Rock Breaking for Rescue Teams

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Abstract

Both wilderness and urban search and rescue teams often need to access and free trapped persons. Rockfall, shifting boulders and wedge situations can cause people to become entrapped. Underground rescues in caves, mines and collapsed structures are often complicated by poor access conditions and rock hazards.

While USAR teams can utilize cranes, concrete saws and other heavy rescue equipment, backcountry SAR must make do with items that can be carried or helicoptered in. The ability to reduce large, immovable blocks of stone to pieces that can be moved with rope rescue equipment and hand tools is a capability that SAR teams should consider developing.

The wide availability of high-powered, battery-operated rock drills, special explosives techniques and even small-scale “micro blasting” kits have opened up new options for the SAR community.

In this paper, we will follow up on our previous “Blasting for Rescue Applications” work and attempt to show how the equipment and methods we previously developed can be useful to backcountry search and rescue. We will include an overview of the training program currently being implemented at the San Bernardino Sheriff’s Cave Rescue Team, as well as qualitative results from 3+ years of development and use.

Background and Need

Caves, mines and other rock environments present numerous hazards, such as rockfall, and restricted access which pose unique challenges to the rescuer. The ability to move or modify rock structures is a unique capability that can simplify rescue problems.

After studying the unsuccessful rescue effort at Nutty Putty Cave in Utah in 2009, (Anon, 2021a) the Cave Team began looking at ways to improve underground rescue. Additionally, reports of a rescue in Inyo County involving a rock entrapment and the famous Aaron Ralston incident in Utah in 2003 suggested that many technical rescue teams could benefit from rock breaking technology.

Our intent is to both show that it's possible for a technical rescue team to break and move large amounts of rock with portable tools and share the experience our team has had with this capability.

Applicable Specialties: Cave Rescue, Mine Rescue, Technical Rescue, USAR

Enabling Technologies

In our previous paper. four key technologies were identified as enablers for rescue rock breaking:

1. Cordless rotary hammers featuring lithium battery and brushless motor technology
2. Micro-blasting systems that use small-diameter holes and pyrotechnic cartridges to break rock
3. Class 1.4S blasting cartridges that can rival high explosive performance for many applications while presenting fewer risks and less regulatory overhead than high explosives such as dynamite.
4. Traditional stone quarrying and trail work techniques that can be done quickly when combined with modern cordless tools.

Considerations

When we first developed our rock breaking program, we considered the following criteria:

Logistics - All capabilities had to meet the following criteria:

a. Require a minimum of special storage, handling and transportation
b. Be portable in backpacks or parcels under 30lbs/15kg
c. Capable of operating with zero access to AC power at point of use

Legal - Explosives are considered "Division 1" hazmat. Products that can explode from a No. 8 blasting cap or shock such as dynamite are considered "1.1" material. Less hazardous items such as fireworks, flares and the specialized blasting cartridges we utilized in this paper are classed as "1.4" material. Since all explosive products are regulated, we felt that a variety of rock breaking options needed to be available to teams, including:

a. Mechanical techniques and tools that do not use any explosives at all
b. Micro-blasting systems that are regulated similarly to powder-actuated tools and do not require a license to use or possess in most US jurisdictions
c. Small-scale rock-breaking cartridges that, while falling under federal and state explosives regulations, are much less hassle to transport and store than traditional high explosives.
d. The possibility of using conventional high explosives, in coordination with the Sheriff's bomb squad or a blasting contractor

Cost - Developing a new capability is expensive in both money and time. Any new capability must provide a benefit to the public at a reasonable cost. To do this, the following design principles were utilized initially:

a. Each level of capability is built on the one prior. Higher level capabilities leverage the existing investment in training and equipment.
b. Almost all of the tools needed for each capability level can be sourced from normal construction suppliers.
c. The specialized micro-blasting systems and 1.4S explosive cartridges described are available from at least two vendors.

Training - Based on our team's experience, the following principles have proven effective:

a. Teams should first focus on proficiency at breaking and moving small rocks. Since explosives fundamentally turn very large rocks into smaller ones, close-quarters rock breaking and removal is a foundational skill. The only way to do this is with hands-on practice outside.
b. For a team to be proficient in a skill, it is recommended that they not only train regularly on that particular skill (i.e. using drills, chisels and feathers & wedges to break rock) but also seek out "awareness level" training at the next higher level (i.e. micro-blasting or commercial blasting). In our case, this meant working on cave projects and partnering with a blasting training provider. We also actively seek out opportunities to use these skills, such as removing a boulder in the road at one of our SAR training sites.
c. Rock breaking should become an adjunct to other skills the team already practices, such as bolting, mechanical advantage systems and USAR techniques. The ability to break rock is most valuable when combined with a way to move it out of the way with mechanical advantage systems, pinch point bars, and other creative methods.

