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Reconstructing the specimens and history of Howe Quarry (Upper Jurassic Morrison Formation; Wyoming)

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ABSTRACT

In 1934, Barnum Brown of the American Museum of Natural History in New York (AMNH) led a large-scale dinosaur excavation in northern Wyoming, where he had found bones two years earlier. Initially, Brown expected to excavate two skeletons of sauropod dinosaurs, but soon after opening the quarry, the team realized that the site far exceeded their expectations: in the end, they unearthed approximately 3000 bones within six months and sent approximately 144 crates back to the AMNH. Due to the enormous number of bones, the site became world famous as a dinosaur graveyard, and media from all over the United States and abroad reported on the expedition. Soon after, however, the collection shifted away from a curatorial focus. What followed was a history of neglect: inappropriate storage conditions, water and fire damage, collapsing wooden boxes, and deteriorating plaster jackets.

Relocation and further excavation of the quarry by the Sauriermuseum Aathal (Switzerland; SMA) from 1989 to 1991 confirmed earlier finds of skin impressions and resulted in the recognition of a novel diplodocid sauropod: *Kaatedocus siberi*. Given that the amount of bones found by the AMNH far exceeded those found by the SMA, a new project was started in 2017 to reassess the state and scientific value of the historic collections at AMNH. Although most of the bones are heavily fragmented, preliminary results show that overall preservation is still exceptional. Here, we reconstruct the history of the excavation, as well as past conservation and preparation procedures, and provide a report of current efforts to prepare, conserve, and catalog the material that has remained in storage since the 1930s. These current efforts show that historic collections, even after decades of neglect, can be of great and unexpected value, both for research and scientific outreach.

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INTRODUCTION

Howe Quarry is one of the most enigmatic and famous single dinosaur sites in the Upper Jurassic Morrison Formation. It was discovered sometime in the 1920s, on the land of Barker M. Howe, north of Shell, Wyoming (fig. 1), and brought to the attention of Barnum Brown in 1932 by Nellie Austin, a local fossil enthusiast (Brown, 1935a). Initially expecting to excavate two sauropod dinosaurs within a month or two, Barnum Brown's team ended up spending six months in 1934 excavating an estimated 3000–4000 bones from a minimum of 20–25 individual skeletons. Many of these skeletons were semiarticulated and arranged in a criss-crossed way. The bones are dark brown to black, encased in a gray siltstone matrix (Breithaupt, 1997; Michelis, 2004). Photos of the quarry, and numerous media reports made the site world famous as a dinosaur graveyard, and hundreds visited the quarry during the excavation in 1934. Unfortunately, not all the material was shipped to the American Museum of Natural History (AMNH), and only a small portion of it was prepared in the following years (see below).

Even though not much was done with the Howe Quarry material at AMNH in the following years (due to Depression era economics, war time, and Brown's retirement), the fame and fascination with it remained alive, mostly thanks to the publication of photos and a very elaborate quarry map drawn by Roland T. Bird in popular science articles and books (fig. 2; e.g., Brown, 1935a, 1935b; Colbert, 1984; Bird, 1985; Norell, 2019). Most importantly, Bird (1985) also described the excavation itself in some detail, and mentioned that the site was never fully excavated, which prompted several parties to relocate it. In 1989, a preliminary excavation at the historic Howe Quarry led by the Swiss commercial collector Hans-Jakob (Kirby) Siber yielded additional bones, and his team got permission from the Howe family (the fossil rights owners) and from Press Stephens (the land owner) to excavate again. The rest of Howe Quarry was fully excavated by the Siber team in 1990 and 1991, which led to the establishment of the Sauriermuseum Aathal (in Aathal, close to Zurich, Switzerland; SMA) in 1992 (H.-J. Siber, personal commun.). These more recent finds sparked new scientific interest in the area, and in Howe Quarry material itself, and resulted in a number of scientific publications. These reported on sauropod skin finds (Czerkas, 1992, 1994), theropod footprints (Lockley et al., 1998), and a new species of sauropod dinosaur (*Kaatedocus siberi*; Tschopp and Mateus, 2013a), among others. Material from the SMA excavations at Howe Quarry contributed to a more detailed understanding of sauropod anatomy (both of soft and hard tissues; e.g., Czerkas, 1992, Klein et al., 2012; Tschopp and Mateus, 2013a, 2013b), sauropod-theropod interactions (Lockley et al., 1998), and more generally Morrison Formation paleoecology (e.g., Michelis, 2004; Tschopp and Mateus, 2017; Whitlock et al., 2018). Preliminary results from ongoing research on the historic material at AMNH further confirm the enormous scientific value of this site (Moretti et al., 2018; Tschopp et al., 2018, 2019a). Given the scientific importance of the Howe Quarry material, a preparation and conservation project was initiated in July 2017 to reassess the curatorial state and scientific value of the historic collections at AMNH (Tschopp et al., 2018).

The Howe Quarry campaign can thus be divided into three distinct phases, which we try to reconstruct here to provide a complete report of the excavation, preparation, and curation (or historical neglect) of the collection. The phases comprise: (1) the discovery, excavation, early preparation, and curatorial neglect of the remaining unprepared material; (2) the reloca-

