Part 3—Restoration: Horrocks and Roth—Removing Artificial Fill

Section C—Restoring Cave Passages

Removing Artificial Fill from Developed Caves
Rodney D. Horrocks and John E. Roth

Artificial fill changes and potentially impacts the natural conditions of caves in undesirable ways. In developed caves, introduced fill results from disturbing natural sediments, dumping trail construction or blasting debris, or constructing artificial structures. Through a series of mitigating steps, artificially introduced debris or materials can be removed and natural features can be restored. It is important to differentiate natural cave sediments from human-caused debris and to define goals for restoring natural conditions in a cave. Safety issues, tools, and techniques for removing artificial fill are discussed in this chapter.

Reasons for Conducting Artificial Fill Removal Projects

Artificial fill has been introduced since caves were first developed for visitors, but it was not until the late 1970s that show cave managers recognized the need to restore natural conditions by removing unnatural materials (Rohde and Kerbo 1978). The accepted practice, described by Irving (1989), is to “remove all unnecessary, unnatural materials from the cave, but leave natural materials in the cave.”

Cave managers remove artificial fill to restore any combination of natural conditions—airflow, water flow, speleothem growth or dissolution rates, biotic communities, or visual scenes. Fill remediation projects may also remove harmful materials from and restore natural conditions to the cave environment.

Artificial fill can disrupt the volume and speed of air flowing into or out of a cave. The presence of fill, excavated pits and passages, or the altering of cave entrances can lead to unnatural drying out or wetting of passages. These alterations can even cause unnatural freezing or thawing deep in caves. Where feasible, the volume and configuration of an area may be restored to the original state before the fill was introduced. On another hand, borrow pits that were dug to obtain trail construction materials may be refilled with artificial fill, as long as that fill is native to the cave or is similar to the fill that was excavated, and the locations are carefully documented.

Artificial fill can alter temperatures to the extent that bats will abandon some roosts. Likewise, bats may be attracted by temperature changes where there are no historical or paleontological records of their presence. In such cases, the value of restoring natural conditions should be carefully weighed with other factors such as the species present, its vulnerability, and the availability of suitable, alternate roosting sites.

Natural hydrologic flow paths can be disrupted by the presence of artificial fill, trails, or dams. These obstructions can entirely change biotic communities within a cave, as well as the flow of nutrients within the cave ecosystem, especially if formerly dry passages are flooded. Blockages may also change the nature and amounts of speleothem deposition. Speleothem
growth rates can be unnaturally disrupted when covered with artificial fill. This may lead to the cementation of the fill, which adds difficulties and dilemmas to the fill removal process.

By re-exposing a natural substrate that was covered with artificial fill, biotic communities may be restored when original surfaces or food sources are again accessible. Disturbance of some types of natural fill may increase habitat for microbes, egg-laying crickets, and egg predators.

Sometimes, the reason to restore a room or passage is largely aesthetic. Restoration projects may enhance part of a tour route and add interesting visual scenes where none existed since the initial impact (Figure 1).

Various impacts may occur from construction materials that are harmful to the cave, its biota, or to people. The following materials are major targets for fill removal projects:

- Galvanized steel, which may leach zinc into cave waters and impact cave biota (Jameson 1995)
- Epoxy-covered trail chips
- Asphalt (carcinogenic aromatic hydrocarbons)
- Aluminum railings, which may leach aluminum into the cave in the presence of acidic water
- Batteries
- Old transformers, especially any containing PCB’s (polychlorinated biphenyls)
- Control panels with mercury switches

Before removing potentially toxic materials, consult Material Safety Data Sheets (MSDS) for specific information about the safe handling of each substance. (See MSDS, page 70 and page 172.)

**Types of Artificial Fill**

Artificial fill is differentiated from natural fill as material added to or internally disturbed by human activity in a cave.

The goal during any artificial fill removal project should be to avoid disturbing any natural or *in situ* fill. At least two experienced people should evaluate each potential fill area. If everyone involved cannot agree that the material was the result of human activity, then the site should be left until the nature of the fill is better understood.

