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A HISTORY OF PALEONTOLOGICAL EXCAVATIONS AT THE PLEISTOCENE FOSSIL SITE NATURAL TRAP CAVE, WYOMING

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ABSTRACT

The late Pleistocene fossil site of Natural Trap Cave (NTC) located in the Bighorn Mountains of Wyoming has been producing fossils since its first scientific exploration in the late 1960s. This site has exceptional preservation of a wide range of species including megafauna, microfauna, and pollen, and is considered a "treasure trove" among late Pleistocene sites in North America. However, this site presents logistical challenges because of its remoteness and inaccessibility (it is a 24.5m deep sinkhole located at the end of a mountainous road) and understanding how to access and excavate such a site should be recorded for future paleontologists, including how to overcome any logistical difficulties. We summarize the history of excavations of NTC including the three main teams who undertook these challenges, the overall questions the excavations addressed, how the excavations were accomplished, and the overall findings. This published work will serve as a record of how to undertake the logistical challenges of a site as rewarding as NTC.

Keywords: megafauna; microfauna; sinkhole; rappelling; vertical rope techniques; stratigraphy; pollen; volcanic ash

RESUMO [in Portuguese]

O sítio paleontológico do Pleistoceno tardio Natural Trap Cave (NTC), localizado nas Montanhas Bighorn do Wyoming, tem produzido fósseis desde a sua primeira exploração científica no final dos anos 1960. Este sítio possui preservação excepcional de uma vasta gama de espécies, incluindo megafauna, microfauna e pólen, e é considerado um "tesouro" entre os sítios do Pleistoceno da América do Norte. No entanto, este sítio apresenta desafios logísticos devido ao seu afastamento e inacessibilidade (é uma dolina de 24,5m de profundidade, localizada no final de uma estrada montanhosa) e entender como acessar e escavar tal sítio deve ser registado para futuros paleontólogos, incluindo como superar quaisquer dificuldades logísticas. Resumimos a história das escavações no NTC, incluindo as três equipes principais que empreenderam estes desafios, as questões gerais que as escavações abordaram, como as escavações foram realizadas, e as conclusões gerais. Este trabalho publicado servirá de registo de como enfrentar os desafios logísticos de um local tão gratificante como o NTC.

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INTRODUCTION

Natural Trap Cave (NTC) excavations are well-known in the field of vertebrate paleontology, especially among Pleistocene paleontologists. NTC produces a diverse and abundant mega-and micro-vertebrate fauna and palynomorph flora. The accumulation of bones in the cave is so extensive that Wang and Martin (1993) suggested it would take over 100 years to excavate the entire deposit.

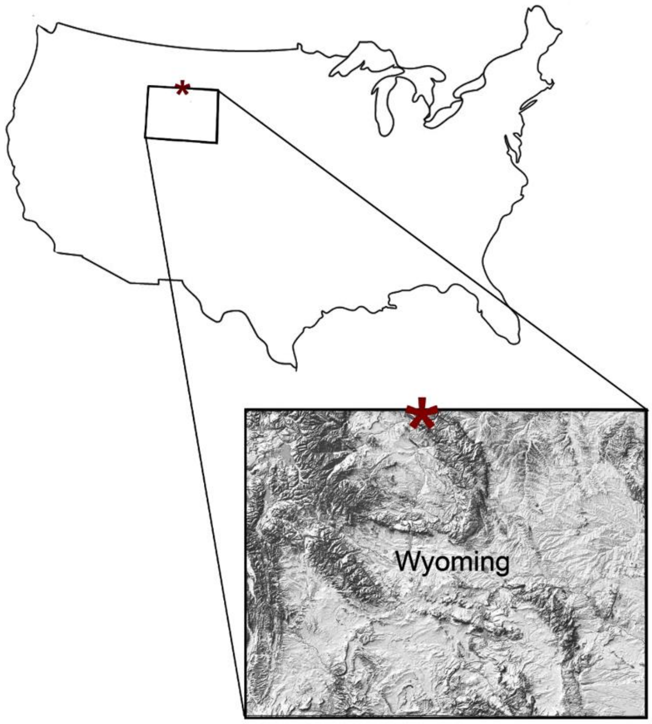


Figure 1. Location of Natural Trap Cave, Wyoming, USA indicated with a red asterisk.

NTC is one of the few sites in mid-continental North America that has both an abundance of fossils and good quality ancient DNA. It is also located directly beneath the corridor between the former Laurentide and Cordilleran ice sheets making it an ideal location to look at migration between the contiguous US and Beringia/Eurasia. Some of the more important findings to come out of NTC include: the first known occurrences of *Haringtonhippus francisi* and *Miracinonyx trumani* in mid-continental North America (Martin et al., 1977; Heintzman et al., 2017). NTC was reopened in 2014 with the goal of getting good quality ancient DNA from a temperate locality in the contiguous US (Shapiro et al., 2004; Barnett et al., 2009; Heintzman et al., 2017; Perri et al., 2021), and to help us understand the patterns of megafaunal migration in the Pleistocene from Beringia to other parts of North America of wolves, bison, and American lions (Shapiro et al., 2004; Meachen et al., 2016; Salis et al., in press).

Fossil excavations at NTC have been logistically difficult since the site is a sinkhole that is 24.5 meters below ground. Three scientific teams have carried out excavations at NTC since 1970, and each of these teams have overcome the challenges of excavation in different ways. This paper focuses on the three teams that have excavated this important site, why they chose to excavate there, and how they excavated. This paper is important specifically because of the logistical challenges of reaching the fossils inside the cave and how to get them out. It serves as a record for future teams at this site specifically, and for other vertical cave paleontological sites, generally.

MATERIALS AND METHODS

Background on NTC

Natural Trap Cave (NTC) is located in north-central Wyoming, about 3 km from the Montana border, on the western slope of the Bighorn Mountains in an area dubbed Little Mountain (Fig. 1). It is a 24.5 meters-deep karst sinkhole in the Madison Limestone (Martin and Gilbert, 1978; Gilbert and Martin, 1984). The only entrance into NTC is through an oval-shaped opening on the surface, 8.5 x 6 meters wide, into a bell-shaped entrance chamber, approximately 42.6 x 44.2 meters in diameter. The entrance to NTC occurs in a shallow depression at the end of a long ridge, just after a small rise in the terrain, making the entrance to the cave deceptively hidden from view, until right on top of it (Fig. 2). The cave is managed by the Bureau of Land Management (BLM) and was gated in September of 1973 to prevent accidental and intentional entrance (Martin and Gilbert, 1978). The cave has extant year-round inhabitants which include packrats (*Neotoma cinerea*) and deer mice (*Peromyscus* sp.). It is unlikely that any other non-volant species would be able to enter and exit the cave safely. Small passerines, specifically Say's phoebe, *Sayornis saya,* seasonally nest at the cave entrance and bats (*Myotis* sp.) may occasionally use the cave as a refuge, but no evidence of bats using the cave as a roost for extended periods of time has been found. The cave still acts as a natural trap for animals small enough to fit through the grate slats and new "taphonomic" specimens are found every year, including packrats, deer mice, snakes, lizards, passerines, and rabbits. There is no evidence that the cave was ever a refuge or a storage cavern for people or their goods, and no human remains have been found in the cave so far. The only artifact that has been recovered was a red jasper knife in 1971 (Rushin, 1973). A putative atlatl shaft was initially reported to have been found in 1971, but it was later determined to more likely be a coup stick and a relatively recent addition to NTC (Loendorf, personal commun., 2021). We would like to acknowledge that NTC is situated on the traditional and unceded territories of the Apsaalooké (Crow), Očhéthi Šakówiŋ (Great Sioux Nation), and Tséstho'e (Cheyenne) people, and NTC and the region remains culturally important to the Indigenous people.

The vertebrate fossils in NTC are late Pleistocene to late Holocene in age and yield radiocarbon dates between 2-9 and 23-47 cal ka BP (95% probability), based on the IntCal20 calibration curve (Reimer et al., 2020). Most animals probably died on impact from the 24.5- meter fall, but it is possible that some animals did not die immediately (especially smaller animals) and succumbed to their wounds and starvation inside the cave.

Since the 1970s the BLM has managed NTC utilizing scientific principles and expertise along with partnerships with various researchers and institutions. The first of the three scientific teams that have excavated at NTC included Larry L. Loendorf at the University of Missouri and the University of North Dakota and Carol Jo (CJ) Rushin at the University of Montana, who explored the cave's paleontological potential from 1969-1973. B. Miles Gilbert at the University of Missouri and Larry D. Martin at the University of Kansas conducted major excavations from 1974-1980 and again in 1984 and 1985. After a 29-year hiatus, Julie A. Meachen at Des Moines University and Alan Cooper at the University of Adelaide started excavating NTC in 2014. Meachen led subsequent large-scale excavations in 2015-2017, with a minor data collection expedition in 2018, and another large-scale excavation in 2021. All calibrated radiocarbon dates reported in this paper have been updated using OxCal v.4.4.3 (Ramsey, 2009) based on the IntCal20 calibration curve (Reimer et al., 2020) and are reported as an average of the calibrated range at 95% probability (Lovelace et al., 2022). A bibliography of all published papers on NTC, to date, can be found as an appendix to this paper (Appendix 1).

Figure 2. Exterior of Natural Trap Cave as it looked in 2016. Photo credit Julie Meachen.

