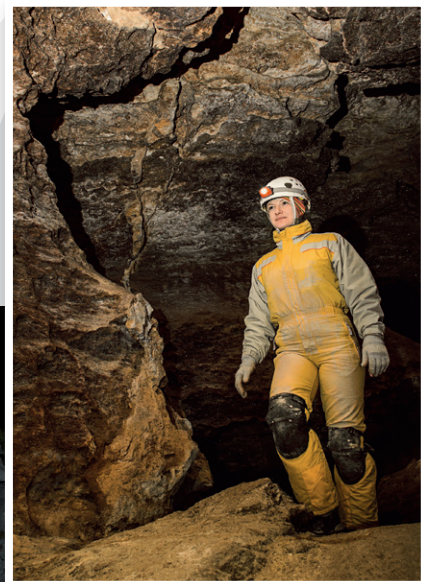


2 CAVE RESCUE

SARTEAM (Portugal)
The Emergency Fire & Rescue Unit (Malta)

Supported by:
Edelweiss (Italy)



Introduction

Human interaction with caves and cave systems has existed for a very long time, for shelter, scientific research, or recreation. However, cave exploration may be inherently dangerous, leading to the need for specialist rescue resources. This chapter gives the reader an insight on various types of caves and their formation, the environment and habitat within, features within cave systems, mapping and orienteering during exploration, caving and rescue equipment, and, rescue planning and techniques.

Definitions

Speleology (from the Latin term '*spelaeum*' meaning cave/cavern) is the science that studies natural cavities and other karst phenomena, aspects of their formation, constitution, physical characteristics and life forms, and their evolution over time.



Figure 2: Caves attract great interest in mankind, both for scientific and recreational reasons.



Figure 1: Hang Son Doong cave, Vietnam.

Officially, the term **caving** refers to the exploration of caves with the intention of surveying and documenting them for the accumulation of knowledge. Meanwhile, the term **spelunking** refers to the exploration of caves as a sport or hobby. However, these two terms are often used interchangeably.

History

The history of caving is as old as man himself. In prehistoric times, caves were the first truly effective shelter from the cold that reigned in the glacial periods. However, it was only in the nineteenth century that caving emerged as a systematic exploration activity of caves.

The French pioneer explorer, Edouard Alfred Martel (1859–1938), is considered by many as the father of speleology. He contributed to the development and dissemination of this discipline. Martel wrote 21 books and over 1,000 articles for magazines on the exploration and surveying of caves. After his death, numerous followers continued on his footsteps to further develop the caving discipline, including prominent figures Robert-Jacques de Joly (1887–1968), who developed the steel cable ladder, Norbert Casteret (1897–1987), and Guy de Lavar (1903–1986).

Ethics

Speleologists, more than anyone else, have the moral responsibility of protecting the caves they explore, minimising impact through the deterioration that occurs whenever a cavity is discovered. One of the golden rules is to not remove anything from inside the cavities. Leave no more than footprints and take nothing more than photographs. In certain locations, not even footprints should be left! Nothing should be disturbed, or worse killed! Caves provide several different types of habitats, as shall be delved into further on within this chapter.



Figure 3: The fragile biodiversity in caves requires visitors to take great care not to endanger it through carelessness.

Cave Morphology

The formation and development of caves is known as **speleogenesis** and it can occur over the course of millions of years. Caves range widely in size, and are formed

by various geological processes. These may involve a combination of chemical processes, erosion by water, tectonic forces, micro-organisms, pressure from the rocks above, and atmospheric

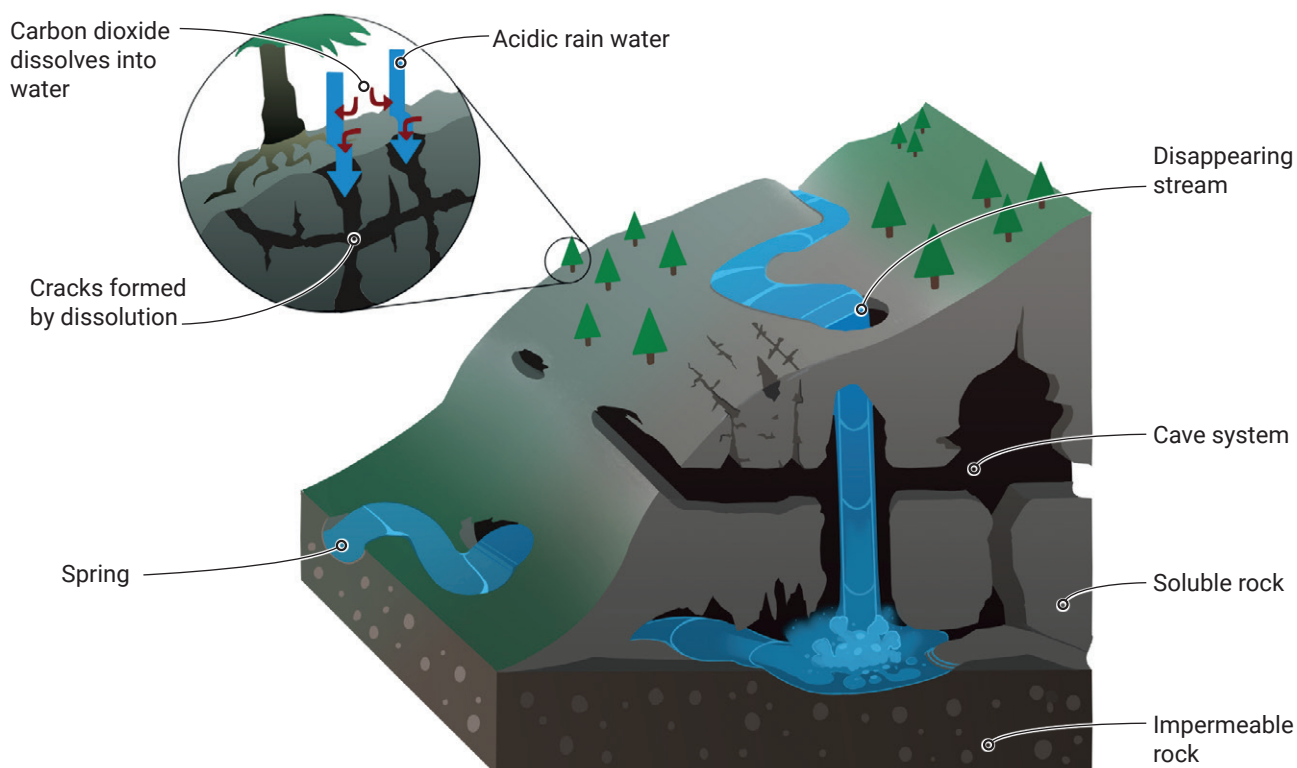


Figure 4: Formation of karst surface and cave features through dissolution of soluble rock.



Figure 5: A lava cave forms at the same time as its surrounding rock through volcanic activity.

influences.¹ The most common types of cave formation are briefly described below.

Cave Formation

Solutional caves (also known as **karst caves**) are the most common, and are formed by the dissolution of soluble rock such as limestone. As illustrated in Figure 4, rainwater dissolves carbon dioxide from the atmosphere, forming carbonic acid with a pH value of 5.6. As rain water percolates through the soil and penetrates through crevices and fractures in the limestone, it dissolves away its calcium carbonates, thus generating underground cavities, and eventually caves.

The dissolution process produces a distinctive landform known as karst, which is characterized by sinkholes and underground drainages. Limestone caves are often adorned with

calcium carbonate formations known as speleothems. These formations, generated by the deposit of secondary minerals, include flowstones, dripstones, pore deposits and pool deposits.

Primary caves are caves which were formed at the same time as the surrounding rock. The most

common are **lava tubes**, formed through volcanic activity (Figure 5), and **reef caves**, formed by ridges and open hollows during the growth of the reef.

Sea caves (also known as **littoral caves**) are found along coasts, formed primarily by erosion induced by sea wave action on a weak zone within the host rock (Figure 6).

Glacier caves (Figure 7), are formed by melting ice and flowing water within and underneath glaciers, forming pathways and caverns through the ice at the bottom of the glacier.

Erosional caves form entirely through erosion induced by flowing streams (or wind) carrying rock and other sediments. They can form in any type of rock, including hard rocks. These caves start from a zone of weakness (such as a fault or joint) to guide the stream, which then continues to erode the rock, deepening the cavity until a cave forms (Figure 8).

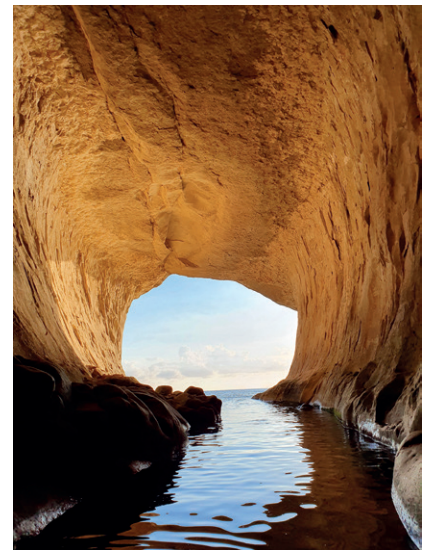


Figure 6: Sea caves are formed through wave action, wearing the weaker rock faster than its surrounding, thus creating a cavity.



Figure 7: Glacier caves form through the melting of ice at the bottom of the glacier.



Figure 8: Erosional caves form by the action of flowing water or wind leading to erosion of the rock.

Though there are several types of caves, this chapter focuses on karst caves, as these are the most frequently occurring. Figure 9 illustrates some of the associated

features both at the surface as well as within cave systems and gives a basic idea of the formation process of karst caves.

Speleothems

Speleothems are secondary mineral deposits and form through the action of carbon dioxide in acidic water, which

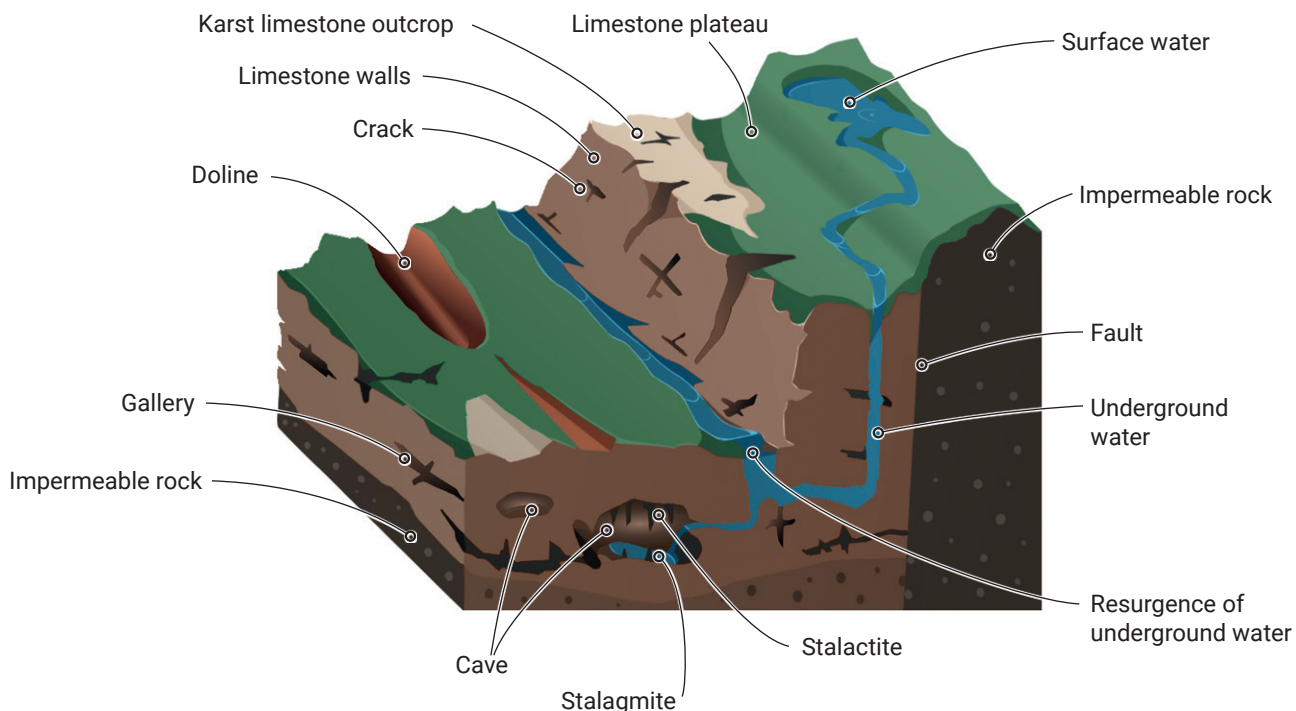


Figure 9: Formation of karst landscape and cave systems.

escapes in the airiness of the cave and the dissolved calcite hardens once again. Speleothems take various forms, depending on whether the water drips, seeps, condenses, flows, or ponds. Many speleothems are named for their resemblance to man-made or natural objects. Some types of speleothems are described below.