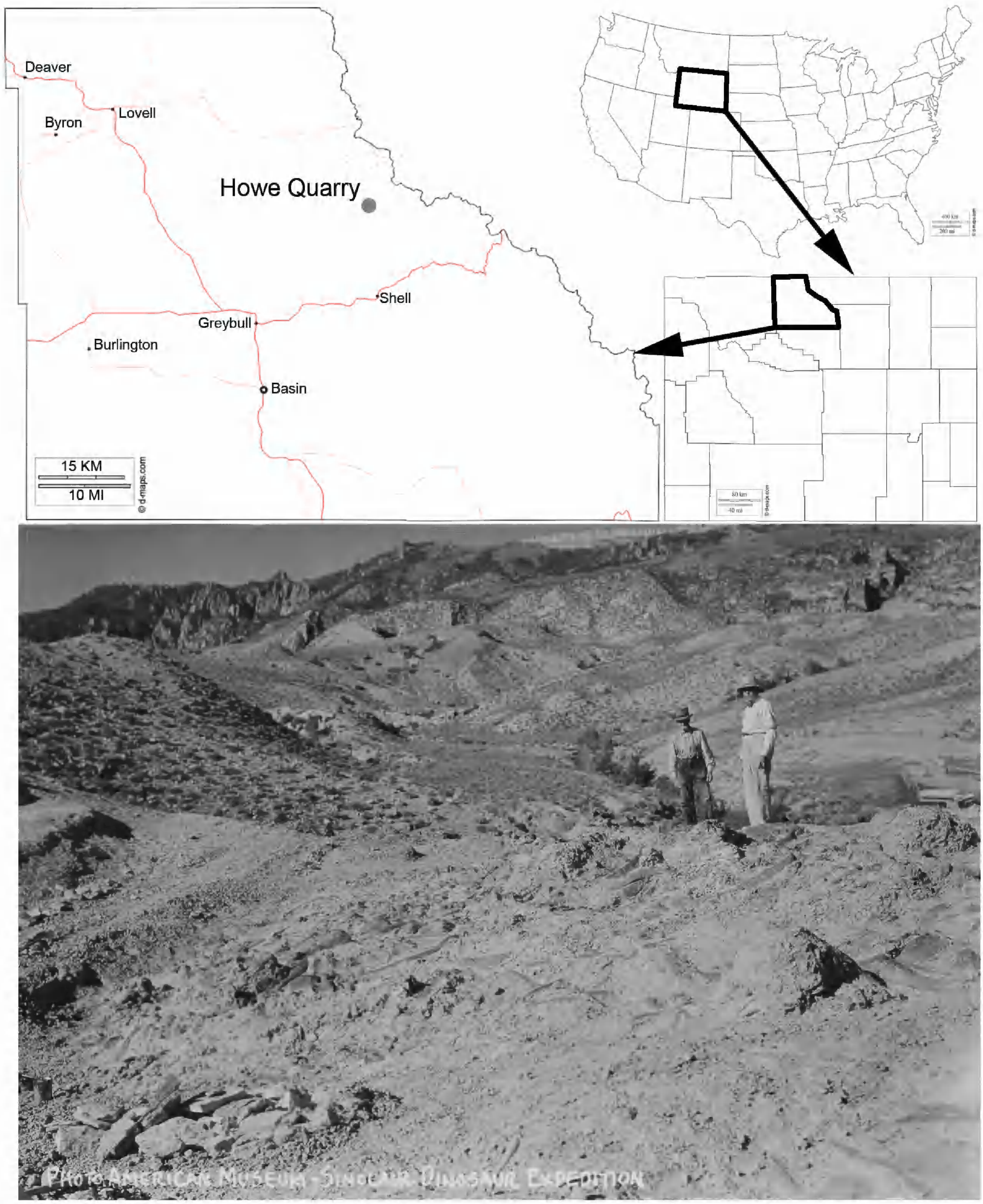


FIGURE 1. Location of Howe Quarry north of Shell, Bighorn County, Wyoming, with a photograph of Barker M. Howe (left) and Barnum Brown (right) on the site. Some constructions of Howe's homestead can be seen in the center right of the photograph. Maps of the United States, Wyoming, and Bighorn County copyright by d-maps.com, used with permission. Photograph courtesy of the AMNH Research Library (Photo Collection 5: 4, Box 7; "Howe Quarry, Wyoming, 1934").

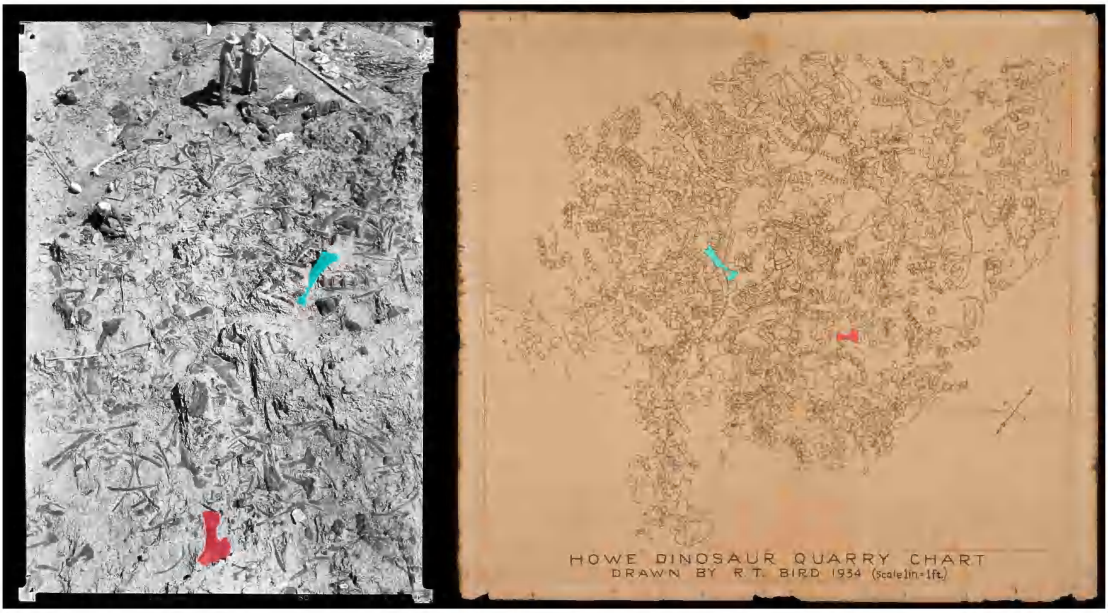


FIGURE 2. Photograph and quarry map of Howe Quarry, Bighorn Basin, Wyoming. A femur (turquois) and a scapula (red) recognizable in both images are highlighted to show spatial relationships. Note the three men in the photograph for scale.

tion of the quarry and salvaging of the neglected collection at AMNH; and (3) the recent conservation project. Thus, we provide both a historical assessment and a summary of recent curatorial efforts to preserve and catalog the previously unprepared Howe Quarry material. Our focus will mostly be on the historic collections at AMNH, highlighting the importance of keeping historic collections no matter their condition.

Institutional Abbreviations

AMNH FARB American Museum of Natural History, Fossil Amphibian, Reptile, and Bird collections, New York
AMNH FF American Museum of Natural History, Fossil Fish collections, New York
AMNH VPA American Museum of Natural History, Vertebrate Paleontology Archives, New York
MOR Museum of the Rockies, Bozeman, Montana
SMA Sauriermuseum Aathal, Aathal, Switzerland
YPM Yale Peabody Museum, New Haven, Connecticut

MATERIAL

Most of the material excavated from Howe Quarry and present at AMNH belongs to sauropod dinosaurs of at least two different taxa: the diplodocine *Kaatedocus siberi*, and a macronarian sauropod closely related to *Camarasaurus* (Michelis, 2004; Tschopp and Mateus, 2013a;

Tschopp et al., 2015). Additionally, fragmentary remains of the ornithischian *Camptosaurus* are present, as well as theropod teeth and a lungfish tooth plate (Brown, 1935a, 1935b; Kirkland, 1987; Michelis, 2004; E.T., personal obs., 2017). Brown (1935a) initially reported mostly *Barosaurus*, with some specimens of *Morosaurus* and *Camptosaurus* but also stated repeatedly in the press that many represented new taxa (e.g., *New York Times*, Sept. 9, 1934). Whereas *Morosaurus* had actually been synonymized with *Camarasaurus* more than 20 years earlier (Mook, 1914), some of the *Barosaurus* material likely belongs to *Kaatedocus siberi* (e.g., AMNH FARB 7530, see Tschopp et al., 2015). Breithaupt (1997) also mentioned the presence of *Diplodocus* and *Apatosaurus*, but referrals of specimens to these taxa in northern Wyoming and Montana have been shown to be questionable (Tschopp et al., 2019b). The faunal list from the Howe Quarry in Foster (2003) represents several distinct quarries on the Howe Ranch, which are from different stratigraphic levels (including the Howe-Stephens and Howe-Scott quarries; see Schwarz et al., 2007; Tschopp and Mateus, 2017). A detailed assessment of the taxonomy of all the remaining Howe Quarry material will be necessary to definitively confirm which taxa were preserved here. Such a study is out of scope of the current paper and will be addressed in later contributions.

HISTORY (1932 TO 1970s)

Excavation (1932 to 1934)

Barnum Brown first visited the site in the summer of 1932 with Peter Kaisen and Darwin Harbicht. They soon realized that there were too many bones to excavate that summer, so they covered them, and left the excavation for the following year (Brown, 1935b; Michelis, 2004). Brown's team found evidence for two individuals, with two tails, one connected to a sacrum, the other one associated with a hind limb (Brown, 1935a). In 1933, a limited amount of money was available through the Frick Fund (AMNH Annual Report, 1933), allowing Brown to remove six feet of overburden from an area of 65 × 45 feet, but not to further excavate the area (Brown, 1935b). Significant sponsorship by Sinclair Oil and Refining made the excavation possible in 1934 (Brown, 1935a, 1935b).

