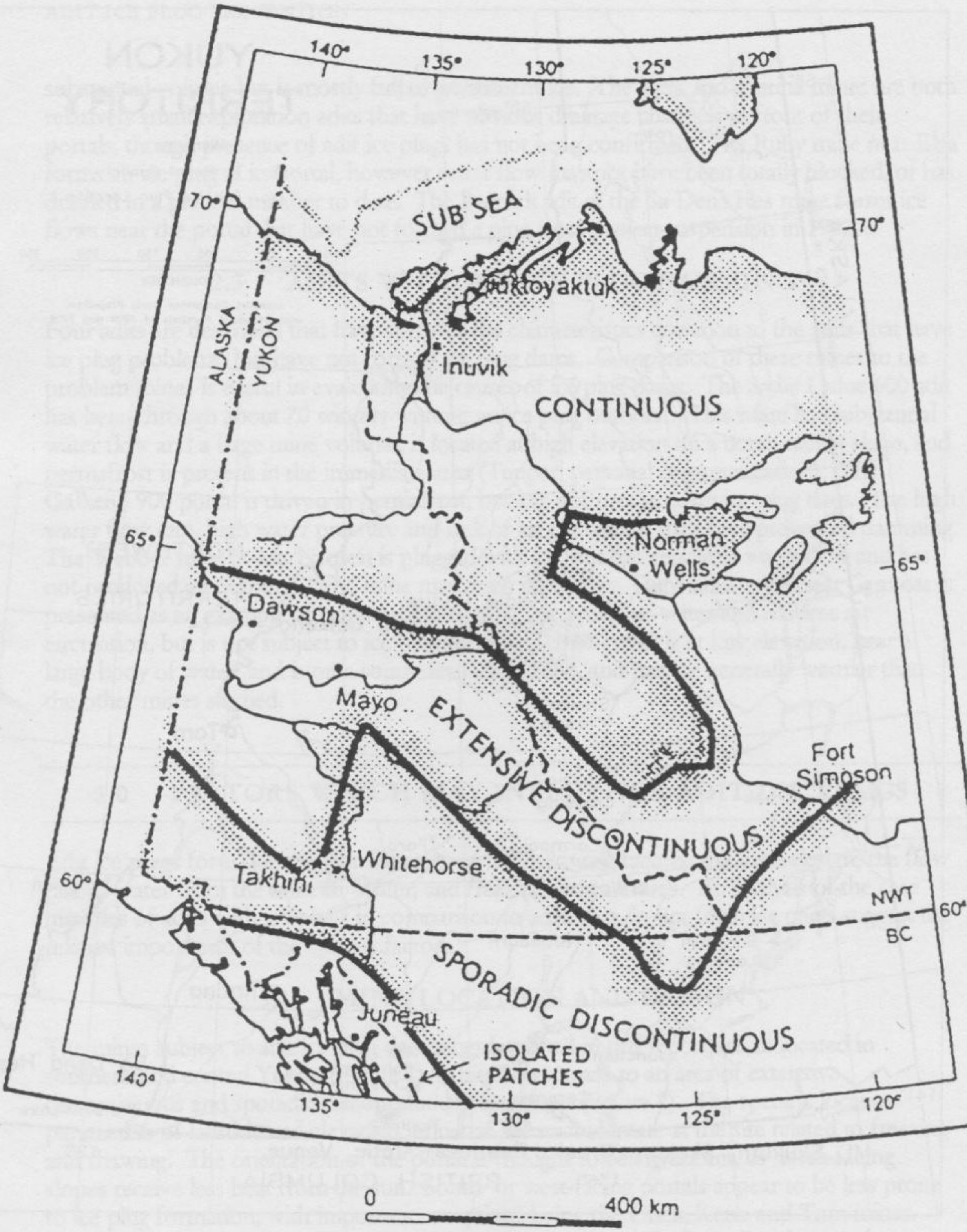


Figure 2. Permafrost map of Yukon and adjacent Northwest Territories (from Burn, 1998).

related to high elevation, and if the portal faces north to minimize solar thawing. Adit ice plugs are reported to form in Colorado at higher elevations and in shady canyons (Rehn, 1997). Adits at high latitudes or developed in intense permafrost might be more susceptible to adit ice plug damming if a southern exposure promoted cyclical thawing. A northern exposure might remain permanently frozen in these locations.

3.1.1 ADIT INCLINATION

The layout of a mine is a critical factor in determining whether significant adit ice plug dams will form. All of the mines described in this report have adits that are gently inclined from the portal. A low slope allows water to slowly drain from the mine by gravity. Most of the adits in the Yukon have this configuration; especially those constructed more than about 20 years ago, as this is the appropriate layout for a conventional tracked mine. Rail cars can only operate on very gentle slopes. Mechanized, rubber-tired mining has become dominant in recent years, and allows for adits with slopes as steep as plus or minus 16%. A declining adit will (in most cases) fill with water upon abandonment, and in winter a very thin layer of ice will form at the portal that does not seal the mine. There are no known ice plugs in adits with steep inclinations. Adit inclination for the mines studied is presented in Table 1; in many cases these values have been estimated or rounded.

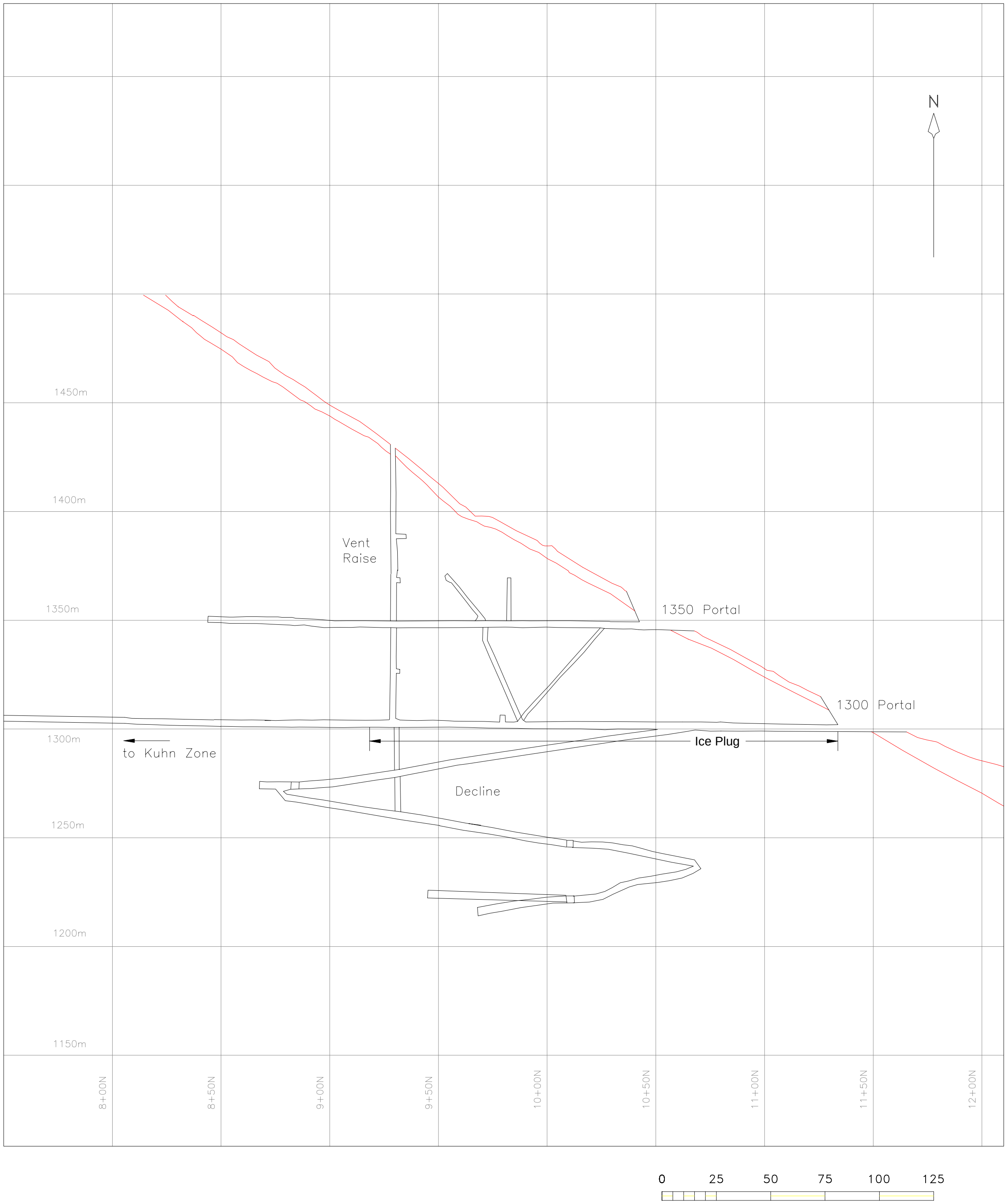
The size of the adit may have some influence on ice plug formation. A portal that is very high or wide requires a larger volume of ice to form a plug. If the mine has a low water flow rate, winter may end before ice fills the adit. Mechanized mines require larger adits, as the mine equipment is not confined to rails. Adit height and width for the mines studied is presented in Table 1; in some cases these dimensions have been estimated.

3.1.2 MINE VENTILATION

Most mines and larger underground exploration adits have more than one connection to surface to provide ventilation and an emergency exit. Multiple openings at different elevations result in a natural flow of air through the mine, as dense colder air falls or warmer air rises. In winter, the flow of cold air promotes the freezing of mine water. At the Skukum Creek mine, ice was observed to form along the length of the discharge adit from the portal to just past the ventilation raise, a distance of over 200 metres (Figures 7,8). Water remained liquid about 10 metres further into the mine past the vent raise, where there was little airflow. The presence of natural (as opposed to forced air) ventilation is presented in Table 1 for the mines studied, however some of the openings may have been permanently sealed by backfilling.

