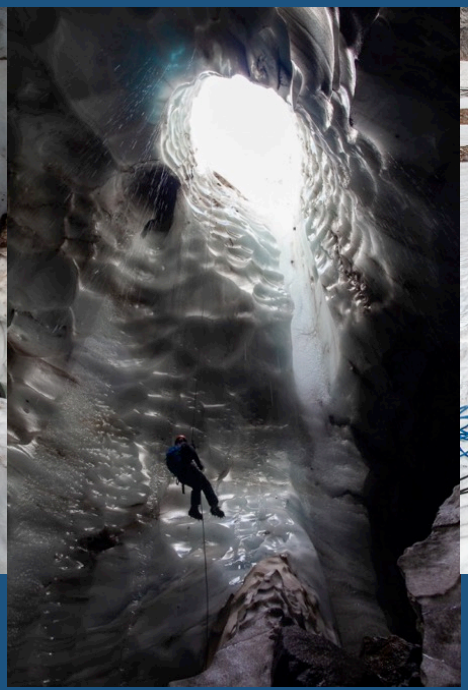
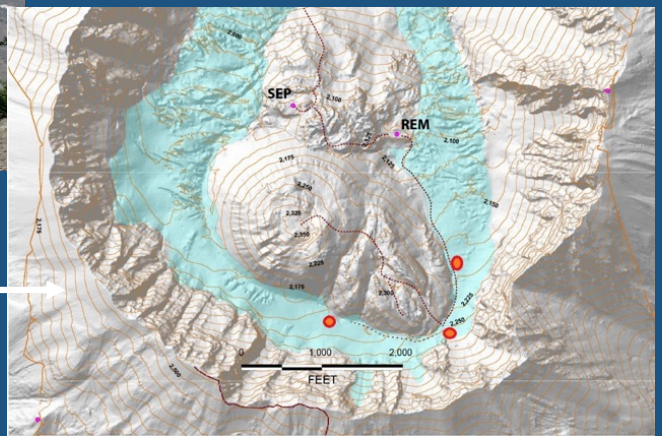
Glacier Cave Rescue Considerations & Techniques in the Cascade Range



Glacier Cave Studies on Three Pacific Northwest Volcanoes

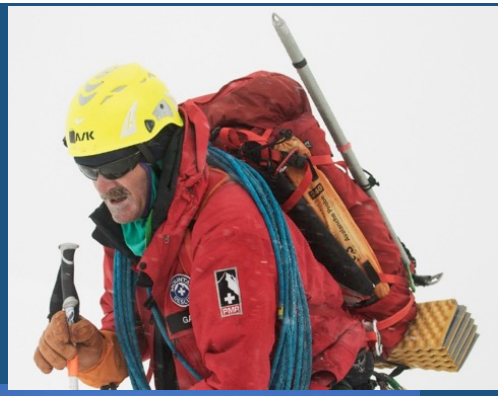
One primary objective is to establish rescue pre-plans for each system.

Mt. St. Helens



A joint NCRC and MRA project to establish rescue maps and pre-plans for each glacier cave system

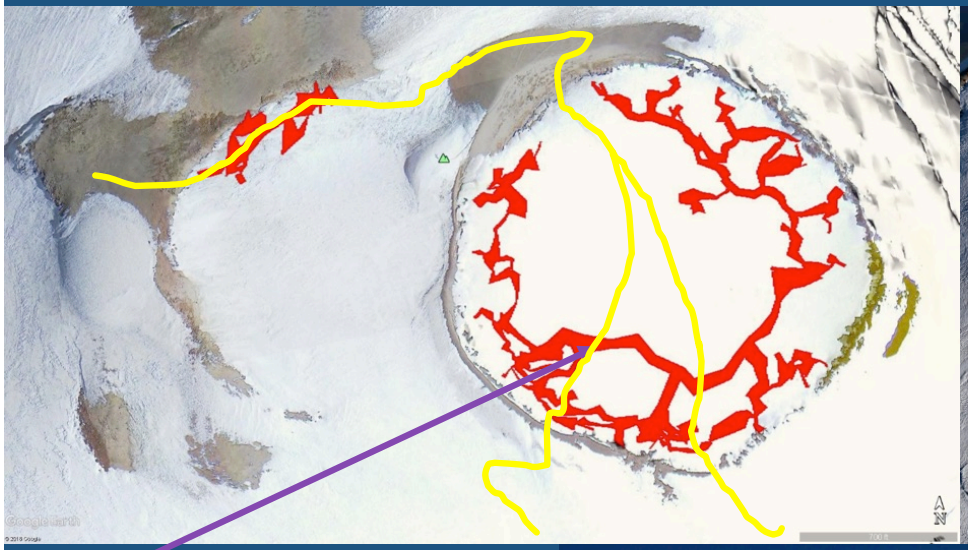
Mapping instruments funded by MRA Grant!!

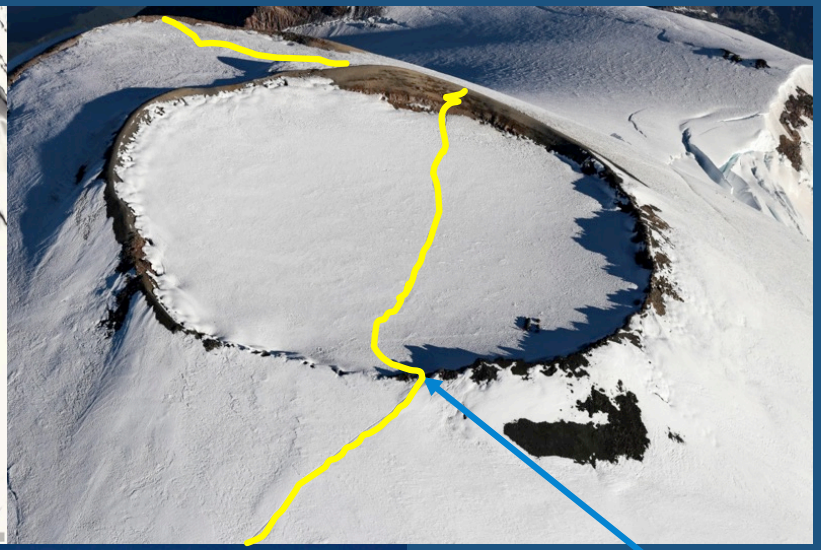


Projects made possible by volunteers from MRA teams throughout the USA & Canada

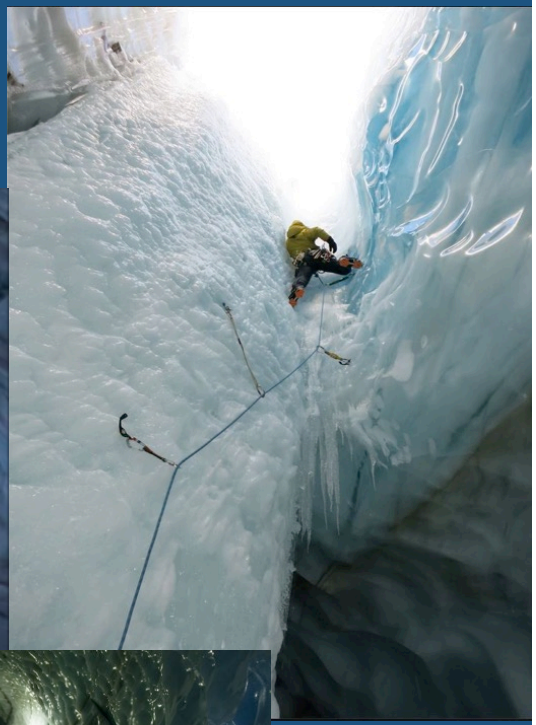
Many lessons learned throughout the project, from 2011 to 2018.

For some….glacier caves are unknown. Many climbers pass over or near them without knowing of their existence, or the dangers they pose.

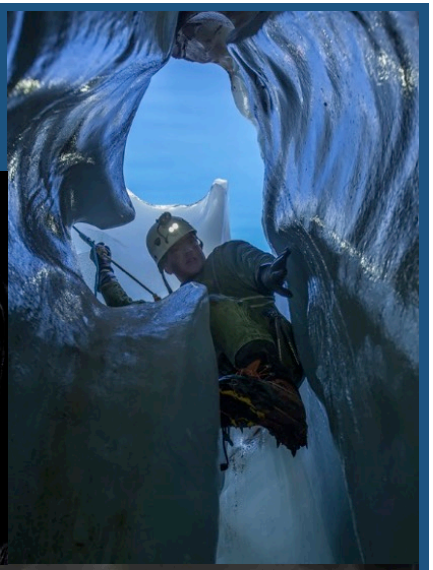


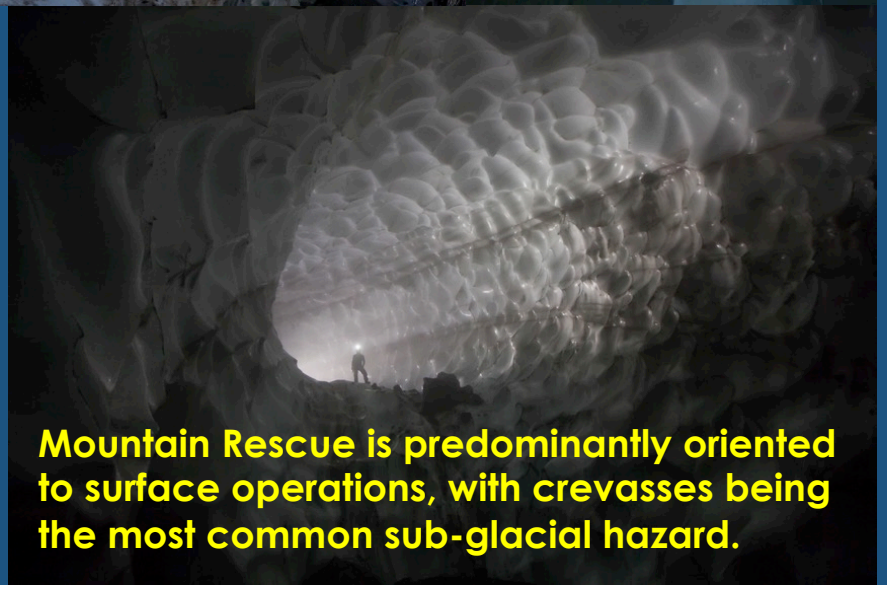


For others, the caves are destinations for winter activities.



For **Mountain rescuers**, these are alien environments with many unseen hazards, and where some adjustment to conventional mountain rescue techniques are required.





Mountain Rescue is predominantly oriented to surface operations, with crevasses being the most common sub-glacial hazard.

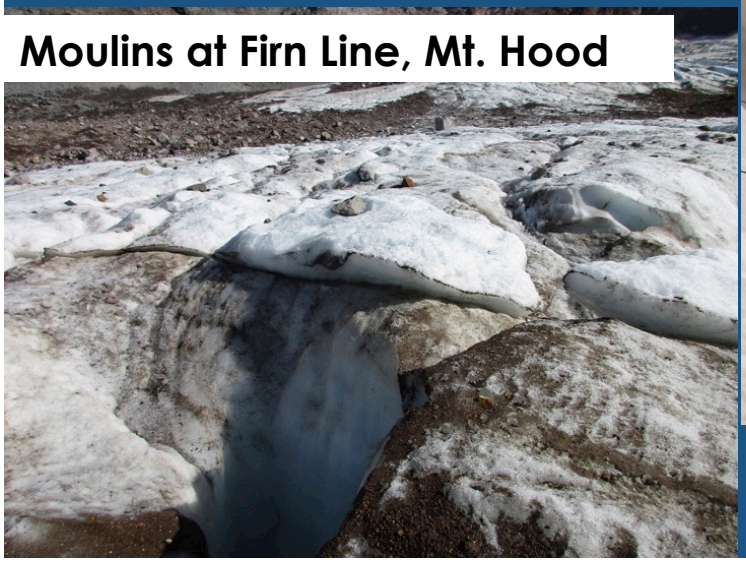
Glacier Caves are NOT Crevasses!