Dropstone: Water emerging from a joint in the cave ceiling hangs for a while as a pendant drop. During this time, a small amount of calcium carbonate is deposited in a ring where the drop is in contact with the ceiling, before the drop falls off. This process is repeated over and over again, and an icicle-like speleothem called a **stalactite** builds up (Figure 10). Stalactites vary in shape from thin, straw-like features to massive pendants or drapery-like forms. Stalactites have a central canal that carries water from the feeder joint to the stalactite tip. Stalactites may grow so large that they cannot support their own weight, and the broken fragments of large



Figure 10: Stalactites form on the ceiling as water seeps in and deposits minerals, before it falls to the ground.



Figure 11: Stalagmites form on the ground as water droplets fall from the ceiling, leaving minerals on the ground as water flows away or evaporates.

stalactites are sometimes found in caves.

When the drops fall to the floor of the cave, additional mineral matter is deposited and **stalagmites** are built up. Stalagmites also take on many forms, from slender broom-handle to mound and pagoda-like shapes (Figure 11). Stalagmites consist of superimposed caps or layers and do not have a central

canal. Stalagmites can reach heights of tens of metres.

Columns are formed by the union and fusion of stalagmites and stalactites, or when stalactites reach the floor of the cave.

Flowstone: Water flowing along ledges and down positive-sloping walls, leaves behind sheets of calcite which build up a massive deposit known as flowstone (Figure 12). The deposits may grade into thin sheets called *draperies* or *curtains* where they descend from overhanging portions of the wall. Some draperies are translucent, and some have brown and beige layers.

Speleogens: These are geological features within solutional caves and are created by the dissolution of bedrock. Speleogens can form where the bedrock is not uniform in chemical composition. Consequently, through time, the less soluble rock dis-



Figure 12: Flowstone form in a similar way to stalactites, except that they flow along sloping ledges and thus form drape-like vertical structures.

solves at a slower rate than the adjacent, more soluble rock. The less soluble rock tends to stand in relief and projects from walls and ceilings of caves (Figure 13).

Karst Surface Landscape

Karst landscapes have two peculiar characteristics which make them immediately identifiable even where rocks are covered by soil and vegetation. One is the particular form of dissolution on the surface and the second is the practically total absence of watercourses on the surface, as all the water, or most of it, is rapidly swallowed into the depths. The best-known and most striking karst forms



Figure 13: As parts of the soluble bedrock dissolve more quickly than others, speleogens form over time on what eventually become the ceiling and walls of a cave.



Figure 14: Karst landscape features include characteristic furrows and small depressions in the bedrock.

are the karren or lapiez, furrows and small depressions created by the dissolution of rock (Figure 14) which are formed on a small scale. Another karst form is the doline, a closed funnel or bowl-shaped hollow sinkhole. In most cases, dolines which form by collapse give access to cave systems underneath and are most often shafts of a sub-circular cross-section (Figure 15).

Dolines can be very deep, and at times allow direct access to flooded systems, as in the case of cenotes (Figure 16). More complex and larger forms are polje and ponores. Polje consist of large, flat-bottom depressions characterised by caves. Ponores act alternately as sinkholes during the dry season or as



Figure 15: Dolines, or sinkholes, form large depressions in the surface relief, and sometimes may be connected to cave systems underneath.



Figure 16: Part of a doline may collapse into a cave underneath, which may eventually be flooded to form a cenote.

springs during the rainy season, when water flowing within the karst system exceeds its drainage capacity. Water rising up through the sinkholes from which it flows out often forms temporary lakes.

Underground Landscape

Cave morphology is often complex and difficult to describe, however there are a few elementary features, some of which are illustrated in Figure 17.

Galleries are prevalently horizontal or slightly inclined,

and are generally large, as opposed to passages.

Meandering channels (also known as **canyons**) are horizontal tracts, characterized by very deep and narrow channelling, which have been eroded by flowing water. Very often, these are the most difficult passages to explore, because they are frequently very narrow at the base and have flowing water courses that can be quite violent.

Shafts tend to be vertical and can either be perfectly cylindrical tubes with smooth vertical walls, or may develop in ledges or steps with erosion potholes at the bottom. Shafts formed in a zone of saturation or at high mountain altitudes due to the presence of snow or ice generally have smooth walls. Vertical shafts originating from water courses on the surface, which recede due to the erosion of a waterfall, generally have multiple levels. Shafts can be of incredible heights with absolute vertical drops reaching up to 500 metres.

Chambers (also known as **rooms**) form following collapses, and are the places where shafts and galleries meet. The size of an underground room may, at times, be immense.

Cave Ecosystem

Cave ecosystems are characterized by lack of light. As a result, there is a dependence on connectivity to the surface or the supply of organic material brought about through different mechanisms as a supply of energy (Figure 18). Such energy sources sustain

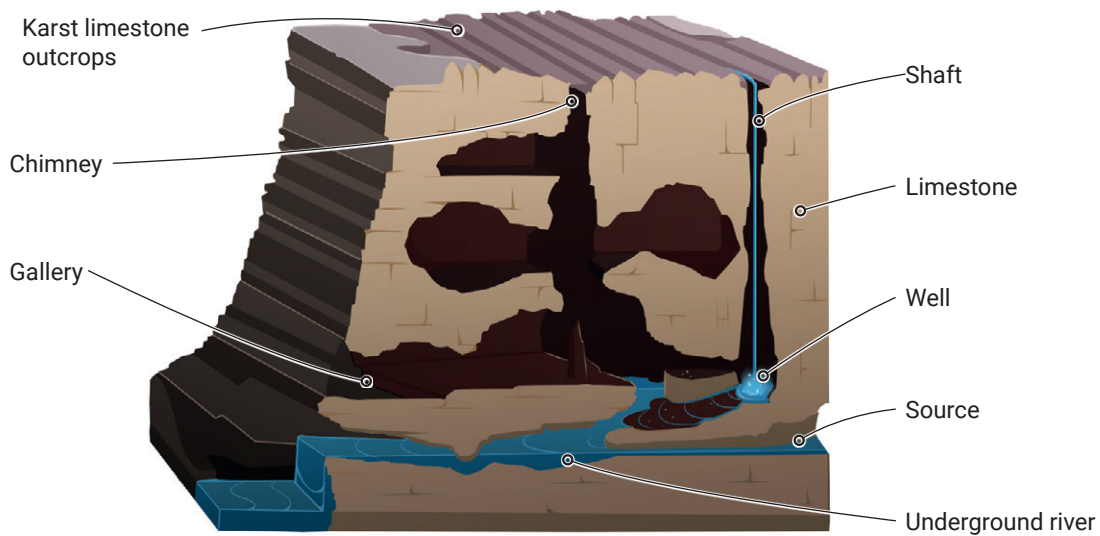


Figure 17: Underground karst landscape features.

the activity of decomposers and microorganisms that feed omnivores and herbivores. These, in turn, sustain predator requirements. Predators support the ecosystem through the generation of more organic material.

Caves are actually part of a larger karst ecosystem that is the entire drainage basin through which water, energy, and matter move. Within these karst ecosystems lie a diversity of habitats and organisms that can differ substantially, yet are highly inter-

connected and interdependent. While often thought of as stable, karst ecosystems are extremely dynamic and subject to natural and human-imposed disturbance.

Cave Zones and Life

A cave has three distinct zones: the **entrance zone**, the **twilight zone**, and the **dark zone**. These three zones are essentially defined by the extent of sunlight access (Figure 19). The zonal conditions impact the type of

life that can be sustained, and hence are directly related to the categories of animals that live there: troglaphiles, troglloxenes and troglobites. These may inhabit different parts of the cave for different spans in their lifecycle.

The **Entrance Zone** defines the entry point of a cave, which usually receives adequate direct sunlight. This part of the cave opens to the outside environment and experiences varied temperatures, as it adjusts to the external environment and

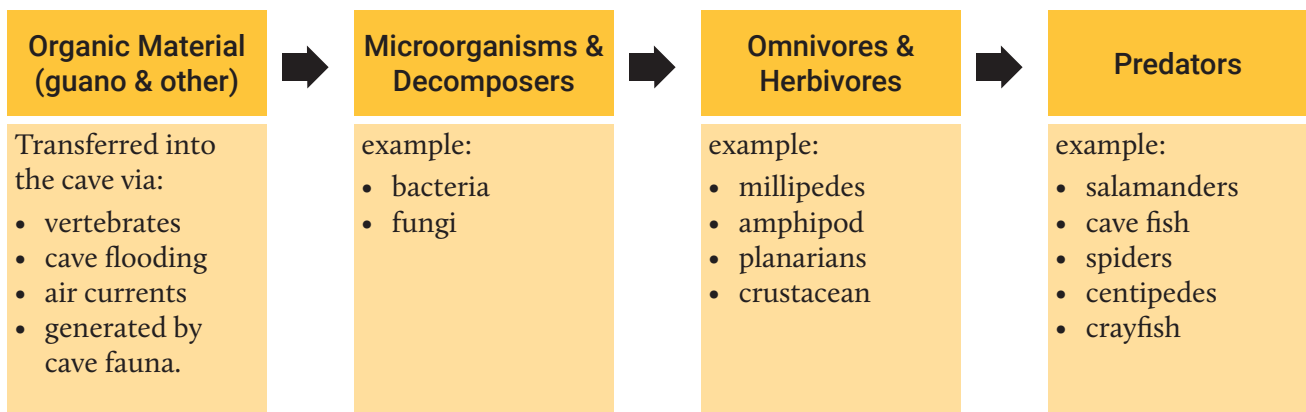


Figure 18: The food chain within the cave ecosystem.

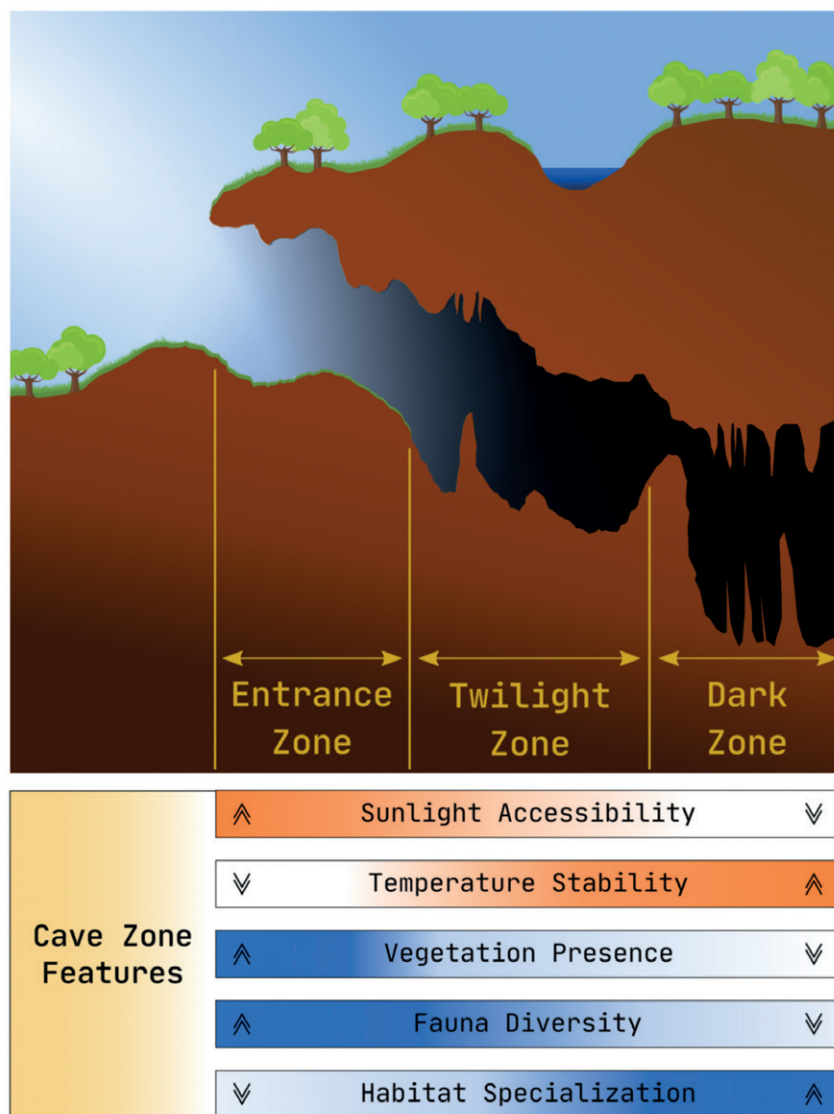


Figure 19: Cave zones offer distinct habitat conditions, in terms of physical characteristics (sunlight access and temperature changes) and biological characteristics (vegetation, fauna diversity and specialisation).

climate. The entrance zone can be either naturally formed or created by humans.