Figure 3: (A) Interior of Natural Trap Cave, just below the entrance, unexcavated in 1969, photo credit Larry Jack; (B) Same area of Natural Trap Cave, main excavation area in 2015, photo credit Cory Redman.

Excavations from 1969 – 1973 (Loendorf & Rushin expeditions)

The cave was first formally mapped between 1968 and 1972 by the Vedauwoo Student Grotto using the Brunton Compass and steel tape method (Hill et al., 1976). It was at this time that the paleontological potential of NTC was first explored by Rushin and Loendorf **(**Fig. 3A-B). Rushin first entered NTC in June of 1969, when the annual convention of the National Speleological Society was held in Lovell, Wyoming. Rushin did some minor collecting of float material in 1969 and dug a test pit in 1972, as part of her master's research. Loendorf first entered the cave in 1970, while conducting his doctoral research on the archaeology of the Pryor Mountains to the northwest of NTC. Loendorf collected float specimens from NTC in 1970 and directed the digging of multiple test pits in the entrance chamber from 1971-1973.

NTC was well known by local residents and amateur collecting from the cave for paleontological and archeological artifacts would have occurred prior to 1969, as evidenced by a small, abandoned trench that was found directly below the entrance when Rushin first entered the cave. The floor of the entrance chamber was noted to be littered with faunal remains in 1969 and 1970, but the three test pits dug in 1971 yielded little to no bone. This was probably due to their small size and being less than three feet (0.9 m) deep. In 1972, Rushin excavated a ten foot (3 m) square test pit that achieved a depth of 6 feet (1.8 m) and was divided into nine arbitrary intervals; all measurements were taken from a datum stake. The test pit was located near the bottom of the steep slope, in the northern part of the entrance chamber (Fig. 4). Sediment samples were taken from each interval to determine the presence of vertebrate microfossils and palynomorphs. Eight of the seventeen megafaunal species currently known from NTC were recovered (Table 1) including rabbits, *Antilocapra americana*, *Bison* sp., *Haringtonhippus* and *Equus* sp., wolves (likely *Canis* sp.), felidae, and *Mammuthus*, with pronghorn, bison, and horse being the most abundant. However, mammoth bones were also recovered, which are rare in NTC. Loendorf assigned Barry Fuller, who had been part of Rushin's excavation team, to dig another test pit in 1973, which reached at least four feet (1.2 m) in depth, exposing three strata. Loendorf invited his anthropology colleague, B. Miles Gilbert (University of Missouri), to spend a week at NTC in August of 1973. Gilbert would become a principal investigator at NTC for the next decade.

Excavations conducted by the Loendorf and Rushin expeditions were done by carbide and Coleman lamps, using trowels, paint brushes, rock hammers, and shovels. All test pits were back filled, but the datum stake for Rushin's 1972 test pit was left. Crew members rappelled into the cave using a rope anchored to the front axle of a vehicle and ascended out using two jumars and a Tenstron prusik safety knot.

Excavations from 1974-1985 (Gilbert & Martin expeditions)

The preliminary work by Loendorf and Rushin demonstrated that NTC produced well preserved bone, a diverse vertebrate assemblage, and had stratified sediments that varied in number, thickness, and dip, indicating a complex deposition history. Based on this work, it was hypothesized that NTC's

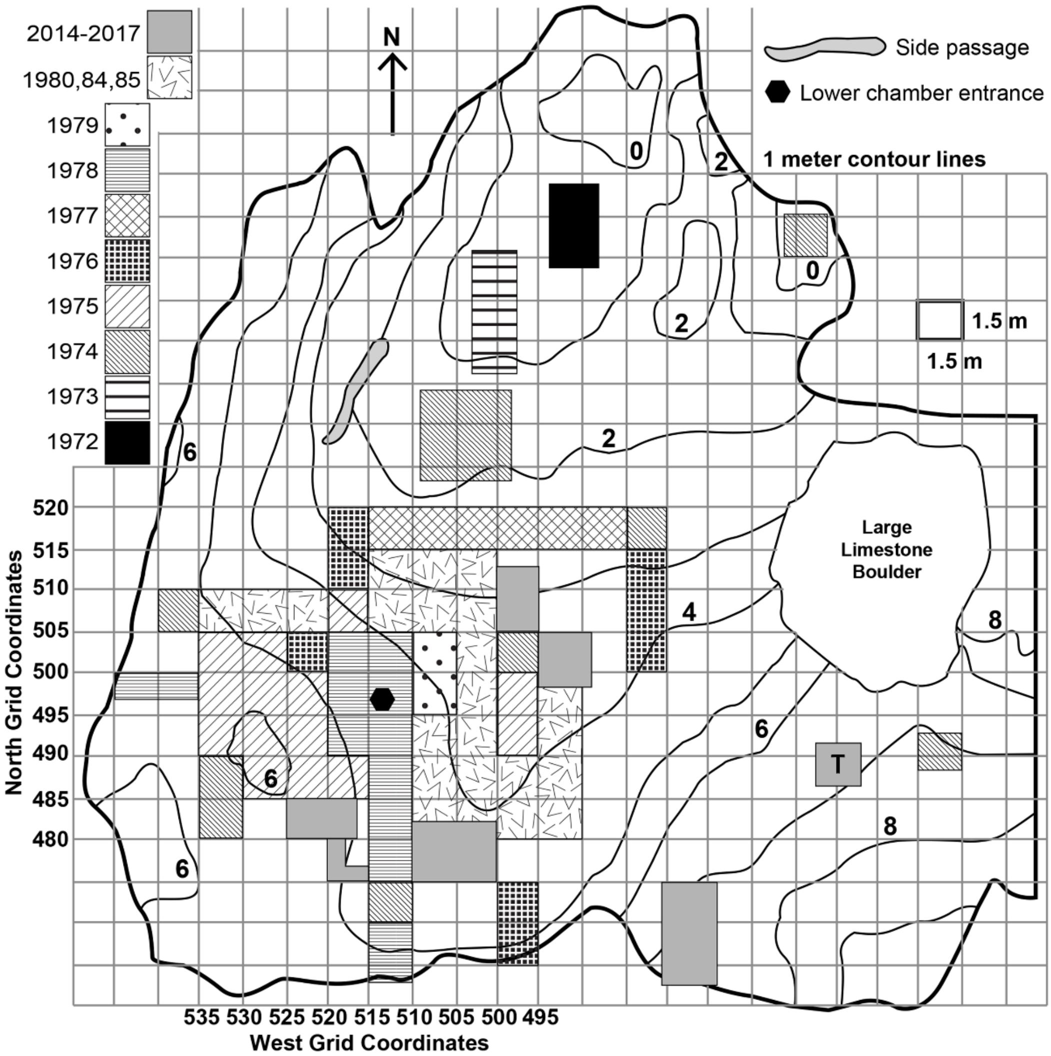


Figure 4. Interior map of Natural Trap Cave showing excavation areas through time. Legend shows years that excavations occurred. Square marked with a "T" is the test pit dug in 2015. Figure modified from Wang and Martin (1993).

sedimentary deposits would cover the time span of 15-10 ka BP. A period of time that included dramatic climate fluctuations and an extinction event. The goal of the Gilbert and Martin expeditions was to determine if changes in the cave's mammalian fauna and strata corresponded to climatic events. Gilbert asked Larry D. Martin (University of Kansas), who was enthusiastic at the prospect of obtaining and curating a wealth of fossils, to join the project. Financial support for these expeditions came from the University of Kansas, the U.S. National Science Foundation, the National Geographic Society, and Educational Expeditions International (now called Earthwatch). Earthwatch also provided a significant portion of the field crew every summer.

1974 Excavations

The goal of the first field season in NTC was to excavate an area adjacent to the 1973 test pit to collect more vertebrate fossils and verify the entrance chamber's stratigraphy. Kerry A. Lippincott (crew chief) set up a random sampling procedure to help identify what areas of the entrance chamber had bone-bearing sediments. A contour map of the entrance chamber was created, and the cave floor was divided into five-foot square grids (1.5 meters square). Grid designations were assigned by the coordinates in the northwest corner (e.g., 505 NW 500 was the designation for the 1.5 meters square grid between 500-505 N and 495-500 W). Using a random numbers table, nine grids were selected for test excavation (Fig. 4). Three of the randomly selected grids were back under the ledge from the entrance and not considered likely places to produce bone. However, all grids produced fossils and were excavated to a depth of 36-108 inches (91-274 cm). A ten-foot (3 m) square area, reaching a depth of 8 feet (2.4 m), was excavated near the 1973 test pit. Over the course of the 1974 field season, 300 square feet (91.5 m) were excavated, with over 2,500 bones collected, mostly horse.

American lion (*Panthera atrox*), short-faced bear (*Arctodus simus*), American cheetah-like cat (*Miracinonyx trumani*), camel (*Camelops* sp.), and wolverine (*Gulo gulo*) were also recovered from NTC for the first time. A 'white sand' unit, four to six inches (10-15 cm) thick, that pinched and swelled, was also encountered, but was not identified as a volcanic ash until 1976.

Even though NTC was strictly a paleontological site, it was felt that archaeological field methods would be better suited to the cave's research potential. Excavation was done using trowels and whisk brooms in six-inch (15 cm) intervals/levels, using a carpenter's line level and steel measuring tape to determine depth. To recover small bones and fragments, excavated matrix was screened in the cave using a shaker box with 0.25-inch (6.35 mm) mesh screen. An *en bloc* sample of matrix (12 x 12 x 6 inches, 30.48 x 30.48 x 15.24 cm) from each six-inch level was taken from the northwest corner of each grid for laboratory sediment and microfossil analyses.