Safety and Risk Management – After publishing our original guidelines, we believe the following principles are a reasonable way to explain this capability to a public agency:

a. In most cases, there is a rock-breaking option that is safe to use even in direct proximity to a live subject. This has been proven during training and on actual missions,
b. The capabilities described can mean the difference between life and death for a trapped subject. They may be the only viable option for saving someone facing imminent death due to hypothermia or crush injury.
c. The risk to rescuers can be reduced by modifying the rock environment, especially underground. Hazards such as rockfall and squeezes can be greatly mitigated.
d. The class 1.4S cartridges and micro-blaster charges described will not detonate unless confined inside rock. They produce a minimum of fumes and are safe to use in non-ventilated areas. We have to date not been able to produce a hazardous air environment while utilizing these products. Flyrock can be controlled with tarps, blankets and similar material.

Capability Level Model

We previously developed a 4-tier model of team capability. The levels defined below can be met within a single team or by utilizing a composite team such as Sheriff's Search & Rescue (SAR), Fire/USAR and private contractors working together.

At this time, the SBSD Cave Rescue team is at around level 3 in terms of capability. We have successfully utilized level 2 (micro blasting) on a mission and level 3 (small-scale 1.4S class blasting) on an extended underground training. Our Sheriff's bomb squad stocks material for level 3 and 4 techniques and is on call for missions. The team keeps the tools and materials for level 1 and 2 rock breaking in its gear cache as well as drilling tools for level 3 and 4 problems.

A recommended set of equipment and techniques for each level is outlined in Appendix 3.

Level 1: Can use mechanical rock breaking techniques such as "feathers and wedges," (Anon, 2021d) chisels, cordless tools, sledgehammers and pry bars. Can crack and remove rock flakes or modify openings with power and hand tools. Can utilize existing technical rescue capability such as bolting and rope systems to move rock. A level 1 team should also have awareness-level training on micro-blasting and moving larger rocks USAR-style with pinch point bars.

Level 2: Adds proficiency with at least one commercial micro-blasting system. This complements mechanical splitting and prying techniques with the ability to break up boulders or rock one (1) cubic yard/meter or less in size using these 1-5g explosive charges. The team should have awareness-level training on explosives and blasting and ideally, should have one person working towards becoming a licensed blaster or equivalent.