Crevasses are stress features.

Glacier caves are hydrological and thermodynamic features in the ice, and are very dynamic…changing rapidly.

They are part of the glacier's hydrological system / aquifer, and / or a conduit for geothermal energy to vent to the surface.

Moulins at Firn Line, Mt. Hood



Glacier Cave versus Ice Cave

Ice caves are rock caves (limestone, lava, etc.) that contain perennial ice masses.

- Made of **ROCK**
- Cave is a cold trap.
- Ice forms in the caves later.

Glacier Caves

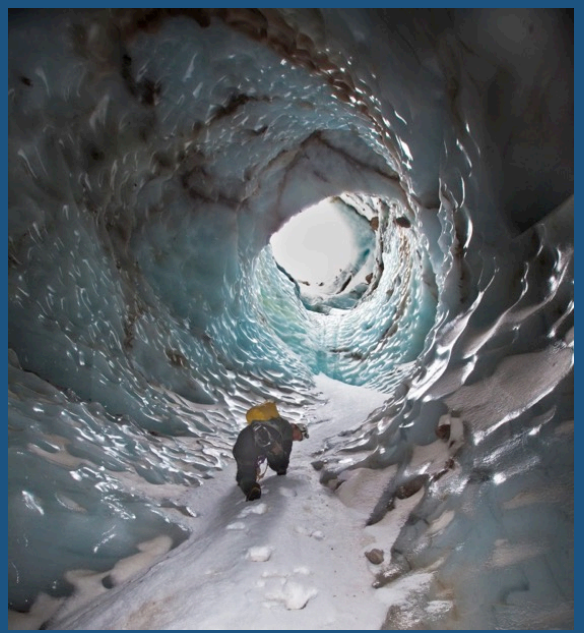
Glacier caves are formed (walled) in **glacier ICE**.

Formed initially by **WATER** (liquid or steam), then expanded by **AIR** and **PLASTIC DEFORMATION**.

Contact Caves

Endoglacier

Moulins



Firn Snow: Swiss German meaning "last years". It is ice that is in an intermediate stage between snow and glacier ice.

The glacial – firn interface

Glacier ice is hard, dense, stratified ice that lasts for many years.

Fumarole Glacier Caves

- Form in the active craters of volcanoes with ice caps.
- May be up to 200 meters deep
- Most have dangerous firn roofed entrances
- May contain lakes, gas hazards, and very steep topography, with crumbly, clay-like, hydrothermally altered rock.

The hydrothermal system

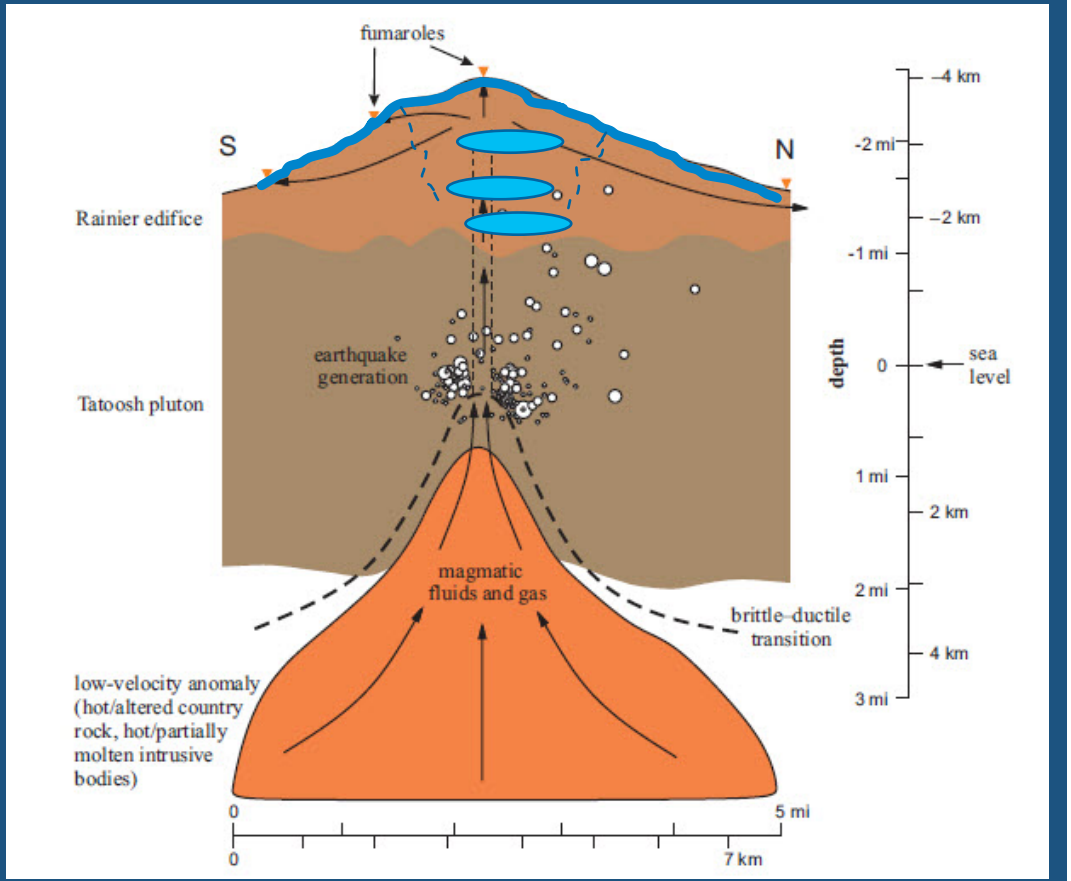
Solar and geothermal heating melts the glacier ice which sends water percolating down through the rock.

Water is heated and rises back up as steam, with acidic magmatic gases in solution.

This steam emerges at the glacier-bedrock interface as fumarole vent.

Rising steam melts ice, forming upward trending cave passages and pits.

Increased surface melting due to climate change also increases this cycle.



Climate Change, Glaciers, and Glacier Caves

- The Cascade volcanoes are highly visited, and yet little is known about the glacier cave systems on them.
- Warm glaciers are highly responsive to climate change as well as geothermal change at their base.
- Climate Change in the Pacific Northwest is rapidly effecting the glaciers. Cave systems are growing, entrances are widening, and sub-glacial flooding is more common.
- One symptom of glacial recession, or an increase in volcanic hydrothermal activity, is the formation of large glacier caves.

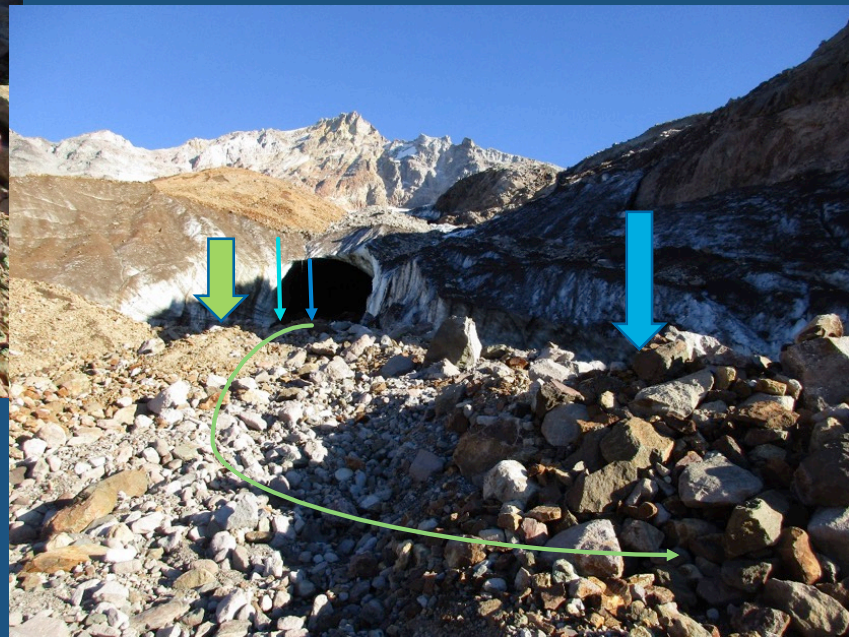
400% volume increase in 2 years

The Droolin Moulin: November 2014

The Droolin Moulin: October 2015…11 months later!!

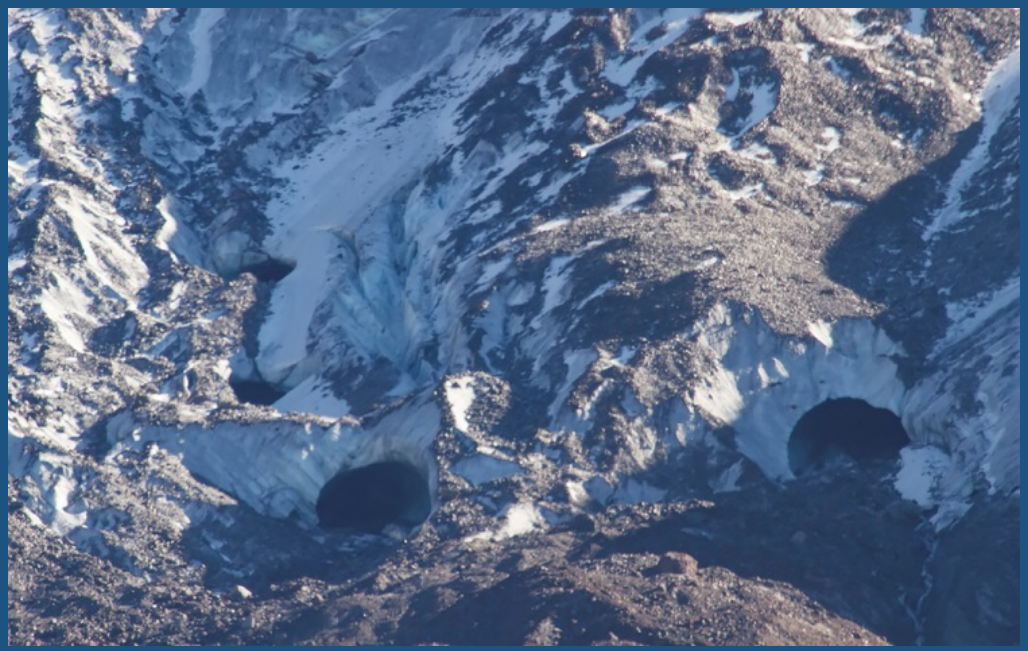
Moulin was totally sealed over with snow and relatively unchanged from December to June 2015. This expansion happened in 4 months of "breathing."