1975 Excavations

The *en bloc* matrix samples collected in 1974, demonstrated that the cave's strata were continuous over a wide area of the entrance chamber and produced sparse, but interesting vertebrate microfossils and eroded pollen grains. As a result, tons of matrix were collected and hauled to the surface to be water screened in the field, using 0.25- and 0.0625-inch (6.35 mm and 1.58 mm) mesh hardware cloth. The goal was to recover sufficient mammalian microvertebrates and palynomorphs to determine if these assemblages represented a grass-conifer parkland, as indicated by the cursorial megafauna already recovered. Determining whether *Dicrostonyx*, a collared lemming, was present in NTC was also an objective, since this taxon had been recovered from regional caves (Jaguar & Box Elder Caves)

Table 1: Species and common names of the mammalian megafauna found in Natural Trap Cave.
* indicates one of the first species found in the original excavations in 1969.
?indicates the species that may have been found in 1969, but it is unclear.

Taxon	Common Name
Mammuthus sp.*	Mammoth
Camelops sp.	Camel
Equus sp.*	Caballine horse
*Haringtonhippus francisci**	Stilt-legged horse
Bootherium bombifrons	Musk ox
*Bison antiquus**	Antique bison
Bison bison	Extant bison
Ovis canadensis	Bighorn sheep
*Antilocapra americana**	Pronghorn
Arctodus simus	Short-faced bear
Panthera atrox?	American lion
Miracinonyx trumani?	American cheetah-like cat
Canis lupus?	Beringian wolf
Aenocyon dirus?	Dire wolf
Gulo gulo	Wolverine
Vulpes vulpes	Red fox
Lynx sp.	Bobcat or Canadian lynx

and was considered indicative of colder temperatures and a steppe tundra environment (Guilday et al., 1967; Anderson, 1968; Anderson, 1970).

As bones were uncovered, their position and orientation in the grid was mapped before removal. By comparing grid maps, it was possible to re-associate bones from an individual that had become scattered over several contiguous grids. The grid mapping also revealed that bones on the perimeter of the talus slope, below the cave entrance, were dominated by shapes that enabled rolling, sliding, or easy transport. Rocks the size of a fist or larger were also mapped, so the relative amount of roof-fall could be compared among the strata. As excavations deepened and more of the cave's stratigraphy was exposed, it was discovered that the underlying stratum dipped 20-25° to the north and about 30° to the east. This necessitated a change in excavation strategy. Grids were excavated in three-inch (7.6 cm) intervals/levels and a grid floor should follow the contours of the stratum, opposed to trying to maintain a level floor and potentially mixing bone from different strata and thus different ages.

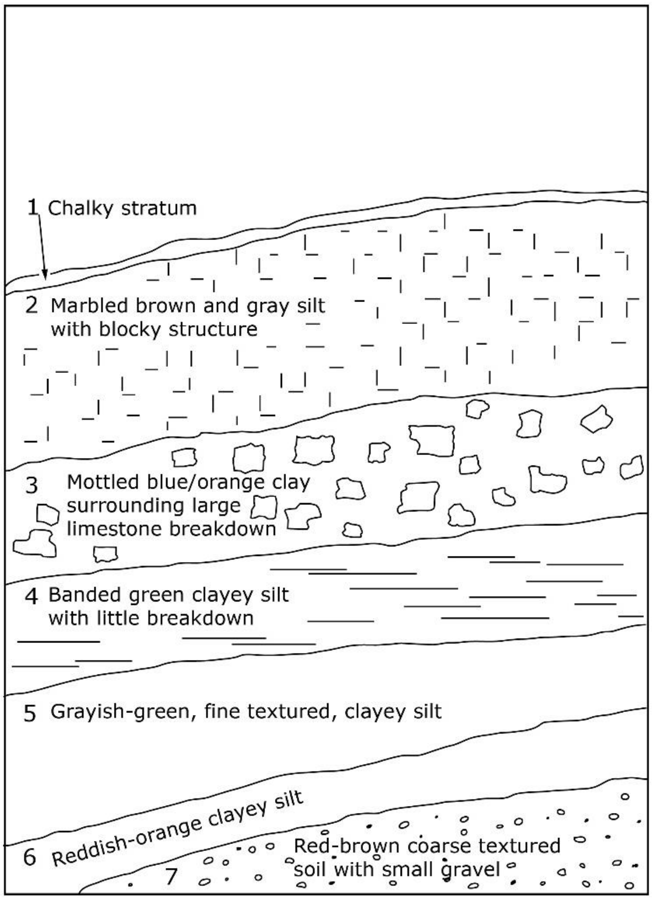


Figure 5. Stratigraphic profile used by Gilbert and Martin in their original excavations showing one of their stratigraphic frameworks. Redrawn and modified from Chomko and Gilbert (1987).

Dicrostonyx was recovered from the matrix screen washed during the 1975 field season and two bones excavated during that field season were radiocarbon dated by Irene C. Stehli of DICARB Radioisotope Company. These bones produced an uncalibrated date of 14,670 +670/-730 yr BP (DICARB 689) and 17,620 +1490/-1820 yr BP (DICARB 690) (Martin et al., 1979), but also see Lovelace et al. (2022). The *Dicrostonyx* and the radiocarbon dated specimens, both came from the bottom of stratum two and the top of stratum three, following Martin and Gilbert (1978) stratigraphic nomenclature (Fig. 5). This suggested to Martin and Gilbert that a local environmental shift from a grass-conifer parkland regime (indicated by the cursorial megafauna) to a colder and drier regime (indicated by *Dicrostonyx*) occurred between 22.5-17.9 cal ka BP.

1976 and 1977 Excavations

One of the goals of the 1976 field season was to determine how deep the bone bearing sediments continued below the oldest radiocarbon dated level. It was also decided that a professional geologist should be brought onto the project, due to the complexity of NTC's stratigraphy. John Albanese, from Casper, Wyoming, was asked to join the expedition because of his broad experience with Wyoming's geology. Albanese quickly recognized the 'white sand' found in 1974 was a highly rhyolitic volcanic ash that may have come from an eruption on the Pitchstone Plateau in Yellowstone National Park and was potentially much older than the radiocarbon dates obtained so far. To facilitate the examination of the cave's stratigraphy, an east to west trench was dug in 1977 to connect the areas excavated in 1975 and 1976 (Fig. 4). Within this trench, Albanese recognized channel-fill deposits and a semi-articulated American lion was found at its western end.

During the summer of 1977, the NTC expedition received more visitors and publicity than ever before. The field crew hosted a summer field trip of the Rocky Mountain section of the *Friends of the Pleistocene* and two groups of senior Honors Biology students (Michigan and Texas) visited. *The Billings Gazette* featured an article on NTC on the front page of the August seventh Sunday paper and a crew of TV/radio majors from Stephens College made a documentary film of the expedition called *Wyoming 20,000 BC,* under the supervision of James Corbett.

1978 Excavations

Prior to the start of the 1978 field season, a tentative age range was established for the volcanic ash found in 1974, which was greater than 13 ka BP and probably closer to 70-100 ka BP. This range was obtained from Virginia Steen-McIntyre using obsidian hydration analysis and assuming the ash had a similar composition to Yellowstone tephra (Gilbert, personal commun., 2020). Glen Izett at the USGS also examined the ash and determined that it had certain chemical affinities with Yellowstone derived pyroclastic materials, but did not match the three known Pearlette ashes (Type B, O, or S) and was probably an order of magnitude younger than type O (Izett, 1981). Dating the ash using thermoluminesence was going to be tried by Ralph Rowlett at the University of Missouri, so radiation dosimeters were implanted in five strata for four months to provide background dosage levels.

Excavations also continued to look for fossiliferous sediment below the 17,620 yr BP (DICARB 690) level. Previous efforts had yielded four feet (1.2 m) of unfossiliferous sediment but extending the excavation towards the location of the 1974 ash and following the dip in strata down slope, produced bone 14 inches (35 cm) below the 17,620-year level. Among the bones recovered were elements from a muskox. Muskox was first found in NTC in 1976, but the bones were tentatively identified as *Cervalces* (elk/moose), until 1978. Careful study by John F. Neas at the University of Kansas determined these remains belong to *Bootherium bombifrons* (Neas, 1991).

Increased interest in the relationship between what was found in the cave and the surrounding environment at the surface, led to the excavation of three rock shelters (Prospects, Shutdown, and Eagle) by Stephen A. Chomko (Chomko, 1978; Chomko, 1982; Chomko, 1990). The rock shelters were approximately at the same elevation as NTC (4,921 feet/1,500 meters) and a few hundred meters away. Prospects and Shutdown shelters produced a small mammal Pleistocene record and the Eagle shelter contained a stratified Holocene sequence (Chomko, 1978; Chomko, 1982). These shelters also produced some megafauna. At this point, the vertebrate microfossils from NTC were considered to be meager and only sixteen mammalian genera had been identified (Chomko and Gilbert, 1987).