Green plants grow in this zone because of sunlight access, which is needed for photosynthesis. It can be inhabited by various forms of life, including beetles, small rodents, spiders, snakes, salamanders, earthworms, millipedes, owls, and snails. Additionally, certain terrestrial animals,

such as raccoons and bears, may take refuge in the entrance zone to sleep, eat, and nest. Within this zone, we also find accidentals, which are organisms that wander, fall or are washed into the cave. This category includes snakes, groundhogs, frogs, and turtles, which cannot survive inside a cave, and will therefore die if they do not eventually exit. If accidentals die inside a cave, they

become a rich source of nutrients for the cave ecosystem.

The **Twilight Zone** is the part of a cave that receives a small amount of sunlight through indirect rays, since it is not too far from the entrance. This zone is cool and damp and there is minimal fluctuation in temperature. The twilight zone is shared by both outside organisms and cave dwellers, resulting in the transfer of energy, in the form of nutrients, from outside the cave to the inside.

Animals that live in the twilight zone are troglloxenes (also known as **subtroglloxiles**). This category refers to cave guests. These are animals that use the cave only for shelter, breeding or feeding, but leave for other stages of their lifecycle as they cannot live exclusively in such habitats. All cave mammals can be classified as troglloxenes, with the most common ones being bats (Figure 20), bears, skunks, and raccoons. Spiders, bats, moths, cave crickets, cave beetles, and millipedes may also be found in the twilight zone.

The **Dark Zone** is the deepest and darkest part of the cave. It is located at the back of the cave and receives no sunlight. As a result, the dark zone is always cool, dark, and its temperature is constant.

This zone is inhabited by highly specialist species, known as trogllobites, such as the eyeless shrimp and blind crayfish. These animals spend their entire life cycle within a cave and would not be able to survive outside due to the way



Figure 20: Bats, like other cave mammals, spend only a part of their lifecycle inside the cave.

in which they have adapted to cave conditions. Animals in this zone possess certain features like poorly developed or absent eyesight but with long antennae and legs, allowing them to move and locate food more efficiently in the dark. They have little or no pigmentation, hence are usually white, pink or colourless. These dark zone dwellers, such as several types of cave fish, insects, crustaceans, annelids and arachnids, have also developed the ability to live with very low metabolic rates, allowing them to survive without food for long periods.

Another category of cave-dwellers is that of the troglophiles, animals that can survive outside the cave, but would prefer living inside it. Despite this, they have not specialised in a manner that prohibits them from thriving outside the cave, and thus, they are fully capable of dwelling for

their entire life cycle either within the cave or outside. Given their preference to remain within the cave habitat, they generally leave the cave only in search of food. Some examples of troglophiles include beetles, worms, frogs, salamanders, crickets, spiders (Figure 21) and even some



Figure 21: Spiders, similarly to other troglophiles, spend most of their time inside the cave.

crustaceans like crayfish. Given the partial specialisation for cave life, these animals would tend to be found in the entrance and twilight zones of the cave.

Cave Surveying and Cartography

A cave survey is a map of all or part of a cave system. Such survey may be produced to meet differing standards of accuracy depending on the cave conditions and equipment available underground. Cave surveying and cartography is the creation of an accurate and detailed map. This is one of the most common technical activities undertaken within a cave and is a fundamental part of speleology.

In-Cave Data Collection

The goal of a cave survey is to collect as much information as possible on the cave. During the survey, the distance and angles



Figure 22: Speleologists perform cave surveys to document the characteristics of a cave.

between selected temporary fixed locations (called stations), chosen primarily for their ease of access and clear sight along the cave passage, are measured and recorded. Sketches of, and notes about, the cave are also produced.

Survey equipment includes the following:

- Compass for measuring horizontal angles;
- Clinometer for measuring vertical angles and heights;
- Measuring tape or range finder for measuring distances;
- Hard-cover notebook with waterproof paper; and
- Pencil or pen.

Sketch maps record straight-line data, details of passage dimensions, shape, gradual or

sudden changes in elevation, the presence or absence of still or flowing water, the location of notable features and the material on the floor.

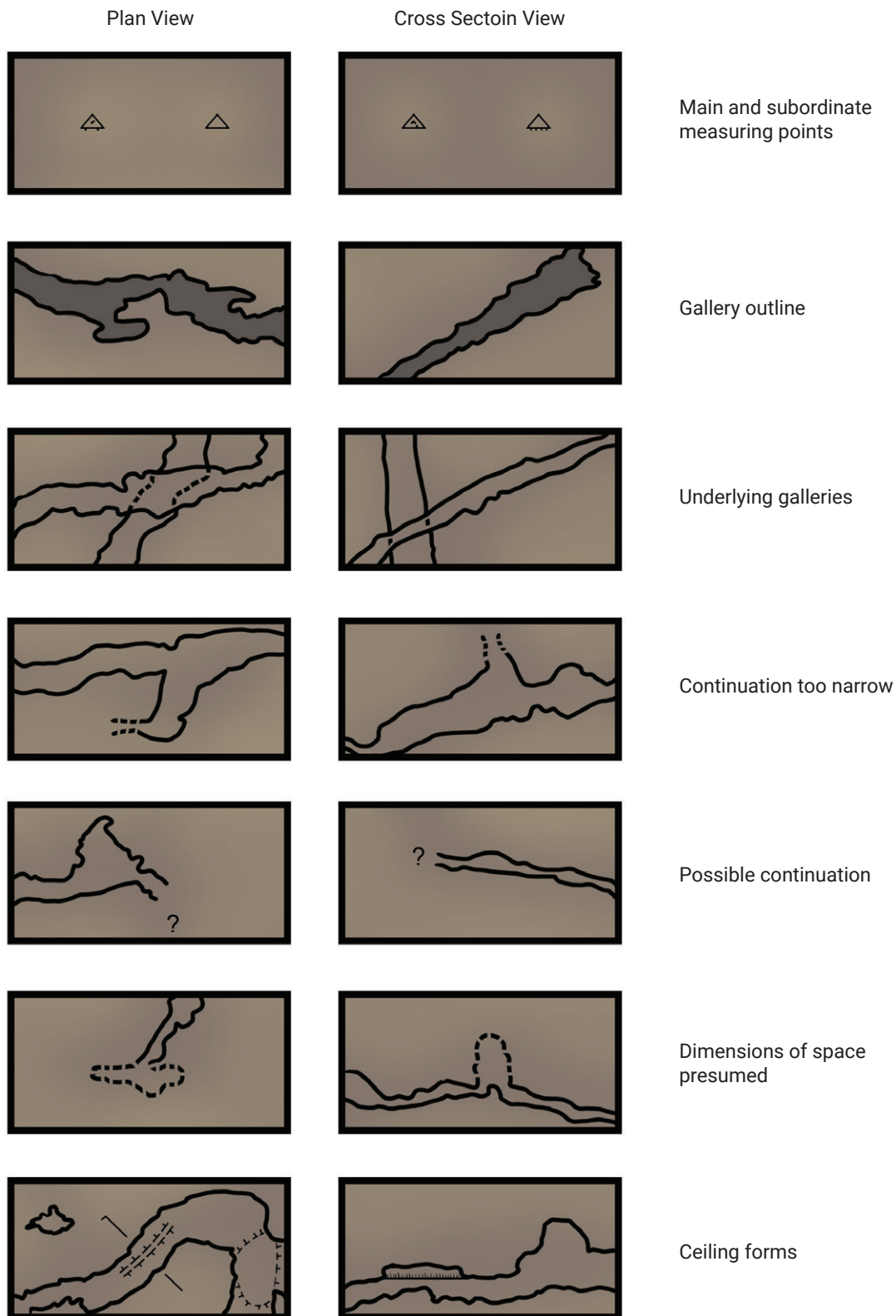
Finalising the Cave Map

After the survey has been completed, all in-cave notes and sketches are handed over to a cartographer, who in turn analyses the recorded data, and converts them into two dimensional measurements through geometrical calculations, creating a line-plot. Using the additional data of passage dimensions, water flow, and floor/wall topography recorded at the time, such details are then

drawn around the line-plot to complete the cave map.

To successfully read a cave map, one needs to understand how the general outline is drawn, what the different symbols mean, what the orientation is, and any additional notes left by the surveyor. Figure 23 provides examples of symbols which are used in cave maps to provide a good representation of the features and characteristics to be expected within the cave. One may find various sets of symbols, developed over time by the likes of the National Speleological Society (NSS) and the Australian Speleological Federation (ASF).

A cave map is generally composed of a plan view, a cross-section showing the vertical shape of passages and a side



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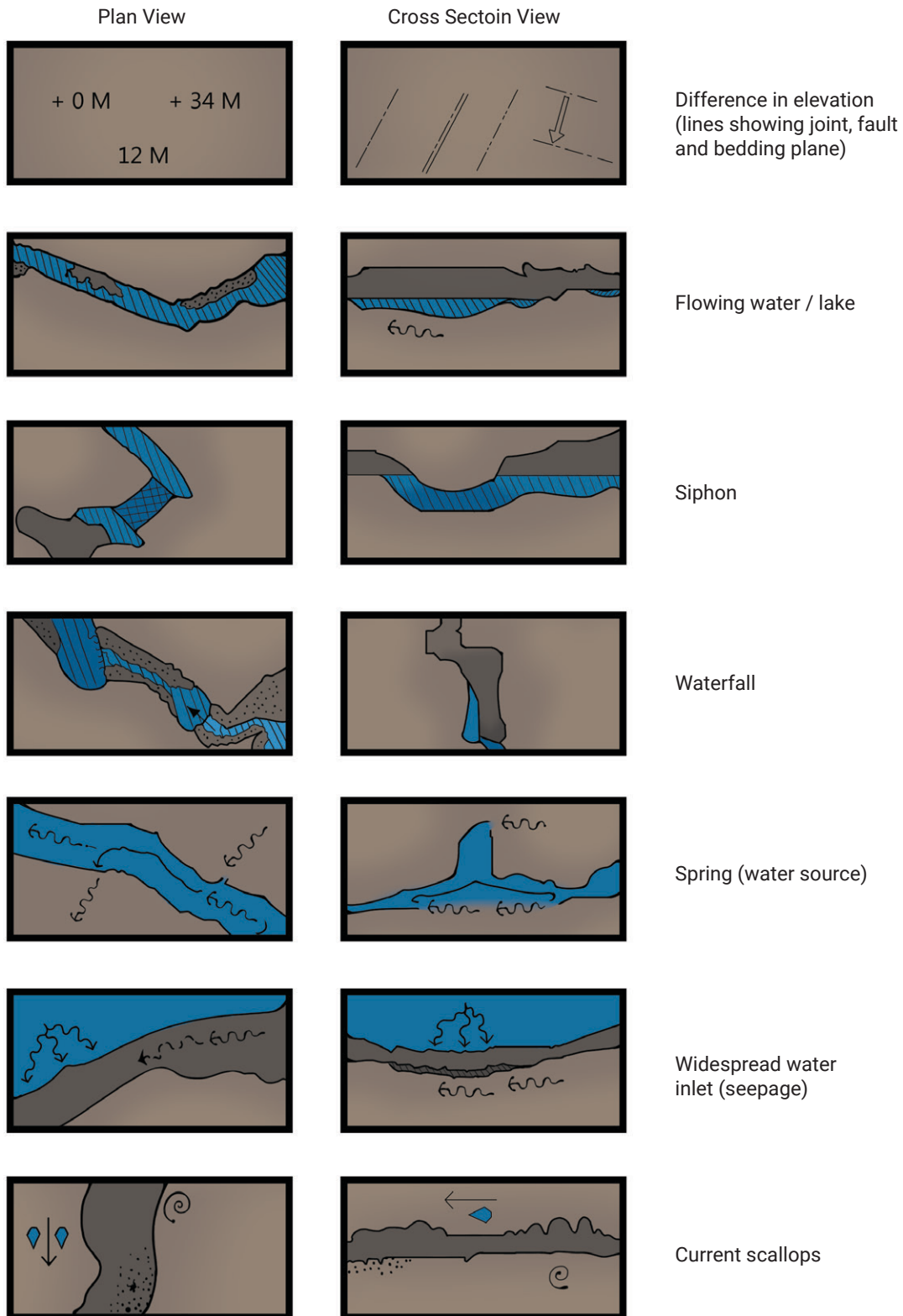


Figure 23: Cave maps make use of conventional symbology to depict the various formations and characteristics of the cave being surveyed and documented. The above selection of symbols is non-exhaustive and is based on ASF Cave Map Symbols.