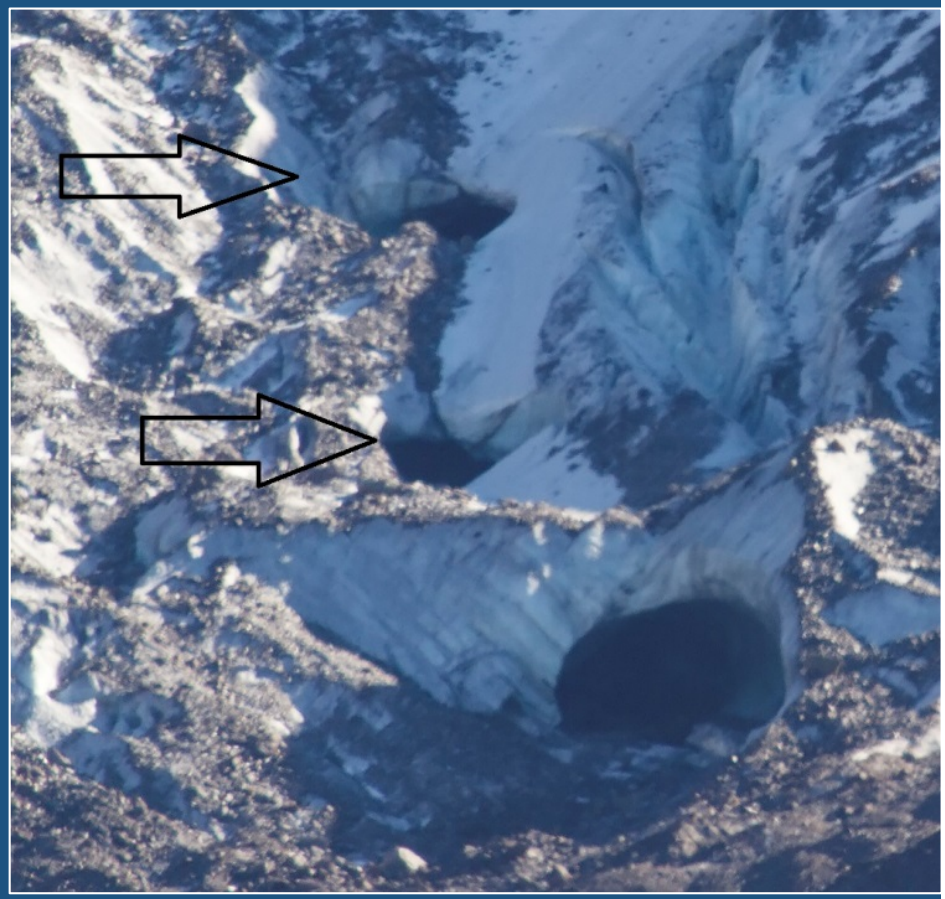
Drip line monuments show annual recession of glacier toe



Catastrophic collapse of Snow Dragon November, 2014

- Process is exponential once airflow is introduced!
- Total collapse between skylights January, 2015.
- Glacier is calving off its own toe as we watch.

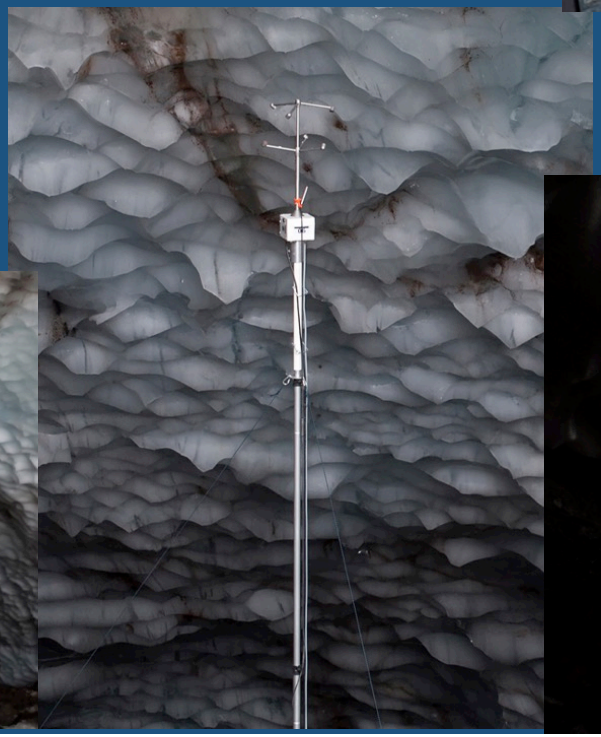


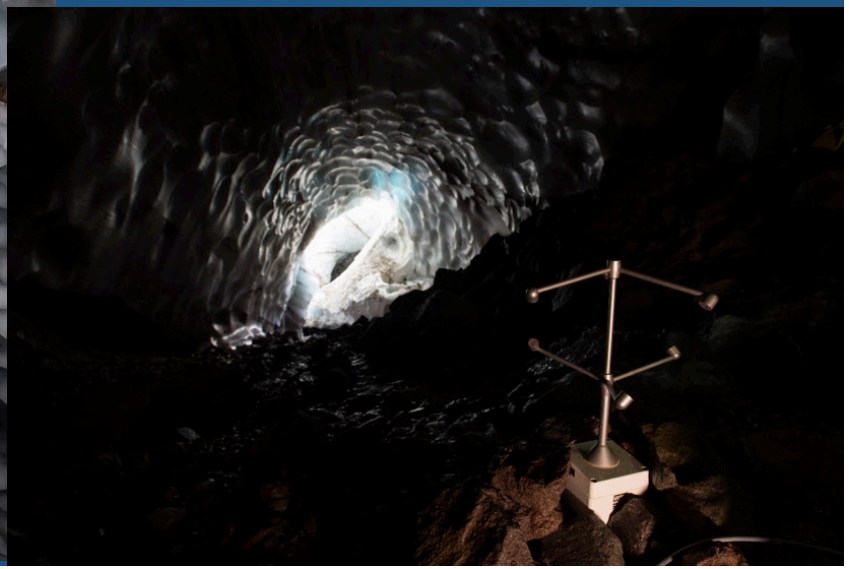


June, 2015 Expedition

- Climatology became key component of the study.
- German scientists brought anemometers to model air flow.
- Thermal imaging discovered 'hot spots.'

Dr. Andreas Pflitsch, Climatologist
Ruhr University of Germany
Conducting Ultrasonic Anemometry





Hazards and Challenges

Clip

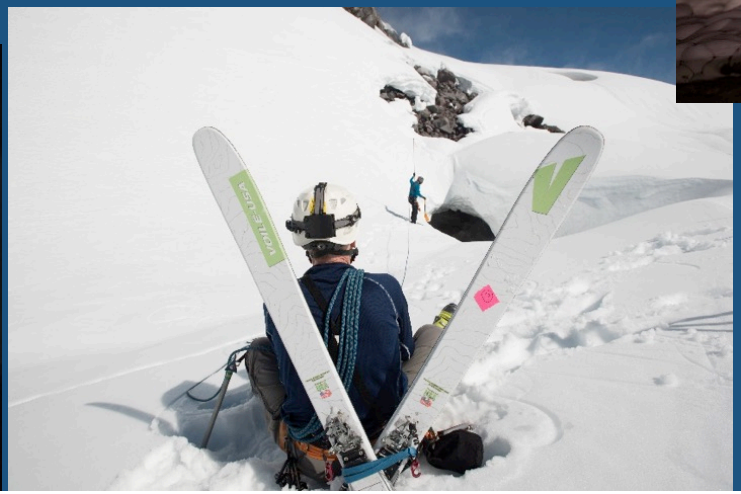
Area around cave entrances usually unstable and has a lot of rock and ice fall.

Sometimes "getting In" is the most dangerous part!

Dripline hazards include lose scree and sediment mounds, shooting gallery piles, and ice collapse.

Moulin entrances often surrounded by precarious rocks and water flows

Thinner snow bridges and cornices over huge entrances either at toe of glacier or moulins near firn line. Many roped parties unaware of them.



Rescuers must be roped and belayed, sometimes from a far distance until the structure of the entrance is visible

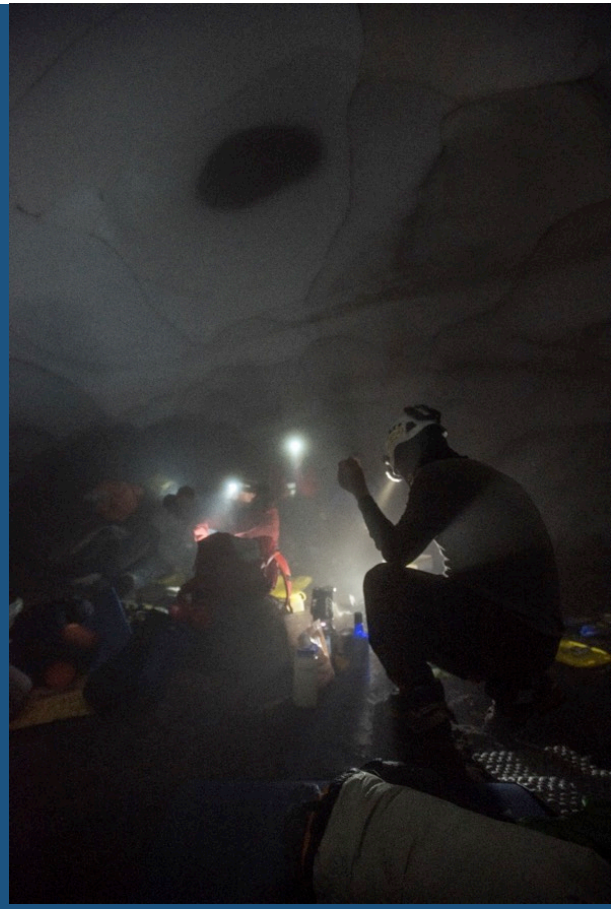
Hard to tell when you are on safe ground near an entrance.

Preferential melting and airflow create large overhangs.

Water Flow can be Deafening and make interpersonal communications difficult

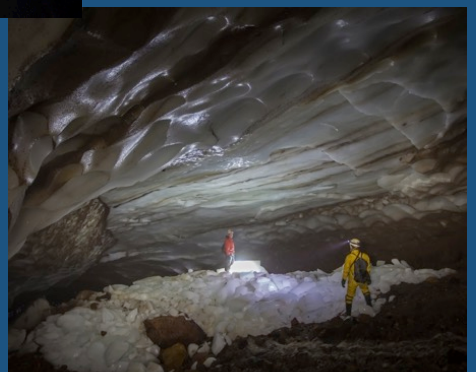
Poor Visibility

- Steam in fumarole glacier caves can reduce visibility to 1 meter!
- Warm outside air meeting cold inner air layers can create a “curtain” of fog very hard to see through, and will disrupt your head lamp light.



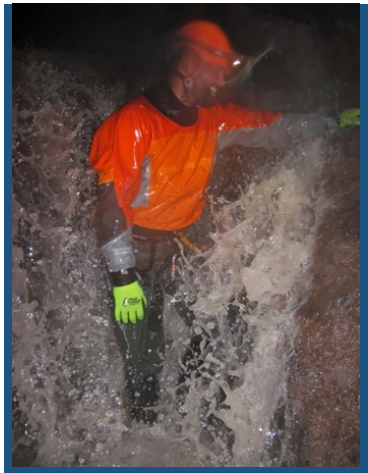
Moving equipment or passing a litter takes many people!

Warmer convective currents inside caves create **ice delamination** and **embedded rock extrusion / melt outs (rock bombs)** (under and downhill hazards…cones of concern)



Underground Serac Falls!

Faster moving glaciers can leave ice towers behind at the contact with bedrock. Very Precarious!!



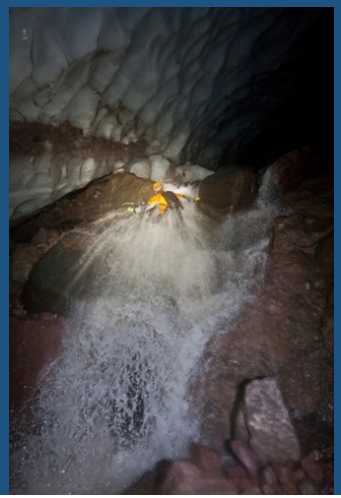
You will get wet!

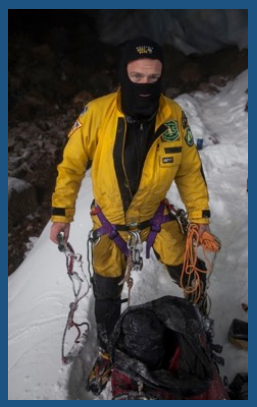
Even in mid winter. Water flows year round, or steam will wet your outer garments.

Must have garments tough enough for crawling over rock, litter handling, warmth, and water repellency!!

Gore-Tex is good for static movement or rigging, NOT very good for patient carry, as it will rip and expose wearer to elements.