Carl Sorensen was appointed to lead the 1934 expedition in Brown's absence. He left New York on Friday, 25 May 1934, and arrived in Billings, Montana, on May 31 (as indicated in a letter from Brown to Edward [Ted] Lewis from May 26th, 1934; AMNH VPA-14). Here, Sorensen met Lewis (from Yale University), Dan Thrapp (AMNH), and Bill Frutchey (New Jersey) (Bird, 1985). They arrived on the Howe Ranch on Friday, June 1 (Brown, 1935a). Later the same day, Roland T. Bird joined the group from Florida (Bird, 1985). Brown and Kaisen were supposed to join the excavations at a later stage, but Kaisen was recovering from surgery that summer. Brown initially planned to arrive around June 20, but got there on July 11 (AMNH VPA-38; *The Greybull Standard*, July 12, 1934: 1). Interestingly, Bird (1985) wrongly reports Brown's arrival to have been on July 3.

Quarry work began either on Monday June 4 (according to Bird, 1985) or more likely on Wednesday June 6 (according to the unpublished "Summary of important dates," which seems

FIGURE 3. Historic photographs from the 1934 excavation at Howe Quarry. **A**, Removing overburden with horses. **B**, Excavating and jacketing. Two original crates are ready to be packed. Box number (109 on the one on the right), year of the expedition, and institution are written on the crate. Crate 109 (on the right) is also marked with "Block 71", indicating that a large jacket from section 71 was packed in that crate. **C,** Documentation of the quarry with photography from a barrel hanging from a hay derrick. **D**, Large or long plaster jackets were reinforced with branches and wooden beams. **E**, Many bones (including ribs) were jacketed as single elements and nearly completely prepared in the field (as in this rib from section 62, which Brown is showing off), likely to reduce weight. Photographs are courtesy of AMNH VPA (A, C) and the AMNH Research Library (B, D, E; Photo Collection 5: 4, Box 7; '"Howe Quarry, Wyoming, 1934").

to be more accurate than Bird, 1985; AMNH VPA-38). They uncovered two articulated tails with chevrons, several ribs, and a scapula, most of which were already exposed and covered again by Brown in 1932 (Brown, 1935a; Bird, 1985). A few days later, the team had already found five scapulae, two more tails, and a neck (Bird, 1985).

Due to the considerable number of newly uncovered bones, Brown sent three more men: Laurence F. Rainsford and his son Laurence K. from Rye, NY (who arrived on July 1; AMNH VPA-38), and Wyman R. Green from Princeton (who arrived on July 2; AMNH VPA-38). After

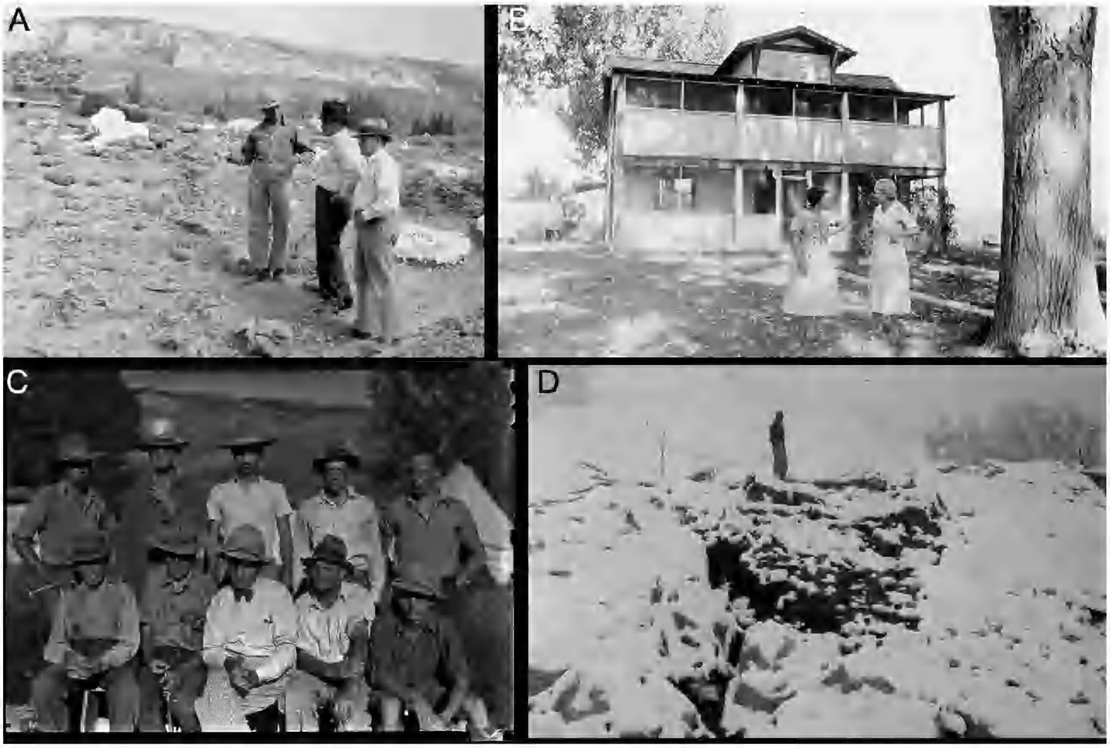


FIGURE 4. Historic photographs from the 1934 excavation at Howe Quarry. **A**, Visitors were common during the excavation. Barnum Brown explains the site to two of them. **B**, The Paton Ranch, where many dinners were held, and where some jackets were stored in 1934 to be picked up later (which never happened). **C**, A picture of the excavation team (sitting, left to right: Barker M. Howe, Laurence Rainsford, Barnum Brown, Carl Sorensen, William Frutchey; standing, left to right: Roland T. Bird, Wyman Green, Ted Lewis, Dan Thrapp, unknown, possibly Rainsford's son). **D**, Snowstorms interrupted quarry work several times between September and November. Photographs are courtesy of AMNH VPA (A, B, D) and the AMNH Research Library (C; photo 132802).

Brown's arrival, Milo Howe (Barker M. Howe's son) started to help in the excavation and removal of overburden with his horses (fig. 3A; Bird, 1985). More people joined later during the season, while others had to leave before the end of the campaign, so that the team averaged between nine and 12 members (fig. 4C; Brown, 1935a).

Given the complicated arrangement of the numerous bones and partial skeletons, Bird volunteered to draw a map to record how all the elements were associated (Bird, 1985). The entire area was divided into squares of three feet (Brown, 1935a, 1935b; Michelis, 2004), which were numbered (Brown, 1935a, 1935b; Bird, 1985), and totaled 378 squares (18 rows of 21 squares each; Michelis, 2004). The bones were sometimes drawn into the map while still partly covered by matrix, so that only parts of certain bones could be drawn. The field sketches were copied to the final, compiled map once back in New York, at R.T. Bird's parents' home in Rye (fig. 5; Bird, 1985). The drawings of incompletely visible bones were subsequently completed for the compilation, vertebrae in particular, so the shape and exact dimensions are not necessarily accurate (according to notes in the AMNH Research Library: Department of Vertebrate Paleontology