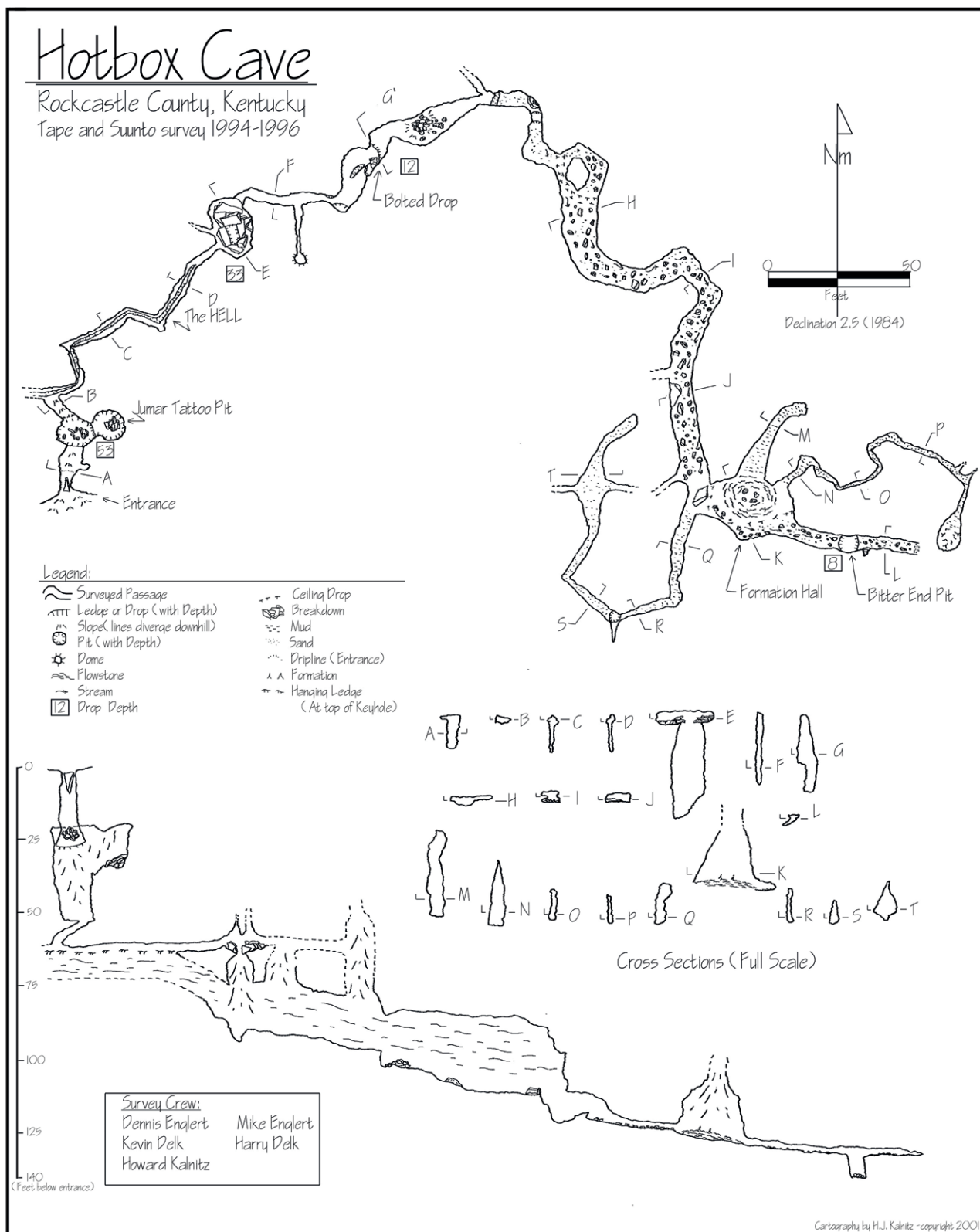


Figure 24: Map of the Hotbox Cave, in Rockcastle County, Kentucky, US.

view or projection, showing the different levels of the cave and how these connect. The map should include:

- cave name and number;
- area name;
- scale;
- orientation;
- legend;
- survey date;
- cave walls, generally drawn in a thick line;
- topographic details (floor and roof steps, and slopes);
- contents such as water, sediments and fauna;
- surface features such as dolines, streams and boundaries;
- navigation and rigging information; and
- other special features.

Figure 24 shows an example of a cave map – the Hotbox Cave. At the top there is a detailed plan providing a good overview of the length, shape, and layout of the cave. The map also contains markers for special passages, with cross-sections for each of the passages. This gives a great impression of what to expect inside the cave. At the bottom of the map, a projection view including the scale of depth gives a general idea of the slope and ceiling heights.

Essential Caving Equipment

It is very important to have the right caving equipment in a technical cave expedition or a cave rescue operation and the following checklists provide an

overview of these items. Gear, equipment and clothing **made specifically for caving** should be used as the harsh conditions inside caves test equipment to its limits. Climbing equipment is not adequate, and will wear out and fail in the trying conditions encountered in a cave.

Personal Caving Equipment

The personal caving equipment that is required by a rescuer is listed in Table 1 and further illustrated in Figure 25, which shows a cave rescuer wearing the required clothing and equipment.

Team Caving Equipment

The necessary equipment depends on a number of variables, including the horizontal and vertical profile of the cave, distance and topography. The basic team equipment required to sustain a functional rescue team of three to four personnel includes:

- 400 metres of static rope (split into 50 metre lengths);
- 8x 3 metre lashing rope;
- 50x steel carabiners;
- 10x single pulleys with carabiners;
- 6x pear shaped alloy carabiners;
- 2x descender devices;
- 2x kits containing a caving hammer, self-drilling anchors, and complete caving bolt hangers;
- Cordless drill with durium bit;
- Radio for communications;
- Stretcher; and
- First aid kit.

Survival, Camping and Food Supplies

Survival is a critical aspect of a cave expedition or cave rescue, as the caving team has to live and be fully functional inside the cave for hours or possibly days.

It is extremely important that all rescue personnel entering the cave are well-prepared and equipped. Apart from personal and team caving equipment, rescuers must also be equipped with appropriate survival equipment and supplies. The team must also be conversant with the cave map and its topography prior to entering the cave. Caves can be extremely confusing, and the rescue team needs to exercise situational awareness throughout and mark the way out at all intersections. Furthermore, members of the team must always remain together. A resting schedule should be established, and adhered to, thus avoiding exhaustion. Areas designated as camp sites (with basic necessary facilities) must be identified to facilitate rest.

It is imperative that all rescuers stay warm and dry. Caves are frequently cold, and hypothermia is one of the most dangerous hazards that may be encountered. While food, water and battery supplies should be rationed and conserved, it is important to hydrate well and avoid movement in total darkness. Caves offer dangerous unpredictable environments, and the risk of injury outweighs all other hazards.

Personal caving equipment	
Helmet	• A helmet is a must for head protection. • Caving helmets are rugged, low profile and lightweight. • A good chinstrap is mandatory. • Needs to have attachment points for a headlamp.
Headlamp	• Good quality, rugged, and easy to operate when wearing caving gloves. • Adjustable brightness is useful. • Avoid headlamps with elastic headbands which can break. • Mount the headlamp on the helmet.
Backup independent light sources	• The basic rule is to have at least three independent light sources. • A headlamp mounted to the helmet as the primary light. • A spare headlamp carried in the pack is the second light. • The third light may be a flashlight in a secure inside pocket. • Keeping the light sources in different places (helmet, pack, inside pocket) ensures that in the event of getting separated from some of the equipment, one does not lose all light sources.
Boots	• Sturdy boots for caving with good rubber soles. • Wellington boots (calf-high rubber boots with a grippy sole and protective steel toe-caps) are commonly used by cavers.
Oversuit	• A one-piece, abrasion-resistant, flexible, caving cordura oversuit with neoprene and velcro seals.
Undersuit	• Fitness, body weight and degree of fat, age, and metabolism are all factors that affect how easily one gets cold. • It is important to be properly prepared. • Clothing requirements will vary with the temperature and humidity of the cave, duration, degree of activity, and how wet one is expected to get. • Polypropylene long underwear as a base layer is one of the most important items for comfortable caving, with synthetic jogging pants and shirt or sweatshirt as an intermediate layer.
Socks	• Neoprene socks are recommended. • Toenails should be properly trimmed. • Zinc oxide tape over hot-spots may prevent blisters.

Gloves	• Dextrous. • Flexible. • Waterproof. • Quick to dry. • Made of rubber.
Knee pads	• Thin, soft and flexible knee pads should be worn.
Harness	• A full body speciality caving harness (both waist and chest harness). • Caving harnesses should be lightweight, made from durable material and high strength webbing, and have minimal or no loops, which would otherwise get caught on rocks.
Chest ascender	• Fitted to the chest harness to aid the ascent. • Used in combination with hand or foot ascenders
Hand ascender	• Complete with foot loop, a three-point cow's tail or Purcell Prusik and carabiners. • Used in combination with chest ascender to help during ascents. • Can also be used as a rope grab, to attach other equipment such as pulleys.
Descender	• Complete with friction carabiner. • The descender must be specifically designed for caving (to avoid blockages caused by mud), such as the Petzl STOP or Petzl SIMPLE.
Cow's tail positioning lanyard	• Three-point Purcell Prusik. • Complete with carabiners. • At least one attachment point should have an adjustable length.
Single pulley	• Complete with Prusik and a carabiner.
Progress Capture	• Petzl Shunt, Petzl I'D or similar. • Complete with a carabiner.
Cave backpack	• A flexible, small, nylon, heavy duty, water proof backpack with shoulder straps, and without any outside pockets. • The pack should contain spare batteries, chemical light sticks, waterproof and shockproof watch, food and drinks, personal first aid kit (which includes a space blanket), and a folding multi-tool with a knife.

Table 1: Characteristics and considerations for personal caving equipment. Some devices are illustrated in Figure 27a-f.



Figure 25: A cave rescuer wearing some of the required personal caving gear. Some of the equipment is not shown.



Figure 26: Cave rescue operations may take days, therefore rescuers may need to pitch tents to rest.



Figure 27: (a) Chest ascender. (b) Hand ascender. (c) Three-point Purcell Prusik (cow's tail) (d) Friction carabiner (e) Descender devices: SIMPLE (left), STOP (right) (f) Progress capture device.

Survival Equipment: The following essential equipment should be carried by every rescuer as part of the survival kit. The expected conditions and duration of the rescue operation drive the need for each individual item:

- Sleeping bag
- Sleeping pad
- Lightweight small tent
- Camping stove
- Sand bags

Sustenance: Water and food are very important. Food must be

light, nutritious and containing the necessary sources of energy. Caving is an activity that involves substantial energy consumption. Granola or cereal bars, dried fruit, trail mix, chocolate or anything that is not completely inedible after being bashed over rocks is a suitable snack. For longer durations it is recommended to opt for pasta.

Water should be carried in durable plastic (Nalgene or Platypus) or metal bottles. Nalgene and metal containers are nearly indestructible. Platypus bottles are soft, and could

possibly puncture. Disposable water bottles have leaky tops and can crack, so avoid carrying them if possible. Lots of water will be required during the activity!

Maintenance of Caving Equipment

Caving equipment is crucial to the safety of the operator or the casualty in case of a rescue. Careful maintenance is therefore very important to ensure that the equipment does not fail when needed. The manufacturers' instructions on care and

maintenance should always be followed. In *Rescue Techniques for Emergency Response Volume 1*, both *Chapter 1 – Basic Rescue* and *Chapter 3 – Rope Rescue* provide recommendations on standards and care of equipment related to ropes. In caving and cave rescue, environment and conditions to which equipment is subjected makes it even more important to rigorously clean the equipment to remove any dirt and mud. After cleaning it should always be thoroughly dried (Figure 28) and inspected for deterioration and damage before packing it to be ready for the next use.

Rescue Planning

The success or failure of a cave rescue operation mainly boils down to the emergency plan and responses, the inter-organisational coordination, the skills and the infrastructure that is needed to respond effectively. Cave rescue is extremely complex, with the major constraints being space and time. It is therefore crucial that emergency plans are optimised for maximum efficiency.