3.1.3 MINE VOLUME

The volume of mine workings present at and above the adit level does not have a direct effect on the formation of an ice plug, but is the most important factor in determining whether there is a significant hazard at the site. Water dammed by an ice plug can fill all of the mine volume up to the next mine opening. If the mine volume is low (less than 5,000 cubic metres), then the flow from an adit ice plug outburst is not likely to have much



ADIT ICE PLUG PREVENTION - MERG 009		
SKUKUM CREEK MINE VERTICAL LONGITUDINAL SECTION		
William D. Mann, Geological Consultant		
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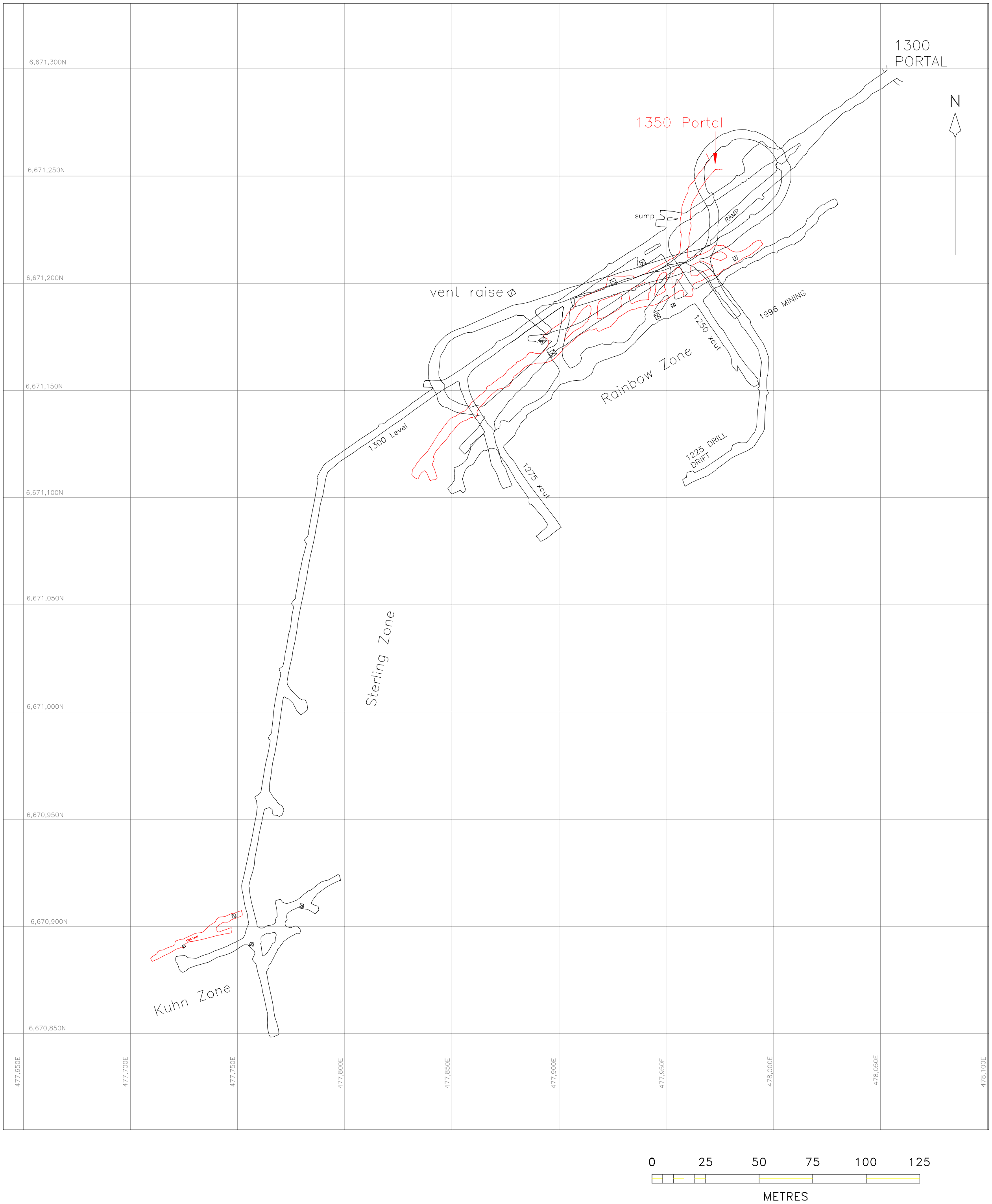

ADIT ICE PLUG PREVENTION - MERG 009		
SKUKUM CREEK MINE PLAN VIEW		
William D. Mann, Geological Consultant		
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physical impact. Larger volumes (more than 10,000 cubic metres) are more likely to create a public safety hazard and cause property damage. The mine volumes in Table 1 are an estimate of the volumes at the adit level and stopes and raises above it to the elevation of the next mine opening.

Some underground mines are stoped through to surface to form a "glory hole'; or an open pit may be mined to remove a crown pillar of ore left from underground mining. These operations may greatly increase the flow of mine water, as the openings tend to trap drifting snow and funnel runoff into the mine. Examples studied in this report include the Onek, Mt. Skukum and Sadie Ladue mines. Mt. Skukum is particularly significant, as a small creek flows near the opening and leaks into mine, producing a relatively high flow rate. It is common for water dammed by ice plugs to completely fill the glory hole.

3.2 WATER

Formation of an adit ice plug requires a flow of water from the mine through the winter. In most cases this water will be groundwater, not surface runoff, as surface water freezes during Yukon winters. Many adits are essentially dry, and may have some flow only during spring runoff. Other mines may drain internally, such as the decline at Skukum Creek, and possibly the Jewelbox Hill mine at Sa Dena Hes. Adit flow rates vary considerably at the mines studied, from a low average flow of about 0.3 L/s at Onek to a high of about 14 L/s at Tom. At the low rate, it might be expected that all of the adit flow would become frozen to form an ice plug during cold weather. At higher rates, some of the adit flow may continue as the ice plug forms. Flow rate determines the rate of filling of a mine once an ice plug begins to dam water.

The surface area of water exposed to cold air is a factor in ice plug formation. If the water is channeled into a deep, narrow ditch or a culvert it is less likely to freeze than if the water flows as a thin sheet across the floor of the adit. In some mines sediment or precipitate may fill the ditches over time.

Water quality is an important consideration when evaluating the significance of an adit ice plug. Flooding of mine workings may promote solubilizaton of oxidized ore minerals. If a large volume of poor quality water were released in an ice plug outburst, a toxic surge would impact the downstream environment. A mine with poor water quality may be (very slightly) less likely to form ice plugs, as impurities reduce the freezing point of that water. The Onek mine is known to produce water that commonly exceeds CCME freshwater aquatic life guidelines for cadmium and other metals, at a very low flow rate (CCME, 1999). When this mine experienced an outburst in May 1997 water samples collected downstream are reported to have met Water Licence metal guidelines (Dunn, personal communication). This data was not available to the author. Perhaps much of the water impounded was recent spring runoff funneled into the mine from the open pit that had been in the mine for a relatively short period.

The Tom mine is the only mine studied in this report to produce full-blown acid rock drainage. Discharge from this mine greatly exceeds CCME guidelines for many water quality parameters. An outburst from this mine is expected to be of more environmental significance than one from Mt. Skukum mine, which produces a larger volume of water that meets water quality guidelines. The chemical impacts of adit ice plug floods is a subject worthy of further investigation.

3.2.1 WATER PRESSURE

The water impounded by an ice plug dam produces hydrostatic head pressure as it fills the mine above the base of the plug. Pressure increases as mine workings above the level fill with water, until the water reaches the next mine opening. Water pressure can also build in mines that intersect significant aquifers. The Galkeno 900 adit is developed on one level only, but is hydraulically connected to much of Galena Hill above the level as the adit cuts fault structures that produce a lot of water. The adit ice plug at Mt. Skukum experiences about 90 metres of head pressure when the water level rises to the rim of the glory hole. High water pressure is thought to inhibit ice plug formation, and promote ice plug failure. Water draining at high pressure from a narrow tube through an ice plug is reported to squirt hundreds of metres across the gulley in front of the Mt. Skukum portal (Sherstone, 2000).

3.3 TEMPERATURE

Freezing temperatures present for a significant length of time are obviously essential for the formation of ice plugs. Rock, water and air temperatures are all important factors, and interaction between these various elements affects the formation, length and stability of an ice plug. There is very little data available for these parameters. The presence of permafrost is not always recorded in a mine, and mine water temperature is not available. The microclimate at a mine site can vary considerably from that of the nearest weather station. The significance of these elements is not known, but a discussion is presented below.

3.3.1 PERMAFROST

The Yukon mines known to experience adit ice plug damming occur within or near the discontinuous and sporadic permafrost zones (Burn, 1998). There are few adits developed in the continuous permafrost zone in the Yukon. It is expected that mines developed in very intense permafrost would fill with ice that does not melt in summer, and any water underground would not be released. Permafrost is associated with relatively dry climates.

An adit in warm rock would not be plugged with ice, as melting would occur at the rock – ice interface. It is thought that adit ice plug dams occur in mines where the rock is near zero degrees Celsius. An “active layer” of rock that thaws in summer (or when the mine is heated) and “freezes back” in winter is expected to be present in these mines.

If rock temperature is slightly above freezing the circulation of cold winter air may be enough to produce an ice plug dam. In this situation, melting of the plug would be expected to occur around the periphery of the ice, at the rock contact. A plug melting in this manner could be pushed out of the adit by water pressure. There are no adit ice plugs of this type documented in this report.

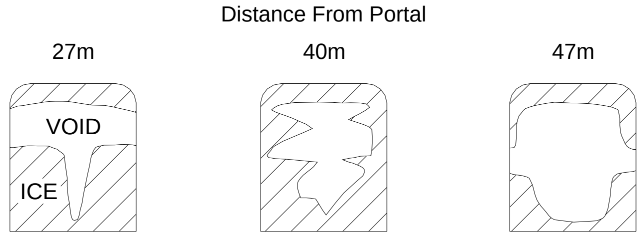
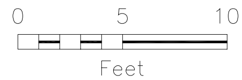


Figure 3. Peerless Adit Cross Sections Showing Ice Distribution
After M.D. Kierans, In: Tindale, 1966



Ice plug dams formed in adits in rock that is slightly below freezing would be expected to drain through tubes within the ice plug. A tube of this type was observed at Mt. Skukum gold mine in July 1997. Cross-sections of a tube through an ice plug were mapped at the Peerless mine, and are presented in Figure 3. A plan and longitudinal section of this mine is presented in Figure 6. Many adits have steel pipes or rails extending out the portal from the mine, which tend to conduct heat and may promote melting.