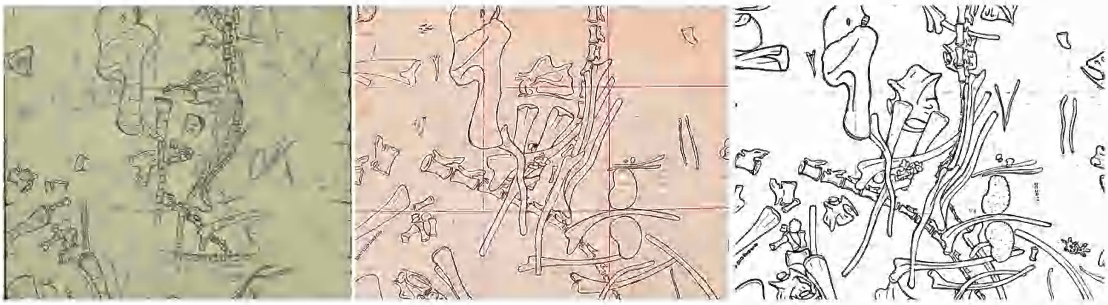
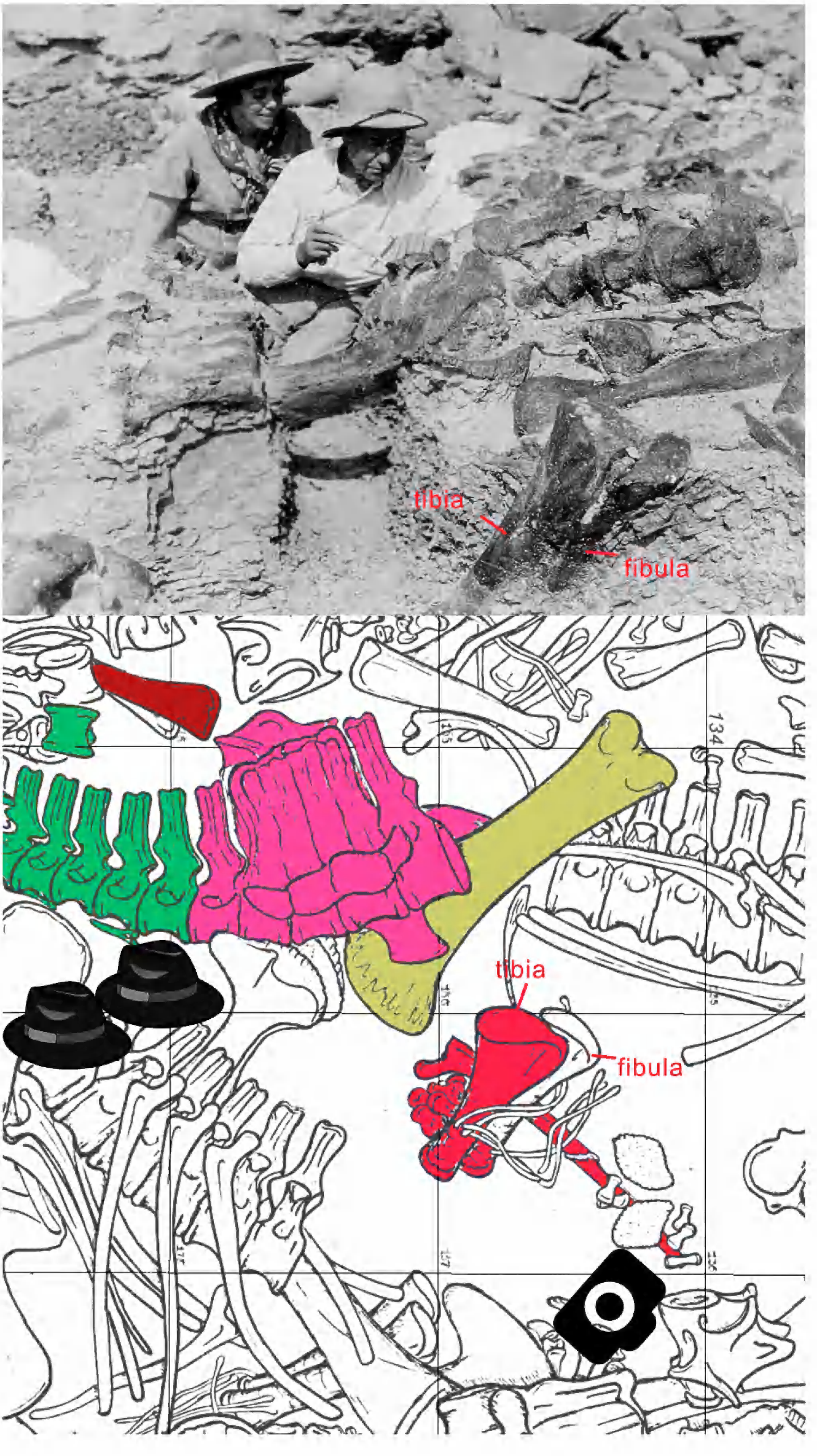


FIGURE 5. Evolution of R.T. Bird's quarry map from sketches to the final, published version. The portion of the map shown here covers section numbers 79–81 (top row), 100–102 (middle row), and 121–123 (bottom row). The sketches (left) were transferred onto large Bristol board plates in Bird's homestead in Rye, NY (center), and then onto the final map (right; see Bird, 1985, for more details). There are numerous notes on the sketches, including numbers given to the jackets, outlines of blocks taken out with more than one bone, and more. Bird also traced the fracture patterns of the single bones, and generally only drew the visible part of the bones in the field. He likely retraced the sketches with black ink before transcribing the data onto the Bristol board plates, the "OK" possibly indicates that he had already transcribed this sheet. During the transcription, Bird fleshed out the drawing of incompletely visible bones, and got rid of the fracture pattern, probably in an attempt to increase readability of the map. This process was even more enhanced in the second transcription step, and can especially be followed in how the ribs are drawn in the center of the figured portion of the map (section 101) and with the cervical vertebrae in section 121. Also, location and proportions of certain bones changed (see the disarticulated caudal vertebra in section 100, and the large cervical vertebra along the section line between 80 and 101), and some elements were not drawn in some of the later iterations (e.g., the fragments in sections 79 and 100, and one of the chevrons in section 79). Proportions and exact location of single elements are likely most accurate in the original sketches.

Roland T. Bird Howe Quarry Field Sketches and Notes, approximately 1934–1940, DR 202). Also, according to these notes, not all the bones were transcribed from the field sketches to the combined plan published by Brown (1935a; see Michelis, 2004), and some bones were discarded on site due to poor preservation. Indeed, some bones in jackets that were unpacked subsequent to 2017 could not be located on the map. These discrepancies are likely to be part of the reason why early estimates by Brown (4000 bones; 1935a) diverged so much from a later count of the bones on the map by Michelis (2004), who identified around 2200 bones. A current count lists 2669 elements (including bones, soft tissue, and sediment samples, and some bones that were discarded on site due to poor preservation). Although this count is likely to increase as more of the remaining material is unpacked, it is unlikely it will reach Brown's estimate.

This richness of fossil dinosaur bones attracted a lot of public interest. Brown was interviewed several times during the excavations by various news outlets including radio shows at KGHL in Billings, Montana, and a Paramount Newsreel (AMNH VPA-38). The New York Times alone published at least 12 articles on this specific excavation in 1934 and 1935. The news attracted more than 2500 visitors to the site (fig. 4A; Brown, 1935a; Bird, 1985), which