With reference to a cave rescue in Germany (Riesending cave) in June 2014, 728 personnel were involved in the retrieval of the victim. A total of five temporary encampments were established during the rescue operation, strategically located to provide sufficient comfort for each team and the victim during the extrication. The costs reached nearly one million euros, and the operation lasted 11 days. The

difficulty and complexity of this operation were unprecedented.

To facilitate planning of the rescue operation, a number of questions help to gather as much information as possible, together with a number of steps that may need to be carried out in preparation for the rescue operation (Table 2). A team briefing is also conducted before entering the cave to ensure that the team members are aware of all the necessary information (Figure 29).

Important considerations during the rescue operation

Extractions involving complex progression techniques (refer to the section *Progression Techniques*) should only be started once all teams are available and ready in position. This is important to avoid unnecessary lengthy stops while waiting for the next team to be available. A cave rescue team is usually formed by three personnel, with one being appointed team leader. The team leader is responsible for the decision on the extrication technique to be used on the spot while the responsibility of the rescue commander is to coordinate the strategic management of the rescue with all responsible individuals. Each team must have all the necessary equipment and supplies as explained in the section *Essential Caving Equipment*, as equipment is never shared between teams.

Whenever possible, nurses or doctors should accompany the victim, allowing a better

assessment of the condition and to administer emergency drugs if necessary. If this is not possible, the local emergency regulation body should be consulted on whether there is a legal allowance or protocol for emergency drug administration by first responders. Also, the victim must be continuously protected from the cold and humid environment. The victim will be spending lengthy hours strapped to a stretcher, making it critical to prevent complications arising from deep vein thrombosis. Very often, due to challenging passageways, the trauma protocol may have to be adapted accordingly.

Progression Techniques

The goal of the rescue operation is to transfer the victim from the location of the mishap to the outside of the cave where the victim may be treated by medical personnel. For this reason, this part of the operation is referred to as progression within the cave. Rescuers utilise a number of techniques to progress over the challenging terrain and conditions inside the cave.

Rope Progression Techniques

Single rope techniques are employed within vertical cave systems. These techniques range from simple processes, such as descending or ascending a free hanging rope, to more complex aspects. Some of the more complex manoeuvres include changing from one rope to



Figure 28: Once cleaned, the equipment should be dried thoroughly before being packed again.



Figure 29: A team briefing is conducted before the start of the rescue operation.

Rescue operation planning considerations

Logistics

- Is the cave entrance accessible? How can it be reached?
- What is the local weather?
- What is the cave type?
- What is the cave topography?
- Is the location of the victim known and what is the travel distance and depth within the cave?
- Worst case scenario: What is the maximum travel distance into the cave and what is the greatest depth that can be reached?
- What is the quantity and depth of vertical shafts?
- Are there any known difficult passageways and what are the associated challenges?
- Is it expected that rescuers find material that needs to be cleared?
- Are any drainage problems expected and what tools are available to clear, divert and drain the area?
- Are there any siphons?
- What are the quantities, availability, expertise and equipment of the rescue personnel?

Victim(s)

- What details of the accident are known?
- What is the number of victims?
- Is there any background information on the victim(s) including age, sex, build, medical conditions and purpose for being inside the cave?
- How long has the victim been inside the cave?
- What is the state of consciousness of the victim?
- What are the probable or suspected injuries?
- Is the pain scale (1–10) known?
- Is the victim's condition known to be stable?
- Are there any known special requirements?
- What is the risk of hypothermia?
- What is the risk of dehydration?
- What is the risk of shock?
- What is the risk of sepsis?
- Is onsite medical stabilization (advanced relief) available?

**Operation
Organisation**

- Coordinate with the local rescue regulation body;
- Organise transport to the cave;
- Plan and coordinate access to first aiders as quickly and safely as possible;
- Establish a communication channel with first aiders;
- Draft the extrication plan (split into sections based on the cave's topography, particularly by vertical shafts);
- Organise logistics, including food and technical supplies;
- Organise the operational teams, assign responsibilities, and assign respective sections;
- Organise base camp (including communication, equipment and food);
- Organise rescue personnel work/rest schedules and replacement system;
- Coordinate the onsite medical stabilisation team for the victim transfer to hospital;
- Organise decontamination for all cave rescuers and kits.

Table 2: Rescue operation planning considerations.



Figure 30: Rescuers extricate a victim from a cave.



Figure 31: Rescuers waiting their turn to negotiate tight passageways.

another, moving along horizontal lifelines (traverse lines), passing obstacles (rebelay or deviations) as well as technical rescue and counterweight systems. Double rope techniques are utilised when handling the laden stretcher, as explained further on in the section *Stretcher Handling Techniques*.

Ascending (also known as a **Prusiking**) utilises a chest and a hand ascender with a foot loop (or alternatively a foot ascender) to climb up a rope



Figure 32: Rescue teams are assigned tasks by the rescue coordinator. A number of teams work in parallel at different levels along the route, and once ready, they move to the next task.

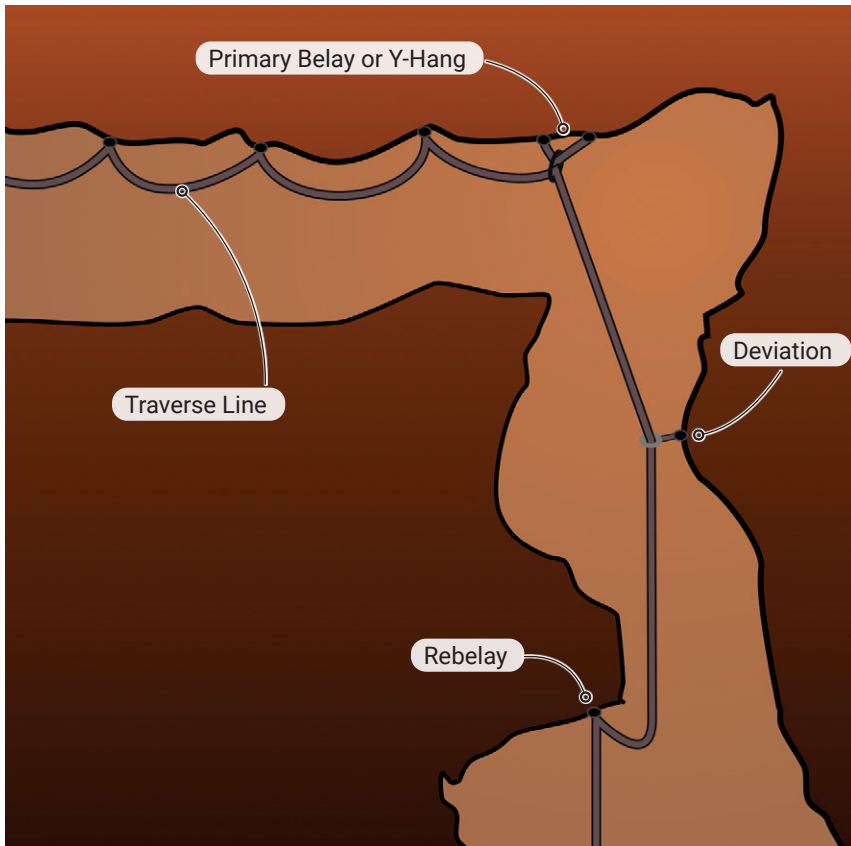


Figure 33: Some rope rigging situations necessitate the rescuer to be proficient in certain rope progression techniques.

(Figure 34). Progress up the rope is made by shifting weight from one ascender to the other and advancing the unweighted ascender. The climbing motion cycles between sitting in the seat harness and standing in the foot loop, somewhat resembling the movement of a frog. A three-point Purcell Prusik is used for various rope manoeuvres, with the longer (and adjustable) of the two tails used as a tether to attach to the hand ascender.

Descending (also known as **Abseiling** and **Rappelling**), in the cave environment, is often done through the use of a descender such as the Petzl STOP or Petzl SIMPLE. These benefit from allowing a lot of

friction control in a variety of conditions (especially mud), do not cause twists in the rope, and allow for the attachment to and detachment from a rope without disconnecting the device from the harness. The descent is controlled through the combined action of pressing the handle (typically with the off-hand), and applying tension on the free rope coming out of the descender (typically with the dominant hand). The descender should be locked (Figure 35a-b).

Changeovers consist of switching between descending and ascending (or vice versa) on a rope. This is a fundamental vertical skill for cave rescuers,



Figure 34: To reach upper levels, the rescuer utilises a chest ascender together with either a hand ascender with foot loop or a foot ascender.

following a number of steps as outlined below.

Changing from ascent to descent:

1. attach the descender to the rope and lock off;
2. step on the foot loop to unload the chest ascender and remove it from the rope;
3. shift the weight onto the descender;



Figure 35: Sequence for locking (a) the Petzl STOP and (b) the Petzl SIMPLE.

4. remove the hand ascender from rope;
5. remove the rope from the foot ascender, if being used;
6. unlock the descender and start descending.
5. remove the descender from the rope;
6. attach the rope to the foot ascender, if being used
7. start ascending.

Changing from descent to ascent:

1. lock the descender;
2. attach the hand ascender with foot loop to the rope;
3. step on the foot loop to unload the descender;
4. attach the chest ascender to the rope, taking up any slack in the rope;

Rigging rebelay and deviations (Figure 36) are very important in cave environments to avoid the rope from meeting rub points, waterfall, or loose rock. While a rebelay bears the weight of the rescuer, a deviation point does not. Deviation points are most often used where there is not a sufficiently strong anchor point for a rebelay. It is important that deviation points are not loaded with the full weight.

Crossing deviations or rebelay are done by following the steps outlined below.

Descending past a rebelay:

1. Abseil until level with the rebelay knot;
2. Clip the short cow's tail into the rebelay knot;
3. Abseil until weight is transferred to the cow's tail;
4. Remove the descender from the upper rope, attach it to the lower rope, and lock;
5. Shift the weight off the cow's tail by either standing on the rebelay loop, or else use the hand ascender and foot loop;

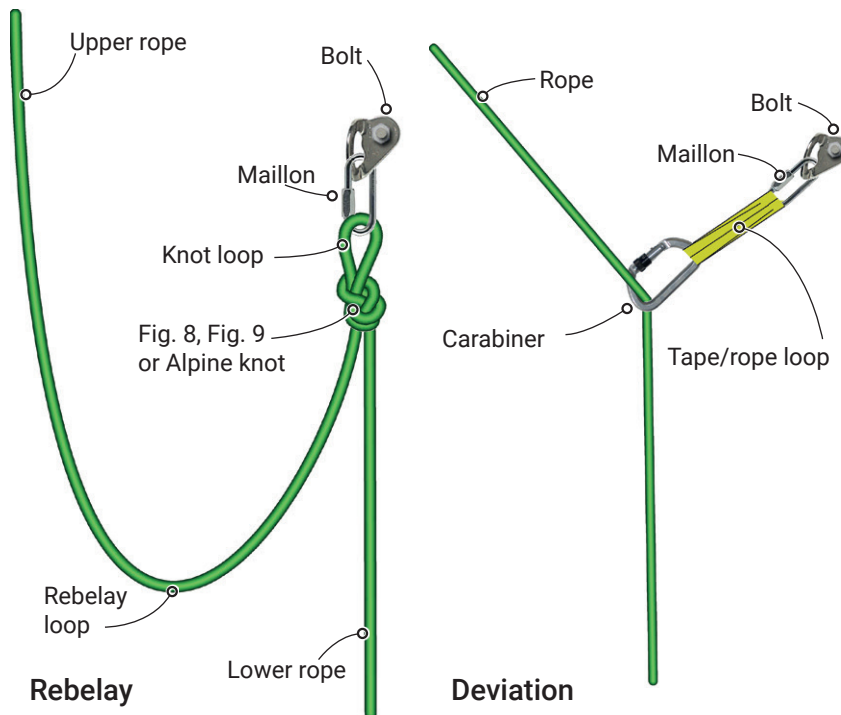


Figure 36: The structure of a rebelay and a deviation.

6. Unclip the cow's tail, and shift the weight onto the descender;
7. Remove the ascender (if used), unlock the descender and continue abseiling.

Ascending past a rebelay:

1. Climb to just below the rebelay knot;
2. Clip the long cow's tail into the rebelay knot;
3. Stand on the foot loop, remove the chest ascender, and attach to the upper rope;
4. Shift weight onto the chest ascender, remove the hand ascender, and attach to the upper rope;
5. Unclip the cow's tail and continue climbing.

When crossing deviations, one must keep in mind that the rope passing through the

deviation carabiner is not fixed with a knot, and therefore will slide through depending on whether the weight is on the upper or on the lower rope.