Packrat (*Neotoma)* middens in the vicinity of NTC were also sampled for macroflora by Philip V. Wells at the University of Kansas. Wells sampled three middens that had produced radiocarbon dates older than 27, 30, and 40 ka BP. All three middens were dominated by limber pine (*Pinus flexilis*), with spruce (*Picea engelmannii)* and juniper (*Juniperus communis)* occurring in very low frequencies. Wells considered this to be indicative of a modern subalpine forest but occurring at a much lower elevation than what was currently seen in the Rocky Mountains. NTC's modern packrat middens were dominated by juniper (*Juniperus osteosperma)* and prickly pear (*Opuntia)*. At a minimum, the older packrat middens indicated patches of alpine coniferous forest occurred in the vicinity of NTC 43.1-31.1 cal ka BP, reflecting a cooler climate (Wells, 1983).

1979 Excavations

From the beginning, an interdisciplinary approach had been taken to studying NTC. As more data become available, Martin and Gilbert set out to test a series of hypotheses:

1) Determine whether the mammalian microvertebrate fauna from NTC and the surrounding rock shelters were sensitive to climatic shifts and produced similar trends seen in the palynomorphs and packrat middens; 2) Determine if climatic shifts are also reflected in the sedimentation and weathering rates within NTC; 3) Test whether a reduction in the body size of large and small mammals occurred as a result of severe climate changes or human predation (i.e., Clovis culture); 4) Test the hypothesis that large mammals migrated seasonally past NTC, moving from their summer and winter ranges; and 5) Compare NTC's bone breakage patterns to other sites, to determine if breakage occurred from a 24.5-meter drop into the cave or rocks falling from the ceiling onto bones.

Deborah Pearsall at the University of Missouri analyzed opal phytoliths from six strata in NTC. Festucoid (cool season, moderate moisture grasses) and Panicoid phytoliths (warm season, moderate moisture, tall grasses) dominated in relative frequency until 13.9 cal ka BP, then Chloridoid phytoliths (warm season short grasses with drier conditions) doubled in relative frequency. The appearance of the *Dicrostonyx* between 20.5 to 17.0 cal ka BP coincides with an 11% increase in the Panicoid phytoliths. This indicated a general decrease in C3 grasses (Festucoid) and an increase in C4 grasses (Panicoid and Chloridoid) through the section. Grasses far outnumbered herbaceous plants, as would be expected in a steppe tundra (Gilbert et al., 1980).

1980 Excavations

By the summer of 1980, additional radiometric dates had been obtained from NTC samples. The ash found in 1974 was confirmed to be 110,000 ± 10,000 yr BP, using fission track (glass) dating by John Boellstorff at the University of Nebraska-Lincoln (Gilbert, personal commun., 2020). This meant the fossil record of NTC spanned from the Sangamon Interglacial through the last great Wisconsin glacial to the Holocene, as Martin and Gilbert had suspected.

Thermoluminescence had produced a date of 47,723 ± 5,716 yr BP for the same ash, but this result was suspect, due to the high levels of background radiation (but see Mahan et al. (in press)). A trace element analysis of NTC's 110 ka BP ash and an ash from Horsethief Cave and two shelters (Prospects and Shutdown) was also done by Michael D. Glascock at the University of Missouri's reactor facility (Gilbert, personal commun., 2020). The results of this analysis suggested three different sources, with the ash in the shelters potentially coming from the same source, given their composition similarity. Three additional, uncalibrated radiocarbon dates were also obtained from Stehli at DICARB and corroborated previous results. A date of 17,870 ± 230 yr BP (DICARB 1686) was obtained from the top of stratum three, 20,250 ± 275 yr BP (DICARB 1687) from the bottom of stratum three, and 21,370 +830/-920 yr BP (DICARB 1689) from 49 inches (1.2 m) below stratum three (Gilbert and Martin, 1984).

William C. Johnson at the University of Kansas employed a heavy-liquid flotation technique to recover pollen from five test samples. These samples were collected at stratigraphic levels approximately 13.9, 18.4, 21.9 cal ka BP, immediately above the 110 ka BP ash, and from below the 110 ka BP ash. The five test samples spanned the section currently exposed in NTC and came from stratigraphic levels where faunal changes had previously been observed. Based on the five samples, there appeared to

Figure 6. Plaster jackets created at Natural Trap Cave: (A) in 2015, of a Vulpes skull (jacket flipped over to expose skull underneath); (B) in 2017 of a bison mandible pedestaled, pre-jacket; (C) Bison skull jacket from 2016 in the lab; (D) bison skull from c partially prepped out in the lab.

be a shift from a warm steppe to a full glacial steppe-tundra during the Sangamon interglacial, followed by steppe vegetation with scattered stands of coniferous forest during the late Wisconsinan. This result compared favorably with Pearsall's opal phytolith data and the mammalian microvertebrate data, but were never formally published (Johnson and Fredlund, 1982).

Excavations in 1980 exposed a second and third ash layer. The ashes in NTC are not laterally extensive but restricted to a 5-10-foot (1.5-3 m) area. Vertebrate fossils were found below the lowest ash, confirming the presence of Sangamon Interglacial fossils in NTC. With the acquisition of so much interdisciplinary data over the course of seven summers, excavations were halted to concentrate on publishing. Though, Gilbert did return in the summer of 1982 to stabilize and construct a roof over some of the open grids.

1984 Excavations

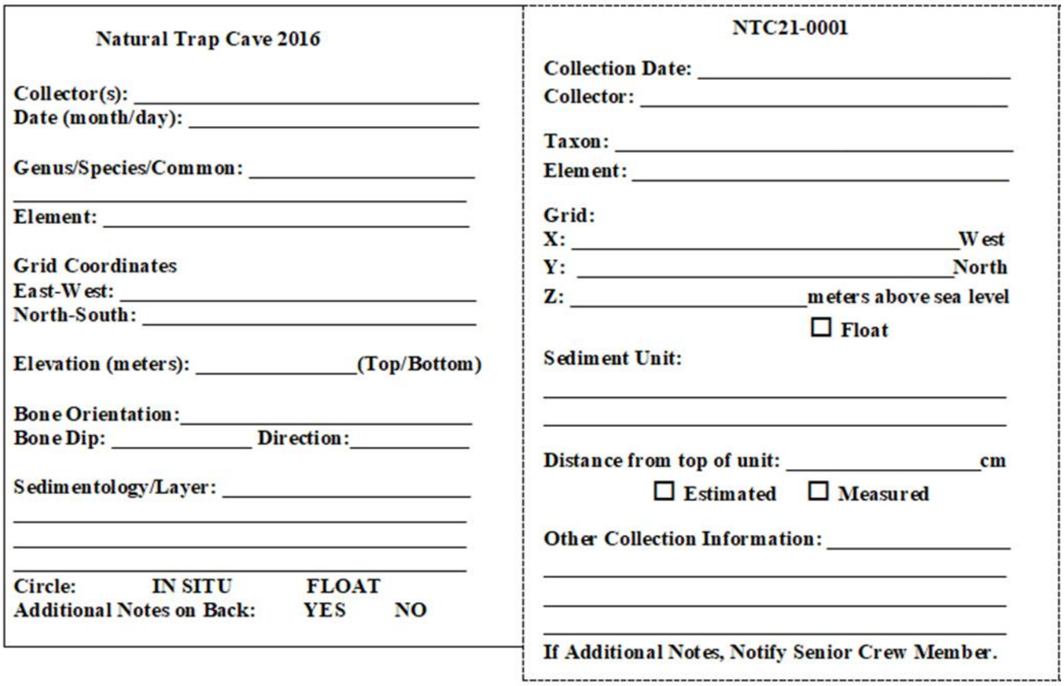
Two adjacent grids at 505 North and 500 West were a focus for the 1984 field season and had already achieved a depth of seven feet (2 m) below the sloping cave floor and approximately 24 inches (61 cm) below the 110 ka BP volcanic ash. Another objective for the season was to carefully document the breakage of bones from rocks falling off the ceiling. A pollen trap was also set up in the cave to determine modern rates of deposition and help interpret fossil pollen percentages. A film crew from Northern Arizona University came out to document the research activities at NTC and a photojournalist from *Life* magazine included NTC in an article about caves on public lands. Before leaving at the end of a month-long field season, open grids were covered with trussed roofs of plywood, to help avoid erosion and slumping from precipitation, and the scaffolding was dismantled and stored on the cave floor for the following year.

1985 Excavations

At the start of the 1985 field season, the depth of the bone bearing sediments was still not known and the objective of this field season was to continue excavating below the 110 ka BP ash. In less than four weeks, an additional three feet (0.9 m) of depth was excavated in a grid 5 x 10 feet (1.5 x 3 m). To the west of this grid, excavators broke through the ceiling of a previously unknown, lower chamber. The lower chamber had a maximum height of six feet (1.8 m), was 28-50 feet wide (8.5-15 m) and 100 feet (30.5 m) long. It had previously been connected to the entrance chamber by a passage that had become filled with sediment. On top of the alluvial fan that extended from the plugged passage, lay the femur of a juvenile mammoth and the best-preserved horse skull found during the entire expedition. The height of the lower chamber indicated that there could be an additional 16-28 feet (4.9 -7.3 m) of sediment yet to be excavated.