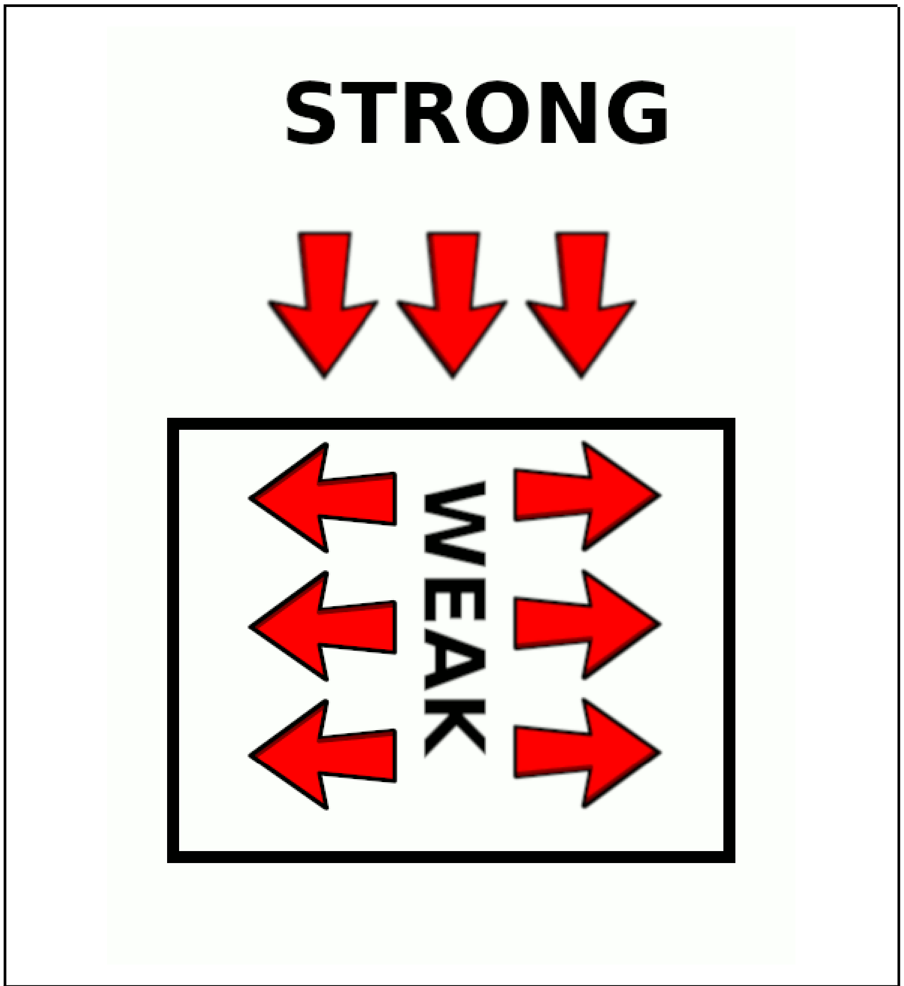
Level 3: Includes class 1.4S blasting with commercial cartridges ranging in size from 5-60g net explosive weight (NEW). A level 3 team has the ability to break multiple tons of rock quickly and manage moderate air blast and fly rock hazards. The team should have at least one licensed blaster and a set of team members with support-level training on explosives use. This capability may be in conjunction with a public agency bomb squad or outside blasting contractor who manages product inventory and provides on-the-ground support.

Level 4: The team is fully integrated with a bomb squad or blasting/mining contractor. A level 4 team can utilize detonating cord and packaged high explosives such as dynamite or Kinepak in conjunction with level 1-3 techniques. A full level 4 team is capable of actually mining 3 feet/1m or more into unbroken bedrock, shattering blocks over 3 cubic yards/meters in size safely and can operate in difficult conditions such as confined spaces underground. Multiple licensed blasters should be able to support the team. In addition, engineers, experienced miners or other specialists must be available for consultation if needed.

General Rock Breaking Principles
The general principle of rock breaking is that rock, while extremely strong in compression, is only about 5% as strong in tension. (Stowe, 1969). This means that beating apart a rock with a sledgehammer or even a pneumatic jackhammer is often not going to do anything unless there are existing cracks and weaknesses.

If we apply force from the inside however, a boulder or other rock can be broken with far less work. The way we access the inside of a rock is usually by drilling holes into it, and the force can be in the form of mechanical wedges, micro-blasting or explosives.

All rock breaking is based on the above principle, combined with materials theory that shows it's possible to split even very large objects via crack propagation if the cracks can be started. The techniques we can use for rescue all operate this way and can use any combination of mechanical and chemical power.



.Figure 1: Rock strength in tension vs. compression

Mechanical Rock Breaking

This is a traditional stone cutting technique that dates back thousands of years. It involves drilling a line of holes, placing two thin pieces of steel (called "feathers") into the hole, then wedging them in place with a third piece of the tool (the "wedge"). When all of the holes have been drilled and made ready, the operator begins applying pressure to the rock using a hammer (typically a 4lb/2kg "singlejack"). As the wedges move downward, pressure on the rock increases until a crack forms. At some point, the rock will fail and break along the line of holes.

Figure 2: Feathers and Wedges in use

Figure 3: Cutaway view of Feather and Wedge

Small rocks or stone with existing fractures can also be broken apart with a hammer and chisel, an SDS+ hammer drill with a chisel tool or with a splitting tool such as a "stonebuster," a type of sledgehammer with a sharp point on one side.

Micro Blasting is a small-scale rock-breaking process that has become widely available in the last 20 years. The general idea is that a small diameter hole is drilled, cartridges containing nitrocellulose or similar propellant are inserted, and the hole is stemmed up with a metal tool and fired.Rock is broken via the hole pressurizing, causing it to fail in tension. No significant shock wave is generated.