Descending past a deviation:

1. Abseil until level with the deviation carabiner and lock the descender;
2. Reach for the lower rope and pull to get closer (horizontally) to the deviation point;
3. Clip the short cow's tail into the deviation tape or rope loop, below the deviation carabiner;
4. Unclip the deviation carabiner from the rope;
5. Clip the deviation carabiner back on the rope, this time above the descender;
6. Unclip the cow's tail, unlock and continue abseiling.

Ascending past a deviation:

1. Climb to just below the deviation carabiner;
2. Clip the long cow's tail into the deviation tape or rope loop;
3. Unclip the deviation carabiner from the rope from above the hand ascender, and control the slight swing outward as

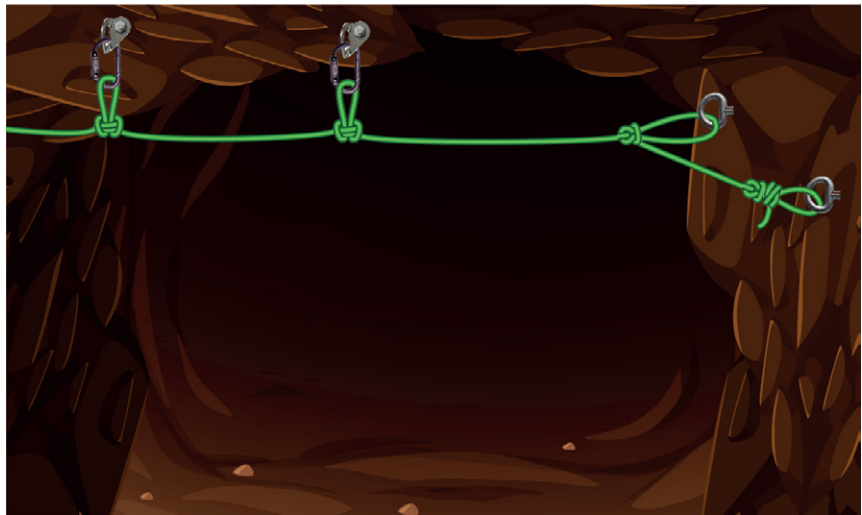
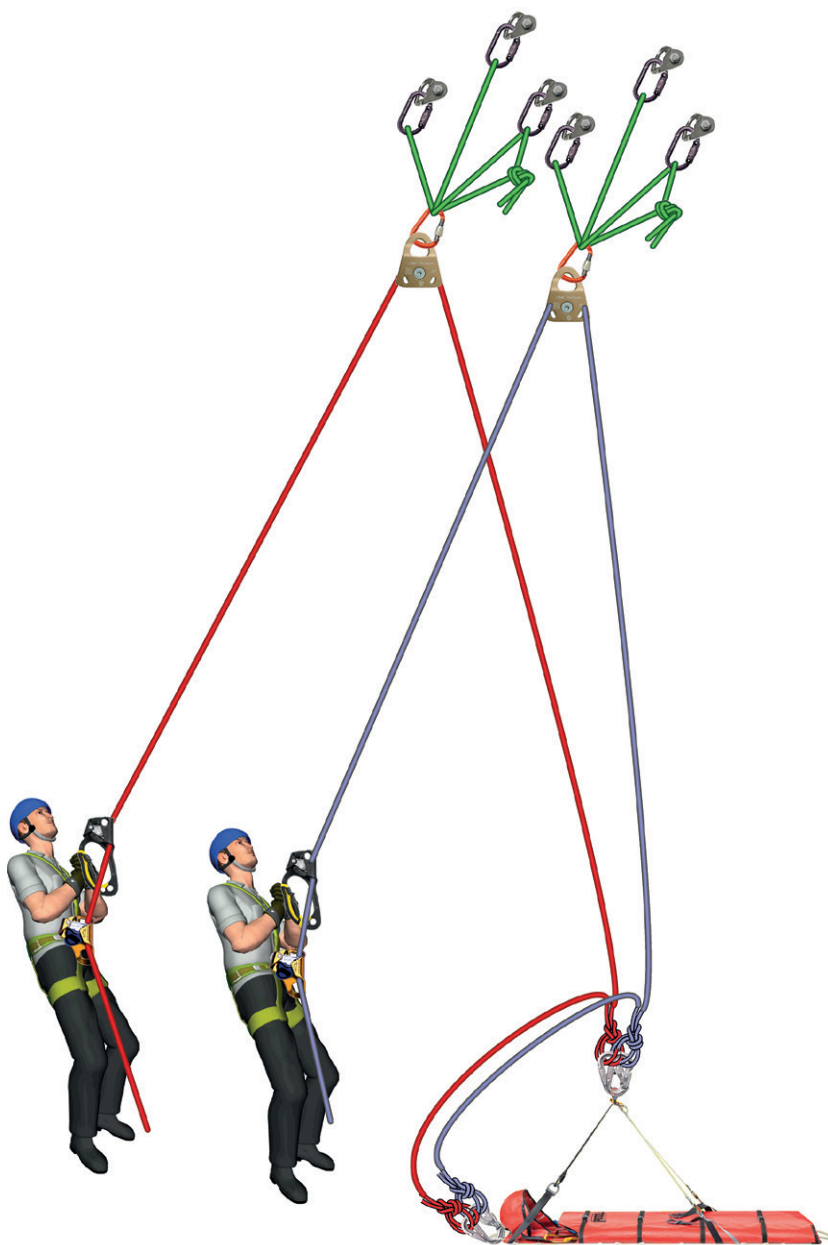


Figure 37: Horizontal lifelines or traverse lines allow for horizontal progression over gaps and voids.



In the case of a deviation, the cow's tail should be attached to the deviation and **ONLY** used to stop the rescuer from swinging away from it. The weight must always remain on the rope.

Traversing through horizontal lifelines can be achieved through the use of a descender bearing the load of the rescuer, attached to the rope using the upper cam only, thus acting similarly to a pulley. The hand ascender is then used by the rescuer to pull themselves forward. Traversing through the clipping points involves the same technique as described for rebelay.

A **counter-weight** system is typically used to facilitate the ascent of the victim strapped to a stretcher. The technique involves the use of two 1:1 pulley systems, each operated by a rescuer using their own body weight (Figure 38). The rescuers can be either physically standing on the floor at the bottom of a vertical shaft or suspended and locked. The two rescuers need to coordinate together and operate the system in the same way as if they are ascending. Such a system is easy to build and operate, with very little equipment. It is important to carefully ensure the system remains under control, especially when the victim is of a heavy build. It is important to note that the first aider accompanying the victim ascends abeam the stretcher using a separate rope.

Figure 38: The counterweight technique is used to haul the victim up.

the long cow's tail comes under tension;

4. Take some slack of rope from below the chest ascender and clip it in the deviation carabiner;
5. Pull all the slack of the lower rope from underneath the deviation carabiner, hold the tension and unclip the long

cow's tail from the deviation tape or rope loop;

6. Control the swing away from the deviation by a controlled release of the lower rope, as the weight shifts in line with the upper rope;
7. Release the lower rope and continue ascending.

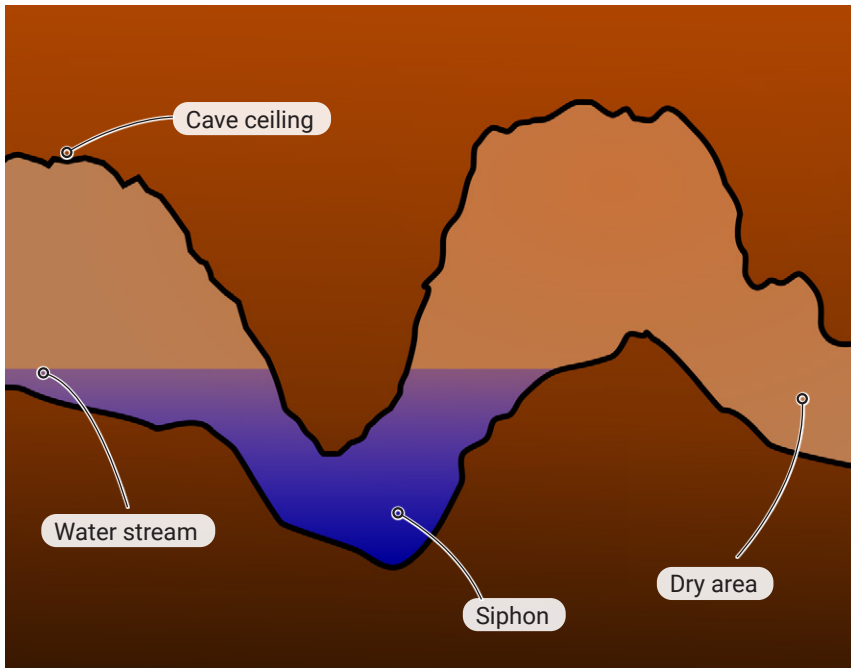


Figure 39: A siphon consists of a flooded part of the cave where part of the ceiling is submerged.

Other Progression Techniques

In addition to rope techniques, other progression techniques may be necessary within the caving environment. One such situation is traversing past **siphons**. Siphons, or sumps, essentially consist of flooded parts of the cave system and can either be static with no inward or outward water flow, or active, with continuous through-flow (Figure 39). Depending on hydrological factors specific to the cave, sumps may fluctuate in water level, depth and length. It is very important to understand these factors prior to traversing past a siphon to avoid getting trapped inside the cave and becoming a victim who needs rescue too! To traverse past siphons, one would need to either dive, or drain the section.

Siphons may be traversed by **diving**. In the case of shallow and short siphons, simply holding one's breath (free diving) may be enough to traverse. On the other hand, longer and deeper siphons may require the use of specialised cave diving underwater breathing apparatus. Cave diving is one of the most challenging and dangerous, as this typically involves penetration diving, extremely tight spaces with sharp protruding rocks, very poor visibility and potentially strong currents.

When practical, siphons can be emptied by **draining** the water using buckets or pumps. The primary factor which determines whether draining is indeed feasible is the rate of the inward flow, which may possibly be controlled by deviating the flow using sandbags. Furthermore, a suitable place must be identified where to collect or divert the

emptied water to prevent it flooding other parts of the cave that may need to be traversed.

In cases where the cave has large underground lakes or rivers, it may be useful to consider **swimming** or using a small **boat** to make progress to reach and extricate the victim.

Finally, as a team enters a cave to perform a rescue operation, a safe passageway must always be ensured. For this reason, consideration should be given to the need to **shore** certain parts of the cave deemed at risk of collapse. Other times, passageways may need to be **cleared of debris** to ensure that rescuers and victim (on a stretcher) will be able to pass through.

Stretcher Handling Techniques

Stretcher handling techniques are among the most important aspects of cave rescue. One of the most appropriate stretchers for a cave rescue environment is the SKED, given its wraparound characteristics, low profile and relative flexibility (Figure 40a). Care must be taken however as the SKED does not offer much protection to the victim and is not very comfortable. An alternative to the SKED is the Petzl NEST. At times, cave sections might be so tight, that the victim would have to be removed from the stretcher, and temporarily lashed onto a short board such as the Kendrick Extrication Device (KED), until the tight passage is negotiated. The stretcher must always be



Figure 40: (a) SKED stretcher (b) Petzl NEST.

accompanied by a bivouac (bivy) to protect the victim from water ingress, a sleeping bag to protect the victim from getting cold, and a complete helmet with visor to protect the head and eyes from loose particles and rock.

Horizontal stretcher work is a basic, but important, progression technique. On difficult terrain

(slippery, perilous or confined), the basic rule is for rescuers to stand ground and pass the stretcher over, either using the **hand-over-hand method** (Figure 41), lay down on the back and pass the stretcher over the head or, in certain confined spaces, even sit down on alternate sides and pass the stretcher

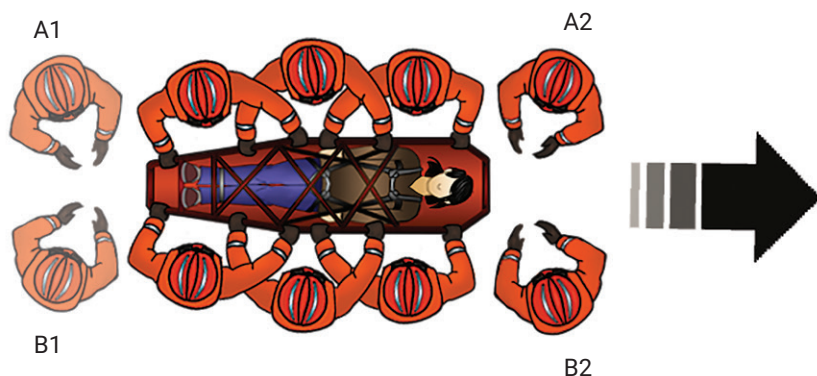


Figure 41: Hand-over-hand method – As the stretcher is passed on in the direction of the arrow, rescuer A at position 1 becomes free and moves to the front in position 2 ready to receive the stretcher. Similarly for rescuer B.