Distribution of permafrost on the scale of a mine site can be erratic. At the Sadie-Ladue mine at Keno Hill the Ladue shaft was sunk in permafrost to a depth of over 80m. The Sadie shaft, located about 600m away on the same geological structure was not in permafrost McTaggart, 1960). The presence or absence of permafrost at a particular adit may therefore not be readily apparent. Rock temperature in Yukon mines is not known to have been recorded.

3.3.2 CLIMATE

The southern two-thirds of the Yukon, where adit ice plugs are located, have mean annual daily temperatures in the range –1 to –8 degrees Celsius (Wahl et. al., 1987). A long, cold winter is required to allow the gradual buildup of ice plugs, while warm spring and summer temperatures melt them. Annual variations in the intensity of cold and warmth may affect plug size, melting rate and other characteristics. Variations in precipitation affect the amount of water flowing into and out of the mine. Snow pack may be significant, as a thick blanket of snow that covers a portal may reduce air circulation and prevent ice plug formation. Snow pack in most of Yukon is relatively low (one metre). Deep (six metre) snow pack at portals in Montana is reported to be beneficial in preventing ice plug formation due to its insulative effect (Sonderegger, 1997). Trapping of snow at the portal is recommended.

3.3.3 WATER TEMPERATURE

The water in a mine may be from surface runoff, from groundwater discharge, or commonly a combination of the two. Groundwater is likely to have a fairly constant temperature, while surface water temperature is expected to vary with the seasons. An ice plug that dams water in pools on surface, such as the glory hole at Mt. Skukum gold mine, may be subject to a significant effect from solar heating.

3.4 IMPACT OF CLIMATE CHANGE

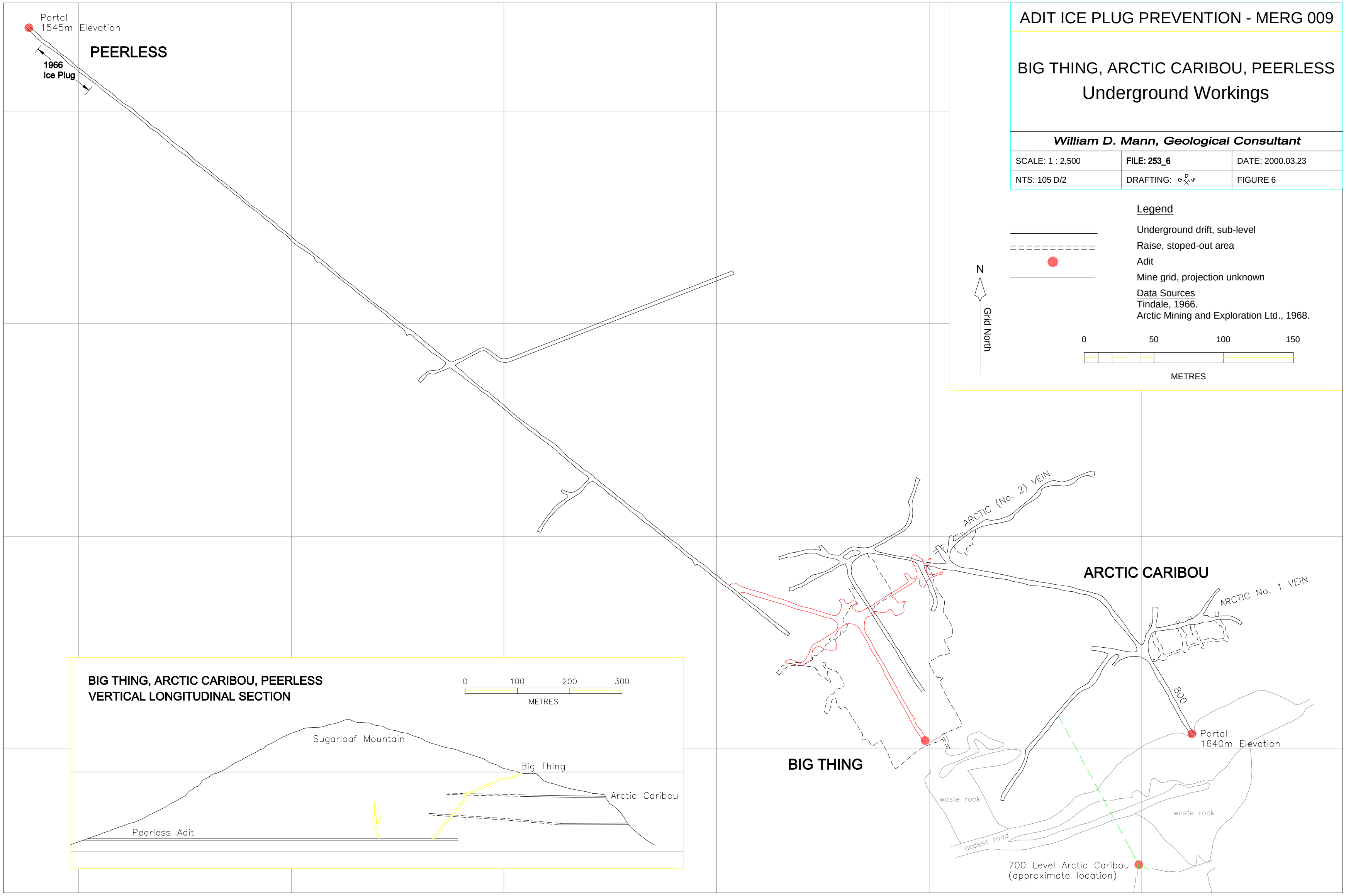
A gradual increase in average global temperatures is thought to be occurring; the temperature increase appears to be greatest in northern latitudes. Some mines that currently host adit ice plug dams may no longer experience this condition if rock, water and air temperatures increase sufficiently. Other mines which are located in intense permafrost, and are completely frozen may begin to cyclically thaw and form ice plugs. The Arctic Caribou mine on Montana Mountain is mostly full of ice, with some runoff in spring and summer that flows out the Peerless adit. If the ice were to melt completely in summer, a greater flow of water would be experienced from the Peerless. It is not known what effect this would have on adit ice plug formation at Peerless, but water quality might be affected, as the Arctic Caribou mineralization is prone to acid rock drainage.

4.0 ADIT ICE PLUG MODELS

Water flowing from adits in winter is observed to freeze in thin layers, in the same manner that a road glacier forms from spring water seeping into the winter air at some Yukon road cuts. The thin layers of ice build up gradually until the adit is completely choked with ice; then water builds up behind the ice plug. "Long" and "Short" are the two types of adit ice plugs that are thought to form, based on the length of the adit that is plugged by ice. Diagrams illustrating vertical longitudinal sections of long and short ice plugs in hypothetical mines are presented in figures 4 and 5. The amount of air circulation appears to be the major factor determining plug length. It is likely that a long plug could form in a mine with free air circulation, and in the same mine a short plug could form if mine openings were sealed.

4.1 LONG ICE PLUGS

Ice plugs 50 to 200 metres in length are documented at the Peerless and Skukum Creek mines. Both of these mines have free air circulation from higher adits, shafts or raises. Figure 4 illustrates a hypothetical mine with a similar configuration with a long ice plug. Ice can form along the length of adit that is exposed to frigid air currents, from the portal to the vent raise. In spring and summer warm air melts the ice back from the portal, and water gradually melts a path through the ice plug from inside the mine. This path widens as water starts to flow, gradually increasing the flow rate until the dammed water is exhausted. The outbursts from the No Cash mine which washed out the Silver Trail Highway were reported to gradually increase in flow over a period of several hours (Hohener, personal communication). The ice plug with a smooth central tube observed at Mt. Skukum gold mine in 1997 is also thought to be of the long type.


ADIT ICE PLUG PREVENTION - MERG 009
BIG THING, ARCTIC CARIBOU, PEERLESS
Underground Workings
William D. Mann, Geological Consultant
SCALE: 1 : 2,500
FILE: 253_6
DATE: 2000.03.23
NTS: 105 D/2
DRAFTING:
FIGURE 6
Legend
Underground drift, sub-level
Raise, stoped-out area
Adit
Mine grid, projection unknown
Data Sources
Tindale, 1966.
Arctic Mining and Exploration Ltd., 1968.
0
50
100
150
METRES
N
Grid North
Portal
1545m Elevation
PEERLESS
1966
Ice Plug
ARCTIC (No. 2) VEIN
ARCTIC CARIBOU
ARCTIC No. 1 VEIN
800
Portal
1640m Elevation
BIG THING
waste rock
waste rock
access road
700 Level Arctic Caribou
(approximate location)
BIG THING, ARCTIC CARIBOU, PEERLESS
VERTICAL LONGITUDINAL SECTION
0
100
200
300
METRES
Sugarloaf Mountain
Big Thing
Arctic Caribou
Peerless Adit