Artificial fill usually results from one of four activities—blasting; trail projects; utility line projects; or construction projects. Typically, these projects were originally instigated to facilitate the visiting public by aiding access, providing services, or artificially enhancing visual scenes. Occasionally, these projects were conducted to create level areas for equipment or to allow returning guides to bypass tour routes.
Blast debris may result from entrance enlargement, tunnel construction; ceiling expansion; platform construction; trail leveling, widening, or deepening. In the past, gravel-sized to very-large angular blocks of rock were sometimes dumped in the nearest convenient spot so that laborers would not have to haul them out of the cave. In some cases, tiny chips of rock reveal that blast debris was dumped into a convenient hole. These activities usually generated large quantities of artificial fill that may partially block existing passages and greatly reduce their volume and aesthetic appeal.

Trail construction and utility line projects in show caves produce varying volumes of debris, including silt, sand, clay, gravel, or broken calcite. During construction, this material was often stuffed into every available pit or alcove along a trail. When flowstone or other speleothems are found among this type of debris, the material should stay in the cave and not be dumped outside where collecting might be encouraged. Materials that belong in the cave may be stored in a dead-end side passage (so it does not affect natural airflow), and certainly away from visitors’ sight and reach.

If possible, speleothems should be repaired and reattached in their original locations. (See speleothem repair and questions, page 441.) Broken speleothems should never be used as interpretive “touching stones” since this type of activity may lead to additional touching when visitors wonder how the other speleothems feel. Touching stones may also encourage collecting and vandalism.

Trail construction projects or artificial structures in developed caves can disrupt natural conditions. Sometimes, minerals in nonnative gravels will cause potential leaching or deposition problems, or even provide artificial food sources for microbial life. Structures such as rock walls, concrete pads, artificial dams, asphalt trails, soil cements, or gates are often found in developed caves. Artificial dams can reduce habitat for some species while creating new habitat for others, both of which disturb cave ecosystems. An improperly built gate can reduce or increase airflow, impede or increase natural biota, and change air temperatures and relative humidity.

Calcium hydroxide in Portland cement is very soluble and is easily dissolved and quickly redepósited as “soda straws” or “flowstone” below concrete structures. These deposits grow at an accelerated pace compared to normal calcium carbonate speleothems. Managers should attempt to keep concrete trails in the lowest part of a passage or in areas where undersaturated water does not drip or run onto the pathway. If possible, visitor trails should not be built under actively dripping stalactites where new speleothems are apt to develop on the constructed path. If concrete structures are built in cave passages, use high tensile strength cement with low amounts of calcium hydroxide. This type of concrete will last longer in cave environments. (See concrete, page 169; also see concrete products, page 476.)

**Recognizing In Situ Deposits**

Because it is often very difficult to recognize in-place, or *in situ*, deposits, artificial fill removal projects should be preceded by testing, and work crews should be supervised closely. As in archaeological excavations, test pits should be dug in the suspected fill to determine what has been dumped, what the natural *in situ* material looks like, what tools are going to be needed, and what issues may be encountered. Even a quick analysis of the types and history of naturally laid material in the cave is helpful in identifying artificial fill and from where in the cave the material was excavated.

The presence of speleothems (such as popcorn lines, moonmilk deposits, cave rims, and the orientation of coralloids) or atmospheric corrosion sites can provide information for identifying areas where fill did not naturally exist. Natural fill is often marked by a change in color. The presence of
Figure 2. An overzealous cave restoration worker dug into these in situ (in place) sediments in the Assembly Cave Room in Wind Cave National Park. Notice the laminations in the natural cave fill, which in this case are multicolored and readily visible.

Speleogens (sculpted bedrock that is sometimes dissolved underneath natural fill), or a change in wall rock color may indicate that natural fill has been artificially removed, although such sediment can be removed by natural process as well. A number of criteria can indicate if the deposits are in situ—layering, compaction, voids, broken surfaces, tool scratching, calcite deposition, organics, and historical artifacts.