FIGURE 6. Photograph and quarry map showing a vertically preserved tibia and fibula. These peculiar finds were drawn in perspective by R.T. Bird. Location of the photographer and Barnum and Lilian Brown in the photograph are indicated on the map for orientation. The colored specimens are cataloged bones in the collections at AMNH (see also fig. 15); the tibia and fibula in question are part of AMNH FARB 7540, together with a pes and a dorsal rib. Note the grid system and the section numbers in the lower left corner of each square of the grid.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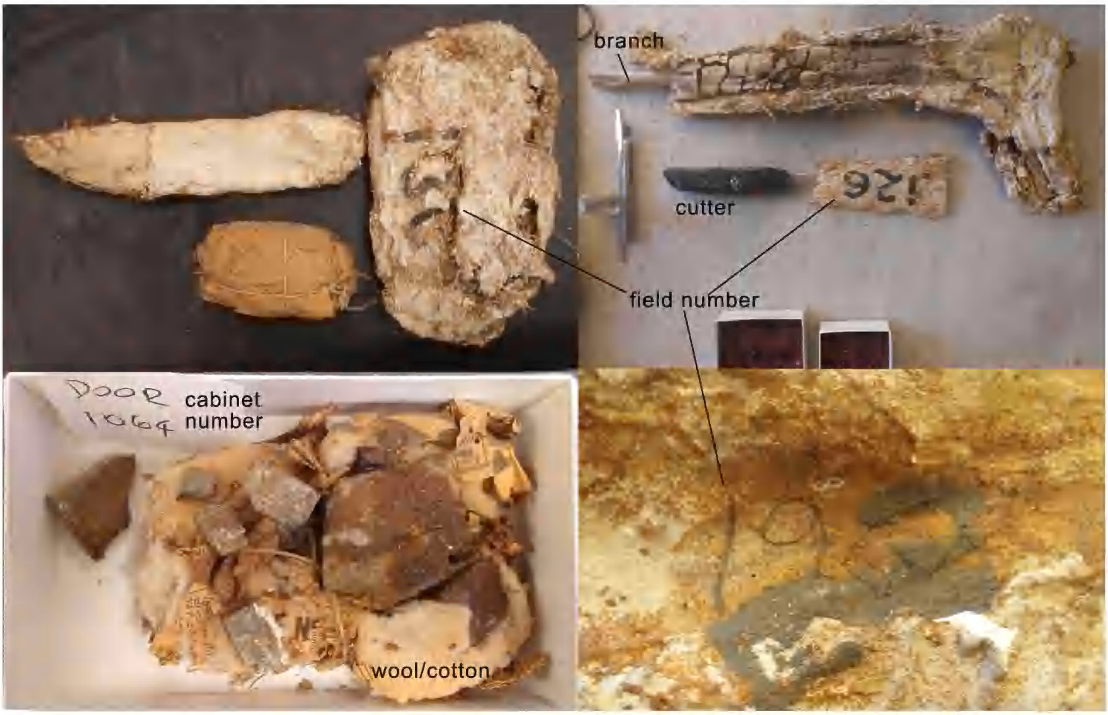

FIGURE 7. Original jackets and packages from 1934, when being unpacked after 2017. Note the number painted (upper pictures) on the plaster-and-burlap jackets or scratched into it (lower right), indicating that these specimens were excavated from sections 130 (upper left), 126 (upper right), and 196 (lower right) of the quarry map. Small specimens were packed in newspaper, in some cases with a cushioning layer of wool or cotton (lower left). Plaster jackets were supported with cedar as well as possibly cottonwood branches (upper right). A cutter was used to cut the jackets open after 2017, and the section numbers were preserved where possible. The number of the cabinet where the specimens were housed ("door 1064"; lower left) before the recent conservation project was noted and kept associated with the specimens throughout the entire process.

all had to sign a guest book (AMNH VPA-16a). In late July, the local community erected signs along highway 14 to direct tourists to the dinosaur dig (*The Greybull Standard*, July 19, 1934: 1). Some of these visitors damaged and even stole bones (mostly claws, but also parts of ribs and possibly other elements) exposed in the quarry (Bird, 1985). Other bones were damaged during a nighttime thunderstorm, when the crew did not expect rain, and had to cover the quarry by night. A scapula also shattered into pieces while turning a plaster jacket (Bird, 1985).

The site did not only seem important for its richness of bones: skin impressions were found too, but "much of it had to be destroyed in preparing the bones for shipment" (Brown, 1935a: 6). Bird found potential stomach contents, with 64 gastroliths. The team also found several articulated lower legs that apparently got stuck in the mud and were preserved nearly vertically (fig. 6; Bird, 1985).

The bones were extensively cracked when discovered. Shellac was used to consolidate the bones once uncovered (Brown, 1935a; Bird, 1985), as was typical for the time (Linares Soriano and Carrascosa Moliner, 2016). In some cases, several rounds of consolidation were necessary (Brown, 1935a; Bird, 1985). In order to protect the bones for transport to New

FIGURE 8. Historic photographs from the 1934 excavation at Howe Quarry. **A,** Many bones were jacketed alone, as these dorsal ribs ready to be packed. **B**, Crates 42, 44, 45 are being transported to the truck. **C**, The specimens are loaded in a box car in Greybull, Wyoming, for shipment. Photographs are courtesy of AMNH VPA.

York, large bones were jacketed with plaster and burlap, whereas smaller ones were wrapped in wool and newspaper, according to Bird (1985). When opening some of the original newspaper packages since 2017, however, we found that in some cases, only newspaper was used, and in other cases, the cushioning material seemed to be cotton rather than wool (fig. 7). On August 1, the team started to make the first plaster jackets (AMNH VPA-38). According to Bird (1985), rice paper was used to separate the bones from the plaster, although this was apparently not always the case, as subsequent opening of the jackets in 2017 revealed. Sticks were used to stabilize large and long, narrow jackets (figs 3D, 7; Bird, 1985), and some bones had to be divided into two packages, because they were mingled too much with other bones in the quarry to remove them safely as single elements (Brown, 1935a). The jackets were numbered to correspond with the squares on the quarry map (Brown, 1935a, 1935b; Bird,

FIGURE 9. The henhouse on the Paton Ranch in 1934 (with R.T. Bird and an unidentified person, left; and posing as a cowboy with Rowena Paton, Sr., center) and in 2017. The jackets were stored along what is the far side of the henhouse in these pictures. Historic photographs courtesy of AMNH Research Library (Photo Collection 5: 4, Box 7; "Howe Quarry, Wyoming, 1934"), recent photograph by C.M.

1985), usually with black paint, but in some cases also scratched into the plaster (figs 3E, 7, 8A). Generally, a point at the end of the number or a line below it indicates which way the number should be read in cases where it could be rotated ambiguously. However, this was not always the case, and the numbers have in some cases faded on jackets while they were in storage. Newspapers used for small packages found and unpacked since 2017 date from between May 17 and October 17, 1934, so some newspaper must have been kept by local people and given to the team for the purpose for at least a month (given that the AMNH team did not arrive until late May and started excavation in June). Papers from *The New York Times*, *The Billings Gazette*, *The Greybull Standard*, and *The Denver Post* were identified among the remaining packages.

In September, Brown realized that there was not enough time to excavate the entire site in one field season. Excavation and packaging was interrupted several times between September and November due to snowfall (fig. 4D; AMNH VPA-38), while the team decreased in number because many members had to return east, and Brown was away for two airplane surveys to find possible new sites to explore for fossils (Bird, 1985). In November, plastering was still not finished, and the crew worked even at night (Bird, 1985). The last blocks with bones were plastered on November 16 (AMNH VPA-38).

The jackets and packages were packed into wooden crates (figs 3B, 8B), which were built by M. Howe, Ben Allen, and Dallas Hurst, and filled with straw (Bird, 1985). The last box shipped to New York was sent on November 17, 1934 (Brown, 1935a), which was also the day when Brown left the quarry for Los Angeles (AMNH VPA-38). Brown (1935a) estimated the number of bones excavated to be 4000, packed into 144 boxes, which were shipped to New York in a railroad boxcar "loaded literally to the brim" (fig. 8C; Colbert, 1984: 173). However, there was apparently not enough space in the boxcar to fit all the material, so some plaster jackets were stored behind a henhouse on the Paton Ranch in Shell (figs 4B, 9; C. and R. Manuel, personal commun., 2010, 2016).