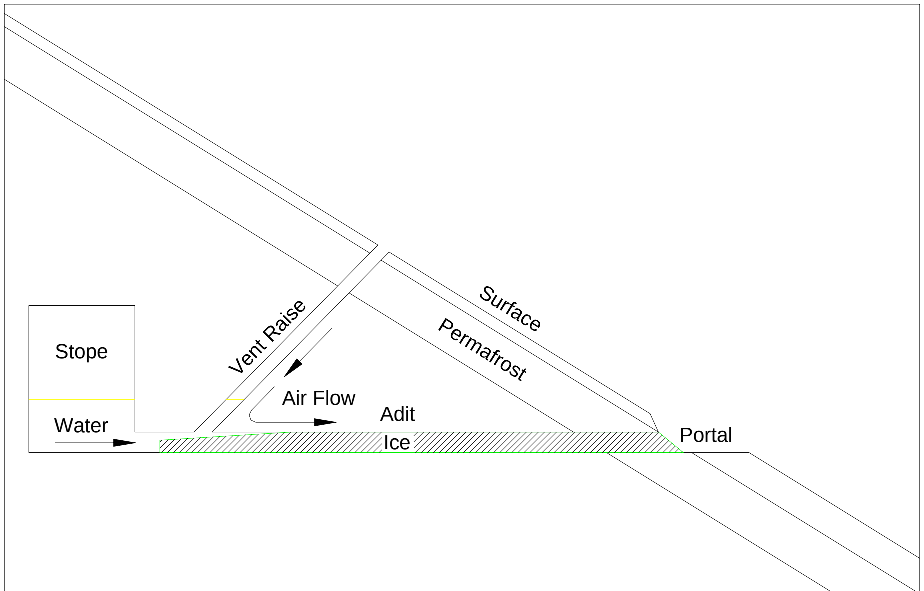


Figure 4 LONG ICE PLUG

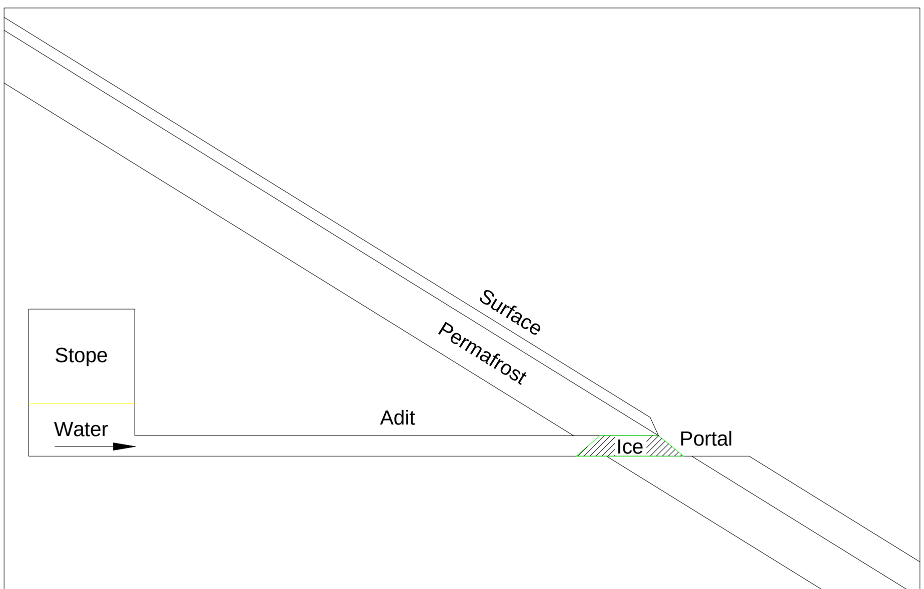
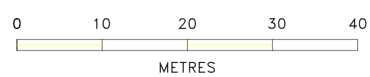


Figure 5 SHORT ICE PLUG



ADIT ICE PLUG PREVENTION - MERG 009

ICE PLUG TYPES

William D. Mann, Geological Consultant

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4.2 SHORT ICE PLUGS

Ice plugs estimated to be 2 to 10 metres in length are reported from the Mt. Skukum Gold Mine (in 1991), the Onek mine (in 1997), and likely from the Tom mine. The Mt. Skukum ice plug was estimated to be only 1.5 metres long about one month before the outburst (Polyck, 1991). There was little or no ice left in the adit after this event (Doherty, personal communication). In these cases there was little if any air circulation to extend the ice plug into the adit. Figure 5 is a diagram of a hypothetical mine with no air circulation and a short ice plug. Short plug formation may be promoted by the presence of tight-fitting portal doors which inhibit the flow of water from the mine. Failure of short ice plugs is thought to be rapid, and potentially catastrophic. The dam is small, therefore ice may be quickly washed away or melted, and water can flow freely from the mine. The 1991 Mt. Skukum outburst produced a powerful torrent, indicating rapid failure of the ice plug and draining of the large volume of mine water.

The 1997 Onek mine "short" ice plug is an unusual case, as the plug was shortened by portal excavation the previous spring (Dunn, personal communication). Despite the 5 to 10 metre plug length, the mine drained from a narrow (approximately 0.5m diameter) tube through the ice plug (Dunn, Enns, personal communications). The ice plug did not "blow out" despite rapid flow of a large volume of water. A plan and longitudinal section of the Onek mine is presented in Figure 9.

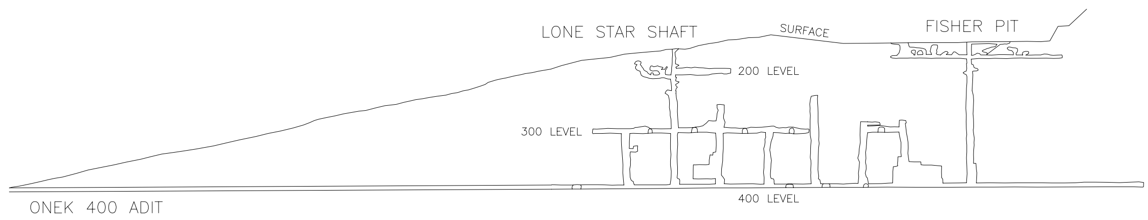
The Tom mine outburst was not observed, and the role of ice plugging is somewhat speculative.

4.3 AN ANALOGY – GLACIER OUTBURST FLOODS

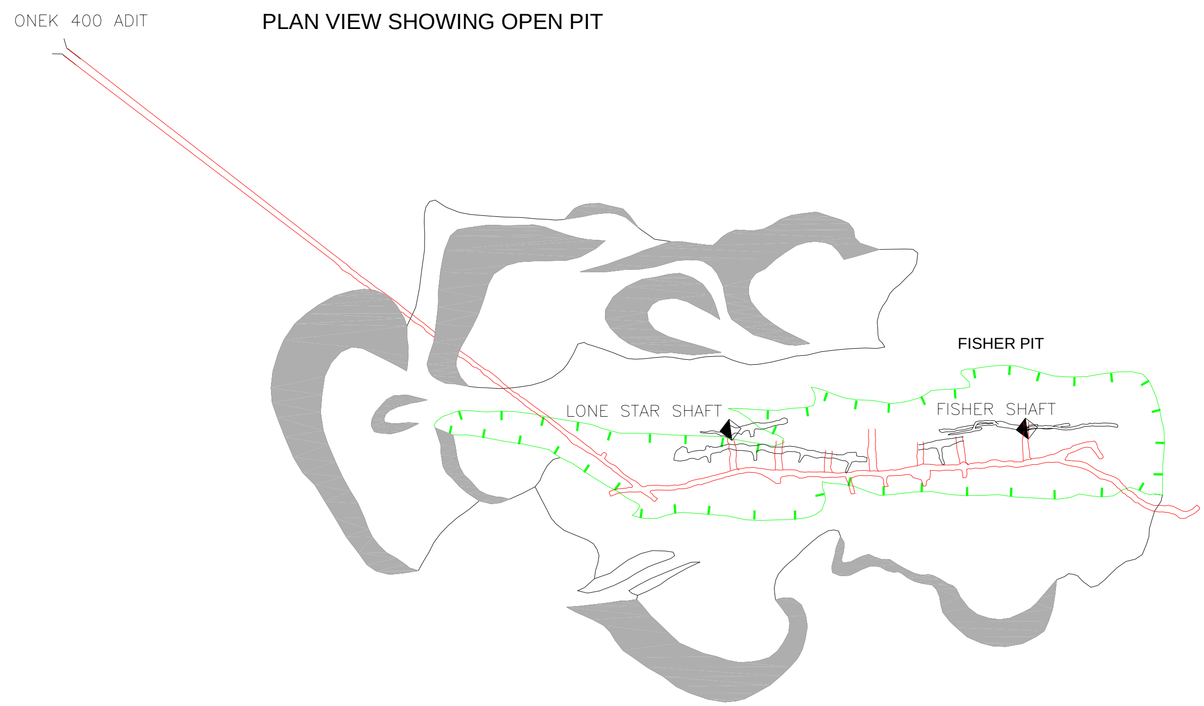
Glacier outburst floods (or *jökulhlaups*) are a natural phenomenon that may be compared to adit ice plug outbursts. Glaciers commonly impound lakes in ice-free tributary valleys. These lakes are prone to sudden, catastrophic release by flow over, under or through the glacier dam. Discharge from an outburst flood increases rapidly to a peak, and then ceases abruptly when the lake is drained. It is not uncommon for the peak discharge during a glacier outburst flood to exceed by an order of magnitude a flood due to snowmelt or rainfall in the same watershed. The floods are commonly cyclical, and may occur annually or at intervals of several years (Ryder, 1998). They are most common in summer, but may occur at any time of year. Many factors influence the outbursts, including climatic factors, glacial advance or retreat, the character of the ice, water temperature, water pressure, and the rate of filling of the lake.

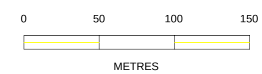
Glacier dams are common in the St. Elias Mountains of Yukon, and in other parts of the world. There are probably more than 200 basins in the Kaskawulsh-Slims, Donjek and Generc-White River drainage systems that are or have been ice-dammed (Collins & Clarke, 1977, Clarke, 1982). A well-studied recent example is from "Hazard Lake", a lake that formed after the 1965-66 surge of the Steele Glacier. The lake was filled by 1967, and was observed to drain in 1975, 1977 and annually thereafter (Clarke, 1982). The lake has a maximum volume of 19,620,000 cubic metres. The lake drains through a 13 kilometre long tunnel at the base of the glacier ice. A roughly tubular tunnel in the ice was observed at both the lake drain and discharge ends of the tunnel. The peak discharge from the lake was

VERTICAL LOGITUDINAL SECTION



PLAN VIEW SHOWING OPEN PIT





ADIT ICE PLUG PREVENTION - MERG 009

UNITED KENO HILL MINES LIMITED
ONEK MINE

William D. Mann, Geological Consultant

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calculated at 640 cubic metres per second.

A larger Yukon example occurred around 1850, when the Lowell glacier surged to block the Alsek River, forming "Lake Alsek". The lake impounded by the glacier extended beyond the present location of Haines Junction, a total distance of more than 60 kilometres. The volume of Lake Alsek is estimated to have been 4,700,000,000 cubic metres (Clague & Evans, 1994). This event ended with a catastrophic outburst that devastated the Alsek valley below the glacier (Clague, 1987), with an estimated peak discharge of 30,000 cubic metres per second.