By the end of the Gilbert and Martin excavations, over 31,000 megafaunal specimens, with a maximum depth of 14 feet (4.27 m) had been excavated. All the vertebrate fossils collected from the Gilbert and Martin expeditions were reposited at the University of Kansas' Vertebrate Paleontology Collection. Horse skeletal elements were the most abundant fossil found in NTC, representing two to four taxa and an ongoing source of study. Two genera are currently recognized at NTC, a more abundant stilt-legged (*Haringtonhippus*) and a rarer caballine horse (*Equus*) (Heintzman et al., 2017). Bighorn sheep (*Ovis canadensis*) are the second most abundant taxon with over 4,400 identified elements recovered, mostly male (Wang and Martin, 1993). Gilbert and Martin initially recognized NTC's bighorn sheep as a larger, extinct species (*Ovis catclawensis)*, but morphological analyses of cranial and postcranial elements show they still fall within the documented size range of the extant bighorn sheep that still inhabit the area (Wang, 1988). NTC's pronghorns were also determined to be indistinguishable from the extant species living in the area (*Antilocapra americana)*, based on a morphometric analysis of postcranial material (Chorn et al., 1988).

An in-depth study of NTC's small mammalian fauna (<5 kg) would be done years later by Daniel Williams at the University of Kansas, but never published in a peer-reviewed journal. He identified 40 taxa from over 2,500 vertebrate microfossils, with a significant portion of the mammalian fauna spanning the entire stratigraphic section. These taxa were adapted to arid, open habitats or were generalist, as indicated by their large, extant latitudinal ranges. Arctic and alpine tundra taxa were recovered from levels dated at 21.9-18.4 cal ka BP. Williams attributed a significant proportion of the small mammal remains to have been deposited in NTC by packrats *(Neotoma)*, transported into the cave as individual elements or in the scat and pellets of carnivores, owls, or birds of prey (Williams, 2009).



Natural Trap Cave 2016

Collector(s): ______
Date (month/day): ______

Genus/Species/Common: ______

Element: ______

Grid Coordinates
East-West: ______
North-South: ______

Elevation (meters): ______(Top/Bottom)

Bone Orientation: ______
Bone Dip: ______ Direction: ______

Sedimentology/Layer: ______

Circle: IN SITU FLOAT
Additional Notes on Back: YES NO

NTC21-0001

Collection Date: ______
Collector: ______

Taxon: ______
Element: ______

Grid:
X: ______West
Y: ______North
Z: ______meters above sea level
☐ Float

Sediment Unit:

Distance from top of unit: ______cm
☐ Estimated ☐ Measured

Other Collection Information: ______

If Additional Notes, Notify Senior Crew Member.

Figure 7. Field labels from Natural Trap Cave, on the left from 2016, and on the right from 2021.

Excavations from 2014-Present (Meachen expeditions)

From 1986-2007, the cave was closed to public access. In 1995, NTC was designated as a Significant Cave by the BLM. In 2006-2007, the BLM Cody Field Office conducted cleanup operations in the cave to remove old lumber, metal scaffolding, and other debris from the KU excavations. Between 2010-2014, the BLM (Cody Field Office and Wyoming State Office) worked with Meachen to develop, review, and eventually authorize new research and new excavations of vertebrate fossil specimens from the cave.

NTC was reopened in July of 2014 when funding was secured from the National Geographic Society (NGS 9479-14) and Des Moines University. Additional funding was procured from the U.S. National Science Foundation (EAR-SGP 1425059) that enabled the 2015-2017 field expeditions. The initial objective of the project was to examine how late Pleistocene warming events correlated with genetic and morphological changes in the cave’s megafauna. However, these objectives were almost immediately expanded to include research on paleoecology, palynomorphs, sedimentology, geochronology, geochemistry, karst mapping and formation, and vertebrate microfossils as the research opportunities that NTC offered were quickly realized and Meachen was able to recruit more collaborators onto the project. This work is still on-going and additional funding from The David B. Jones Foundation has been secured to fund further field seasons. All fossils recovered during the Meachen expeditions are being reposited in the University of Wyoming’s Collection of Fossil Vertebrates to strengthen the association of this natural resource to the people of Wyoming.

Because the cave was closed for 29 years, the Meachen crew had some logistical challenges that the other crews did not. The Gilbert and Martin expeditions used scaffolding to enter and exit the cave, but it had long been removed and it was decided that the safest and most cost-effective way to access the cave was rappelling in and ascending out using single-rope techniques (frog system) (see Supplementary Materials for detailed rope set-up), similar to those used in the early 1970s by Loendorf and Rushin. However, Loendorf and Rushin did not have a large field crew, unlike all subsequent excavations.

Traveling in and out of the cave now required all field members to be trained or demonstrate competence in frogging and changeover techniques every year. Not a small task, when there could be over 50 people working in the cave over a field season. Cooper was a skilled caver trained in the appropriate techniques, but the success of the Meachen expeditions is due to the numerous cavers that donated their skills and time to the project. Luckily, the project received news coverage before excavations began, alerting members of a number of grottos in the Rocky Mountain region. Indispensable cavers that materialized on the mountain to help the team included Ian Chechet, Steve Langendorf, Doug Warner, and Juan Laden. Laden became the expedition's lead caving and safety expert, joining the Meachen expeditions every year for the entire field season, and devising the rigging system of the cave (see Supplementary Materials). This project would not have been possible without the myriad of volunteers, which included paleontologists, students, museum volunteers, friends, family members, cavers, and even a few reporters. Volunteers helped with all aspects of the field expedition, including excavating fossils, screen washing, setting-up camp, cooking, and supply runs to the nearest town, Lovell, WY, which is only 24 miles away, but a three-hour round trip due to road conditions.

When excavations in NTC began again in 2014, the first priority was to recreate the grid system that Gilbert and Martin used, for the purposes of continuity. This was no small feat, considering that all remnants of the original grid system had been removed. The grid recreation was done using previously published works, mainly Wang and Martin (1993), which included a map of the cave and all previous excavation areas, and by including X. Wang, now at the Natural History Museum of Los Angeles County, join the first year of the Meachen expeditions. The grid system was set up using a series of rebar and construction twine to establish the x-y coordinate system. Because GPS signal cannot be obtained in the cave, setting up the z-coordinate system was more challenging and evolved over the course of the expeditions. For the 2014 field season, the z-coordinate was depth below the existing cave surface, a system used early on by Gilbert and Martin. That was replaced the following year when elevations above sea level were mapped onto the excavation areas using GPS coordinates at the surface, a string, a plumb bob, and a measuring tape.

Before any excavations began all surfaces were prospected for bone that had weathered out. Many of the excavation pits from the Gilbert and Martin expeditions were still open and largely intact, though significant slumping and infilling had occurred due to precipitation during the 29 years of inactivity. Gilbert and Martin had back filled some of their excavation pits, but thankfully had laid down a plastic barrier beforehand, so the removal of overburden and identifying *in-situ* sediments was possible, though not all back-filled areas had a plastic liner. Distinguishing between back-fill and *in-situ* sediments in the cave can be difficult and sometimes finding trash (e.g., rusty nails) was the only obvious clue. Once obvious back-fill had been removed, all grids (1.5 x 1.5 meters) were excavated using small hand tools (i.e., trowels, dental picks, and brushes), following a procedure similar to Gilbert and Martin. Grids were excavated along the stratigraphic planes, removing matrix from around rocks and bones, until they could be safely removed without disturbing the surrounding matrix and potentially causing damage to other bones. In sedimentary layers with a high percentage of rock fall, this could be challenging.

NTC's entrance chamber receives abundant natural light and crews can easily work in the cave from 8:30 am to 5:30 pm during the summer months. Battery-powered head lamps provide supplemental lighting for excavation. The cave yields a diverse assemblage of mega- and micro-vertebrate fossils. Skeletal elements from megafauna are typically found disarticulated, with little to no weathering. In certain areas of the cave (e.g., directly below the cave entrance), the bone can be soft and crumbly, due to water saturation, but will stabilize if left to air dry for 12-48 hours. Almost no field consolidant was used, due to the high-water content in the sediment and the constant temperature (3-5°C) and high humidity in the cave. A couple of larger and more delicate specimens were jacketed using Gypsona plaster bandages, but these needed over 48 hours to set (Fig. 6). Field tags listing the north-west grid coordinate, z-coordinate, sedimentary layer, tentative species and skeletal element ID, and *in-situ*/float status of the fossils were included with each specimen (Fig. 7). For specimens over seven centimeters, the orientation and dip of the long axis was taken using a geological compass, prior to the use of a total survey station in 2016 and 2017.

Microfaunal specimens were collected in NTC led by the team of Jenny McGuire (Georgia Tech). Sediments containing possible microfauna were collected in sediment bags in several centimeter sediment layers and hauled to the surface for screen washing. Holocene microfauna was abundant in field years 2014-2017, with Pleistocene microfauna less abundant.

All equipment was lowered into the cave using a 2:1 haul system attached to a pulley and bucket in a bucket harness. Equipment that was too large to fit in the bucket (e.g., a wheelbarrow or a ladder) were rigged using rope slings and lowered using the haul system. To remove fossils, sediment bags, and equipment from the cave, this same system was used, rigged 3:1 for heavy loads, along with a hauling crew at the top to pull everything up. See supplementary materials for details on the hauling system.

In 2015, two test pits were excavated to the east and upslope from the main excavation area. One of the test pits was located directly under a dome in the entrance chamber's ceiling. The goal was to test a hypothesis that one or more of the ceiling domes might represent a solution hole that opened to the surface in the past and was subsequently filled in with debris. The domes are obvious concavities in the ceiling, usually with distinctive red staining from the Amsden Formation that overlies the Madison Limestone (Figs. 4, 8A-B). The test pit that was directly under a dome was worked for six days, achieving a size of 3.5 x 2 meters and over 60 centimeters deep. While mega-and micro-vertebrate fossils were recovered from both test pits, productivity was low compared to the primary excavation area below the entrance, so excavations were halted, and the test pits were backfilled.