A variation on this, variously called "capping" or "Tic-boum" in Europe, utilizes widely available .22-.27 caliber blank cartridges made for nail guns that are fired with a slide hammer or similar tool that can both stem the hole and strike the cartridge's primer. This is the predecessor to the commercial systems now available and are still used by cavers. The advantages of these systems include the ability to utilize very small charges, but he disadvantage is that it is not commercially supported and more of a "DIY" project.

Commercial systems include a pneumatically-activated system called the "EZ Break" that utilizes 5/16" (8mm) diameter holes up to 18" (45cm) deep and an electrically-fired system called the "Sierra Blaster" that uses 10mm drill holes and waterproof cartridges. The net explosive weight (NEW) of a micro blasting cartridge for both systems is around 1g. Both systems can break up and remove 1-3 cubic feet (.03-0.1m^3) of rock at a time and typically do not require licensing nor magazines in most cases. The cartridges cost US$1-5 each and can be shipped via Fedex or UPS in North America.

Figure 3: Two Sierra Blaster heads prepared for firing. Approximately 4 grams total explosive.

Figure 4: Post-blast results on medium boulder

1.4S Cartridge Blasting is a rock breaking process similar to micro-blasting. This method uses pre-assembled blasting cartridges containing a pyrotechnic compound and range in diameter from 9mm to over 90mm. They are typically waterproof and come equipped with an electric initiator and a length of wire pre-installed. In the US, they are regulated as a "low explosive" by the Bureau of Alcohol, Tobacco, Firearms & Explosives (ATF).

To use these products, the blaster drills one or more holes into the rock with a hammer drill. The holes must be deep enough to allow the cartridge plus 2-3 cartridge lengths of stemming material (usually fine gravel) to be inserted. Once the cartridges have been placed and sealed in, they are connected to an electric blasting machine. The blaster then clears the area and fires the shot.

On firing, high-pressure gas (up to 140,000psi) is generated in a "deflagration" or rapid combustion process. As the pressure builds, existing micro-cracks from the hole drilling process begin to expand, allowing gas to enter and initiating movement of the rock. Once the rock begins to fail and come apart, the reaction slows down and any remaining explosives burn off in air. Each gram of material produces approximately 1 liter of gas when fired.

The cartridges used in 1.4 blasting contain smokeless gunpowder and other additives and are typically oxygen-balanced to not produce significant quantities of fumes if initiated within a well-stemmed borehole. During testing, we were able to briefly cause a CO (Carbon Monoxide) alarm underground, but the fumes rapidly disperse and are not a significant hazard.

These products are available in weights from 3g to over 1kg. The NXBurst products from NXCO Mining Technologies tested ranged from 10-60g and were capable of breaking very large boulders and even bedrock.During one test, we completely destroyed a limestone boulder weighing over two tons at an underground mine and were able to break up the larger pieces easily with the micro blaster.

In the US, they are classed as class 1.4S material and can be stored in a simple type 4 magazine such as a ”job box” storage bin. They do not represent a significant explosion hazard and will simply pop or burn when not confined in a borehole.

Figure 4: Drilling 1 ¼” holes for 1.4S blasting.

FIgure 5: 2xNxBurst 20g cartridges ready to be placed at the bottom of holes drilled in ~4,500lb (2,000kg) boulder and stemmed.

Previous Investigation

In order to develop this idea into a real capability for the team, several questions needed to be answered about these technologies. Most of the literature around blasting and mining assumes that large pneumatic rock drills, road access and other infrastructure is available.We needed to know whether cordless rotary hammers could substitute for electric and air-powered rock drills, which techniques could be scaled down for rescue use and what would be needed to make all of this into a real capability.

Starting in 2017, we started interviewing expedition cavers, trail builders and blasting industry professionals. Members of the team went to a commercial blaster’s training course and a Level 2 USAR course and one of the authors (JN) trained for, and passed the state blaster’s exam.

Tools were rented or purchased, and the different blasting systems tested. Since publication of the paper, we have utilized these techniques underground, moved a lot of rock and have come up with a solid list of things that we believe work. Here is a brief summary:

1. Using manufacturers' data sheets, we identified the tool types and drill bit sizes available that could be useful for rescue rock breaking. The larger 18-19V SDS+ drills were found suitable for drilling deep holes ⅝" (16mm) and smaller. The new cordless SDS Max drills are suitable for holes up to 1 ⅜" (38mm) and bits for both are available in 36" (1m) or longer lengths.