Normally, fine-scale layering is a sure sign of in situ deposits. However, artificial layering can be created by maintenance workers spreading down alternating layers of sand or gravel to prepare an area for trail construction. Coarser layering can be caused by dumped materials that came from multiple sites. In such instances, coarser blasting material may be overlain by finer materials that were dumped on top, creating artificial layering. However, if fine laminations, cross bedding, or pebble imbrications are present, the layers are natural (Figure 2). Natural sediments may show varying degrees of calcification and may create weakly cemented deposits.

Compaction is another good indicator of in situ materials. Fine-grained water-lain materials usually have very little air space between the grains. However, compaction can also result when a deposit has been walked on for extended periods of time. Tests pits will reveal that such compaction is less than 15 centimeters (6 inches) deep. Voids, especially those near natural walls, are often good indicators that material has been re-excavated and dumped.

Pack rat nests can indicate when fill removal efforts have reached the natural floors. Sometimes the organics have decomposed from these nests, leaving only bones to indicate their former existence and the presence of in situ materials below.

Undisturbed in situ rocks in caves are often covered with a thin veneer of calcite or other materials—however, fresh fractures on rocks commonly indicate the presence of artificial fill. Carbonate rocks broken during blasting and other construction activities often have a sparkly surface with small amounts of calcite dust. However, blast debris may be covered with a thin film of mud, which may be calcified and mask fractures or tool scratches.

Scratches are sometimes found on rocks that have been excavated with tools. Thus, scratches, especially randomly oriented ones, are good indicators of artificial fill. Since the calcite dust produced by scratches is easily dissolved, prehistoric scratches are often not visible.

The easiest fill restoration projects involve the removal of artificial fill dumped on flowstone, calcified sediment, crusts, or stalagmites where identification of the material is more obvious. However, watch for sediments that may be deposited on calcite surfaces, mimicking artificial fill conditions. Other calcite deposits can also indicate in situ materials—examples include floor coatings, wall coatings on rocks, and corallloids such as popcorn.

Metal tools should not be used to remove fill when approaching these surfaces because the soft calcite is easily scratched. Plastic tools such as putty knives, hand brooms, and gardening hand shovels work well, depending on the material encountered (Netherton 1993). However, sometimes a thin layer of partly cemented fill or blasting mud can only be removed with dense-bristled metal brushes, which may cause minor scratching. Only clean, rust-free, nonpainted stainless steel and new nylon
bristles should be used in cave projects—old ones tend to shed steel, rust, or nylon into the cave. (See restoration tools, page 406.)

Lumber or burned wood may indicate the presence of artificially dumped debris. Look for squared ends and saw or axe marks on such pieces. Creosote or pressure-treated wood usually should be removed. Be careful not to remove cultural resources without the assistance of an archaeologist.

Removal of rotting wood piles may cause population crashes among cave-dwelling species. Check wood for fauna and consult a biologist if cave-dwelling species are found. (See wood piles, page 37.) Wood may have to be removed in stages to mitigate impact to cave biota. Wood should not be removed if it will disintegrate during transport and thus provide an unnatural nutrient windfall (Lewis 1993). Buckets or bags may be used if this is a concern.

The presence of recent cultural items usually indicates the presence of artificial fill. However, burrowing animals may take items into in situ materials. These objects may also fall into cracks between rocks or be washed in during flooding. Many states consider cultural objects more than 50 years old as having potential archaeological significance and an archaeologist should be consulted on the disposition of these items (more information is included below).

The presence of construction debris is usually a good indication that the fill has been disturbed. Such debris may include pea gravel, sand, cement splatter, or trash. If the gravel and sand is a rock type not native to the cave and is not in a stream deposit, it is usually safe to assume it has been dumped at the site. Sharp, angular gravel or boulders with some calcite dust usually indicate blasting. Blocks of breccia are sometimes hard to distinguish from concrete, but usually will have some amount of calcified mud, as opposed to mud-free concrete surfaces.

Certain natural processes may produce materials that resemble artificial fill. If the project is near an entrance, piles of frost-wedged wall rock or thin layers that have spalled off speleothems may resemble artificial fill. Speleothems desiccating in domes, humidity changes on gypsum layers, or atmospheric corrosion of ceilings may leave piles of debris on the floor that resemble artificial fill. Additionally, flood events may wash material into a cave. The presence of charcoal in these flood deposits may help in determining what is natural and what is not.