Figure 42: When the ground is too uneven to walk with a stretcher, it is possible to pass the stretcher along on the knees of rescuers sitting opposite each other.

over the knees (Figure 42). This ensures that the rescuers have a stable position before taking the weight of the stretcher and thus avoid the possibility of tripping and dropping the stretcher.

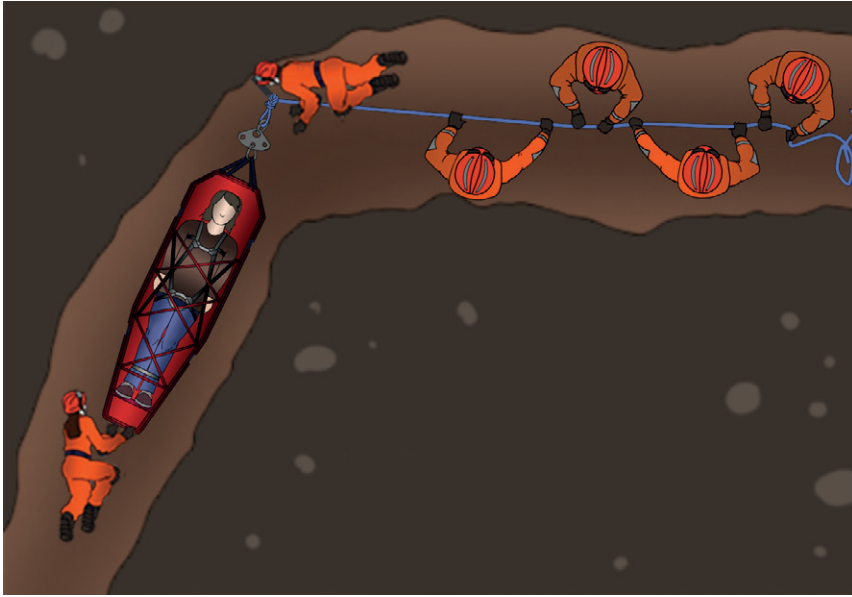


Figure 43: Anchor points and pulleys may provide an option to pull a stretcher around bends and corners (top view).

At times, a passageway may have a low ceiling that prevents rescuers from being able to move freely with the stretcher. Provided that the ground is smooth enough, the stretcher may be pulled using ropes, making this technique faster and more efficient than using

hand-over-hand methods. When the rescuers pulling on the rope cannot stay in line with the stretcher, an anchor point and a pulley may provide a change of direction on the rope, thus making it possible to pull a stretcher round bends or corners. Once the stretcher reaches the



Figure 45: Stretcher attachment point with three carabiners attached.

pulley (placed in the corner or outside of the bend), a rescuer will simply remove the rope from the pulley and the hauling team can continue pulling the stretcher towards them (Figure 43).

Prior to passing the stretcher through obstacles (either involving horizontal or vertical progression through the use of rope techniques), all rescuers must be ready in position before the stretcher starts to be moved and should remain there until



Figure 44: Stretcher attachment points.

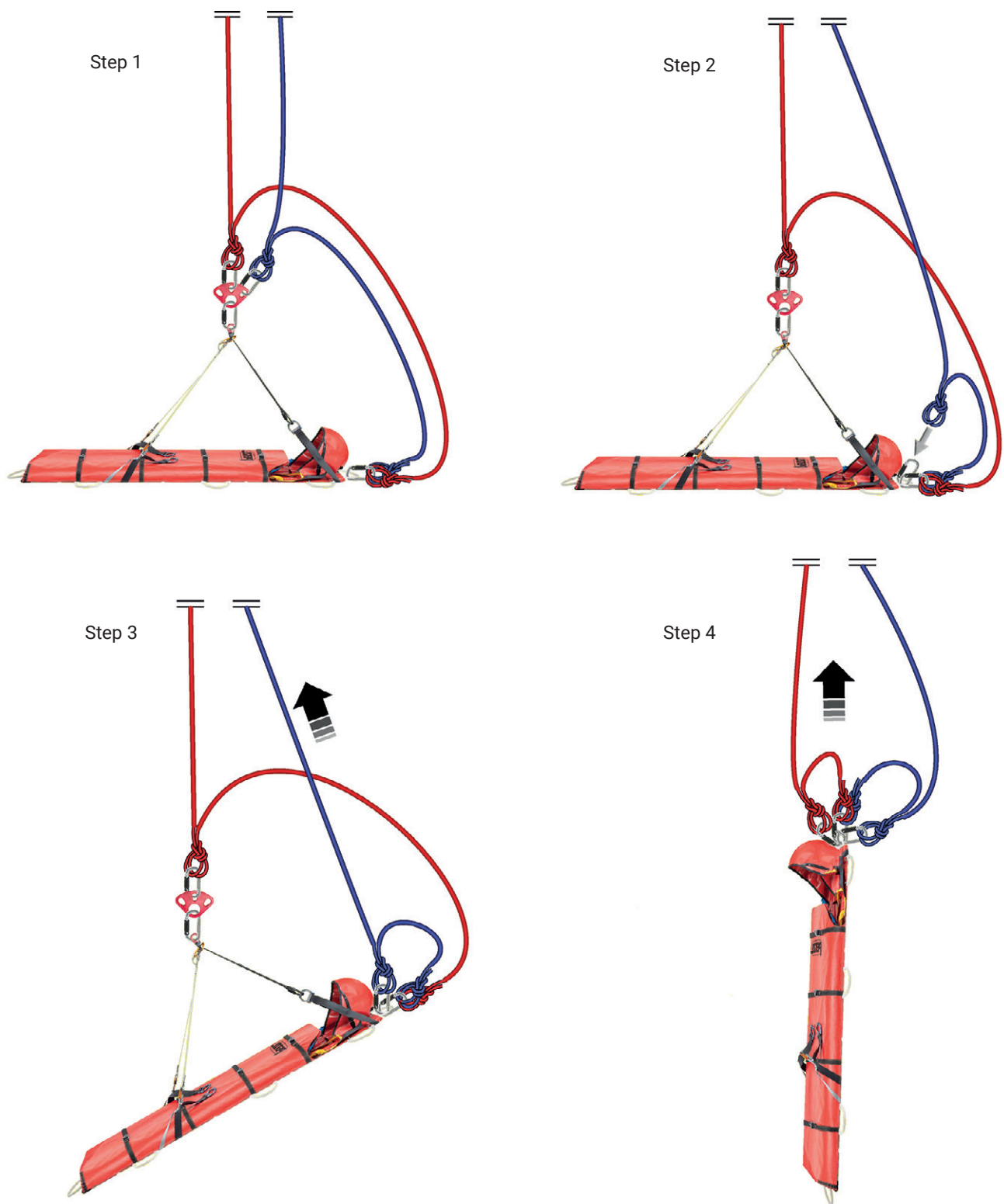


Figure 46: Changing orientation of the stretcher is done step by step, unloading one of the ropes, unclipping it from its original position to the other attachment point, then loading it to rotate the stretcher and to be able to release and relocate the first rope connection point.

Selection of descender device

While a Petzl I'D may be used as the descender device (as shown in Figure 47), it is recommended to use other devices, such as the Petzl STOP or Petzl SIMPLE, that are less prone to getting clogged with mud and dirt, thus enhancing the efficiency of the operation in challenging cave conditions. This applies to all rope progression techniques illustrating the use of descender devices in this book.

their task has been completed. Stretcher transpositions should be tackled either manually, by rescuers placed at strategic locations, or through the use of ropes.

In cave rescue, double rope techniques are employed for the suspension of the stretcher. The two parallel systems will not only guarantee enhanced safety in rope and anchor point redundancies, since stretcher handling involves heavier loads, but will also provide ease of movement through change of directions to overcome obstacles. Each system must always be completely independent and complete with all the necessary

deviations, rebelay, anchors, and pulleys.

The stretcher must have the possibility of three large connection points, to allow the attachment of three carabiners each (Figure 44). It is very important to connect the three carabiners (Figure 45) into the stretcher head and the centre point from the beginning of the evacuation operation. These are to be left there throughout, as all the progression manoeuvres require them.

The ropes coming from the anchor point must always be connected to the stretcher central point first, then allowed a slack of around one metre and connected

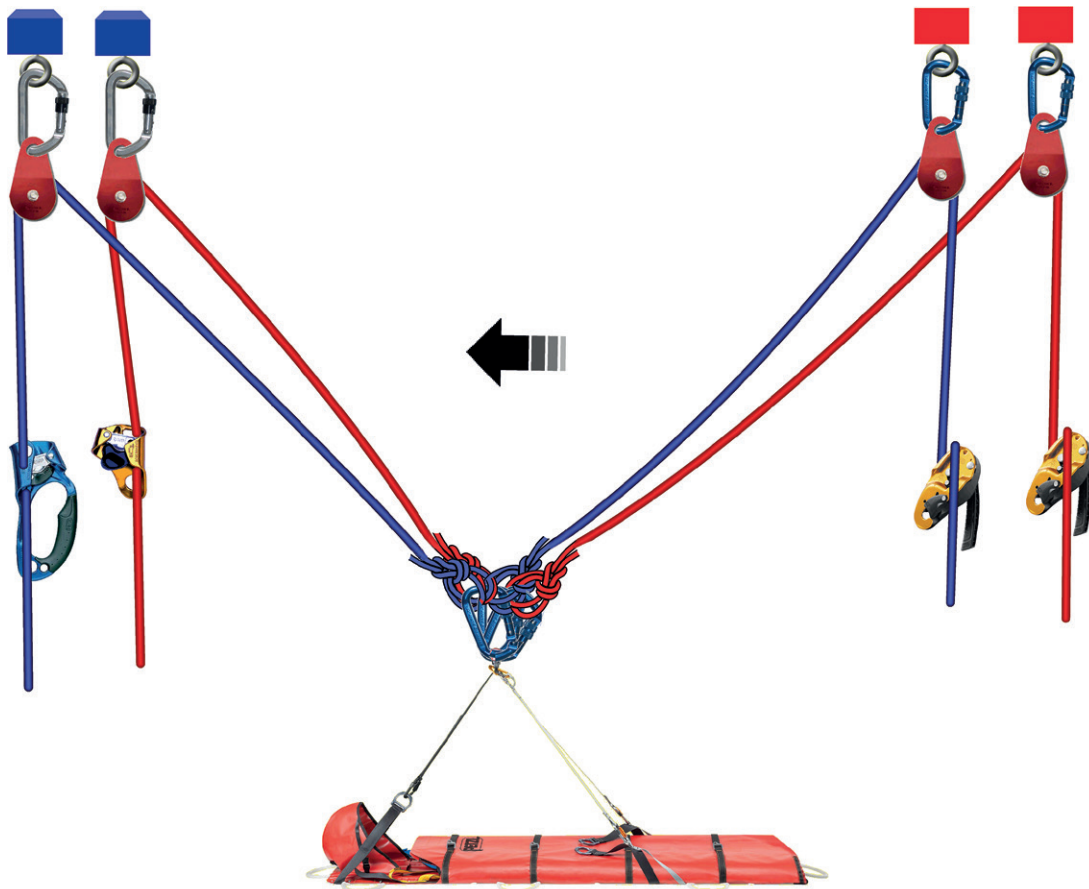


Figure 47: This technique enables stretcher movement both horizontally (to the left) as well as vertically when required.