Wet suits, cave suits, even dry suits may be needed on short notice





Droolin Moulin, Mt Hood, Oregon

Pure Imagination Cave, Mt Hood, Oregon

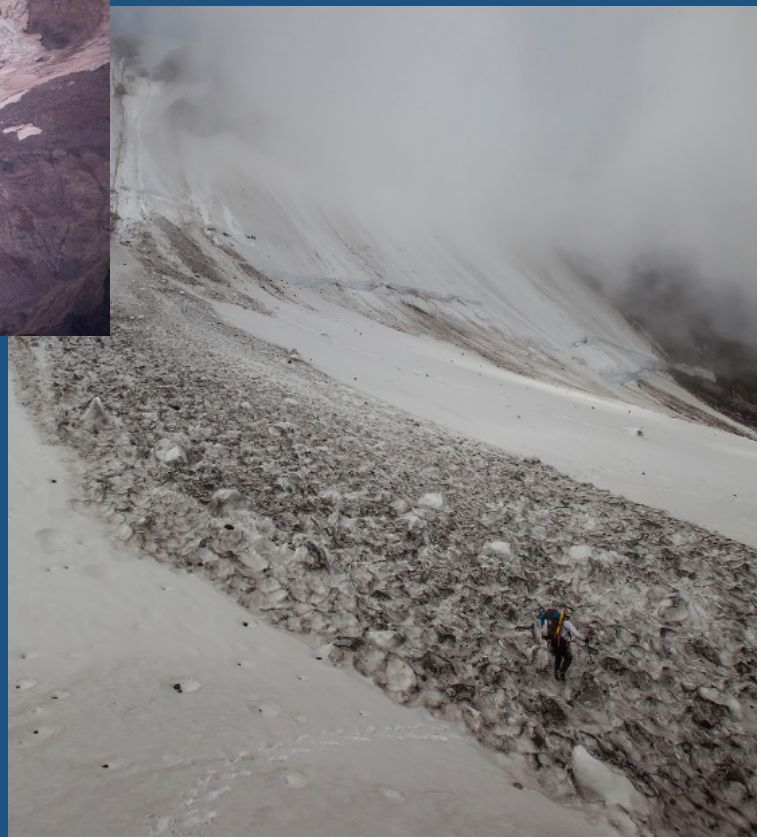
Only way out of cave is down passage.

How would you belay or lower a patient in litter?

Surface operations can be very hard on responders

- Most surface responders will be stationary.
- Information from cave takes a while to come.
- Plan to have surface shelter and wire communications with underground teams.

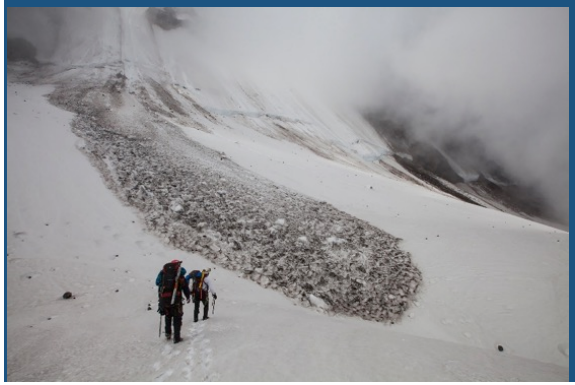
Avalanche Concerns

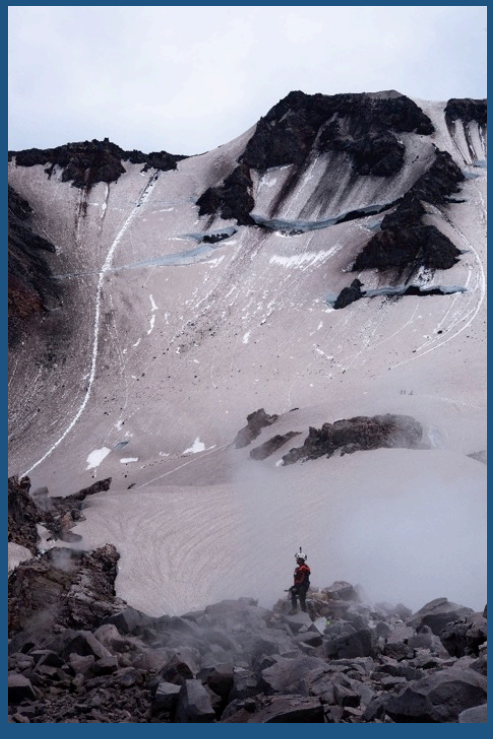


Glacier caves occur where more snow falls than melts, so avalanches are ALWAYS part of the response considerations!

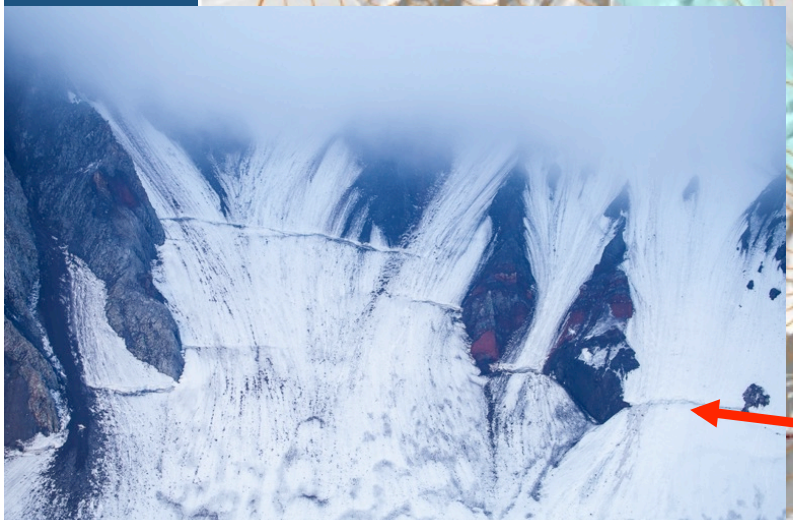
Many glacier caves and moulins route avalanches right down into their system

- Avalanche in crater glaciers can come from many sides, and often carry large rocks with them….displaced accumulation!
- Many glacier cave entrances act like "funnels" and draw rolling rocks and avalanche flows that might have otherwise passed by.
- Avalanche could bury the only entrance to cave at anytime





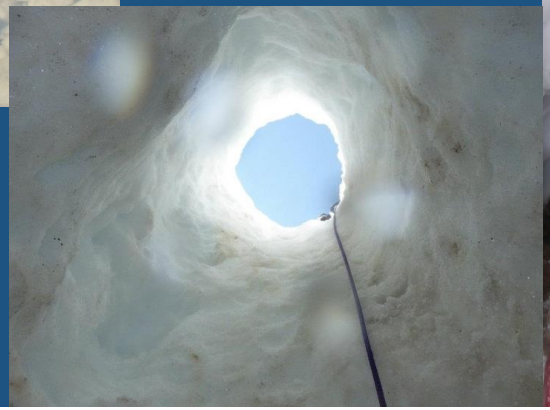
Crater Glaciers form massive Terrain traps and caves act as debris catchments

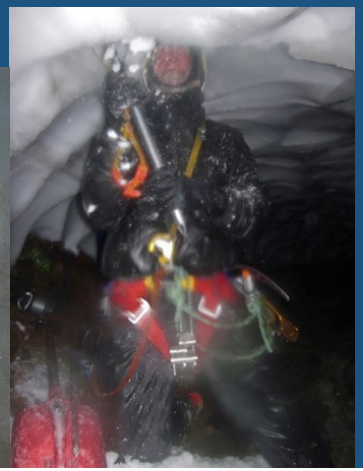


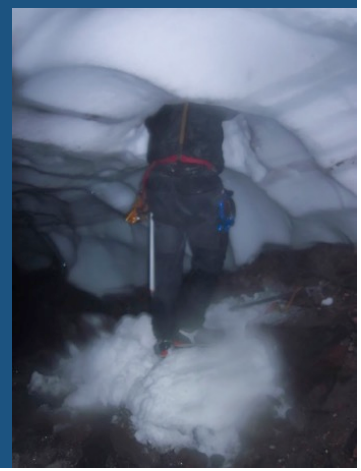
- Avalanches can run UP and down glacial tubes, especially if avalanche enters system via a moulin and gains momentum.
- Must wear avalanche beacons underground and carry all avalanche gear.
- Avalanche debris can also change airflow patterns in the caves, or push CO2 tides up to make a place formerly safe to sheltering climbers suddenly toxic…even if the climbers are nowhere near the avalanche entry point.

Beacons work underground through ice!

Can be used to track patients and rescuers 50 to 60 meters down.



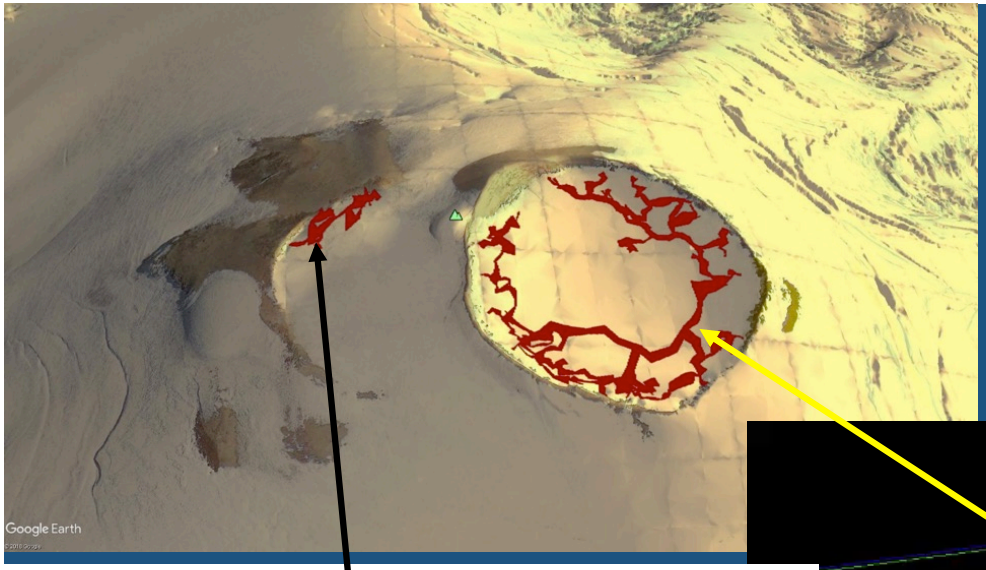


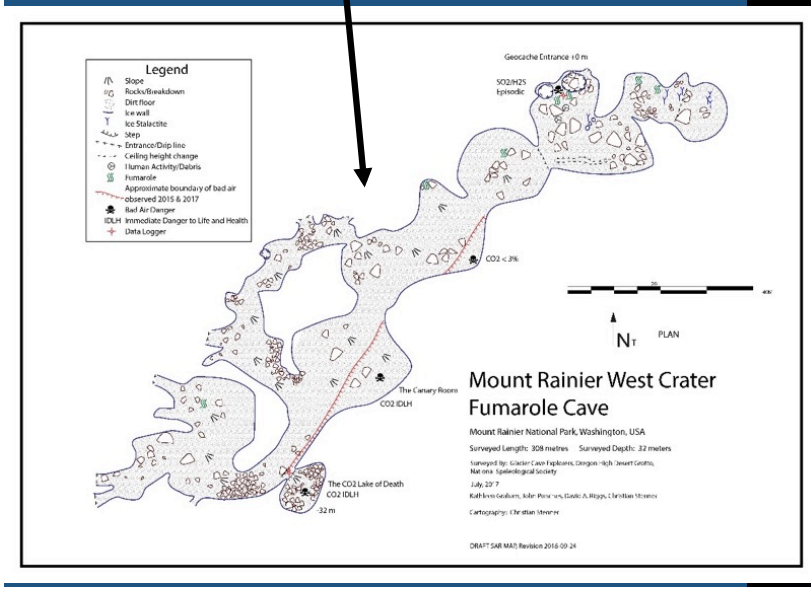


Solutions

Mapping and exploration: Imperative to conduct rescue pre-planning and surveys if you have glacier caves in traveled areas.