In 2016, the BLM granted permission to use modern cartographic technologies to produce a new map of the NTC system. The previous cave map was published in 1976 and was not sufficient for developing a better understanding of the cave's depositional system and formation. The 2016 mapping efforts were led by Blaine Schubert (East Tennessee State University) who organized the cartographic team and facilitated equipment. In addition to providing a more detailed map, the team surveyed the cave for additional paleontological resources and searched for potential ancient entrances. This included exploring multiple domes in the ceiling of NTC's entrance chamber. The new NTC cave map was produced using Disto X surveying, which uses a modified Leica laser distance meter to measure distance, azimuth, and vertical angle once it has been calibrated to the area for declination. The entrance chamber of NTC was also documented using photogrammetry and a portion of the NTC system was mapped using LiDar. Aspects of the new map (drafted by Hans Bodenhamer) and the LiDar data are presented further in Lovelace et al. (2022).

During the 2014-2016 field seasons, skeletal elements from a wide variety of megafauna were sampled in the cave for ancient DNA (aDNA) by a team from University of Adelaide (Alan Cooper, Laura Weyrich, and Kieren Mitchell). The objective was to maximize the recovery of aDNA before fossils had been subjected to DNA degrading conditions, like desiccation, climate fluctuations, and curatorial techniques, such as consolidation. Cooper had recovered mitochondrial DNA from NTC specimens previously collected by Gilbert and Martin and housed in the University of Kansas' Vertebrate Paleontology Collection. The hope was to recover the longer strands of nuclear DNA from

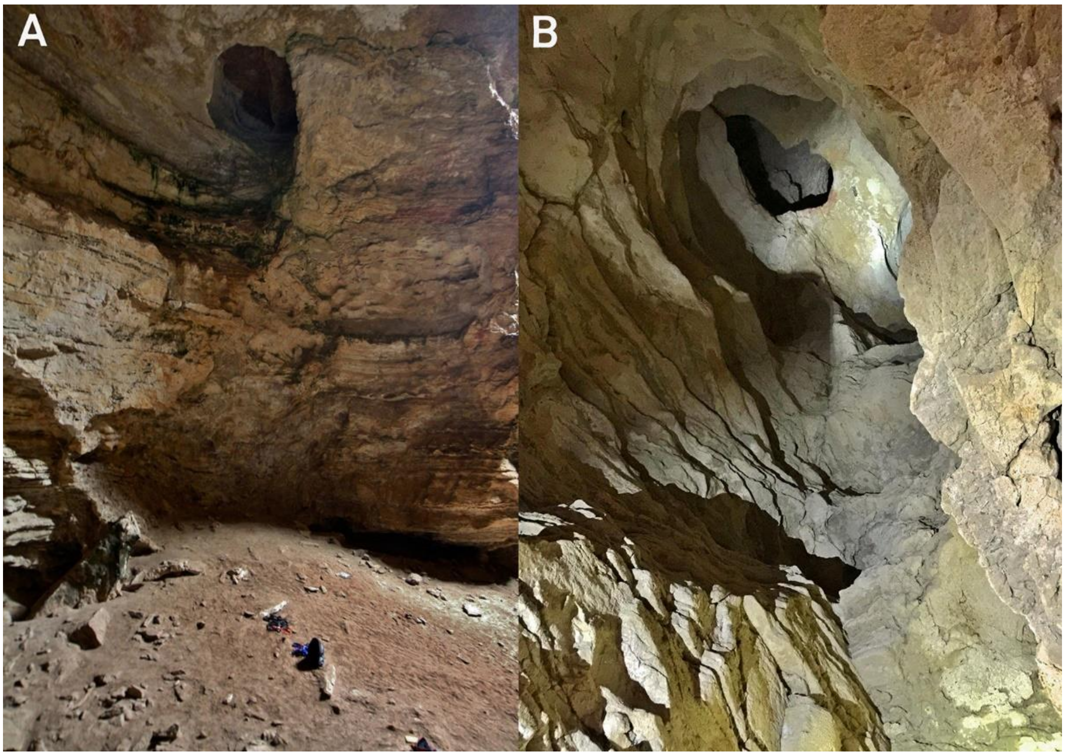


Figure 8. (A) Shows location of one of the two test pits dug in 2015; (B) Close-up image of the overarching dome, and potential solution hole that was explored as a possible former entrance. Photo credits Justin Sipla.

the fossils still buried in the cave. NTC is a significant locality for aDNA studies, because most of the genetic record of Pleistocene megafauna come from fossil localities in the high latitudes and subarctic environments, while species found at lower latitudes and more temperate environments are not well documented. Most of the aDNA recovered from NTC has been mitochondrial DNA, with preservation typical of aDNA recovered from caves in permafrost (Shapiro et al., 2004; Barnett et al., 2005; Weinstock et al., 2005; Barnett et al., 2009; Heintzman et al., 2017; Richards et al., 2019). All excavated fossils were wrapped, bagged, and stored in the cave until the end of the field season, to minimize climate fluctuations and contamination.

In 2016 and 2017, a total survey station was used to map the position and orientation of every bone excavated, taking multiple points per element. The total survey station is the most accurate methodology for mapping bone position and features in the cave, but it requires access to an expensive piece of equipment, specialized software to evaluate the data, and having a trained person to run the total station in the cave at all times. A professional survey crew composed of Landon Woodward and Brian Mayfield was used in 2017. This simplified data collecting, because they provided a total station and shot in data points for most of the megafaunal fossils recovered that year. In addition, Woodward and Mayfield checked the expedition's 2016 data and corrected any errors. No total station was used in the 2021 excavations because the PIs did not have access to any equipment.

As per BLM requirements, at the close of the 2017 field season, all rebar and construction twine denoting the grid system was removed in anticipation of closing the site for the foreseeable future. At that time additional funding had not been secured to continue field excavations. Small magnetic slugs were inserted into the rebar holes and covered by aluminum caps, to allow for the easy reconstruction of the grid in the future. All excavated grids were covered with clear plastic sheeting, secured with large rocks, and covered with approximately 0.5 meter of dirt. Between 2014 and 2018 over 3,000 megafaunal specimens were recovered. Although all of the taxa recovered during the Meachen expeditions had previously been documented at NTC, our understanding of the assemblage is still advancing. For example, Gilbert and Martin recognized two species of wolf at NTC, an abundant gray wolf (*Canis lupus)* and a rare dire wolf (*Aenocyon dirus,* formerly *Canis dirus*) (Gilbert and Martin, 1984; Perri et al., 2021). Meachen morphologically assigned most of NTCs wolf specimens as gray wolves (*Canis lupus*) belonging to an extinct subspecies known as the Beringian wolf (Meachen et al., 2016), but a recent aDNA study confirms the presence of dire wolves at NTC (Perri et al., 2021), although they are rare.

Over the course of the 2014-2017 excavations, numerous film and media crews came to NTC to document the work. These crews included local newspapers (*Billings Gazette* and *Powell Tribune*), broadcast networks (Wyoming PBS, and local Cody news) and education and outreach crews (Barefoot Films productions). Additionally, through interviews with mainstream media sources, NTC was covered by NPR, the BBC, the CBC, the Associated Press, and many individual online news sources.

After the 2018 season, the excavations were covered with native material and protected from the elements. For various reasons, the cave was not worked during the 2019 or 2020 seasons.

In 2021, Meachen and her crew again excavated NTC with J. McGuire as the co-PI. The major challenge for this field season was un-remediation of the site. Plastic sheeting had to be re-excavated and removed, and the grid system had to be re-created again. This was facilitated by the magnets and aluminum caps that were put in place in 2017. Rebar poles were set up to outline the grid system as used in previous years, but contractor's twine was not used. Depth was again reconstructed using GPS coordinates at the surface a plumb bob, string, and a long metric tape measure. Excavations ran smoothly and additional megafauna, microfaunal, and sediment samples were collected. Some bountiful Pleistocene microfaunal sediment sites were discovered in 2021. Additionally, in 2021 the lower chamber that Gilbert and Martin had discovered in 1985 was explored and mapped using the same techniques we used for the upper chamber and back passage in 2016.

DISCUSSION

Future work at NTC will follow up on the scientific questions that are still unanswered at this important Pleistocene site, which include questions about climate change, and subsequent faunal changes. Additionally, this site may help us determine questions such as whether the enigmatic American cheetah (*Miracinonyx trumani*) was responsible for the evolution of speed in the pronghorn

(*Antilocapra americana*), whether the wolves at NTC gave rise to coyotes, and how many species of horses were found in the Pleistocene of the American west. The utility of this site is far from over, and as new scientific techniques arise, we will be able to explore more hypotheses and answer more questions using the data from NTC.

The success of the excavations at NTC were due to the accumulation of knowledge that the three teams had acquired since 1970. Using all available resources these three teams were able to overcome the logistical challenges posed by the 24.5-meter vertical drop in the cave. Each excavation season presented new or interesting challenges for the PIs and field crew, and this publication serves as a record of those challenges and how they were met. This record will help future teams to excavate at NTC, and at other vertical cave sites, and serve as a history of how things were done previously to provide some historical context to future generations.