Special Issues

It is very useful for cave restorers to include or at least have access to experts with engineering, archaeological, biological, and paleontological experience to address the many special issues encountered in artificial fill removal projects. Special concerns include cultural artifacts and graffiti, broken speleothems, cement-covered speleothems, recemented fill, destabilization, utility lines, and artificial lakes.

It is common to find cultural items mixed in with artificial fill. A qualified archaeologist should determine their preservation, age, historical significance, and whether they should be collected or discarded. Cultural artifacts include any manufactured item that is over 50 years old. (See cultural resources, page 110; also see 50-year rule, page 341.)

If a qualified archaeologist directs that certain cultural items are worthy of collection, they should be bagged with a completed artifact label. Mark locations on a large-scale map and record the depth items were found below the fill surface. Number and bag each item separately. Record these data at the time of collection, even if the value is not immediately obvious—this important information cannot be accurately re-created at a later date. The presence of datable artifacts may aid in determining when overlying layers
of fill were dumped.

Pieces of flowstone, rocks with popcorn, or wall coating mixed in with artificial fill are often found and should remain in the cave. These materials may be hand-picked from the artificial fill if they are in large pieces or sieved out if in smaller pieces. If they are dumped outside, they may encourage collecting, both by individuals and commercial operators. Reattach identifiable speleothems where possible. Dump remaining materials in an area of the cave that is not accessible or visible to visitors, near their origin, and where they do not impact natural airflow or clog natural hydrological drains. Thoroughly document in-cave dumping sites.

Concrete was often applied directly to flowstone surfaces as sidewalks, platforms, and light shields. Concrete also can be found splattered on speleothems adjacent to paved trails or covering wire runs between transformers and light fixtures. Restoration should not be attempted if speleothems would be damaged to a degree greater than the benefits derived from restoring the natural surface. However, rapid deposition can cover over shallow scratches resulting from restoration. Concrete can often be removed with hammers, chisels, and dental picks. It may sometimes be popped off using a light blow to a chisel parallel to the contact between smooth flowstone and concrete. This technique cannot be used when bumpy surfaces, such as popcorn, are covered with concrete. Any chiseling should be done at an angle and not perpendicular to the surfaces being cleaned (Schaper 1995).

If a significant amount of time has elapsed since the artificial fill was dumped, dripping water may have cemented the fill together. If more than a thin film has accumulated, several questions should be asked and answered before proceeding:

- Is the artificial fill impeding natural airflow or hydrological drains?
- Is the fill preventing the growth of buried speleothems?
- Are there biological considerations?

If the answer is yes to any of these questions, seriously consider removing the fill. When buried speleothems are encountered below a drip point, dripping water may have already cemented the fill to those speleothems and the resulting conglomeration will have to be carefully removed.

Removal of artificial fill can destabilize large breakdown blocks. Carefully supervise volunteers if they dig underneath or around such rocks. If a large block is also artificial fill, it may be broken up before becoming unstable. A hammer drill with plug and feathers is a highly effective, low-impact technique for breaking up large blocks (Figure 3). Exercise care to reduce dust caused by hammer drills. Another technique involves filling drilled holes with expanding materials. Expanding materials need to be completely removed after they have broken up the rock.

Anytime artificial fill is removed from a developed cave, workers may encounter buried utility lines, especially electric cables, water lines, or phone lines. High-voltage cables can be life threatening. Maintenance employees or

**Figure 3.** Use a hammer drill with plug and feathers to split large blocks of rock into smaller, safer chunks of rubble. This is a low-impact technique when workers take care to contain the dust that results from drilling.
the original developers should be contacted before work begins. If an electrical cable is known to be buried in a certain area, turn off the power before the project begins. Test all continuous wires with an electromagnetic device to make certain they are not live, and then carefully remove the artificial fill. Once found, use hand tools to uncover the wire throughout its entire length. Lines can then be bundled together and lifted, or tied out of the way so they are not stepped on or hit with metal tools as the project progresses.