- Fumarole / gas hazards
- Staging areas
- Junction markers
- New moulins forming from underneath, especially if near climbing route, or access routes for rescuers.
- Evacuation routes


Google Earth


Legend
Slope
Rocks/Breakdown
Dirt floor
Ice wall
Ice Stalactite
Step
Entrance/Drip line
Ceiling height change
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Approximate boundary of bad air observed 2015 & 2017
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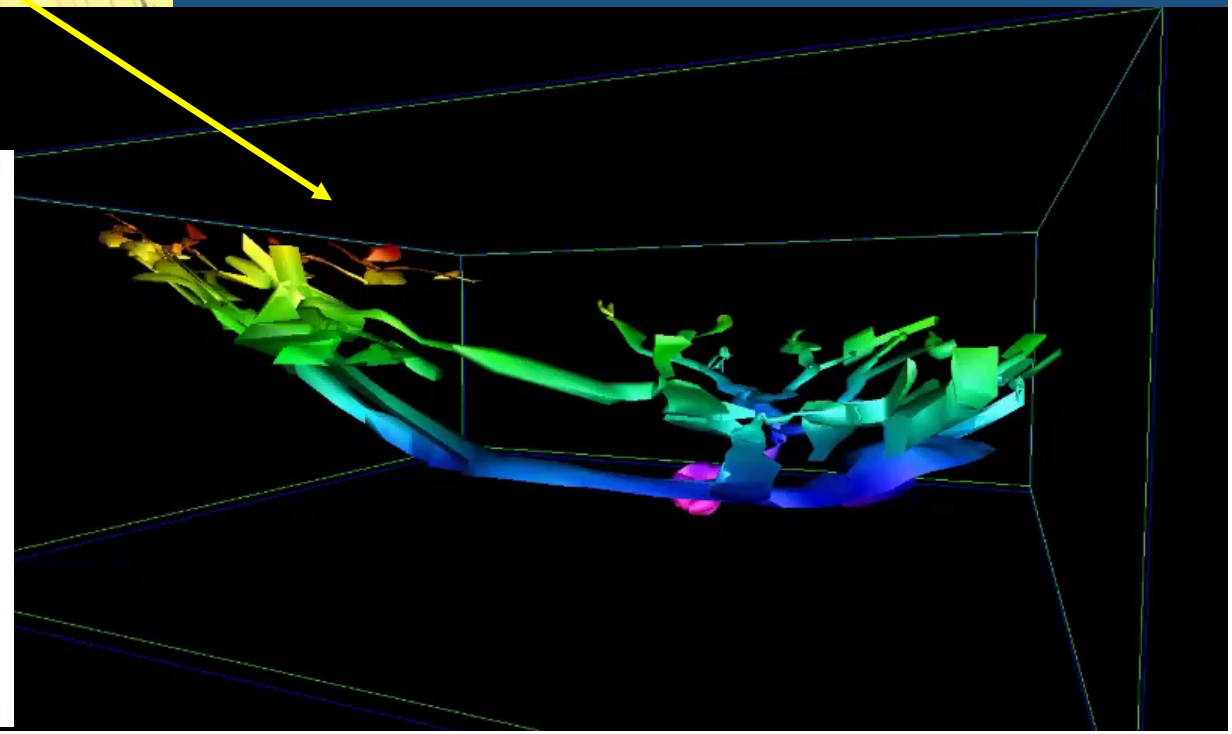
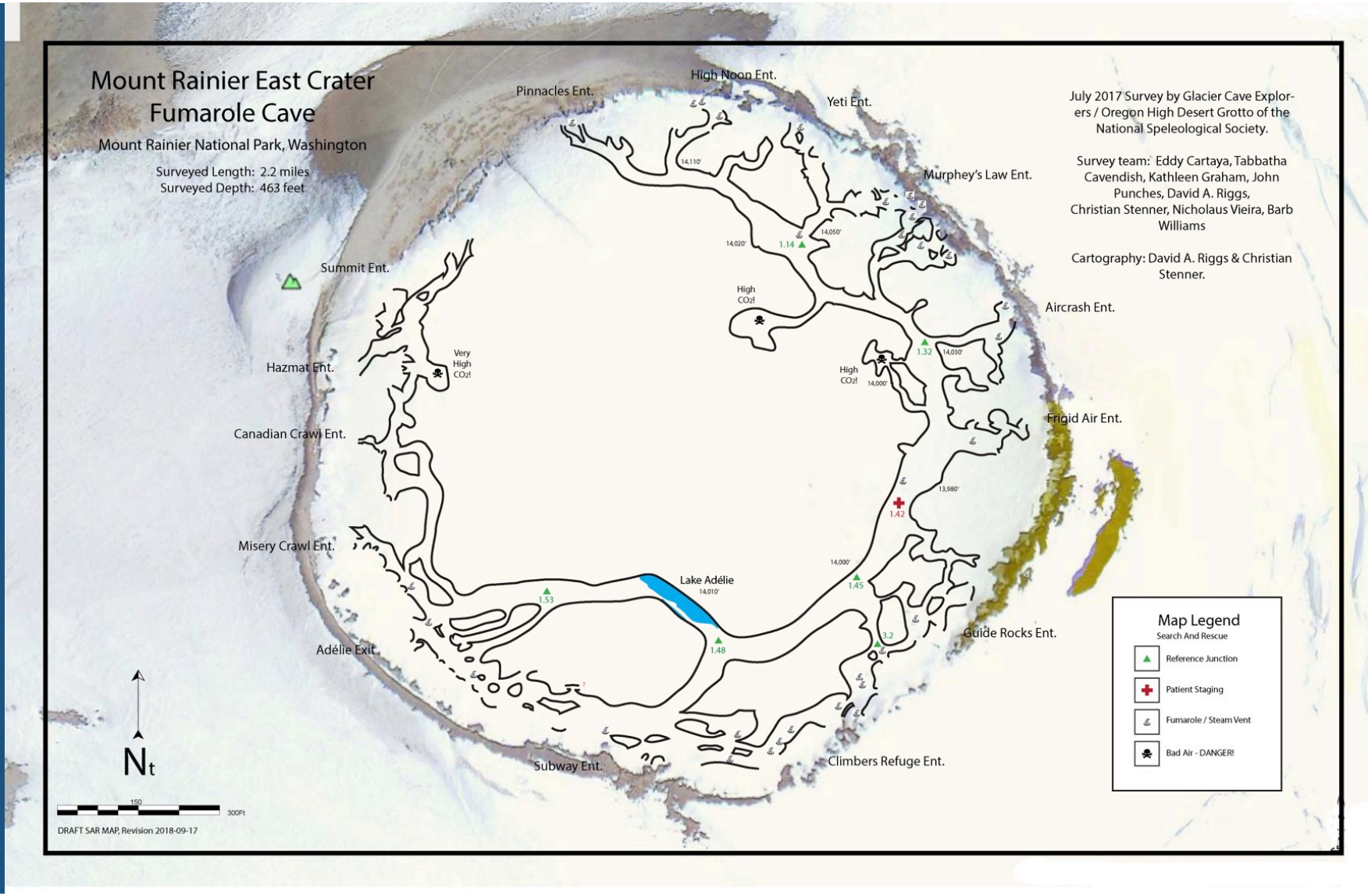
PLAN
Mount Rainier West Crater Fumarole Cave
Mount Rainier National Park, Washington, USA
Surveyed Length: 308 metres Surveyed Depth: 32 meters
July, 20 7
Cartography: Christian Stevens
DRAFT SAR MAP, Revision 2016-09-24




Mount Rainier East Crater
Fumarole Cave
Mount Rainier National Park, Washington
Surveyed Length: 2.2 miles
Surveyed Depth: 463 feet
July 2017 Survey by Glacier Cave Explorers / Oregon High Desert Grotto of the National Speleological Society.
Survey team: Eddy Cartaya, Tabbatha Cavendish, Kathleen Graham, John Punches, David A. Riggs, Christian Stenner, Nicholaus Vieira, Barb Williams
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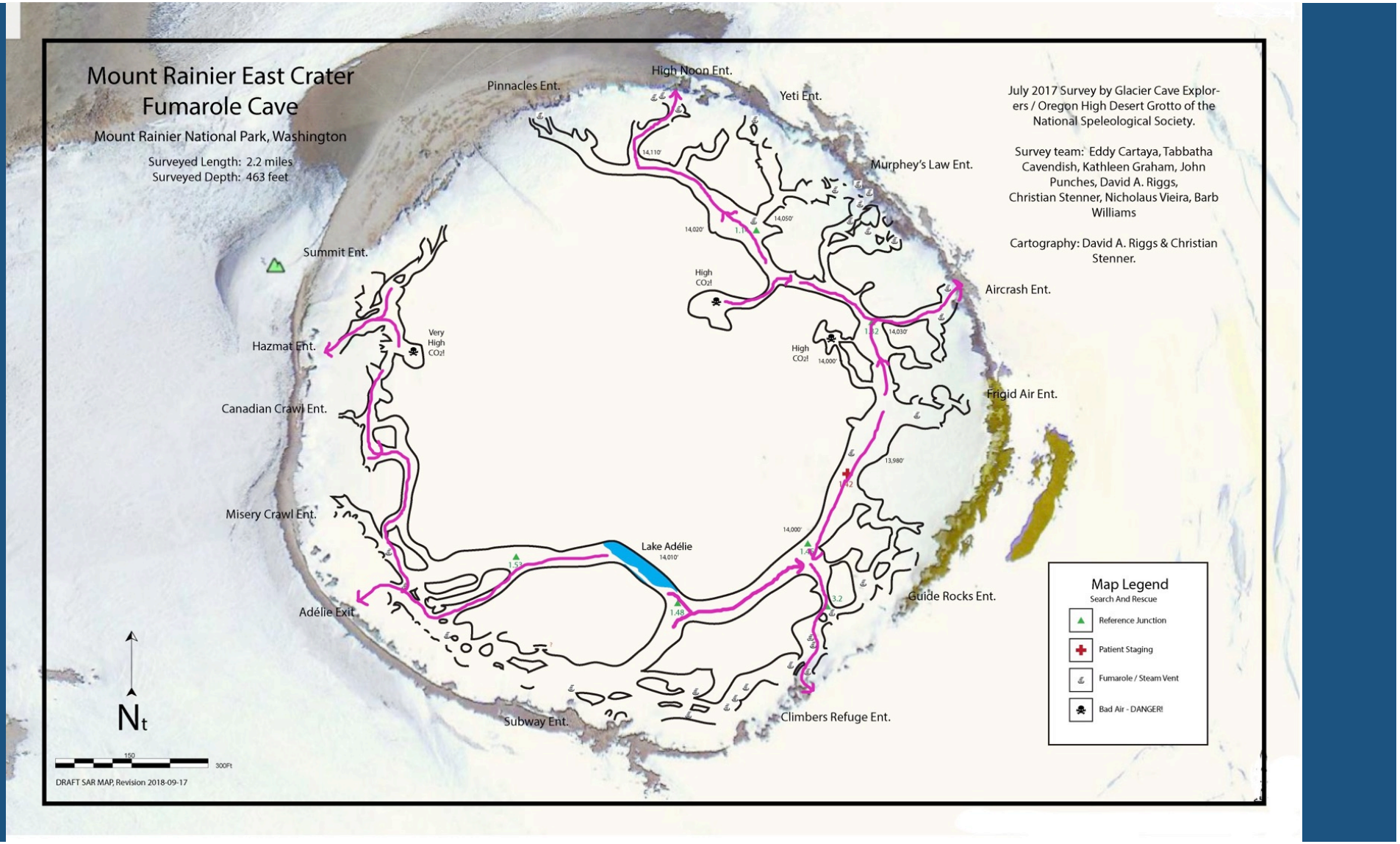
Guide Rocks Ent.
Climbers Refuge Ent.
Subway Ent.
Adélie Exit
Misery Crawl Ent.
Canadian Crawl Ent.
Hazmat Ent.
Summit Ent.
Lake Adélie
14,010'
14,110'
14,050'
14,020'
14,030'
14,000'
13,980'
1.14
1.32
1.42
1.45
1.48
1.53
3.2
High CO2!
Very High CO2!
Map Legend
Search And Rescue
Reference Junction
Patient Staging
Fumarole / Steam Vent
Bad Air - DANGER!
Nt
150
300Ft
DRAFT SAR MAP, Revision 2018-09-17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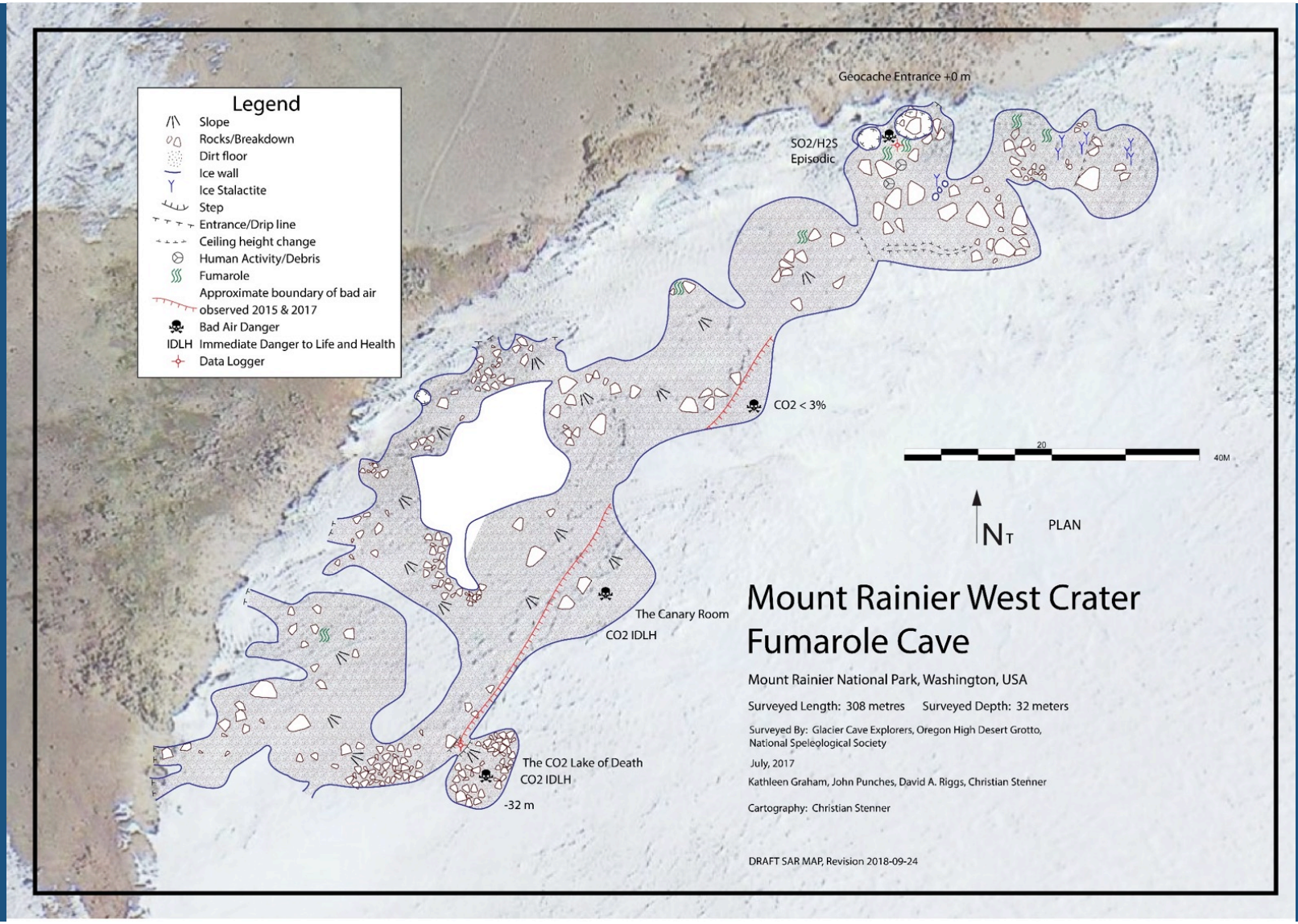
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DRAFT SAR MAP, Revision 2018-09-24