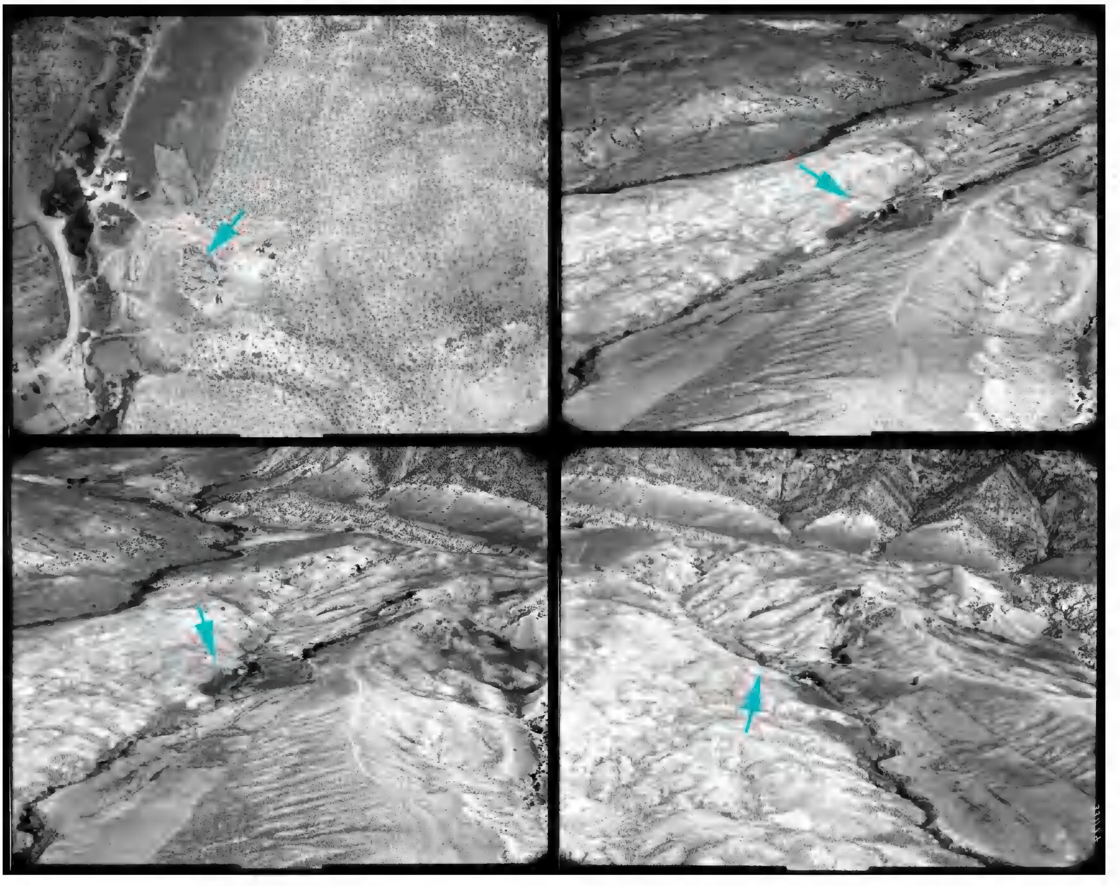

FIGURE 10. Aerial photographs of Howe Quarry (indicated with an arrow). Courtesy of AMNH Research Library (photos 331171 to 331174).

Documentation

Apart from the quarry map, the excavation was fairly extensively documented with black and white photography (see figs. 1, 2, 3, 4, 6, 8). The official photographer was Lewis, but other participants (e.g., Bird, Green) had their own cameras with them, and visitors to the quarry also took photographs, some of which are available in the archives of the AMNH Research Library and/or the Department of Vertebrate Paleontology. In order to take survey photographs of large parts of the quarry, the crew set up a derrick normally used to stack hay, and pulled up a barrel with the photographer inside (fig. 3C), who could then take subaerial pictures from the quarry (fig. 2). Aerial photographs were taken when Brown went on prospecting trips by airplane in September and October of 1934 (fig. 10).

Fieldnotes could not be located (as is typical of Brown expeditions), other than a list of expenses, and letters between Brown or other members of the field crew and the museum. Additionally, the departmental archive holds a list with important dates and photos and captions, which were scanned during the recent conservation project, as well as a number of letters

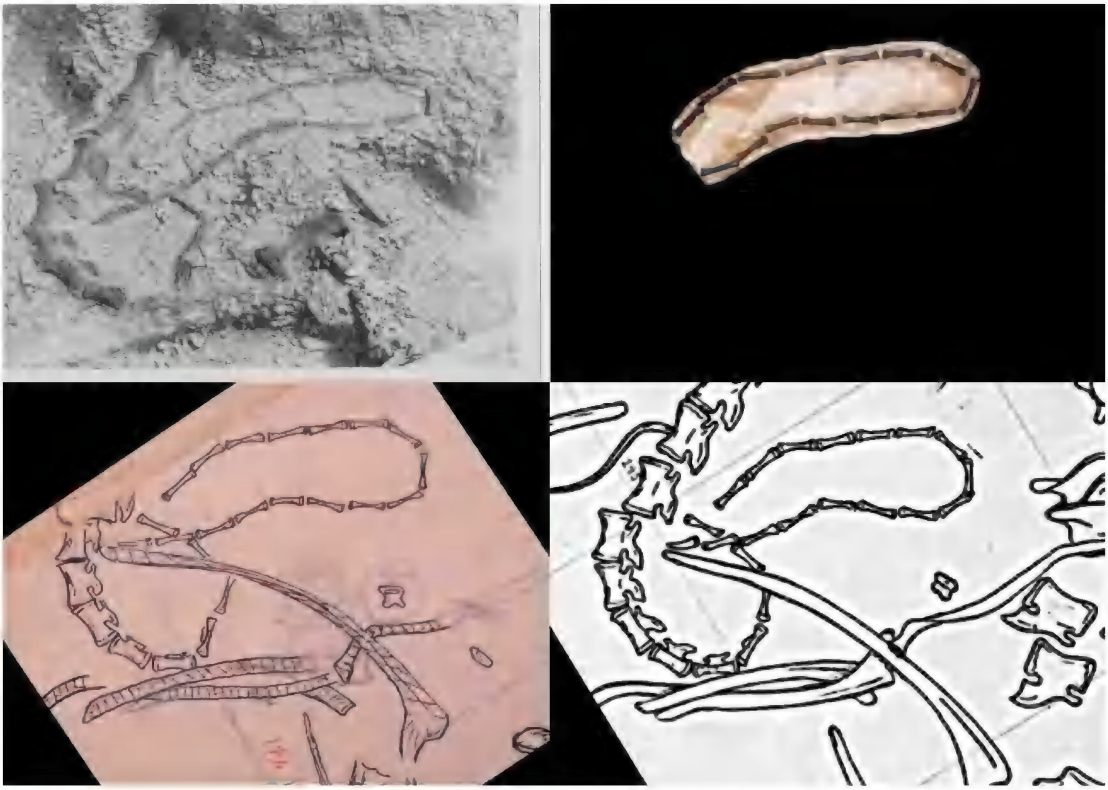

FIGURE 11. AMNH FARB 7531, from the field to the collections. Photographs of part of the tail in the field (top left) and once it was prepared and mounted on a plaster support (reversed here to match the photograph from the excavation and the drawings—the tail must have been prepared from the bottom side and mounted that way), in the position in which it was found (top right), and respective section of the first sketch (bottom left) and the final, compiled quarry map (bottom right). Note that there are 15 distal caudal vertebrae in the field and on the mounted plaster support, but only 14 are drawn on the sketch and map. The rib overlying the tail on the sketch was probably removed before taking the picture in 1934. Two additional vertebrae can be seen in the field photograph, and are drawn with pencil on the sketch, but were not transcribed to the compiled map. The fractures in the ribs drawn in the sketch were left out from the final version as well, probably to increase clarity.

and meeting minutes reporting details from the excavation. Finally, Bird's original, onsite sketches for the quarry map were transferred from the archives to the AMNH Research Library during the recent Howe Quarry project, together with documents listing: (1) the contents of the single squares of the grid ("sections"), (2) the crate location of jackets sent, listed by crate number, (3) the crate location of material sent, listed by the field section where it was found, and (4) the contents of certain crates that were opened sometime in the 1930s.