2. We performed field tests to determine if suitable blast holes could be drilled by rescuers using only cordless equipment. Test drilling took place using brushless SDS+ and SDS MAX drills and fully-charged lithium battery packs. We determined that the SDS+ drills with 72WH battery packs could drill approximately 6' (2m) of ⅝" (16mm) holes and the SDS Max with 216WH batteries could drill a similar distance of 1 ¼" (32mm) holes in limestone or other medium-hard rock.

There is considerable variation between hard and soft rock types, but this is a reasonable starting point. Larger tools drill faster, and may be somewhat more efficient on battery use, as total drilling time is reduced.

3. The team obtained and tested two different micro-blasting systems. Both the EZ-Break and the Sierra Blaster performed similarly. The Sierra Blaster cartridges are waterproof and electrically initiated. The EZ-Break cartridges must be waterproofed with wax or similar material and are non-electric. Both were found suitable for rescue applications.

4. Our licensed blasters John Norman and Don MacFarlane tested high explosives including dynamite, Kinepak, detonating cord and shaped charges against a variety of rock types. Additional testing was done with 1.4S cartridges donated by the manufacturer. Detonating cord and packaged explosives installed into holes were found to perform very well. Shaped charges were less useful, as they require large amounts of explosives and work best on free-standing rock that can usually be destroyed by other means.

5. The micro-blaster and full-size 1.4S cartridges were safety-tested by initiating them in open air to determine if they represent a significant storage/transport hazard. All products were initiated using a BTS-50 Handi-Blaster machine. The cartridges typically fail by opening up at the ends and ejecting a plastic plug.

No detonations occurred, and we believe that an accidental initiation of one of these products inside a backpack or outside the hole during loading would not be a major problem for a rescuer wearing safety glasses and gloves.

Trade Size	Rock Type	Metric (mm)	Area (cm^2)	Drilling Effort	CM of holes per 72W/H (measured)	CM of holes per 72W/H (predicted)	CM of holes per 320W/H (measured)	CM of holes per 320W/H (predicted)	Standard Blast Hole (cm)	Blast holes per battery	Product Type	Applicable Techniques
5/16		7.94	0.49	0.39		332.80			45	7.40	EZ Break (4x1gm)	1,2,4
10mm		10.00	0.79	0.62		209.68			60	3.49	Sierra Blaster (3x1gm)	1,2,4
7/16		11.11	0.97	0.77		169.80			60	2.83	Autostem 9mm x 10gm	
½	Hard	12.70	1.27	1.00	130	130.00			60	2.17	Autostem 9mm x 10gm	1,3,4
14mm		14.00	1.54	1.22		106.98			60	1.78	NXCO (13mmx10gm)	1,3,4
9/16		14.29	1.60	1.27		102.72			60	1.71	NXCO (13mmx10gm)	1,3,4
5/8	Medium	15.88	1.98	1.56	140	140.00			65	2.15	Autostem 17mmx20gm	1,3,4
5/8	Hard	15.88	1.98	1.56		83.20			65	1.28	Autostem 17mmx20gm	1,3,4
¾		19.05	2.85	0.36				388.89	80	4.86	Autostem 17mmx40gm	1,3,4
7/8		22.23	3.88	0.49				285.71	40	7.14		1,3,4
1		25.40	5.07	0.64				218.75	65	3.37		1,3,4,5
1 ¼	Medium	31.75	7.92	1.00			140.00	140.00	65	2.15	NXCO 28mmx20gm	1,3,4,5
1 ¼		31.75	7.92	1.00				140.00	65	2.15	NXCO 28mmx40gm	1,3,4,5
1 3/8		34.93	9.58	1.21				115.70	65	1.78	NXCO 34mmx40gm	1,3,4,5
1 ½		38.10	11.40	1.44				97.22	65	1.50	NXCO 34mmx60gm	1,3,4,5
1. Feather & Wedges 2 – Micro-blasting, 3- 1.4 Blasting 4 – Pre-splitting 5 – Conventional Blasting												
Note: 1/2" holes tested with Ryobi SDS+ drill, 3AH high-output Lithium battery, med & hard rock. 1.25" holes tested with Hilti TE-60A36 in medium rock.												

Table 1: Cordless Drilling Test Results (ISEE paper)

Findings and Subsequent Experience

1. It is definitely possible to break and move large rocks with mechanical tools. Holes for feathers and wedge work need to be 4-6” deep (12-15cm) and at least ⅝” (16mm) or larger. They can break a rock flake 3X or more the length of the wedges. This is particularly useful for breaking up large, flat rocks. Larger sizes suitable for use with the SDS Max drill are also available..