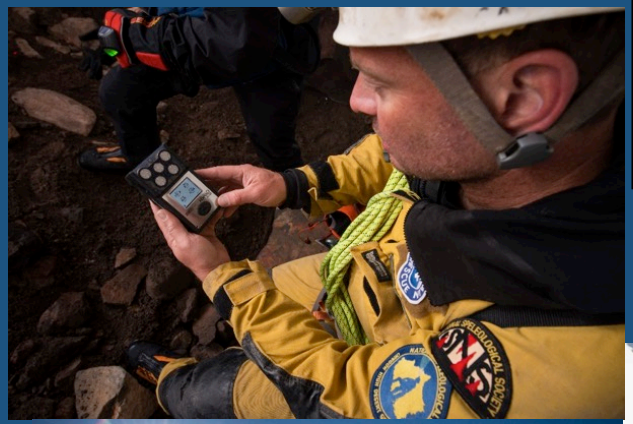
These are FLY-In missions!

Someone injured a regular cave is subject to hypothermia very quickly.

Someone injured in a glacier cave is MUCH MORE at risk due to the cold temperatures, water, ice, and wind.

Gas monitors and escape rebreathers required if entering volcanic glacier fumarole caves.

Even normally safe passages can episodically contain toxic air.



- Some areas may contain deep CO2 lakes and require full breathing apparatus to work in.
- Know where to get these quickly. Fly SCBA to the rescue site.
- Must have personnel trained.
- Practice using this in cave, and on rope!

Helmet with 3 sources of light.

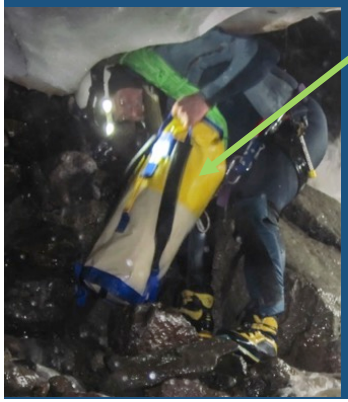
PVC or durable water resistant suit

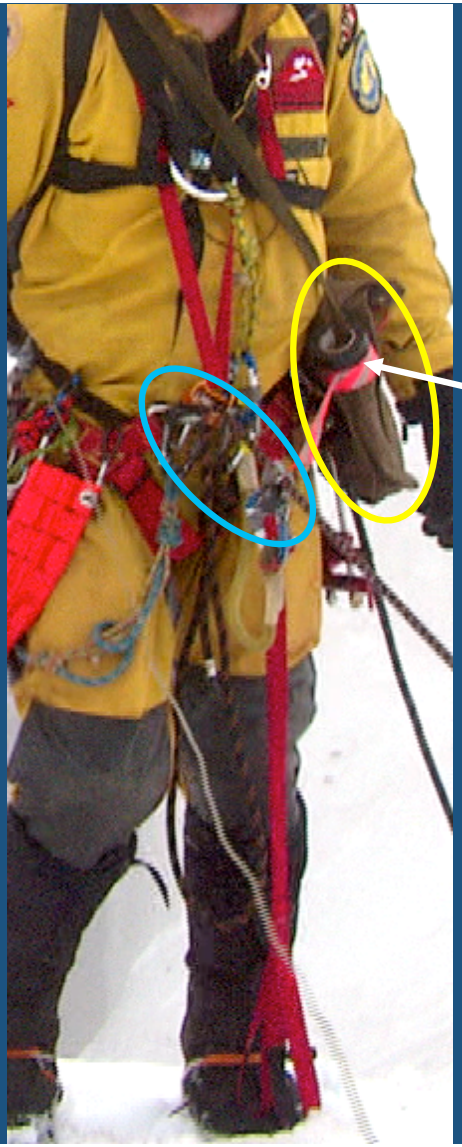
Mini escape rebreather (30 minutes)

Gas monitor

Avalanche beacon

Durable PVC cave pack





Mechanical ascender rope climbing system (avoid prusiks)

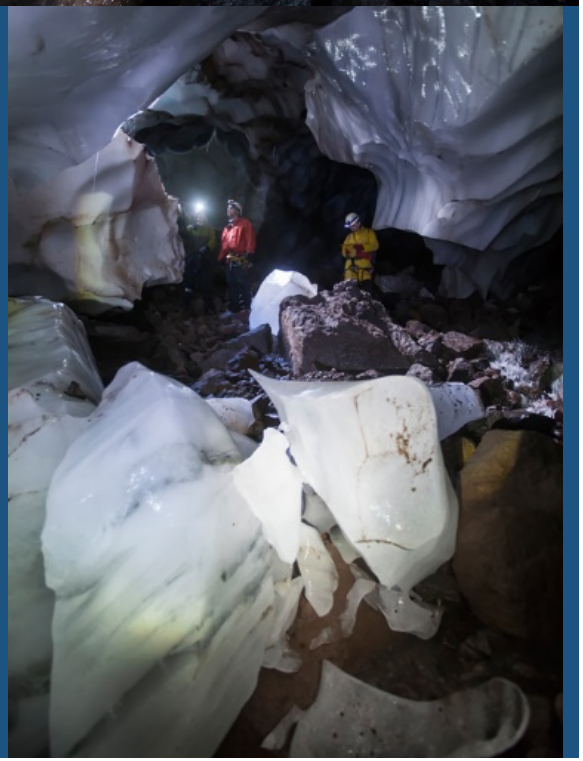
Reflective flagging tape, to make route to patient

Wire phone and line repair kit

Always carry crampons AND Ice axe!
…even if floor looks just rock.

- Delamination debris or short ice tubes may require crampons & ice axe for short distances to get through.

- Freezing gusts could create a band of verglas or ice pearls that make travel impossible without them.

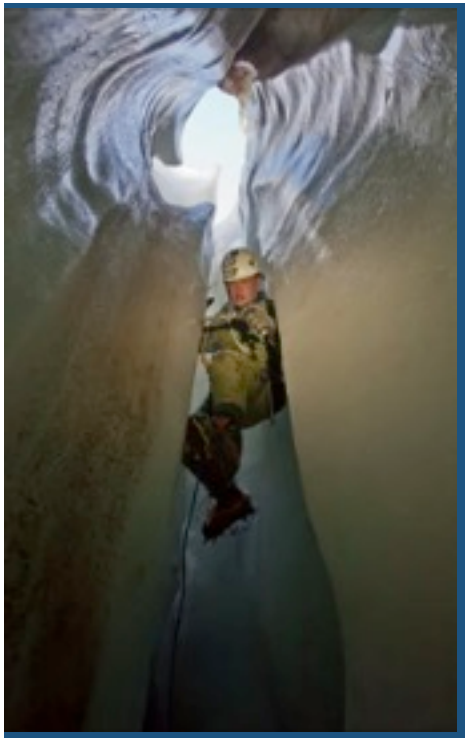


Line phones recommended for communications between rescuers above and below.

- Radios, GPS, phones do not work.
- Cave can be very loud and not possible for voice communication to top of pit.
- Especially if chance for corniced entrance collapse…at least STAGE a phone and wire inside…crossing all unstable areas. Mark phone with light stick and stock emergency shelters there. (Address Mt St Helens cave entrance collapse 2017)
- Mark com wire with reflective tape.
- Have a dedicated operator at surface in a **sheltered location** (snow cave, tent, etc.)
- BE SURE underground teams are given a TURN-AROUND TIME and report in time.

Avalanche beacons can be used through significant ice to locate people in tubes. Everyone wears one.

Unique type of search in that your TARGET may be moving under you.