Glacier outburst floods begin imperceptibly, but discharge increases exponentially with time until the water supply is exhausted. The accelerating flow rate suggests a progressive development of tunnels within or beneath the ice (Mathews & Clague, 1993). The release of thermal and gravitational potential energy from relatively warm water results in tunnel enlargement. Some outburst floods may occur by floating of the ice dam due to hydrostatic pressure. Another possible outburst mechanism is slow, plastic deformation of ice at depth due to water pressure. This process may be speeded up by water entering pre-existing cracks in the ice. The mass of ice in a glacier may lead to the resealing of drainage tunnels by plastic deformation due to gravity.

Adit ice plugs differ from glacier dams in that the ice is contained within a rock tunnel, and the mass of ice is much smaller. Glaciers are commonly several kilometres across, while a "long" adit ice plug may be tens or hundred of metres long. The water cannot flow over, or lift the ice plug that completely fills the tunnel, so it must move through the ice. Adit ice plugs are not subject to the movement experienced by glaciers; therefore, tunnels formed in the ice will not be resealed by ice movement or gravity squeezing the ice. Head pressure in Yukon mines subject to adit ice plug dams is generally about 100 metres maximum; pressure in glacier dams may be much higher, therefore the plastic deformation model is less likely for adit ice plugs. Enlargement of drainage tunnels by thermal energy released by water is therefore the only similar mechanism for outburst flow from long adit ice plugs.

5.0 ICE PLUG PREVENTION

Prevention of adit ice plug formation and subsequent damming of mine water can be accomplished by a variety of methods. The method employed will vary depending on such circumstances as whether the mine is active, suspended or permanently abandoned, the magnitude of the problem, the consequences of adit ice plug outbursts, and whether funds are available. Adit ice plugs are not allowed to become a significant problem at active mines. Installation of a concrete plug is an expensive and permanent solution to the problem that is often not appropriate. It may be possible to design systems to *a*) prevent buildup of ice plugs and/or *b*) prevent buildup of significant water pressure behind an ice plug using inexpensive, passive technology. At new mines engineers should consider the potential for adit ice plug damming, and possibly modify mine design to minimize the risk.

5.1 ACTIVE MINES

Ice buildup is prevented at operating mines through the use of a combination of methods. Portals are commonly covered by insulated snow sheds, which retain heat and reduce circulation of cold air. Mine air and water may be heated to minimize freezing. Wastewater is channeled into narrow ditches or culverts to facilitate drainage, and heat tracing may be used to prevent freezing. Ice accumulations may be removed mechanically, or by steaming if necessary.

5.2 CONCRETE PLUGS

In some cases permanent sealing of adits by installing cemented rockfill plugs is the best solution to adit ice plug damming. This is appropriate when the mine has been completely depleted of ore, or if there is a significant acid rock drainage problem, or if the mine presents a significant public hazard. This solution can be expensive because the structure must be adequate to withstand the head pressure that will build up behind the plug. A hydraulic plug is directly analogous to a high dam. It requires careful engineering and construction (Access Mining Consultants, 1996a). In rare cases, concrete adit plugs have failed.

A concrete plug is reversible. A mine closed with a concrete plug can be re-entered by first drilling holes through the plug to drain the water behind it, and then mining through the plug with conventional drilling and blasting.

5.3 TEMPORARY SOLUTIONS

It is common in Yukon and other jurisdictions for mines and underground exploration projects to be inactive for years at a time. The general practice for temporary abandonment in cases where ice plugs are expected has been to seal all mine openings with doors or bulkheads to reduce air flow. This practice appears to have been somewhat successful in preventing ice plugs, notably at the No Cash mine since the early 1970's. However, it is common for people to enter inactive mines and leave the doors open. It is therefore important for the mining company to inspect these adits regularly to ensure that mine openings are sealed during the winter, and that the mine drainage is not blocked. It is important to note that tightly sealing the mine openings may lead to poorer underground air quality.

The mine drainage should be channeled into a narrow, deep ditch or culvert near the portal to reduce the water surface area and minimize freezing. Steel culverts or pipes are commonly used to drain adits, but this may tend to accelerate freezing, especially if the culvert is oversized and cold air flows through the pipe.

In mines with multiple openings, it is recommended that the upper openings be sealed as tightly as possible, while ensuring that the lower portal is open enough to allow free drainage of mine water even if the primary drain becomes blocked. Tight sealing of the drainage adit appears to have facilitated the formation of thin ice plugs at Mt. Skukum and Skukum Creek.

5.4 IDEAS FOR INEXPENSIVE LONG TERM SOLUTIONS

The ideal solution would prevent ice plug buildup, or would allow the drainage of water if an ice plug does form, and would reduce flow rate if an ice dam bursts. This solution would be inexpensive, and would prevent access by the public while allowing company personnel to enter. Unfortunately, such a solution does not yet exist.

It is generally agreed that all upper mine openings should be sealed as tightly as possible to reduce air circulation. This may involve construction of doors or bulkheads, or backfilling with waste rock. In some cases sealing of the mine openings alone may be adequate to prevent ice plug damming.

One possibility for blocking access to the mine while allowing water flow is to tightly wedge used tires from large heavy equipment into the adit (McIntyre, personal communication). Another is to construct a grate of closely spaced timbers or steel rails with gaps too narrow for people to enter that is bolted onto the rock walls (Phillips, personal communication). These methods prevent access and allow drainage, and would probably reduce the flow rate from an outburst flood. However, this may not sufficiently block air circulation to prevent ice plug formation. Construction of an airtight door far enough into the mine to be beyond the limit of permafrost might be an effective solution to this problem (Pearson, personal communication).

The use of insulated water lines for adit drainage is worth investigation (Turner, personal communication). It is thought that the latent heat available from water may be adequate to maintain flow in a well-insulated pipe. This type of pipe is commonly used at operating Yukon mines for surface transport of water or tailings, and may be available for secondhand purchase. The discharge end of the pipe should have sufficient gradient to ensure flow away from the pipe. Insulated pipe of this type often has heat tracing built into it, so that if it became frozen into an ice plug the heat trace could be connected to a generator to thaw the pipe and prevent water pressure buildup.

A small dam (1 metre high) inside a drainage adit (beyond permafrost), connected to an insulated pipe might drain all of the water from the mine without significant ice build-up (Pearson, personal communication). The discharge end of the pipe should have significant gradient to promote continued flow, and perhaps be located in a ditch to trap snow, providing insulation.

Reducing air circulation is a challenge at the Mt. Skukum gold mine because the adit is connected to an open stope that extends to surface, called a "glory hole" type of open pit. Filling of the glory hole would be an expensive solution. It might be possible to strategically place rock fill to block the adit – stope connection. This would slow air circulation to reduce ice plug formation while allowing percolation of water. It would also likely slow the flow of water from the glory hole during an outburst.

5.5 DESIGN OF NEW MINES

Recognition of the potential for adit ice plug formation at a new mine site may influence the design of an underground mine. Free drainage is an asset at a mine in production, as it reduces pumping costs, however it promotes ice plug formation in an abandoned mine. Constructing the lowest adit as a decline will result in flooding of the mine upon abandonment, preventing adit ice plug damming. Further benefits of a flooded mine include the reduced potential for acid rock drainage, and the blocking of access. Most new mines are trackless and have more steeply sloping adits, which appear to be less susceptible to ice plug formation. Another potentially beneficial design modification is to choose a portal site that maximizes exposure to solar heat, or that avoids permafrost.

6.0 SUMMARY AND CONCLUSIONS

It is common for Yukon adits to glaciate to the point where a plug forms and impounds water. If a large volume of water is impounded, the eventual outburst can have significant consequences for public safety, the environment and property damage. The Onek and No Cash mines have washed out the Silver Trail Highway with ice dam floods. The Tom mine released a substantial volume of contaminated water when it suffered an outburst. The 1991 Mt. Skukum Gold Mine ice plug failure released a torrent that could have jeopardized people if any had been present. Other Yukon ice plugs have had less significant physical effects to date. The environmental impacts of adit ice plug floods are unclear, due to a lack of water quality data from the flood events.

Ice plugs form in adits with a gentle inclination from the portal, where water flows from the mine in winter. Free air circulation from other mine openings through the portal promotes ice plug formation. Adits at higher elevations on north-facing slopes are prone to glaciation. Portals in permafrost or with rock temperatures near freezing are at risk. The environmental impact of an ice plug outburst is proportional to the volume of water impounded, the level of contamination of the water, and the character of the aquatic environment downstream. The risk to public safety and property from an outburst is related to mine volume, head pressure, rate of flow from the adit, and location of the portal with respect to people, structures and roads.

Long ice plugs, up to hundreds of metres long may form when cold air circulates freely through an adit. This type of ice plug fails in a gradual manner, with water flow steadily increasing as the drainage tube through the ice widens. Short ice plugs, about ten metres long occur at portals where there is little circulation of air. A short ice plug can fail rapidly, and the resulting outburst can be catastrophic.

Ice plugs can be permanently prevented by construction of a concrete plug, however this solution is expensive and inhibits future mine exploration. Formation of ice plugs can be prevented in some cases by sealing the upper mine openings to prevent air circulation. Water draining from the adit should be focused into a deep, narrow ditch or culvert to minimize surface area exposed to cold air. Portal doors at draining adits should not be tightly sealed, to allow for continued drainage if the main drain freezes. The use of an insulated drainage pipe may allow water flow to continue through the winter, as it would retain more latent heat of water than would an uninsulated pipe. New mines can be designed to minimize the risk of adit ice plug formation.

6.1 RECOMMENDATIONS FOR FURTHER STUDY

Further study of adit ice plugs is recommended, as the risks associated with the problem are significant and there is little hard data available. The assumptions and analysis presented in this report should be tested in the field. The Keno Hill area is suggested as a study area because there are many accessible adits located in a small area, with a variety of ice plug situations available for study. There is also strong local knowledge of mine history that could provide further insights. It may be possible to obtain further data on local adit ice plugs from the mine records kept in United Keno Hill Mines data vaults at Elsa, or from the Keno City Mining Museum.