If an artificial lake has been built in a developed cave, the lake can be slowly drained using small tubing. Or the water might be used for cleaning and restoring muddy or soiled areas, but not relatively pristine areas. If this water is safe to use for cleaning, collect the restoration run-off and do not allow it to run onto cave floors. Avoid relocating any problem to a new place. (See restoration runoff, page 339 and page 396.) Use lint-free rags or sponges to sop up the cleaning water. Exercise care to avoid causing unnatural erosion.

**Equipment and Tools**

Before an artificial fill removal projects starts, several items should be gathered or constructed:

- Permits (from agency/owner)
- Rocking screens (detailed information below)
- Large-scale cave maps
- Parental Consent Form (if youth volunteers are used)

Additional items that will be useful are listed here:

- Camera, film, and flash
- Wheelbarrows
- Buckets, 20-liter (5-gallon) with handles
- Powerful portable lights
- Extension cords
- Square-nose shovels
- Round-nose shovels
- Short-handled shovels
- Folding shovels
- Garden trowels (nonpainted metal and plastic)
- Push brooms
- Tarps

When final, detailed restoration is performed after the bulk of the artificial fill is removed, the following tools may be needed:

- HEPA filtered vacuum cleaner with special tools to reach into cracks
- Hand-held squirt bottles
- Paint brushes (2.5- to 5-centimeter width or 1-inch to 2-inch)
- Auto part brushes (to reach into small places)
- Toothbrushes
- Rags (lint-free) and sponges
- Handled scrub brushes

Some artificial fill removal projects may require specialty equipment:

- Breaker bars for moving large blocks
- Impact hammer for use with plug and feathers
- Plug and feathers for breaking up large blocks
The most common safety hazard in cave fill removal is overfilled buckets. Big, heavy buckets can easily cause strained muscles, back injuries, or bone-bruised heels.

Each worker should have the following personal gear:

- Helmet
- Helmet-mounted light
- Leather gloves
- Knee pads and elbow pads
- Sturdy boots
- Change of clothes
- Goggles (depending on job)
- Ear plugs (depending on job)
- Dust masks (depending on job)

Safety Measures

Safety is the most important aspect of cave restoration. Planning can greatly increase the safety margin at artificial fill removal projects. When youth volunteers are participating, their parents should sign a parental consent form. Volunteers may need to sign a liability release form.

It is important to inspect the restoration site beforehand to look for potential safety hazards. At the excavation site, each worker should wear gloves, safety helmet, sturdy boots, and appropriate clothes (layered clothing for cold caves—layers can be removed if workers overheat).

There should be at least a 1-to-6 supervisor-to-worker ratio to properly oversee the progress of the excavation. The supervisors or team leaders are responsible for monitoring the safety of workers and assuring protection of cave surfaces.

- Make sure that no excavator is undermining sediment banks or large rocks.
- See that workers are wearing appropriate safety gear for individual tasks.
- Monitor whether workers are overtiring or overheating.
- Assure sufficient spacing between workers (so they are not swinging equipment and hitting each other or the walls).

Buckets and wheelbarrows should be operated by individuals physically capable of handling them. No one should be tossing rocks or tools. Many cave restorers are inexperienced cavers and need to be trained in safe and conservation-oriented caving and climbing techniques. Vertical or climbing skills are needed to reach many fill sites.

The most common safety hazard in cave fill removal is overfilled buckets. Big, heavy buckets can easily cause strained muscles, back injuries, or bone-bruised heels. Overfilling is hard on the buckets, and causes them to break or spill. Depending on the volunteers participating, buckets should be marked inside with a line only one-third to two-thirds above the bottom of the bucket and supervisors should be careful in seeing that workers do not exceed that mark. The weight should be geared to the smallest member of the crew or the individual in the most awkward position for carrying a bucket. If possible, individuals in assembly-line crews should be of similar size. Remind workers how to lift buckets to
avoid causing back strain.