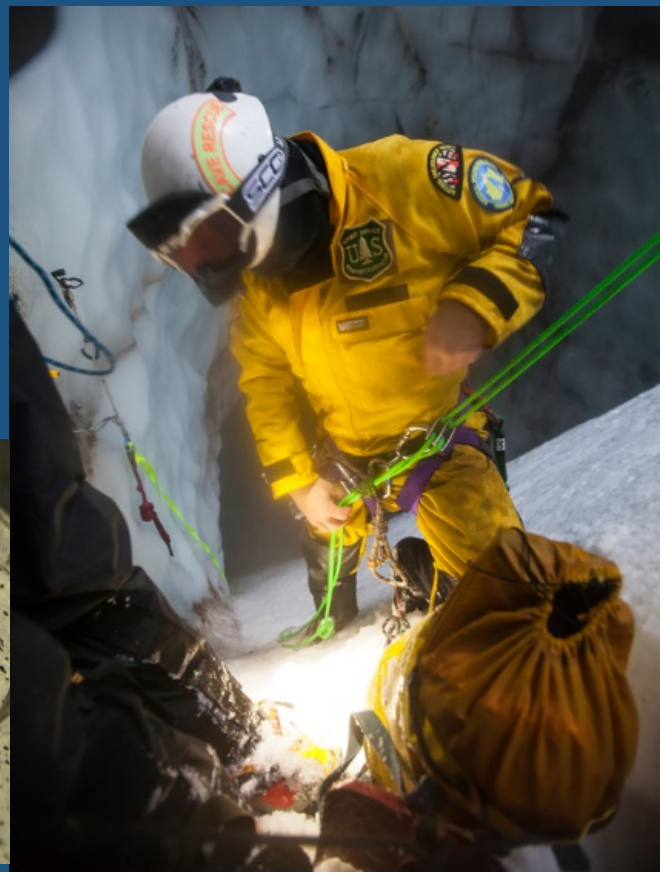


In Cave Anchors

- Subglacial Ice under extreme compression or tension. Subject to massive fracturing and propagation if struck with ice tools…dinner tabling , not dinner plating!!
- In some extreme cases, just an ice screw detonates an energy release and massive fracture.
- Must use ice aide climbing techniques to gain high leads or high directional. Short screws preferable.

- Ice screws near fumaroles, or in warm drafts fed by fumaroles will melt out screws very quickly as screw conducts heat into the ice.

- May need to insulate screws from air. Aluminum foil cupped over screws and hung by the screw knobs help preserve viability time in fumarole caves.



In some firn systems, ice screws will not hold…

- May have to pound pickets into ceiling and walls
- Warm metal will cause melt out very quickly….

Flag obvious routes for responders through and around “cones of concern” from rock bombs and areas of delamination. This will steer your litter evacuation route.

Must use REFLECTIVE tape or markers! Everyone will have a headlamp!

- If doing vertical problems and rescue systems in glacier caves, need GOOD SRT devices.
- Avoid prusiks.

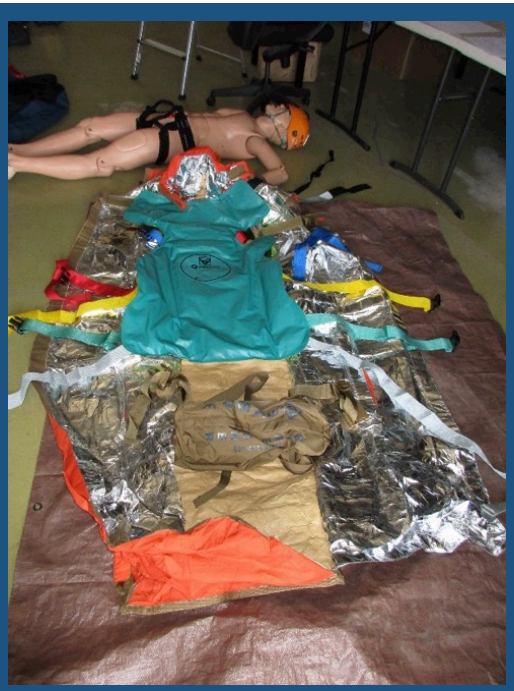
Carry shelter inside cave

- Refuge for responders, and also to package patient
- Bothy bag: for shelter in place / in-cave patient stabilization.

Ultralight patient packaging:

- Ferno SPED
- APLS Bag
- Micro SKED

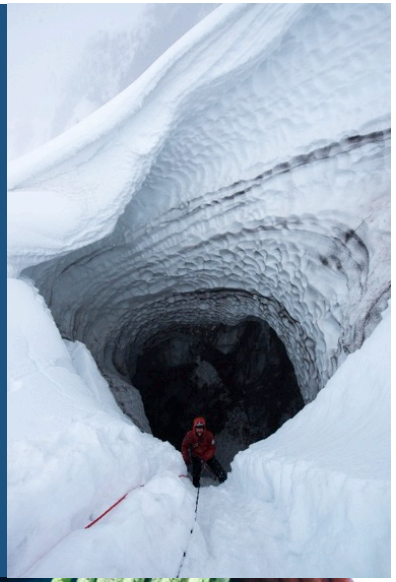
Must plan for cold, wet, and windy passage conditions.



Specialty Rope Systems for Glacier Cave Problems

Use static rope!!

- Many mountain rescue respond only with dynamic.
- Haul systems, counterweight systems, and single rope technique suffer with dynamic lines.
- Consider hi Viz rope for handlines and SRT due to steam / lo viz (PMI retro-reflective in 10mm and 8mm.



First drops into suspect fumaroles

- Lower responder in with a surface system ready for immediate change over.
- Responder attached to rope via a mechanical climbing system.
- Responder trails the communication wire for phones and carries a phone.
- Responder should have gas monitor, emergency escape rebreather, and / or sulfur mask as conditions dictate.
- Lower SLOW, to allow for gas monitor reaction.
- May need human relay over lip for communication.
- Watch for very overhung and corniced entrances, especially with steam coming up.

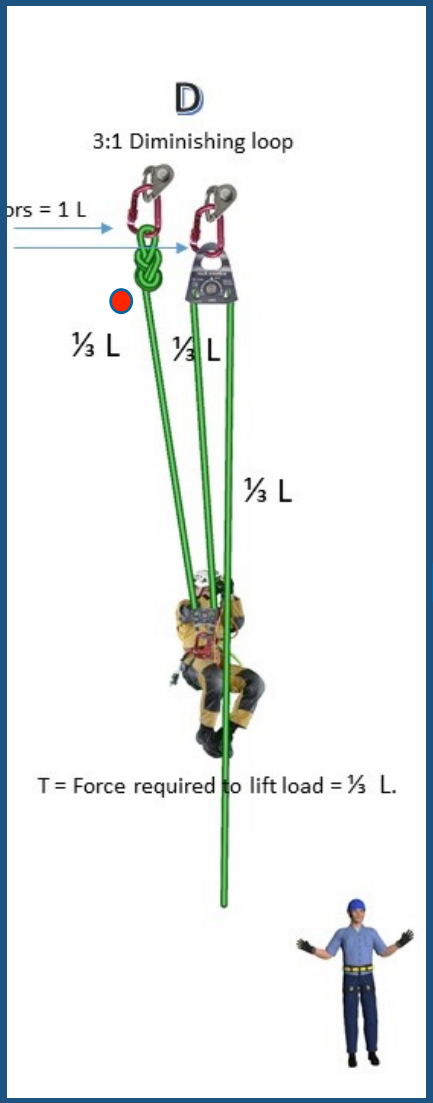
Two rope belays with alternating Ice Aid climbing the safest option for vertical ice passage.

Traditional lead ice climbing with ice axes extremely dangerous due to stress forces in deep glacial ice!!

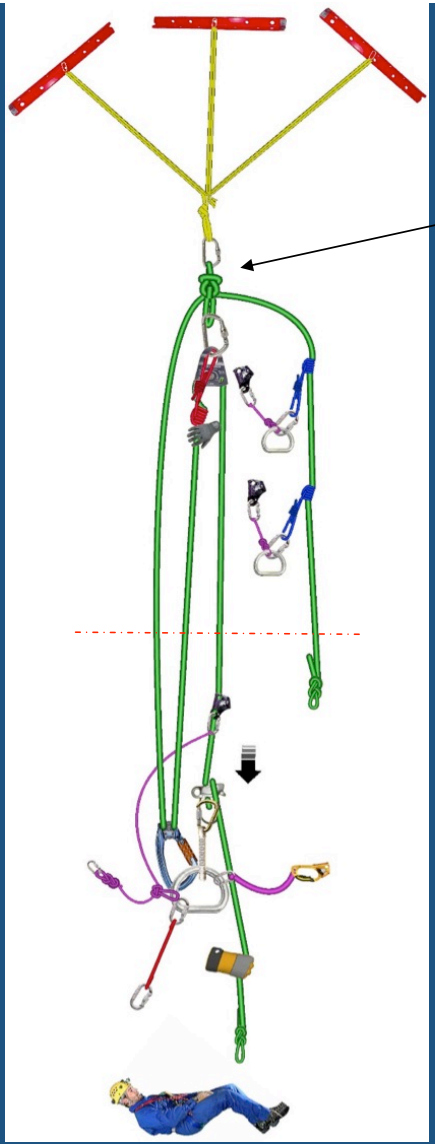
If you feel sudden grabbing or pressure on ice screw as you install it…and see no rock, STOP! You are cutting through a stress zone!!

Fumarole Cave Rescue / Pick off

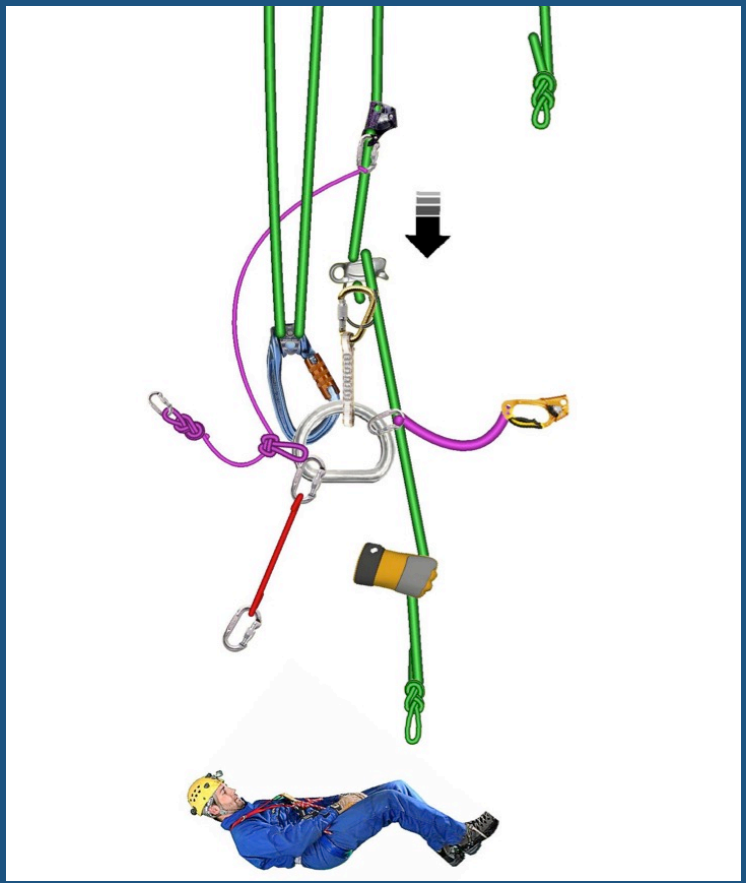
- Very Urgent Rescue…like Avalanche burial
- Likely will only have very small team and minimal gear.
- Must be able to build fast operating system, with redundancy, with one rope and only glacier travel gear.
- Goal is a quick grab of the patient and get them out of the hole!
- System should allow for unexpected problems and have autostops for responder in hole as well as surface team.