A field test of the use of insulated pipe to maintain mine drainage through an ice plug would be worthwhile. This type of pipe could provide long term prevention of major outbursts at a modest cost. The Keno 700 or Onek 400 portals are recommended for this test.

The chemical and environmental impacts of adit ice plug floods is poorly understood, and is worthy of future research. It is difficult or impossible to sample the water impounded by an ice plug prior to a flood, and the floods are short-lived events. Mines in the Keno Hill area tend to have seasonally variable water quality, therefore the water quality of floods is likely to be variable.

7.0 ACKNOWLEDGEMENTS

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APPENDIX - YUKON ADIT ICE PLUG CASE HISTORIES

Adit Ice Plugs: Case Histories

EXAMPLES OF ADITS WITH MAJOR ICE PLUG DAMMING:

MINE: **Mt. Skukum Gold Mine 1635 Adit**
YUKON MINFILE No.: 105D 158
LOCATION AND ACCESS: The mine is located at the headwaters of Butte Creek, on the north side of Mt. Skukum, above the Wheaton River valley. Access is by road from the Annie Lake road, however bridges along the road have recently been washed out.
MINE HISTORY AND DESCRIPTION: Mining began at the 1635 portal in 1984, and continued through 1988. The Main Cirque orebody was mined from the 1635 level through to surface, with a "glory hole" remaining open. 201,000 tonnes of ore were mined from this deposit, therefore the mine volume at and above 1635m is approximately 85,000 cubic metres. The surface elevation of the glory hole is approximately 1725m, indicating 90m of head pressure when the mine is full of water. More than 1000m of horizontal development was mined on the 1635 level, and these workings are connected by raises to the Lake Zone development at 1750m elevation. The 1635 portal faces north, and discharges water at 4 to 23 L/s. The mine was permanently closed in 1990, and the snow shed and portal facilities removed. At closure the portal was covered by a small shed, and sealed by a timber barrier with a steel door.
ICE PLUG DATA: The portal was noted to be plugged with ice by September 6, 1990. By September 10, 1991, the open pit was noted to be full of water, with the portal sealed by ice. At this time the portal ice plug was estimated to be about 1.5m thick (and holding 85,000 cubic metres of water!). On October 31, 1991 the ice plug failed in a catastrophic manner. The timber and steel barrier and shed at the portal were washed away, and waste rock estimated to total several thousand tonnes was washed away from the portal area. The torrent from the mine carried a 16 foot long 12" by 12" beam for a kilometre down Butte Creek. The surge was sufficient to lift the ice off the Wheaton River for a stretch of several kilometres below its confluence with Butte Creek, and the river carried a heavy sediment load from the outburst. Inspection of the portal indicated that no significant amount of ice remained in the adit.
Intermittent inspection of the portal and open pit in subsequent years indicates that the portal has been ice plug dammed and released in a cyclical manner at least 3 or 4 times.
One report suggests that the adit ice plug is shot from the portal a couple of hundred metres across the valley, and that water scours the valley wall opposite (Sherstone, 2000).
In July 1997 the portal was full of ice, but a smooth tube about 1 metre in diameter was cut through the center of the ice plug, extending up from the rails. This tube apparently had drained the mine, and water was flowing at a normal rate, and the glory hole was empty. The ice plug tube could be seen to extend

into the adit at least 10 metres. There have been no reports of catastrophic outbursts subsequent to 1991, despite the filling and draining of the open pit. The mining exploration camp at the Mt. Skukum mill site was occupied during the spring and summer of 1997, and a torrent similar to the 1991 event would have been noticed.

INTERPRETATION: The timber and steel barrier which sealed the portal upon abandonment may have blocked air circulation, and promoted the formation of a "short" ice plug, which failed catastrophically. The sudden release of a significant volume of water at high head pressure produced a torrent. The short ice plug interpretation is supported by the 1.5 metre thickness estimate from September 1991, and the report that no ice remained after the outburst.

In subsequent years there has been open circulation of air, so a thicker ice plug may form, perhaps along much of the length of the mine from the portal to the pit (about 800m). When this plug fails, a tube is cut through the ice plug which gradually widens as the water is released. The tube has a maximum diameter of about 1 metre, which restricts the flow rate (relative to the full diameter of the adit). The outburst is therefore more of a gradual flood, and not a catastrophic torrent. The portal was observed to be plugged with ice on October 4, 1999. The report of an ice plug being shot across the valley is considered to be unlikely, however water moving under high pressure through a narrow drainage tube may be projected for a great distance.

DATA SOURCES: Personal observation by the author, 1997. B. McAlpine. A. Doherty. Love, D. A., 1997. MSGM, 1990. DIAND, Water Resources Files – Memos, Reports, Photos and Correspondence. MDA Consulting Ltd., 2000. Sherstone, D. quoted in Tobin, C., 2000. Polyck, 1991.

MINE: **Onek 400 Adit**

YUKON MINFILE No.: 105M 001

LOCATION AND ACCESS: The adit is located at the northeast end of Keno City. Several residents live within about 100m of the portal.

MINE HISTORY AND DESCRIPTION: The 400 level adit was developed in 1950–52, and connected with two shafts and sublevels that had been mined in the early 1920's. A long, straight tracked drive intersects the ore zone, and several raises and stopes are developed above the level. Open pit mining in 1987-88 removed the crown pillar and filled in the shafts. The open pit funnels water into the underground workings. The mine volume below the pit to the 400 level is estimated to be about 16,000 cubic metres, with 100m maximum head pressure. The portal is at a relatively low elevation (1065m), and faces west, catching a lot of sunshine. Flow from the adit is low, averaging about 0.3 L/s, but is commonly high in dissolved metals.

ICE PLUG DATA: The portal and shafts were not sealed upon abandonment in the 1950's, so air circulation was possible. Ice plug outbursts are reported from the 1962 and 1967, however no data is available for these events. Heat traced pipe was apparently used subsequent to these outbursts to prevent ice plug damming. Open pit mining in the late 1980's sealed the shafts and reduced air circulation. The portal was blocked by wooden doors. It was thought that blocking air circulation would prevent an ice plug problem. At some point the heat tracing was no longer used to drain the mine, and in January, 1996 an ice plug formed.

In early spring 1996 the mining company test drilled the ice plug with a jackleg and extension steel to determine ice thickness and possibly drain the adit; the steel became stuck in the ice at about 36 metres (Dunn, personal communication). In August, 1996 a backhoe removed the first 20 metres of the adit, which was totally plugged with ice. This part of the adit was mostly in overburden, not bedrock. In April of 1997 substantial flow of meltwater was observed flowing into the Onek open pit. On May 9-10, 1997 an outburst flood occurred when the ice plug failed. The flood was first noticed at about 11 pm, in full flow, and was finished by about 2.30 am. After the outburst the adit was observed to still be substantially plugged with ice, with a drainage tube about 0.5 metres diameter through the ice. The tube in the ice extended at least 5 metres into the adit.

The Silver Trail Highway was partially washed out by the flood, and the water flowed into Christal Creek downstream from the highway. The bridge across Christal Creek on the Wind River Trail was not washed out by this event. Residents living near the portal and downstream were very concerned, although no major property damage was reported. Assuming a water volume of 16,000 cubic metres and a flood lasting 4 hours, the average flow would be about 1 cubic metre per second during the outburst. Water samples were collected from Christal Creek, downstream from the portal during the flood by company personnel. The results are not available, but are reported to have been within Water Licence discharge guidelines (Dunn, personal communication).

A heat traced pipe was installed in the adit after the outburst, and the portal was sealed with an insulated wooden barrier. The heat trace burned out in January, 2000, and ice began to form; the situation is being monitored by company and government employees.

<u>INTERPRETATION:</u> The ice plugs that formed in the 1960's were likely of the Long type, as there was air circulation through the adit at that time.

Air circulation was limited at this portal in 1996, however an ice plug about 40 metres long formed. The first 20 metres of the plug were removed by backhoe; melting (from both ends?) of the remaining 20 metres reduced the plug to about 10 metres by May, 1997, therefore this plug may be considered to be of the Short type. Despite the relatively short length, the mine drained through a narrow tube in the ice, and the ice plug was not washed out of the adit.

<u>DATA SOURCES:</u> Personal observation by the author, 1999. Access Mining Consultants Ltd., 1996b. V. Enns. B. Dunn. M. Phillips. Sveinson, 1997. Sherstone, 2000.

MINE: **No Cash 500 Adit**
YUKON MINFILE No.: 105M 001
LOCATION AND ACCESS: The mine is part of the Keno Hill camp, and is located on the north slope of Galena Hill. It is about 2km east of the village of Elsa, and is accessed by road from the Silver Trail Highway.
MINE HISTORY AND DESCRIPTION: The upper levels of the mine were developed starting in 1928. The 500 level (500 feet below the top of the mine) was developed in 1948, with production continuing until 1988. The mine has two adits, a shaft, and 4 raises to surface. Over 130,000 tonnes of ore were produced from this mine. The 500 adit was driven for 1115m in a straight line drive at a slight inclination, and is connected to upper levels of the mine by raises. The 500 level was an important production level for ore stoped above the 300 level, however there has been little stoping at the 500 level. If water filled the workings from the 500 to 100 levels, it would total about 30,000 cubic metres, with 120 metres of head pressure. Water flow from the adit averages about 4 L/s, and is directed from a ditch beside the tracks into a culvert which flows under the waste dump. The portal faces northwest, and is covered by an insulated shed. The north slope of Galena Hill is underlain by permafrost.
ICE PLUG DATA: Adit ice plugs are reported to have blown out twice in the period 1969 – 1971 (Hohener). These events washed out the Silver Trail Highway, about 500m downhill from the adit. Flow from the adit began gradually, and increased steadily. The flow lasted about 4 hours. At the time of the event the mine was not active, and the portals and raises were not blocked off. Since that time the portals and raises have been covered to reduce air flow. In September 1999, there was about one metre of ice at the portal, extending about 15 metres into the adit. Water was flowing freely in the ditch and under the ice.
INTERPRETATION: Circulation of cold air led to the formation of an ice plug near the 500 portal, and the impounding of water. Sudden release of the water washed out the highway. If the 500 level was filled with water, it would contain about 6,000 cubic metres. Additional volume is present if raises and shafts are filled, adding substantial head pressure.
Subsequent sealing of the portal and raises cut air circulation sufficiently to prevent or reduce ice plug formation. The presence of significant amounts of ice in September suggests potential for future ice plug damming.
DATA SOURCES: United Keno Hill Mines – Supplementary Water License Information QZ96-001. Correspondence between UKHM and regulators and interveners in the environmental review process, 1996 and 1997. B. Dunn. H. Hohener.