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Original raw images at full resolution and animated material can be downloaded at
http://www.jpaleontologicaltechniques.com

SUPPLEMENTARY MATERIAL

CAVE RIGGING SET-UP FROM 2014 TO PRESENT

Cave Rigging Set-up

The existing situation for entrance and security for the cave has features that are useful for rigging the cave: the grate and gate over the cave can be used for anchoring (Fig. S1A, B). There is an aluminum ladder that descends to a ledge approximately 10 feet below the grate left in place by Gilbert and Martin's crew. The rigging consists of three main elements: the main travel line (Figs. S1C, 2A), the haul line (Figs. S1D, 2A), and a belay line (Fig. S3), for all people rappelling or ascending on the main travel line. There is a secondary component of rigging: the safety line for the belayer on the ledge (Fig. S4), which also secures the ladder to the grate and into the wall behind (Figs. S2B-C, S4). There is also a self-belay (Fig. S1A), a 7mm doubled rope with knots at the top of the ladder and at the bottom of the ladder that is clipped in with two cow's tails as a safety precaution. Whenever someone is within a body length of the open gate, they should be clipped into this line. This is also used by the person opening or closing the gate in the morning or in the evening, the person receiving material being hauled up, and of course, the travelers that will be rappelling or ascending in and out of the cave.

The main travel line (Fig. S1C), self-belay line (Fig. S4), and the haul line (Fig. S1D) are anchored to a rig plate with 5 points for attachment (Fig. S1B), which is anchored to the main anchor: an approximately 1/2" ring with an approximately 3" diameter eye and anchored in the bed rock. This has been tested with a 12,000-pound winch and was found to be secure enough to haul an 8,000-pound welding truck uphill with its brakes on. The rig plate is anchored to the main ring by a 12mm stainless screw link and two locking carabiners (Fig. S1B).

The belay line, with anchor (Fig. S3), is a 11mm dynamic line running through a Sticht plate belay device. The belay anchor is an 11mm static line attached at two points with a loop of 3/8" chain, screw linked together. A butterfly knot is tied between these points with a locking carabiner that is clipped into a Sticht plate belay device. The belay line runs from the grate on top, where it is anchored and handled by a rope mender (one of the two volunteer cavers on the top), down the entrance to the person on the ledge, that does the belaying. The belayer clips in the person rappelling at the bottom of the entry ladder with a locking carabiner, checks their rigging and then belays through the Sticht plate as the person rappels. The mender is responsible for a second cursory rigging check and to feed the rope to the belayer or take up the rope when a traveler is ascending the rope, when they are also belayed.

The main travel line (Fig. S1C) is an 11mm static line, anchored to the rig plate (Figs. S1B, S2A) with a locking carabiner and a Münter hitch, with enough rope in the tail that is tied off to be able to lower a person the whole way back into the cave (about 100 feet). It then runs into the gate and through a rescue pulley that is chained to the grid with a loop of 3/8" chain screw-linked together. It then drops into the cave just inches out from the edge of the ledge where the traveler will attach themselves to the rope. Up by the anchor is a set-up with a traction pulley to be able to capture the main travel line and apply a 3:1 capture pulley system, with the possibility to make a 9:1 system. The bottom of the rope is tied off in the cave to keep it out of the dig area and to enable someone to assist in the landing at the bottom. This would have to be untied if a haul system was instigated.

The haul line (Fig. S1D) for fossils is an 11mm static line, also attached to the rig plate run through a Petzl Traxion pulley at the gate on the right to work as a fairlead away from the descent ladder and also as a safety for hauling heavy loads. The haul line is a 2:1 system which simply runs through a redirect pulley anchored to the grate, with the same 3/8” chain system, down to another pulley and back up to the grate to a fixed anchor with a load bearing swivel to the 3/8” chain system. This is also set up with another 3:1 capture pulley system to be applied if needed for heavy loads. In an emergency, the fixed end of the haul system can be a secondary travel line.

The belay safety line (Fig. S4) anchored to the grate with the 3/8” chain system north and south of the belayer and parallel with the ledge, and behind the ladder. The other anchors are wired stoppers (Fig. S2C) in tapered cracks just behind the ladder and keep the safety line away from the ladder and into the rock to give little play for the belayer (Fig. S2A). These points are also slung with 1” tubular webbing to keep the ladder from pulling away. At all times the belayer is clipped in with both cow’s tails while working on the ledge. Overview of the set-up can be seen graphically in Figure S1.

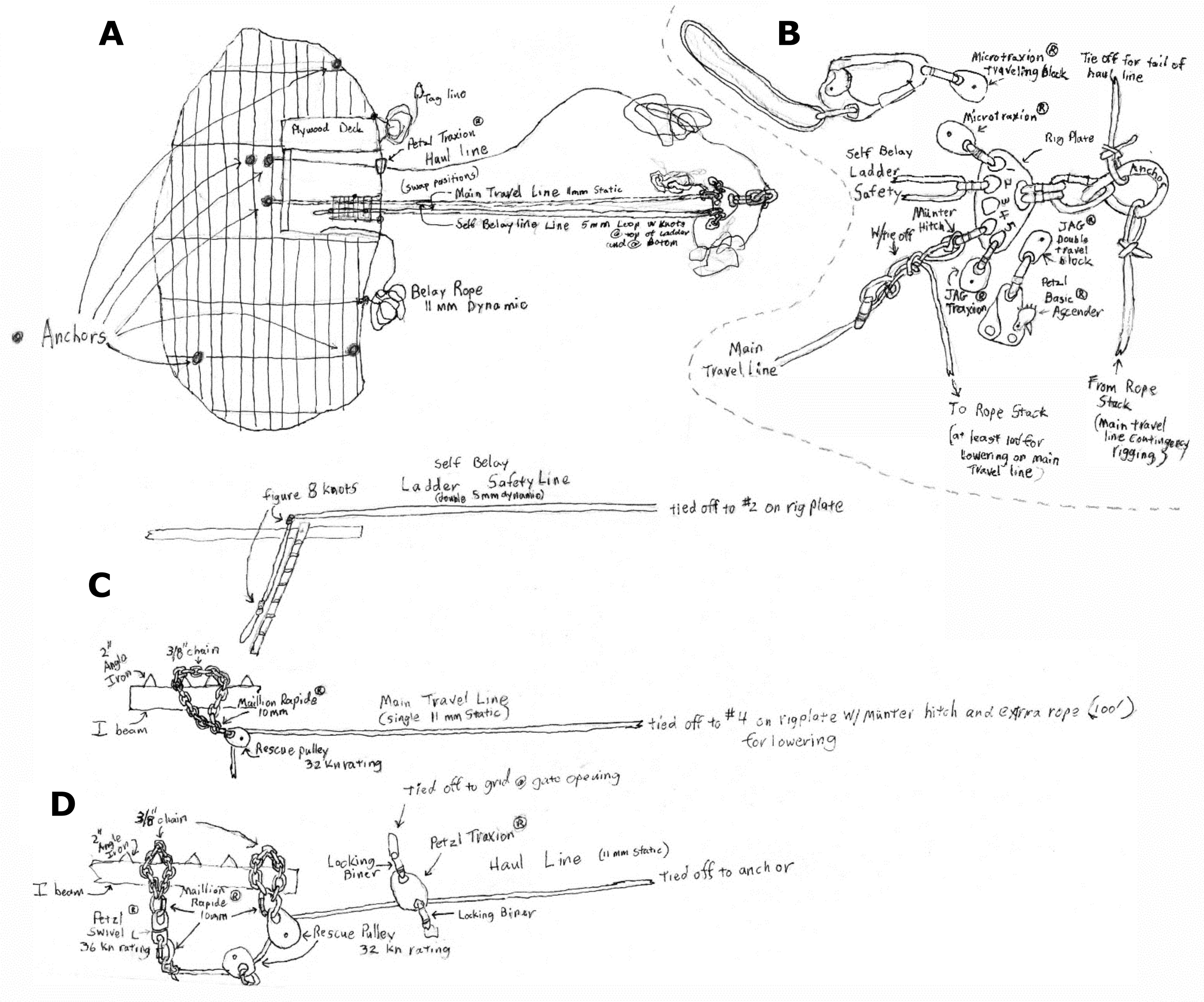

Figure S1. (A) grate over NTC including SRT cave rigging; (B) close-up of the rig plate and rope set-up on the metal anchor near the cave entrance; (C) main travel line set-up; (D) close-up of pulleys from c and haul-line set-up.