2. Micro-blasting is much better suited to removing rocks that are cemented in place, round or difficult to access. The drilled holes can be up to 24” (60cm) deep with some systems, allowing large/thick rocks to be broken very quickly. A 5/16 (8mm) is needed for the EZ-Break and a 10mm hole is used with the Sierra Blaster system. We removed 200+lbs (100kg) of granite with the EZ Break to free a trapped body in Joshua Tree using this method without incident. The main limitation of the micro-blaster is the amount of material that can be removed per shot and the need for solid rock without too many flaws in order for gas pressure to build up.

3. 1.4S cartridges, combined with a large SDS Max rotary hammer can be utilized to break boulders of almost any size. During testing, rocks from 2 tons to over 15 tons were broken using cartridges from 20-60 grams placed in various patterns. The main limiting factor is drilling time and battery usage. The drill will need to cool down after every 1-3 holes and battery packs will need to be swapped out as needed.

4. Detonating cord is extremely reliable at splitting even low-quality rock that won’t hold in pressure. More explosive weight or a closer pattern of holes may be required in fractured or soft rock, but it will reliably split rock linearly or shatter small boulders under almost any conditions. Detonating cord is a type of “high explosive rope” and is carried by most bomb squads and military EOD units. 3/8 (10mm) holes are fine for this. We found that a 50gr/ft (3.7g/m) cord worked well in most applications. It can also be doubled up for larger jobs and water can be placed in the holes to increase energy coupling.

5. Bigger jobs, including breaking or mining through solid bedrock, still require the use of high explosive cartridges such as dynamite or a product such as Kinepak that can be mixed on-site. In

particular, the 1/3lb (150g) Kinepak product is well-suited to this type of work. It requires a 1 ⅜" (38mm) hole which is feasible to drill with a cordless SDS Max drill. It will also work down to about ½" (12.5mm) and can be re-packed into a 1" ID tube for use with the 1 ¼" (32mm) drill.

If time is not an issue, there are expanding grout products that will crack all types of rock, but these require extensive drilling and take 24-72 hours to work.

6. Precision blasting often results in rocks that are broken in place rather than being turned into small fragments that are ejected.Prybars are frequently needed to disassemble the rock post-blast. The two most useful tools we discovered for this were the 48-60" (12-160cm) pinch point bar used in USAR applications and a short 30-36" (75-100cm) "jimmy bar." This tool has a tapered point on one end that can be inserted into drill holes to widen a crack enough to get the much more powerful pinch point bars in. Gravel can be tossed into the crack as it is expanded to capture progress. Large fragments can be moved with levers or by bolting/slinging them and using rope systems.

Conclusion and General Notes

Rock removal with explosives is a viable technique for underground rescue teams, thanks to modern cordless tools and precision blasting products. In particular, micro-blasting, 1.4S blasting and detonating cord pre-splitting were shown to be very effective while keeping air blast and flyrock hazards to a manageable level. The possibility of "breaking the boulder in place" or "mining through to the subject" is no longer out of the realm of possibility for even a remote, trapped caver or other subject.

During the writing of this paper, a cave rescue in South Dakota involving a trapped caver was performed. The combined Custer County SAR and NCRC (National Cave Rescue Commission) volunteers utilized level 1 mechanical breaking techniques to free a person trapped behind an extremely tight restriction. Details are of this rescue can be found in "Appendix 1."

Appendix 1: Case Study: South Dakota Mission

On the weekend of October 7, 2022, a rescue took place in Custer County SD at a privately-owned cave in the Black Hills.

A man was attempting to push a narrow lead in the cave. As he tried to turn around and exit, he became trapped. His party attempted self-rescue but were unable to free him. At this point, a joint mission involving local cavers, NCRC resources (National Cave Rescue Commission) and the Custer County Sheriff's SAR team was mobilized.

"They could communicate with him, but they couldn't reach him," said Sam Smolnisky, director of Custer County Search and Rescue and a paramedic for Custer Ambulance Service.

The episode happened Oct. 7 and 8, and the cave rescue team and emergency responders described the rescue effort in a press conference on Thursday, Oct. 13, in Custer.

Except for cuts and abrasions that are normal for cave explorers who crawl through confined spaces with rough, rocky surfaces, the man was uninjured, according to Smolnisky.