Early Preparation and Curatorial Plans (1935 to 1941)

Lack of money (Bird, 1985) and an ongoing lawsuit between Brown and Howe (AMNH VPA-14) made it impossible to resume excavations at the Howe Quarry in 1935 and during the following years. So, the site was abandoned for about 40 years, during which B.M. Howe

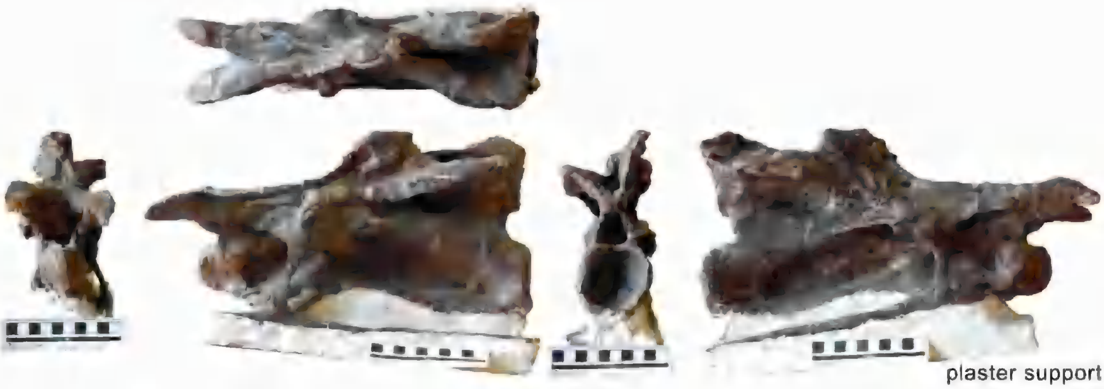

FIGURE 12. AMNH FARB 7535, cervical vertebra 8 on plaster support. The vertebra is shown in dorsal, anterior, left lateral, posterior, and right lateral view. Notable surface gloss is likely due to consolidation and coating with shellac.

passed away (in 1936) and the ranch was sold, although the fossil rights were specifically retained by the Howe family (H.-J. Siber, personal commun., 2003). However, preparation and curation of the material slowly advanced.

In 1935, preparation of the material was started with the plan to mount a single, composite skeleton of a sauropod dinosaur (AMNH Annual Report, 1935). There are no preparation reports from that time, but some information can be gleaned from Bird (1985). The first specimen to be prepared was a tail, with the distal end curled up (AMNH FARB 7531) (fig. 11). Sections of the tail were mounted on two plaster beds, the way the tail was found in the quarry and briefly displayed in the museum foyer with some gastroliths and skin specimens (Bird, 1985). The second specimen to be prepared was a more complete skeleton from the back of the quarry (it remains unclear which one this was on the map). A pelvis was severely damaged while trying to haul it onto a table in the preparation lab (this must be either AMNH FARB 7532 or 7533, the only two specimens with prepared pelves in the collections). A skull and a few additional bones were prepared by Otto Falkenbach, and probably all other specimens by Bird, as no money was available to hire additional preparators (Bird, 1985). Two partial skulls from Howe Quarry are present among the specimens prepared in the 1930s (AMNH FARB 7530 and 7535). Most probably, the skull prepared by Falkenbach is AMNH FARB 7530 (referred to *Kaatedocus siberi* by Tschopp et al., 2015), which is more complete and in a better state of preservation than AMNH FARB 7535 (referred to *Barosaurus* sp. by Tschopp et al., 2015). Falkenbach had much more preparation experience than Bird at the time, so the difference in the quality of the prep job between these two specimens is likely due to that. Some cervical vertebrae were mounted on plaster bases (fig. 12), probably with the idea of putting them on display at a later date. Preparation of Howe Quarry material slowed down when Bird and Brown resumed long-term field expeditions in the western United States in 1936 onward (not at the Howe Quarry, see above; Bird, 1985), and were likely completely interrupted once Brown retired in 1941.

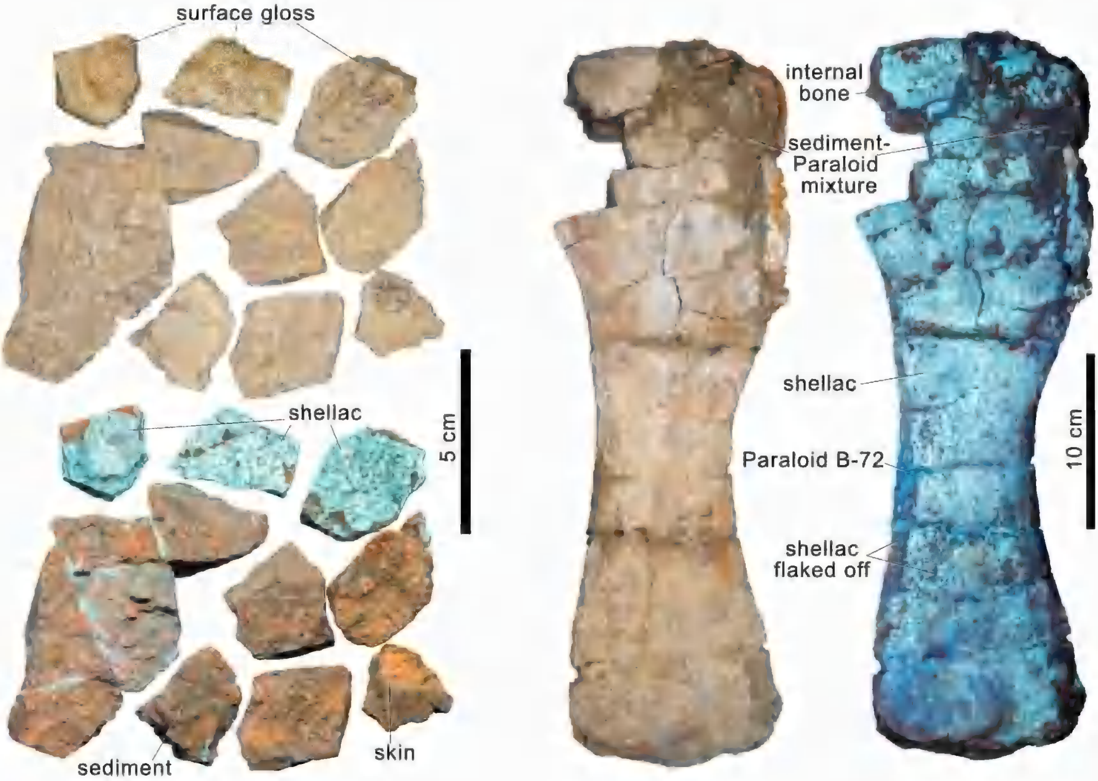

FIGURE 13. Skin (AMNH FARB 7543) and humerus (AMNH FARB 33405) under normal and UV-A lighting (the latter taken with an orange filter; see Eklund et al., 2018). Skin was prepared in the 1930s. Humerus figured upon extraction from original plaster jacket. Historical sources indicate coating with shellac during excavation (see light blue color in UV photo of humerus); some of it flaked off during extraction and minimal preparation of the humerus. Similar color on the coated skin specimens under UV excitation indicates that those were coated with shellac upon preparation. Absence of the light blue color in the exposed internal bone in the humerus demonstrates that penetration of the shellac in the field was minimal. Paraloid B-72 reacts with a slightly darker blue than shellac, whereas the sediment-Paraloid mixture for the larger breaks (see text) does not show any unique reaction. Skin remains react with a bright orange. Scale bars for skin and humerus are of 5 cm and 10 cm, respectively. Photos are copyright by Mike Eklund, used with permission.