MINE: **Tom Adit**
YUKON MINFILE No.: 105O 001
LOCATION AND ACCESS: The mine is located near Macmillan Pass. Access is by road about 3km southeast from the North Canol Highway.

MINE HISTORY AND DESCRIPTION: An exploration adit measuring 2.4m x 2.4m, and totaling 1809m was driven on the 1440m level in 1970-71. In 1980-82 120m of drifting near the portal, and a 923m decline were excavated. The portal has two entrances, one of which was used for mine air heating and other services. There is no ventilation raise. Most of the mine was quite dry, but major inflows of water are reported from certain conglomerate beds. Water flow from the portal varies from 9 to 17 L/s. The portal faces west, and is within a deep north-facing valley underlain by permafrost.

From 1982 to 1994 the portals were blocked with loosely fitting wooden doors which allowed water to drain easily. In 1994 the portals were filled by pushing waste rock into both portals with a bulldozer. Two or three six-inch pipes were installed in one portal to allow drainage of the mine.

Water flowing from the mine is contaminated due to Acid Mine Drainage, therefore a sudden release of this water is of environmental concern in addition to safety concerns.

ICE PLUG DATA: Sometime between 1994 and 1998 the waste rock blocking one branch of the portal was washed out, apparently by a large volume of water.

INTERPRETATION: The pipes draining the mine froze, and an ice plug formed at the portal, impounding water. Eventually thawing and/ or head pressure led to a sudden release of the water. This flow was powerful enough to remove approximately 50 tonnes of waste rock.

Note: The owner of this site, Hudson Bay Mining and Smelting (HBMS) is considering installation of a concrete plug to permanently seal the adit.

DATA SOURCES: W. Fraser. McKay, K.R., & Bidwell, G.E., 1986. Soroka, I.K., & Jack, M.E., 1983. Burns, B. & de Graf, N., 1999.

MINE: **Keno 700 Adit**

YUKON MINFILE No.: 105M 001

LOCATION AND ACCESS: The Keno 700 adit is the main production portal for the Keno No. 9 vein system, and numerous other veins which extend from the peak of Keno Hill to the south. Access is by haul road from Keno City.

MINE HISTORY AND DESCRIPTION: An extensive network of tracked adits, shafts, raises and stopes is developed on a system of veins. Mining began in 1919 at the top of the hill, and veins were followed downwards until 1982. The 700 level was developed from 1958 onward. The mine was entirely within permafrost from surface to the 400 level. More than 257,000 tonnes of ore were mined. Mine volume at the 700 level is about 12,000 cubic metres, with substantial additional potential volume and head present in stopes above the level. The portal is covered by an insulated shed with doors, and water flow averaging about 3 L/s is directed through a culvert. High water flow has undermined some of the fill beneath the portal shed and tracks. A significant portion (about 10%) of the 25,000 tonne waste rock dump has been washed downhill by water from the portal. The portal is at 1550m elevation, and faces southeast.

ICE PLUG DATA: Ice chokes the portal in winter, and water flow is sometimes completely blocked. Water has washed away fill from the portal, but has not had enough force to destroy the portal doors. The rock is not permafrost at the 700 portal.
INTERPRETATION: Very high water flows are present when the ice plug deteriorates, however some or all of the fill washout may be due to glaciation of the drainage culvert. Air circulation is greatly reduced by doors on the adits and raises, but may still be significant due to the large number of mine openings. The presence of intense permafrost higher in the mine suggests that the rock must be close to freezing at the 700 portal. Air circulation leads to the formation of a thick ice plug. Gradual deterioration of a thick plug reduces the risk of a catastrophic release of water.
DATA SOURCES: Personal observation by the author, 1999. Access Mining Consultants Ltd., 1996b. H. Hohener.

EXAMPLES OF ADITS WITH MINOR ICE PLUG DAMMING:

MINE: **Skukum Creek 1300 Adit**
YUKON MINFILE No.: 105D 022
LOCATION AND ACCESS: Located on Skukum Creek, a tributary of Berney Creek, in the Wheaton River area. Access by road from the Mt. Skukum Gold Mine road.
MINE HISTORY AND DESCRIPTION: Underground exploration and development was conducted from 1985 - 89, and 1996-97. The main adit was driven by rubber-tired equipment at a slight inclination at 1300m elevation, and a second adit at 1350m. Access drifts are driven parallel to ore drifts, and connected by crosscuts. Raises were driven to connect the levels, and a ventilation raise was driven to surface. An internal ramp descends from the 1300 level to about 1210m elevation. Most of the mine is dry, but water is produced at the far end of the 1300 level, and a major inflow occurs from a fault zone at the bottom of the ramp at about 1210m elevation. The ramp floods about half way to the 1300 level, but is self-draining. The 1300 level drains from the main adit at about 1 to 5 L/sec. The portal area is about 4m wide and 3m high. The volume of mine workings above the 1300m level and below the 1350 level is about 7,000 cubic metres. The vent raise and 1350 portal are blocked to prevent access, but not fully sealed to prevent air circulation. The portal faces northeast.
ICE PLUG DATA: Ice forms from the portal all the way along the main drift to the ventilation raise, a distance of about 210m. In 1996 the ice was about 2m thick at the portal, and tapered to about 1m thick near the vent raise. The ice terminated abruptly about 10m past the vent raise, and about 1m of water was impounded behind the ice. Some water spilled down the vent raise to the lower levels, and also ran down the ramp. In 1997 a similar amount of ice had formed during one winter. The ice forms in thin layers like a road glacier. Installation of

a tightly sealed and insulated bulkhead at the lower adit in 1997 led to formation of a thicker ice plug by 1998 that may have completely sealed the lower adit.
INTERPRETATION: Free air circulation from the vent raise to the portal during the winter months causes the formation of a very long ice sheet. The wide portal may be more difficult to plug than a narrow portal. The free-draining internal ramp prevents damming of large amounts of water behind ice at the portal, minimizing the hazard presented by this mine. Sealing of the vent raise and upper portal, and allowing the lower portal to drain freely may be more effective at preventing ice plug formation than sealing the lower portal.
DATA SOURCES: Personal observation by the author, 1996-1998. Internal company reports, Omni Resources Inc.

MINE: **Peerless Adit**
YUKON MINFILE No.: 105D 009
LOCATION AND ACCESS: The mine is connected underground to the Arctic Caribou (Big Thing) mine on Montana Mountain. Access is by road due south from Carcross.
MINE HISTORY AND DESCRIPTION: A tracked drift was driven at a slight inclination, in a straight line for 700m in 1911. The adit is about 6’ wide and 7’ high. Some crosscuts follow veins on the level; additional crosscutting was done in about 1967. A raise was driven during the 1911 program from the adit to connect with the Arctic Caribou (Big Thing) mine above. The Arctic Caribou mine drains through the Peerless adit, and is reported to be partly filled with ice. The portal is located at 1545m elevation, and faces northwest. The portal was open in 1996 but had collapsed by 1999.
ICE PLUG DATA: The portal was rehabilitated in 1962, and the adit was found to be choked with ice starting 60’ inside. In 1966 the adit was mapped in detail by M.D. Kierans, P.Eng., who documented an ice plug which had drained (Tindale, 1966). Ice was mapped from 80’ to 200’, with passage through an irregular tube in the center of the ice plug. Sections showing the ice geometry were drawn. The volume of the mine workings at adit level is about 3,000 cubic metres; a much larger volume is possible if the Arctic Caribou workings are also flooded, with considerable corresponding head pressure.
A 1996 Phase II environmental assessment of the property conducted for Public Works and Government Services Canada documents a gulley and associated alluvial fan developed in mine waste rock in front of the portal, in an area where no streams are evident. The adit is reported to flow at less than 1 L/s.
The mine owner reports that there is a substantial air flow through the adit that reverses in direction from winter to summer. Ice crystals grow to partly fill the tube through the ice plug. Ice fills the Arctic Caribou to within about 30cm from the back, but air flow is never blocked. The ice plug doesn’t ever completely block air flow or dam water. The drainage channel is said to be due to spring runoff.

INTERPRETATION: The ice plug mapped by Kierans was quite long, and therefore likely formed due to cold air circulation from the Arctic Caribou, and may also reflect permafrost. The plug likely forms from the portal to 200' inside, and had melted 80' by the time the adit was mapped. It is possible that the ice plug may not completely block the flow of air and water, but it is likely that complete blockage occurs in some years. The irregular tube cut by melt water in 1966 suggests a gradual release of water, however the gulley and fan currently present suggest a rapid release. This mine appears to have formed ice plug dams periodically for many decades. In some years the water may back up into the Arctic Caribou, adding volume and head pressure.
DATA SOURCES: Tindale, J.L., 1966. L. Barrett. T. Donaldson. PWGSC, 1997a. Mann, W.D., 1998. Personal observation by the author, 1999.

EXAMPLES OF ADITS WITH POSSIBLE ICE PLUG DAMMING:

MINE: **Burnick 1200 Adit - Sa Dena Hes Mine**
YUKON MINFILE No.: 105A 013
LOCATION AND ACCESS: This mine is part of the Sa Dena Hes mine complex, and is located north of the mill at North Hill. The mine is accessed by road from the Campbell Highway, north of Watson Lake.
MINE HISTORY AND DESCRIPTION: An portal was collared at about 1300m elevation in 1991, and a decline driven parallel to the ore zone for underground drilling and access to ore. The 1200 level adit was driven in 1992 in a straight line, at a slight inclination, and connects with the decline. The portal has two entrances, one used for mine air heating. The 1200 level was constructed for use as a production portal for rubber tired trucks, and is about 4m x 4m in size. Weak permafrost is present near surface in this mine. Moderate water flow is produced from the workings, estimated at 1 – 3 L/s. Both portals are blocked by bulkheads which substantially reduce air flow. The 1200 portal faces northeast.
ICE PLUG DATA: Ice is reported to build up near the portal in winter, despite construction of bulkheads.
INTERPRETATION: The adit is at relatively low latitude and elevation, and the permafrost here is weak. The portal is large, and may not be completely blocked by an ice plug in one winter. This mine is not currently a significant hazard due to its low volume and incomplete glaciation.
When production resumes, and the ore has been mined there will be a very large volume of empty stopes present at and above the level. Prevention of an ice plug dam is therefore an essential element of a final abandonment plan for this mine.
DATA SOURCES: Personal observation by the author, 1987-1992. R. McIntyre.