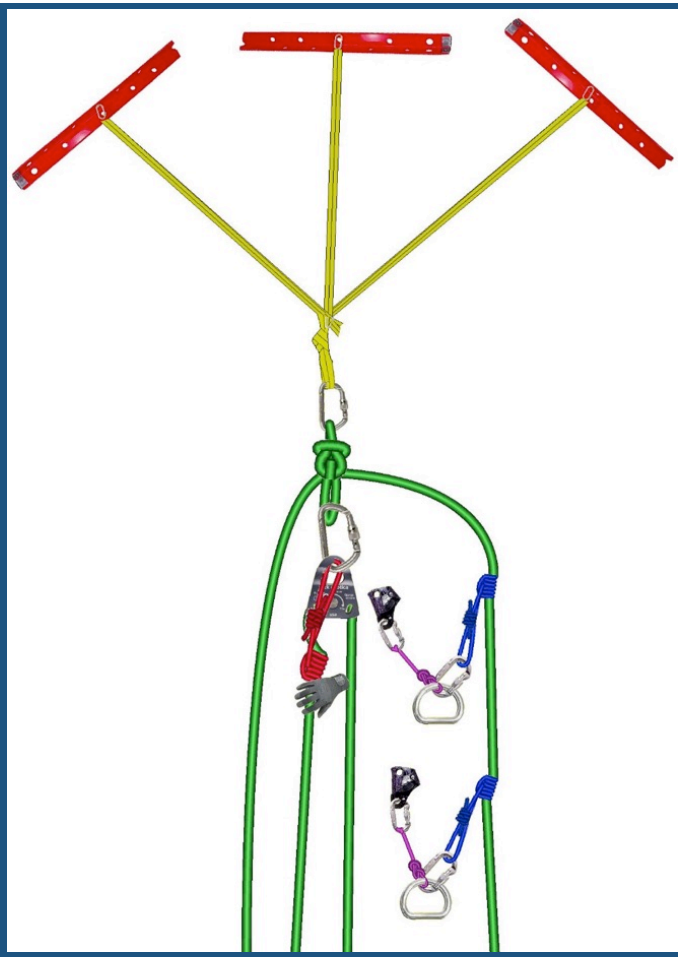


A hybrid combination of the 3:1 diminishing loop rig and the top based climbing counterweight rig.



Bowline on a bight with forward facing loop





Note small extension on ATC to keep controls clear of roller carabiner.

Advantages

- Allows rescuer to be in control of own descent. Important as top crew may lose sight of rescuer and not know to stop descent if rescuer goes unconscious. If rescuer sees a reason to stop, they can do so immediately without the time delay of having to yell up for a stop
- Auto stop for rescuer. Upper ascender thumbed down on top of descender to facilitate faster changeover. Only sees 1/3 rescuer load, so it is easy to unlock autostop ascender if they wish to continue.
- Very little room needed to perform a full haul operation at top. Counterweight system does most of the work in the vertical plane.
- Top rescuers can assist using small counterweight movements, maintaining edge safety, with minimal movement.

Advantages con't

- Auto lock at top also. Progress capture is on the 2:1 side of the system, so it only sees ½ the load minus some edge friction losses. It will be easy to break the prusik if needed…no Load release hitch needed.

- 3 to 1 diminishing loop advantage for rescuer, so rescuer does not have to exert so much to lift to tow patient up…saves on respirations and fogging if wearing a mask PPE.

- Top CW rescuer(s) can clip in and assist with haul to make it easier…OR haul out rescuer if he goes unconscious.

- Can be rigged with one rope and 3 anchors. Only additional gear needed besides personal SRT is a PMP and prusik at top and a roller biner at attached to lower rescuer.

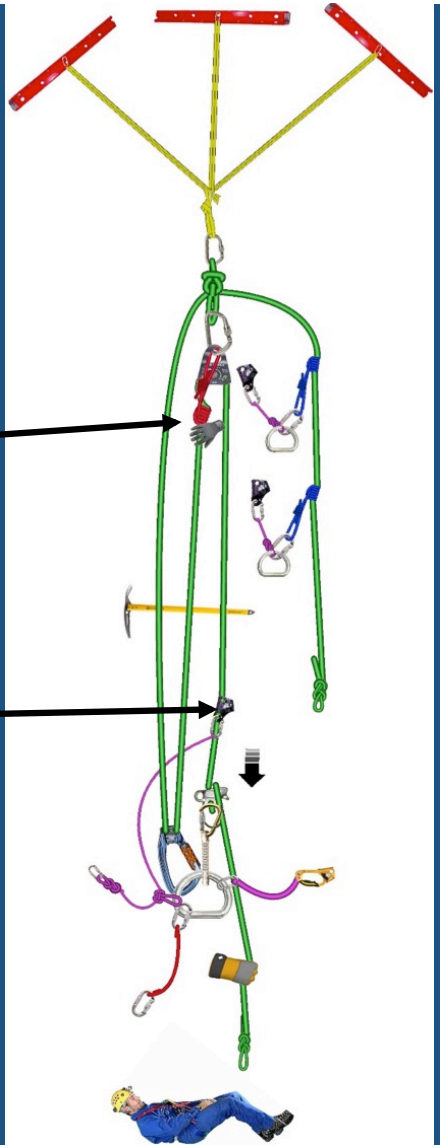
Disadvantages

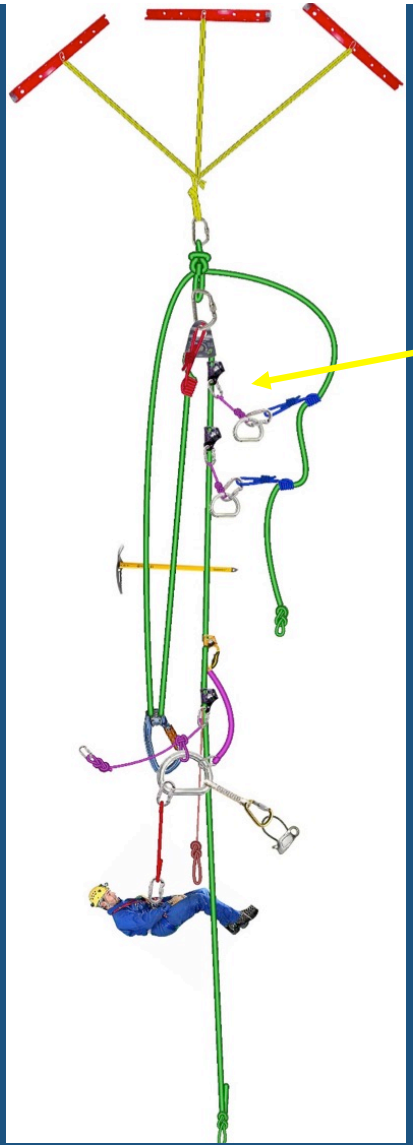
- 2 moving lines over edge. Must groom edge with rigid item to prevent cut-in. Be sure ice axe or picket is tied into static line so it does not fall into hole and strike patient!
- Patient and rescuer in close proximity to each other. Must be mindful of crampons and kicking each other.
- Team must know the set up….not a standard rig.
- System is greatly benefitted by some sort of edge friction solution!

Basic system going down

Top counterweight rescuer must tend PCD prusik while in-hole rescuer rappels down.

Rescuer on rope tends their upper ascender as an auto lock.

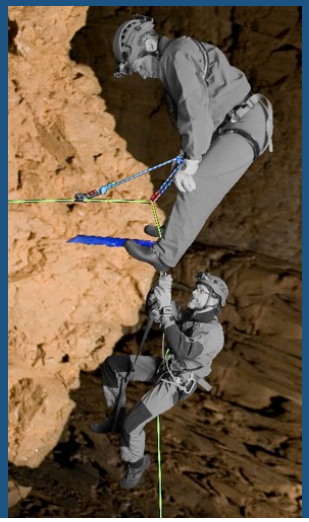




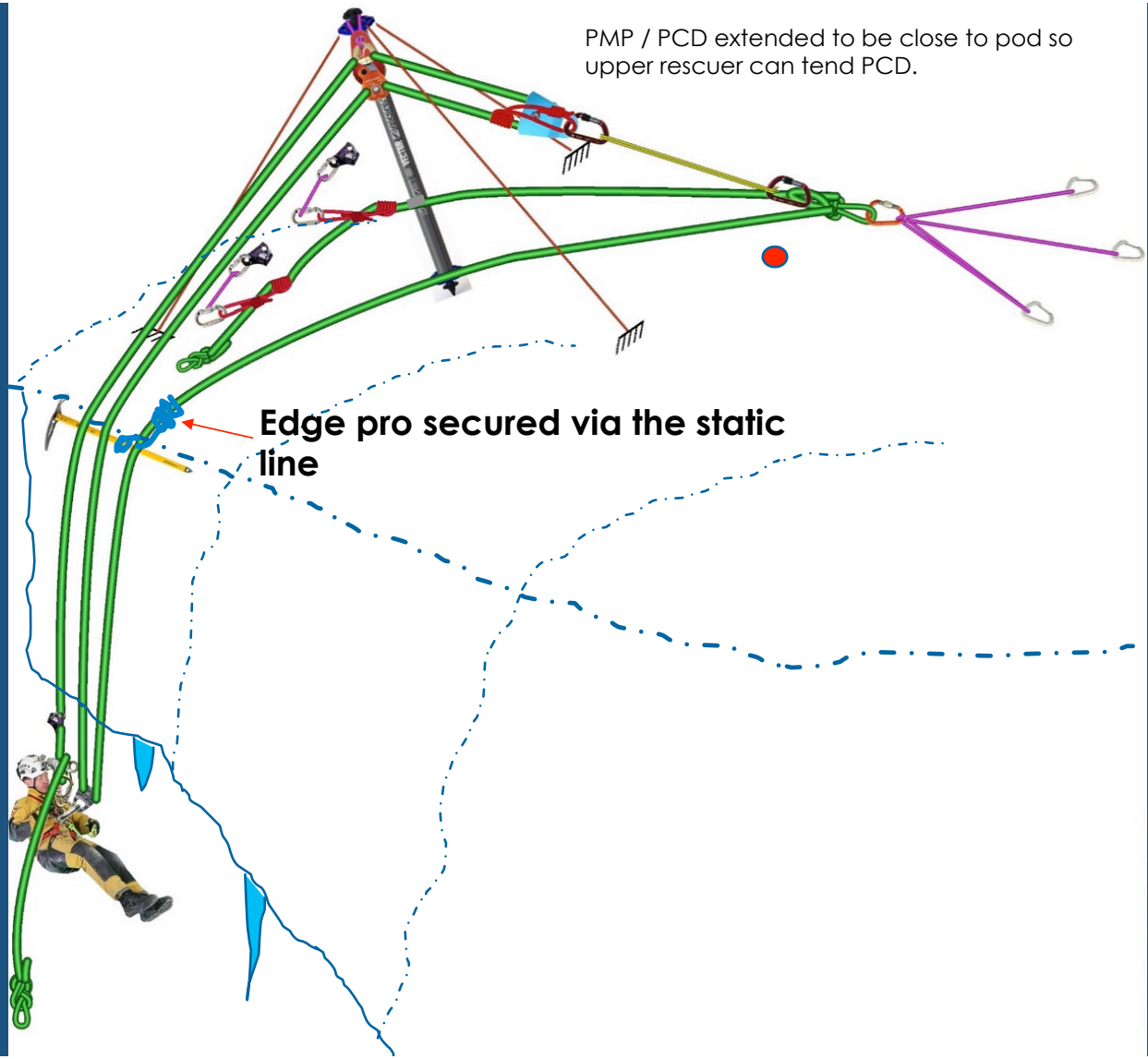
As rescuer nears lip, or gets tired, upper CW rescuers attach their SRT gear to the same SRT down line the in-hole rescuer is climbing.

Edge Solutions

- **<u>You MUST have an edge plan!</u>** Especially with an counterweight solution.
- There are 2 moving lines over edge…each moving in opposite directions.
- This can create drag in two lines.
- Friction going down is your friend. It is your enemy coming up!
- One solution is a human bipod.




Vector Edge Monopod a lightweight option to solve edge friction with the counterweight system!


PMP / PCD extended to be close to pod so upper rescuer can tend PCD.
Edge pro secured via the static line

- Leave static leg of system on snow…not through monopod.
- Each of the two lines running through the monopod pulley will have 1/3 the collective load.
- Do not allow rescuer to traverse along edge…go straight down from monopod.
- Secure all 4 support lines of pod to snow via parachute or picket anchors.

Questions?