The second most common safety hazard is an overtired crew. The loss of coordination in tired workers can lead to accidents. Establish a workload maximum—for example, 3 hours in the morning and 3 hours in the afternoon with plenty of breaks in between and plenty of time to exit the cave at a safe speed. One way to detect tiredness and maintain high morale is for supervisors to banter with workers up and down the line and show interest in what they are accomplishing.

The third most common safety hazard is moving rocks that are too large. Blasted rock can be broken up into smaller pieces before removal. (See the section above on special issues.)

Other potential hazards include the following:

- Insufficient work space—the surrounding space needs to be cleared of people whenever overhead tools are used. Use picks and sledgehammers with fiberglass or plastic handles because wooden ones are more likely to splinter.
- Overheating—high temperatures and humidity may lead to overheating in some cave environments.
- Respiratory diseases—use filter masks in any dusty environment. Use HEPA filter respirators where guano (woodrat, mouse, bat, birds, crickets) or amberat (dried woodrat urine) is present.
- Venomous biota—exercise caution near entrances where disease-carrying mites, rattlesnakes, or the more venomous spiders (Meta sp., black widow, brown recluse, hobo) are present. Check skin for ticks or other mites after hiking to or from a remote cave.
- EMT response time—an EMT should accompany each group or be able to respond within 20 minutes.
- Unusual odors—if any unusual or strong odors are encountered, immediately instruct all participants to leave the artificial fill removal project. The source of that odor should be determined before the group is allowed back to the site.

Techniques

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**Wind Cave Artificial Fill**

Wind Cave National Park, South Dakota

Debris mapped by Jason Walz, 10/9 12002
Drawn by Rodney D. Horrocks, 10/16/02

A Blast Rubble
B Commercial Gravel
C Asphalt
D Wood
E Commercial Sand
F Displaced Sediments
G Lint Deposits
H Trash/Cultural Materials
I Concrete

Artificial Fill (listed in order of most to least numerous)

- Natural Entrance Tour Route

![Wind Cave Artificial Fill Map](image)

**Figure 4:** A section from the restoration map along the Natural Entrance Tour Route in Wind Cave National Park. All the before-and-after photos taken and all the cultural items collected during the restoration project were referenced to the unit numbers assigned to each deposit on this restoration map.
Cave Conservation and Restoration

There are a number of special techniques for accomplishing artificial fill removal tasks—research and testing, documentation, tallying fill totals, excavation, transporting materials, and locating buried speleothems.

A little research before a project begins can be very useful, particularly oral history interviews with anyone who remembers the restoration site prior to being filled (Netherton 1993). Before any artificial fill removal project begins, test the material to determine access issues, potential safety concerns, the extent of the deposit, the nature of the fill, what is in situ and what is not, the number of excavators and haulers needed, the tools required, and the techniques that will work for removing the debris.

It is important to document an artificial fill removal project before, during, and after with photographs. When taking pictures for before-and-after sequences, the camera should be mounted on a recoverable point (from a station that will never be removed during any stage of the project). For thorough documentation, photograph with black-and-white film as well as color and digital imaging techniques. Black-and-white film and photographic prints may last longer than color films, depending on the processing and storing techniques (See photo bullets, pages 209-211.) However, color images in caves will often give more information. A digital camera can be used, but the photographer should remember that the shelf life of digital storage products is largely unknown and files may have to be transferred to new media periodically. (See archival protection, page 210.)

If a project is completed in stages, it is good to document the extent of

Figure 5: Log sheet examples for photos, artifacts, and weights. These tally logs are used during cave restoration projects at Wind Cave National Park.
each period of excavation on a large-scale map (Figure 4).

Keeping track of the amount of fill removed is good for morale. If 20-liter (5-gallon) buckets are used, fill several to a predetermined level and weigh them all on a common-weight scale to arrive at an average weight for that particular type of fill. Individual bucket weights will vary depending on the material being moved and the void space in the buckets. The weights of these buckets may vary between about 14 to 23 kg (30 to 50 lbs). Once the average weight is determined, one person can keep track of the number of buckets dumped into a wheelbarrow or hauled out of the cave using a simple tally sheet (Figure 5). At the end of a work session, the number of ticks can be multiplied by the average bucket weight to obtain a good estimate of the amount of fill removed by a group.