MINE: **Tintina Silver Adit**
YUKON MINFILE No.: 105G 006
LOCATION AND ACCESS: This site is located at the headwaters of the Liard River. It is accessed by air to an airfield, and then by tote road to the site.
MINE HISTORY AND DESCRIPTION: A tracked exploration adit was driven for 558m in 1962. The portal is at about 1600m elevation, and faces north-northeast. It is unknown whether a vent raise is present. Adit volume is estimated to be about 2000 cubic metres.
ICE PLUG DATA: Water flow from the adit is very low, about 0.1 L/s. Ice has not been reported in the adit, but at 1600m elevation in a north-facing cirque it is very likely. A significant adit drainage channel is present, which appears to have washed out about 15m of waste dump and track.
INTERPRETATION: Substantial, rapid flow from the adit would be required to cut the drainage channel that is present. Ice plug water damming and subsequent release is a logical source for this drainage. The mine volume is low, however ice plug failure may have occurred many times since 1962.
DATA SOURCES: PWGSC, 1997e. INAC, 1999.

MINE: **Vera Adit**
YUKON MINFILE No.: 106C 083
LOCATION AND ACCESS: This mine is located on the north face of Rusty Mountain, in the Rackla River area, on map sheet 106C / 5. Access is by air from Mayo.
MINE HISTORY AND DESCRIPTION: A trackless adit was driven for 496m, with 222m of development in four crosscuts in 1981. The portal is collared at 1287m elevation, faces northwest, and has a flow of 0.25 L/s recorded in summer, 1996. The portal is open.
ICE PLUG DATA: No ice has been reported at this portal. However with water flow, high elevation and latitude, and northern exposure ice plug formation is likely. An eroded channel in mine waste rock due to water flow from the portal is reported.
INTERPRETATION: Substantial water flow from the portal is required to have cut an erosion channel in the waste rock. Ice plug damming is the most plausible explanation for the required flow level.
DATA SOURCES: PWGSC, 1997d. Sinclair, A.J., 1983. INAC, 1999.

MINE: **Ruby 400 Adit**
YUKON MINFILE No.: 105M 001
LOCATION AND ACCESS: Located on Galena Hill, above the town of Elsa. Access by Calumet Drive from Elsa.
MINE HISTORY AND DESCRIPTION: A 716m tracked adit connecting to a shaft, raise and stopes was constructed in 1978. About 36,500 tonnes of ore were produced. The shaft and raise are covered, and the portal is blocked by insulated steel doors. An insulated snow shed projects about 10m out from the

portal. The portal is located at 1260m elevation, faces northwest, and is in permafrost. Water flow from the adit averages about 1.5 L/s, and is channeled into a narrow ditch.
ICE PLUG DATA: Ice is evident in the adit year-round, and commonly blocks the portal, however water flow continues. Ice is estimated to extend about 12 metres back from the portal. When the portal doors were opened in summer, ice was found to completely fill the portal shed, but thawed back about 5 metres during the summer. There is no evidence of sudden water release.
INTERPRETATION: It is unknown why complete damming has not occurred. Low air circulation may be an important factor. This adit has potential to completely plug with ice, and dam up to 16,000 cubic metres of water with over 100m of head pressure.
DATA SOURCES: B. Dunn. Access Mining Consultants Ltd., 1996a & b. M. Phillips.

EXAMPLES OF ADITS WITHOUT ICE PLUG DAMMING:

MINE: **Sadie-Ladue 600 Adit**
YUKON MINFILE No.: 105M 001
LOCATION AND ACCESS: The mine is located at the former town of Wernecke, accessed by road from Keno City.
MINE HISTORY AND DESCRIPTION: The Sadie and Ladue mines began production from shafts in 1923. The 600 level adit was driven in 1928 as a drainage and access adit. The mine had 4 shafts, was developed on 5 levels and had numerous raises. Some stopes broke through to surface. Production totalled 221,000 tonnes. The Ladue mine was in permafrost from surface to a depth of over 260 feet, while the Sadie shaft, located about 600m away on the same vein was not in permafrost (due to high water flows?). The 600 portal faces northwest, and is at an elevation of 1150m. Water flow from the portal averages about 10 litres/second. Rehabilitation of the 600 level was undertaken in 1968-70, and there are conflicting reports as to whether ice was present at the 600 level. The shafts, raises and open stopes were filled during high-grade mining of crown pillars in the 1980's.
ICE PLUG DATA: Ice probably forms in this adit, as would be expected given the relatively high altitude and latitude, with a north-facing direction. The mine is partly developed in deep permafrost, but permafrost distribution is erratic. The waste dump in front of the portal has not been washed out by an ice dam failure, at least not in the last 30 years, and probably not in the last 69 years.
INTERPRETATION: It is not known why this adit has not been plugged by ice, as it seems to have most of the predictive factors. The apparent lack of permafrost at the portal, and the relatively high water flow rate must be important factors. Water is channeled into a culvert. The portal area may fill in with drifted snow, insulating the outflow, and blocking air circulation. Air circulation has probably been very low since the mine was sealed in the 1980's;

this may explain the current situation but doesn't account for the lack of prior ice plugs.
Formation of an ice plug may be possible here under certain conditions: a large potential volume (75,000 cubic metres) and head pressure (180m) would result if the mine filled with water. Note that the portal is now partially collapsed, which may affect ice plug damming factors.
DATA SOURCES: Access Mining Consultants Ltd., 1996a & b. PWGSC, Personal observation by the author, 1999. H. Hohener. M. Phillips. D. Tupper.

MINE: **WEBBER 4280 Adit**
YUKON MINFILE No.: 115I 065
LOCATION AND ACCESS: The mine is located on Webber Creek near Mt. Nansen, and is accessed by road from the Mt. Nansen gold mine. The mine is about 2km north of the Mt. Nansen mill.
MINE HISTORY AND DESCRIPTION: Underground exploration was conducted in two episodes in the 1960's and 1970's. A tracked adit was driven with a slight incline to allow drainage. The adit is about 6' wide by 7' high. One vent raise extends to surface. A lower adit stops short of the ore zone, and is not connected to the main Webber workings. There was no significant mine production. Total mine volume is estimated to be about 2,500 cubic metres. A loose wooden door partly blocks the portal. The portal is at 1305m elevation and faces northwest.
ICE PLUG DATA: A vertical wall of ice fills the adit to within about 30cm from the back, starting about 20m inside the portal. Ice fills the vent raise to about 2m from surface. No water flow from the adit has been observed on several visits, and there is no evidence of drainage.
INTERPRETATION: The mine area is relatively dry, and the rock is fractured and may be permeable. The location of the ice face varies with the season, and depending on whether the portal doors are left open. The ice may form a partial plug, with water dammed behind it, or the entire mine may be filled with ice. The volume of the mine is small, therefore no significant hazard is expected from plug deterioration. The mine has been stable for several decades.
DATA SOURCES: Personal observation by the author, 1995-1998. Mining company internal reports.

MINE: **Galkeno 900 Adit**
YUKON MINFILE No.: 105M 001
LOCATION AND ACCESS: This adit is located on the lower east side of Galena Hill, near Christal Lake. Access is by road from the Silver Trail Highway.
MINE HISTORY AND DESCRIPTION: The crosscut adit was driven at a slight incline about 1500m, and then drifted on the mineralized structure for 325m. Mining occurred from 1959 till the early 1960's. The adit was intended to drain the significant mining operation above, although the workings do not directly connect, and to test the mineralized structure. The adit intersected a major

aquifer structure at 1134m; flow from the adit was about 1 metre deep, and prevented reentry for about 6 months. Mining was abandoned here due to very poor ground conditions. There is no ventilation raise, so air circulation is minimal. Water flow averaged about 10 L/s until a concrete plug was installed in 1994. Flow now is about 5 L/s, and is channeled into a culvert which flows to a water treatment pond. The portal is blocked by an insulated door, faces east, and is in permafrost.
ICE PLUG DATA: Ice has been reported at the portal, but there is no record of ice plug damming.
INTERPRETATION: The high rate of water flow, high head pressure, and lack of air circulation have prevented ice plug damming.
DATA SOURCES: Access Mining Consultants Ltd., 1996a & b. Personal observation by the author, 1999. V. Enns.

MINE: **Venus 2600 Adit**
YUKON MINFILE No.: 105D 005
LOCATION AND ACCESS: The mine is located immediately adjacent to the South Klondike Highway, south of Carcross, just north of the B.C. border, beside Windy Arm of Tagish Lake.
MINE HISTORY AND DESCRIPTION: The Venus 2600 level was developed in 1969-70, 1980-81 and 1984. The mine is tracked, and has five levels and sublevels and several open raises. 58,900 tonnes of ore were produced. Another adit is present at the 2700 level, and also produces water; neither adit forms ice plugs. The adits have loose-fitting doors that do little to prevent air circulation.
ICE PLUG DATA: There is no known ice plug problem. Due to the location of the mine, immediately above the highway and near Carcross, failure of an ice plug would have been noticed.
INTERPRETATION: The adits are gently sloping and produce a moderate flow of water. There is air circulation between adits and raises. This mine is located at low latitude, low elevation, has a southeastern exposure, and is situated near a large body of water: these factors promote greater warmth than is present at most of the mines which form ice plugs. The mine is probably not in permafrost, and there is no apparent risk of ice plug damming.
DATA SOURCES: Personal observation by the author, 1997. PWGSC, 1997c.