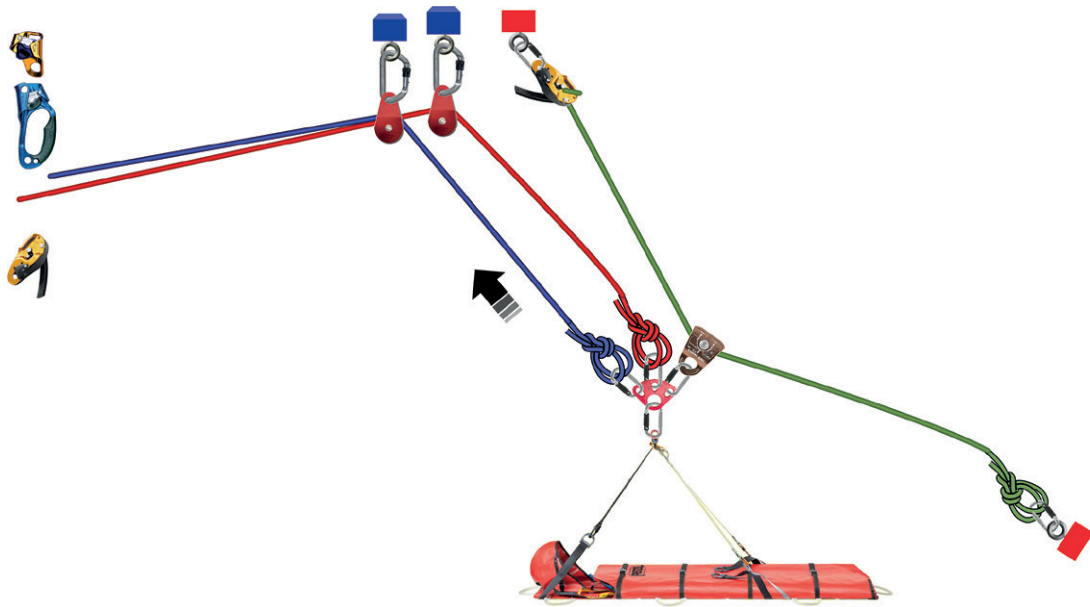


Figure 48: This technique uses a slanting rope (green) that carries the weight of the stretcher and allows it to slide in the direction where the blue and red ropes are pulling.

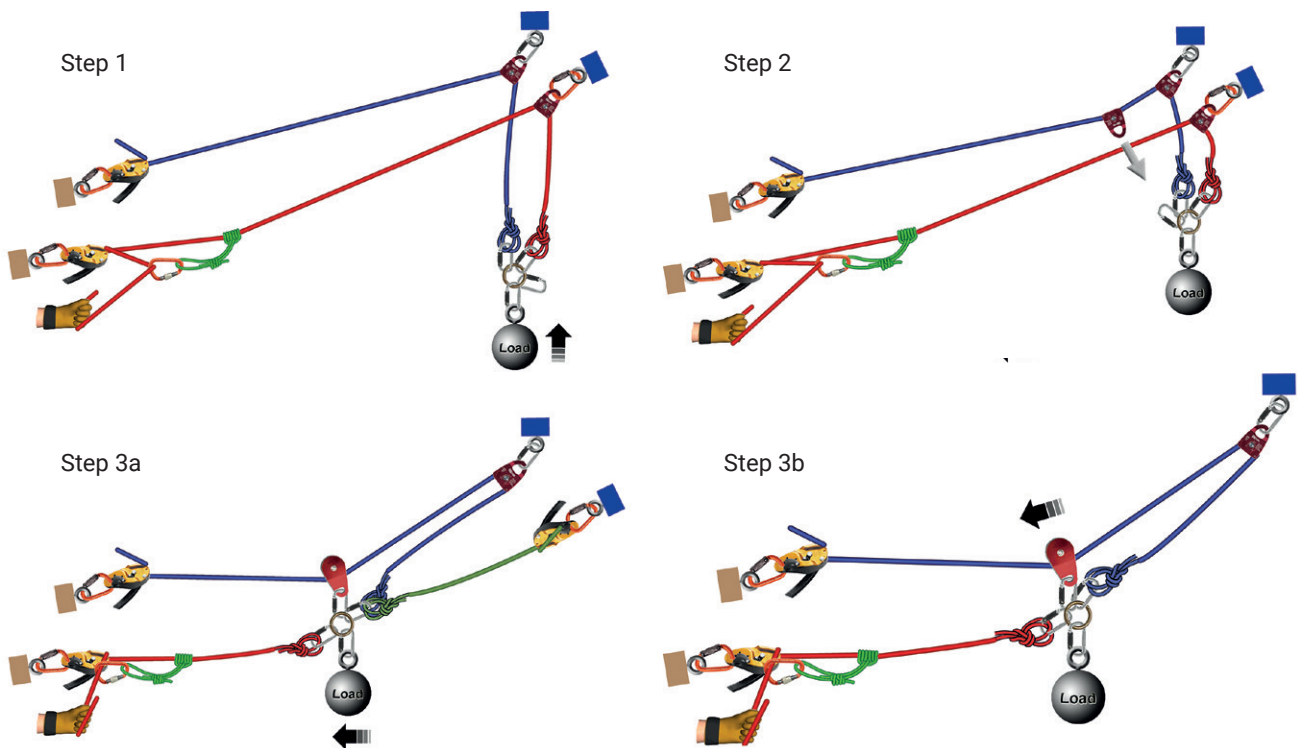


Figure 49: This technique provides the possibility to lift the stretcher vertically first and then continue to a horizontal progression. The illustration presents two alternatives for step 3.

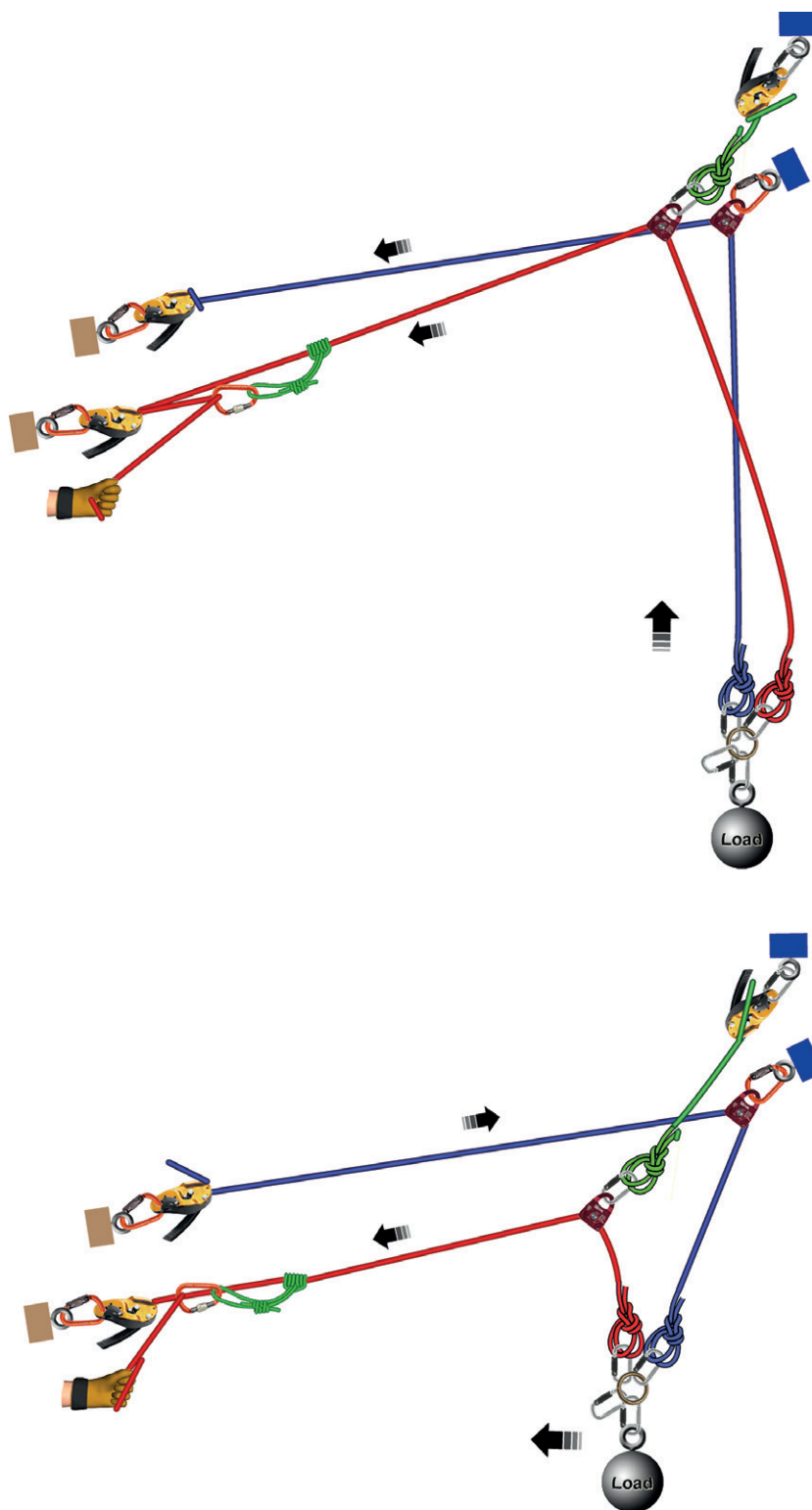


Figure 50: This is a variation of the previous technique, providing the same progression, but introducing a variable trajectory locus pulley controlled by the green rope.

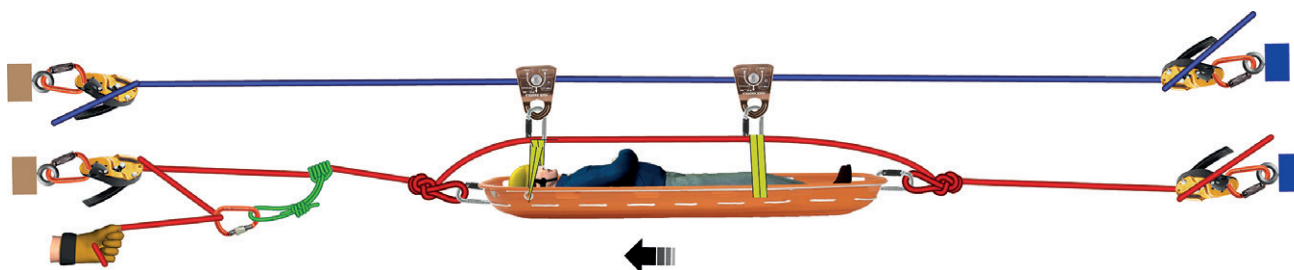


Figure 51: Horizontal progression of a stretcher using a tensioned line.

to the stretcher head carabiners. This facilitates changes from a horizontal to a vertical stretcher orientation (or vice versa) during the ascent or descent while negotiating obstacles or tight spaces. The sequence for changing the orientation is illustrated in Figure 46.

Figure 47 depicts a system which allows simultaneous horizontal and vertical movements of the stretcher. A rescuer is required to be rigged on the belay to operate the descender (right-hand side of the illustration), while two rescuers would be performing the counterweight procedure (left-hand side of the illustration). This effectively pulls the stretcher to the left-hand side. If the rescuer on the right-hand side stops releasing rope through the descender device, the stretcher is pulled upwards in addition to being pulled to the left-hand side.

Other techniques can be employed for stretcher progression, depending on the physical space available within the cave. In Figure 48, the trajectory of the stretcher is determined by the angle and tension of the 'green line'. Tension, and therefore the resultant angle of the loaded rope,

is controlled using a descender device. The stretcher progresses along the intended direction by pulling the red and blue ropes, possibly using counterweight techniques using two ascenders. A progress capture system (either using a Petzl I'D or Prusik loops) stops the stretcher from going back downwards when the rescuers operating the red and blue lines release the tension on the ropes.

There may also be instances where a stretcher needs to be lifted vertically first, then changed to a horizontal progression, all whilst being kept suspended (as depicted in Figure 49 step 1). Once the stretcher reaches the required vertical height, the 'red' system is eased off the load, and the pulley is moved over to the blue line (step 2). The 'blue' system now changes orientation from ascending to descending (step 3). An additional line ('green' system) can be introduced (as shown in step 3a), particularly if the horizontal direction is sloping downwards significantly, to help control the movement rate. However, if the slope is not too significant, the 'green' system may be omitted and descent would be controlled by the 'blue' system alone (step 3b).

This technique is typically used in confined spaces and in well-defined transitions between vertical and horizontal shafts.

Figure 50 illustrates a technique with a slight variation to the previous one, typically used in larger spaces. Instead of shifting the pulley from one system to another when changing the orientation, the pulley on the 'red' system is mounted on a descender, allowing for a variable trajectory locus. Once the stretcher has been pulled vertically upwards to the desired height, the green rope is released gradually together with the blue rope, while the red rope is being pulled, thus resulting in horizontal movement of the stretcher.

Horizontal progression techniques are especially necessary when crossing cavities and involve the use of a tensioned line between two anchor points and a progress capture system with a simple mechanical advantage system to move the stretcher along the tensioned rope, as illustrated in Figure 51.

Conclusion

Cave rescue operations are relatively rare compared to other types of rescues but are among the most complex. Despite borrowing techniques used in other, more common types of rescue, most notably rope rescue operations, the environment and conditions

where they are employed make any errors quite unforgiving. This is why rescue personnel need to have a high degree of knowledge and experience, not only in the use of rescue equipment and techniques, but also about the structure and formation of caves, the associated language

and terminology, orienteering, hazards and survival, as well as meticulous planning. This chapter is but a short introduction that needs to be enhanced by intensive practical training to ensure the safety and efficiency of any rescue operation.

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