"It was a very, very complex rescue as far as the in-cave rescue," he said.

The man became stuck in a very narrow passage, reportedly 9 inches high, which is not unusual for cave explorers, who squeeze their bodies to pass through narrow areas, hoping they lead to rooms or caverns.

Emergency responders provided above-ground assistance while cave rescuers worked underground to free a man trapped for 18 hours in South Dakota.Custer County Search and Rescue photo

The trapped caver had squeezed through a 90-degree bend, and had managed to turn himself around, but wasn't able to return through the sharp bend. His companions tried to free him, but were unable to do so, so they called for help.

The cave rescue was carried out by members of Paha Sapa Grotto, an active group of experienced spelunkers who explore caves in the Black Hills, including Jewel Cave and Wind Cave.

"The local cavers are the ones who actually performed the rescue," Smolnisky said. "They are some of the best in the region."

According to Rene Ohms, at least two local cavers had access to micro-blasting equipment, but the rescue was able to be carried out using hammer drills, chisels and other tools.

"The hammer drill with chisel bit worked great when we had the angle right. There were weaknesses in the rock, and it was kind of punky underneath and would come off in nice chunks at times.

The best chisel bit for the job had a slightly curved blade and was about 1.5 inches wide. Near the end of the rescue, we were able to lower the floor by clearing a space under a 1-inch thick crystal layer with a rock pick (the floor under it was fairly soft) then giving it a whack with a 2 lb sledge.

This was possible after we'd used the chisel bit to expose the crystal edge. A crow bar was used a few times as well. “

“He was able to get out under his own power,” Smolnisky said. Blankets and supplies had been staged in a room inside the cave, where the man was warmed and given food and water to enable him to crawl out the rest of the way.

“He was able to be rehydrated,” Smolnisky said, adding that the cave rescuers did their best to get food and water to the man during the prolonged ordeal.

The man was stuck in a location that was about 40 minutes from the cave entrance, with much of the route traversed by crawling.

Appendix 2: Case Study: Joshua Tree Mission

In July 2021, the SBSD Cave Team was requested to help with recovering a deceased subject in a remote area of the Mojave Desert. A County Fire team had previously been unable to extract this body by conventional means. An evaluation on-scene revealed an adult male pinned on their back inside a deep, narrow cave formed from granite boulders. Only the subject's hand was visible from above. Team members packed up equipment including PPE, a cordless rotary hammer, pry bars, chisels, micro-blasting equipment and rope rescue gear and began the mission.

The plan was for one team to begin removing rock from the bottom, with a goal of enlarging the opening enough to slide the deceased out for packaging. The other team would survey the top and watch for rock movement. Work began by drilling into the largest rock to the left of victim's legs and placement of (3) 1g EZ Break charges and the micro-blasting tool into the hole. After clearing personnel away, the hole was detonated. A rock flake weighing approximately 100lbs/45kg was broken off and removed with scaling bars. More holes were drilled and fired. After 3 such blasts, it was apparent that the rock was quite fractured and did not blast well.

Work shifted to freeing the subject from the top. With 30 minutes of work with hammers and chisels, we were able to visualize victim's head, torso and left arm. The arms were secured at the wrists with webbing and tied off to a 6'/2m miner's scaling bar, to prevent subject from sliding away.

At this point, it appeared that the right arm and torso had swollen and were stuck tightly in the cave opening. Our best chance at recovery seemed to be removing the ring of rock around the cave opening. Team members drilled 3 holes approximately 12"/30cm deep and spaced 6"/15cm apart. The rock was blasted with one cartridge loaded in the center hole. The ledge rock cracked but did not break apart.

Using a hammer and tapered pin, the crack was enlarged enough to insert a pry bar. About 50lbs/20kg of rock were freed and removed. Another 8"/20cm deep hole was drilled lower and to the right and loaded. This was a particularly unpleasant task, as it involved working inches from the decomposing body. On firing, the last remaining rock entrapment fractured off. Team members were able to manipulate the rock piece and lift it free. The victim was lifted out of the hole using a 100' rope and pulley system without incident.

Figure 11: Removing rock in a confined space during Joshua Tree Mission

Figure 12: Subject nearly ready for extraction. Rock tools used in the removal of entrapment at right..