Artificial fill removal projects should be closely supervised by experienced cave restorers. Expertise in archaeology and paleontology is beneficial. Project directors should be ready to bring in subject matter experts. Several potential disasters may occur if workers are not closely watched—avoid digging into in situ materials, destabilizing large breakdown blocks, damaging or not documenting historic artifacts, and spilling wheelbarrows or buckets in the cave.

Wheelbarrows should be operated only by the stronger workers. To prevent creating dust or spilling debris, wheelbarrows or buckets should not be emptied or transferred while inside a cave. Supervision should be available for each work crew, whether excavating, hauling, or screening.

Each artificial fill removal project will require different excavation techniques and tools, some of which will have to be developed specifically for individual projects. When developing these techniques, consider the following issues:

- Worker safety
- Minimizing dust and flying rock chips
- Proximity to speleothems
- Tool durability
- In situ materials

Workers should be able to adapt different tools to a specific project. If gravel-sized material is being removed, workers can get downhill from the area being excavated, put 20-liter (5-gallon) buckets between their legs, and simply use a garden trowel or a folding shovel to pull the fill into the bucket. Whenever the natural floor is approached, (see the section above on recognizing in situ deposits), the worker should switch to carefully remov-

When large groups of volunteers are available, an assembly line is the fastest method of moving large volumes of rubble. By spacing workers an arm's length apart, 20-liter (5-gallon) buckets can be passed out of an excavation, down passages to paved cave trails, and up or down stairs.

**Figure 6.** Rocking screens are used to screen for items that should not be discarded with the artificial fill—for example, broken speleothems, fossils, and cultural materials. This project was located outside the Hansen Cave Entrance, Timpanogos Cave National Monument, Utah.

**Figure 7.** A volunteer group hauls debris out of the cave in "assembly-line fashion." Crews of cavers have been known to pass up to one ton of debris in 15 minutes or less using this method at Timpanogos Cave National Monument, Utah.
ing the fill with hand tools, or use plastic tools if speleothems are present. If concrete walkways on artificial fill are being removed, they can be broken easily by tunneling underneath and using a sledge hammer to break the surface.

If historical artifacts, broken speleothems, or pieces of calcite are present in the fill, many of them can be hand picked during careful observation while excavating. If the fill is gravel size or smaller, the remaining fill should be screened so that small historical artifacts, fossils, and pieces of calcite are not dumped outside the cave—items that tend to encourage uninhibited collecting. If delicate fossils are uncovered, they can be water screened with nonrocking, fine screens (1-millimeter mesh). Large rocking screens with double handles on one or two sides work well (Figure 6). Screens can be constructed out of lumber, PVC, or fiberglass, bolts, and window screen material.

When large groups of volunteers are available, an assembly line is the fastest method of moving large volumes of rubble. By spacing workers an arm’s length apart, 20-liter (5-gallon) buckets can be passed out of an excavation, down passages to paved cave trails, and up or down stairs (Figure 7). If a longer distance must be crossed, the group can pass a collection of buckets, stack them up and then move the line forward, repeating the process until the paved trail is encountered. At Timpanogos Cave in Utah, volunteer crews were able to move up to a ton of fill out of an excavation site every 15 minutes using these methods (Horrocks 1994). Once the paved trail is reached, loose fill can be dumped into waiting wheelbarrows (if it doesn’t create dust) and buckets can be stacked on dollies and rolled to the entrance.

It is also important for morale and efficient documentation to limit projects to a workable scale. Plan small enough projects so that workers can complete final cleaning of an area and see the results.

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Summary

Through the mitigating steps described in this chapter, artificially introduced debris, rubble, and fill materials can be removed from the cave and natural cave features can be restored. Be certain the supervisors or team leaders can differentiate natural cave sediments from human-caused debris. In this volume, also see the brief list of trash and rubble guidelines describing safety, tools, and techniques (page 363).
Cited References

Additional Reading