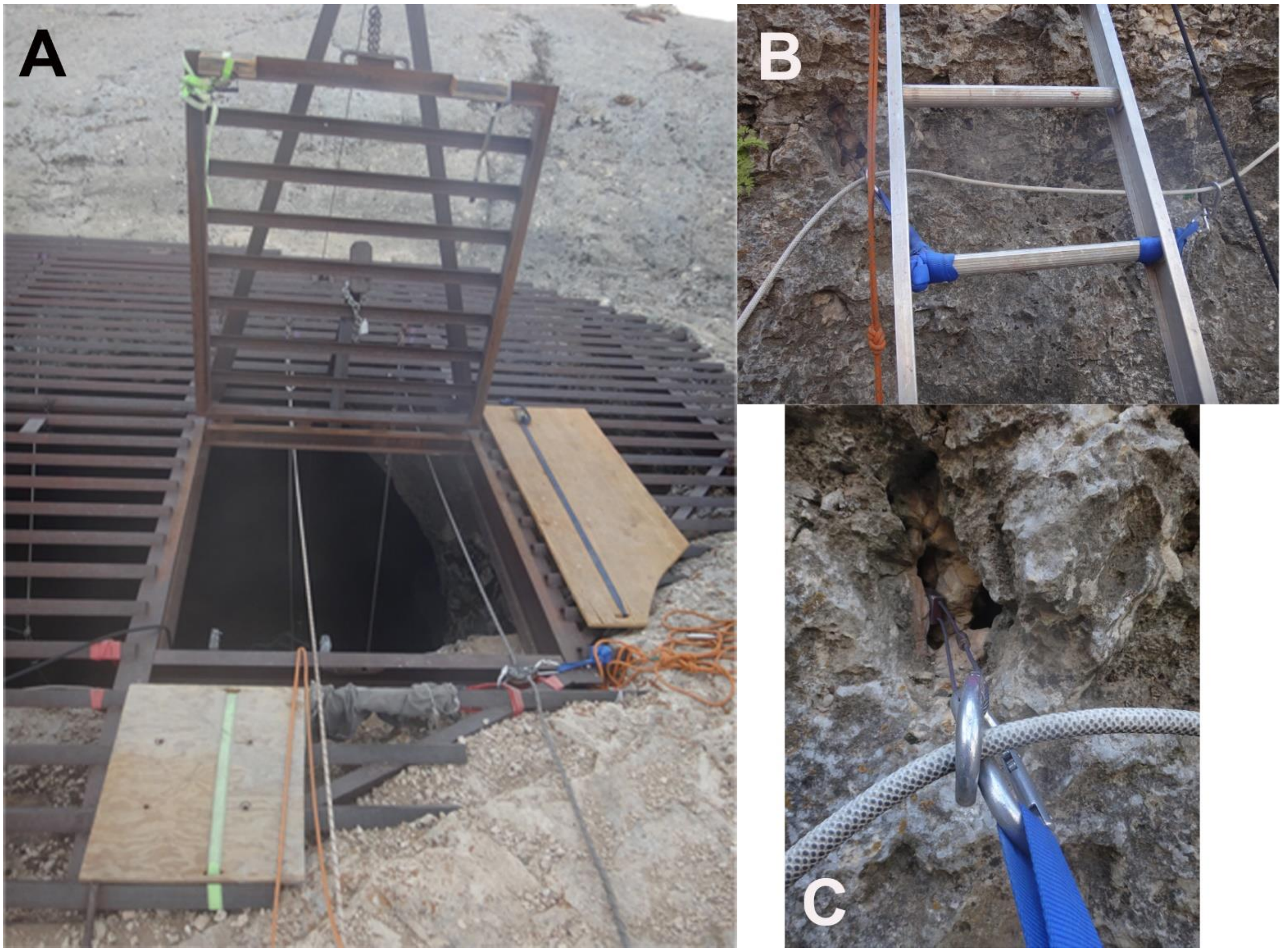

Figure S2. (A) entrance to Natural Trap Cave in the grate placed over the opening by the BLM, showing caving rigging set-up; (B) ladder from cave opening to ledge where travelers begin their rappel and end their ascent. This figure shows how the ladder is secured with ropes and webbing. (C) figure showing where ladder is anchored into the rocks with wired stoppers.

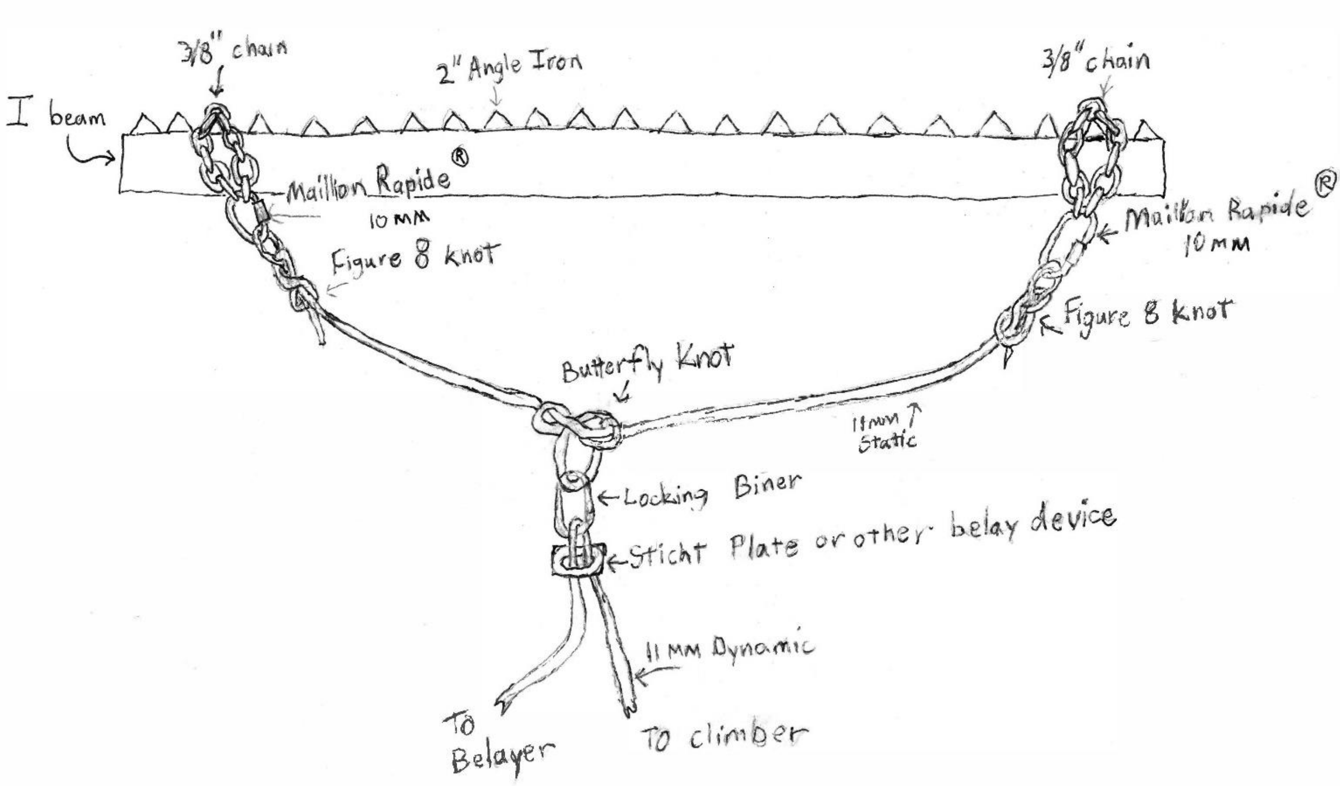

Figure S3. Belay Anchor and Rope set-up for NTC 2014-present excavations.

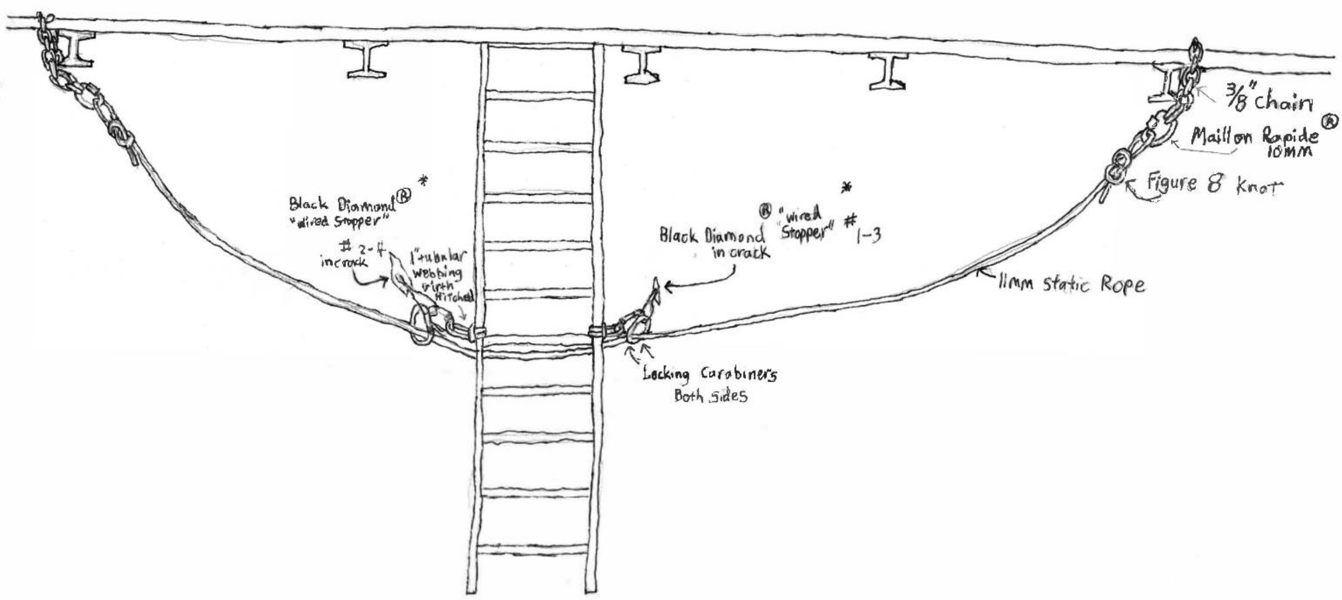

Figure S4. Safety and ladder anchor rope set-up for NTC 2014-present excavations. We were unable to remember the exact size of the wired stoppers, hence the ranges in sizes here. Both sides of the anchoring were the same. Anchors should be as tight as possible. Safety rope has to be long enough that the belayer can work both edges of the ledge for haul system and belaying.