Appendix 3: Recommended Equipment List

Level 1 Equipment List

Qty.	Description
1	Hearing & eye protection for each team member
1	Fitted P100 half-face respirator or PAPR for each team member
1	SDS+ hammer drill
4	Large (72WH equivalent) batteries.
1	Group charger for above batteries
12	Wedges and shims in ⅝” size.
6	SDS+ drill bit sized for W&S set above, 150mm-300mm length
2	SDS+ moil/jackhammer bit for above drill
2	Pinch Point Bar, 4-5’/1.2-1.5m
2	Single jack hammer, 1-2kg/2-5lb
2	Sledgehammer, 8lb/4-5kg
1	1m/30" Jimmy Bar
1	2m/6’ scaling bar
2	Cold Chisels, 1”/25mm width
12	Hardwood wedges, 4”/100mm wide x 8-12”/200-300m length
12	Hardwood blocks, 4x4x12”/100x100mm 300mm length
2	Car jacks, scissor type, 1.4ton capacity
1	Canvas tarp for flyrock protection

Optional:

Qty.	Description
1	SDS MAX hammer drill
4	Large (200WH+ equivalent) batteries.
12	Wedges and shims in 7/8" or larger sizes
4	SDS+ drill bit sized for W&S set above, 200,300mm length
1	SDS+ moil/jackhammer bit for above drill

Level 2 Equipment List

Qty.	Description
1	Micro-Blasting Kit w/2-3 heads
1	Sandbag for each head, theatrical type
1	Air blower for hole clean-out, pump type

Equipment for Sierra Blaster System

Qty.	Description
50	Electric cartridges
50	Booster cartridges
8	10mm SDS+ drill bit for above system, 150-600mm assortment of lengths
1	Blasting machine, 50 cap/3.0J capacity
1	10m firing wire per head
2	Spare 9V batteries

Equipment for EZ-Break system

Qty.	Description
100	Non-electric cartridges
2	5/16" SDS+ drill bit for above system, 150mm length
2	5/16"SDS+ drill bit for above system, 300mm length
2	5/16"SDS+ drill bit for above system, 450mm length
1	Spare CO2 inflator or bulk tank w/regulator and manifold
1	Spare CO2 tank or box of cartridges
1	Spare CO2 hose

Level 3 Equipment List		Level 4 Equipment List	
Qty.	Description	Qty.	Description
1	Blasting machine, 50 cap or 3.0J+ capacity such as the BTS-50	1	100m Detonating cord, 50gr/ft
1	25m firing wire on small reel. 3D printer spools work well.	1	Case, 1/3lb (150g) Kinepak or other small diameter, high-VOD explosive cartridges*
1	Wire cutter/strippers		
1	Blaster's circuit tester	50	Electric or non-electric detonators
5	Rolls, electrical tape	2	Type 3 day boxes
1	Small type 4 portable magazine w/ATF approved locks	2	Type 2 magazines
1	Air blower for hole clean-out, hand pump or cordless		Assorted blasting equipment as appropriate for products in use.
2	Wooden tamping rods, 10,20mm dia.		Equipment as required if using generator or compressed air drilling
50	10g Electric blasting cartridges		
25	20-60g Electric blasting cartridges	2	SDS Max drill bits, 1 ⅜" (38mm) in 24" and 36' lengths (600-1000mm)
12	Unfilled sandbags for stemming		
5	Assorted heavy canvas mats for fly rock protection		*Can be repacked into 1" (25mm) tubes for use with 1 ¼" (32mm) holes.
3	SDS+ drill bit for above 10g cartridge, 450-600mm length		
1	SDS MAX hammer drill		
4	Large (200WH+ equivalent) batteries.		
4	SDS MAX drill bit for above 20-60g cartridge, 450,600,1000mm lengths. 1 ¼" (32mm) or recommended size		
12	Wedges and shims in 3/4 or 7/8" or sized for largest blasting cartridge		
2	SDS+ moil/jackhammer bit for above drill		

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Additional Resources

NPS Blaster's Handbook
https://www.nps.gov/parkhistory/online_books/npsg/explosives/Table_of_Contents.pdf

NXCO Training Manual 21/8/19
https://www.nxburst.co.nz/wp-content/uploads/2020/05/nz_NxbursT_manual_full.pdf

Capping:
https://www.braemoor.co.uk/caving/capping.shtml
http://mdemierre.speleologie.ch/?p=1560
http://www.souterrain.ch/michel/speleo/ticboum.htm