Recent reassessment of the specimens revealed that many, but not all, of the bones and retained skin remains were coated with a substance that produced surface gloss (figs 12, 13). Although we have not confirmed this chemically, most likely the coating is shellac, probably the same kind used in the excavations. Under UV excitation, coated skin specimens react in the same way as the surface of bones we recently extracted from their original plaster jackets, and for which Brown (1935a) and Bird (1985) reported to have used shellac for consolidation (fig. 13). Large cracks are filled with a brown to reddish-pink material, which probably represents colored plaster (fig. 14).

The bones prepared in the 1930s were labeled both with the field number and the newly assigned specimen number. These marks can be in black or white paint (fig. 14). At least in one

FIGURE 14. Right tibiae AMNH FARB 3030 and AMNH FARB 7547. Note the different preparation and resulting coloration and gloss of the bones and the fillings used to join breaks. The distal portion of the tibia AMNH FARB 7547 was erroneously labeled with field number 157 (should be 197) and catalog number AMNH FARB 7540 (which belongs to a left lower hind limb) in the 1930s, and the error was repeated in the 1990s. Preparation of the distal portion of AMNH FARB 7547 likely happened later than preparation of the proximal portion or the piece was reprepared subsequently. Photographs by Bruce Javors.

case, the numbering of different parts of a single bone (a right tibia) was botched, erroneously referring the distal part to AMNH FARB 7540 instead of AMNH FARB 7547 (the correct catalog number of the bone, marked on the proximal part; fig. 14). These proximal and distal portions are a near perfect fit, although even the associated field numbers marked on the two portions were different (197 on the proximal part and 157 on the distal part). A second, complete, left tibia was also marked with field number 157 and catalog number AMNH FARB 7540, like the distal portion of the right tibia. When checking the field numbers on the quarry map, section 197 only included a single right tibia (AMNH FARB 7547) and section 157 only a single left tibia (AMNH FARB 7540), confirming that the distal half of the right tibia AMNH FARB 7547 was erroneously labeled AMNH FARB 7540. Since the two parts of tibia AMNH FARB 7547 had been housed in

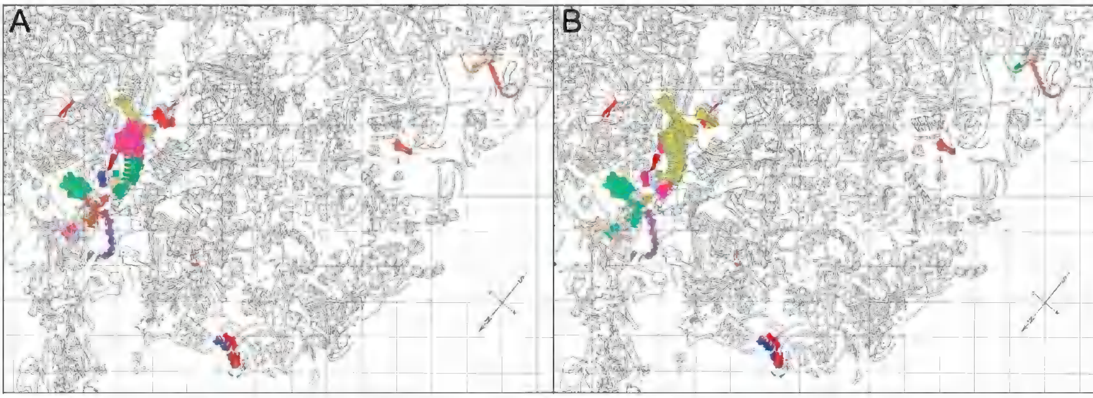

FIGURE 15. Portion of the quarry map with **A,** specimens cataloged in 1930s versus **B,** individual skeletons represented within those cataloged specimens. Some material was subsequently recataloged to better represent the actual association of the bones and their referral to single individuals.

different cabinets in the collections, we rehoused the two in a new drawer in the cabinet that held the distal portion previously, during the recent conservation project.

The hind limb that was excavated in 1932 had already been prepared in advance of the 1934 expedition and had been cataloged as AMNH FARB 3030 (fig. 14). The specimens prepared immediately after the 1934 excavation, and likely prior to Brown's retirement in 1941, bear the catalog numbers AMNH FARB 7530 to 7549, as well as AMNH FARB 7551 and possibly AMNH FF 10702. These numbers, however, do not all represent parts of individual skeletons. It is unclear what exactly the reasoning was behind the cataloging at the time; most likely the numbers follow the section numbers on the plaster jackets, with the exceptions of isolated teeth (of various taxa, including sauropods and theropods; AMNH FARB 7544) and skin remains, for which the original association was not known or not recorded at the time of excavation (AMNH FARB 7543; see Brown, 1935a). Two individual skeletons that were found partly articulated have parts of their bones cataloged in a series of numbers, which also include bones that do not belong to those partly articulated skeletons. In total, 23 specimens were cataloged. These include 21 sauropod specimens, one specimen including sauropod and theropod teeth and purported gastroliths (AMNH FARB 7544), and a tooth plate of a lungfish (AMNH FF 10702). In terms of individual skeletons, the specimens prepared in the 1930s belong to at least 12 (more likely up to 16) distinct sauropod specimens, one fish, and an indeterminate number of theropods (fig. 15).

Neglect (1941 to 1990s)

After Brown retired from the museum in 1941, Howe Quarry definitively shifted out of curatorial focus. The jackets left in Shell in 1934 were never recovered, and remained behind the henhouse of the Paton Ranch, where they became covered with poultry dung, and suffered temperature and moisture changes in the fairly extreme climate of the Bighorn Basin, with very cold winters, hot summers, and occasionally monsoonal rains (C. and R. Manuel, personal

FIGURE 16. Crates from the AMNH-Sinclair expeditions in 1934 and 1937. Localities were not marked on the crates.

commun., 2010, 2016). In the 1950s or 1960s, when the Patons sold their ranch, the new owners did not want to keep the jackets. After several attempts to contact the AMNH, Rowena Paton (senior) and some of her daughters (including Rowena junior, now Rowena Manuel) took them to the community dump, where they lined them up around the edge of the dump (C. and R. Manuel, personal commun., 2010, 2016). Some of this material to be discarded in the 1960s might actually have been saved from the dump by people from Shell, and eventually donated to the local museum in Greybull, Wyoming (C. and R. Manuel, personal commun., 2016). However, this remains impossible to verify. Some bones present in the collections of the Greybull Museum do have a similar appearance in color and preservation as the AMNH Howe Quarry material, but the only associated specimen data are notes on who donated the specimens (E.T., personal obs., 2019). Interviews with Wanda Bond, the director of the museum, and with descendants of Bill Greene, the main donor, did not reveal any additional information on where and how these bones were collected.

In the years after the Howe Quarry excavation, Brown undertook field expeditions across the West, including a 1937 season close to Rock Springs, Wyoming, with Bird as a field assistant, also financed by the Sinclair Oil and Refining Company. Crates from these years were labeled "American Museum of Natural History, New York City" with the year, but without any other specific information on locality (fig. 16). At a later stage, many of these original crates from different years and localities that remained to be opened were stored together. Due to a lack of appropriate storage space, these crates (including material from Howe Quarry, from the Rock Springs 1937 expedition, and others as well) were apparently moved several times, and some of them also spent a considerable amount of time outside in the museum yard, covered with a tarp, where they had to endure freezing winter temperatures and summer heat. At some point, the wooden crates stored in the yard caught fire and partially burned. About half of the damaged material was later discarded (E. Gaffney, in Dingus and Norell, 2010), whereas the rest was repacked but could not always be clearly associated with their original locality or year of excavation. The repacked crates were put into another storage area not meant for collections (a room originally meant for a rifle range under Margaret Mead Park on the west side of the complex), and suffered additional water damage, freezing, heat, and the actions of rodents and other pests, until finally several of the stacked crates gave way under their own weight, collapsed, and telescoped into each other.

RELOCATION, SALVAGING, AND FIRST SCIENTIFIC STUDIES (1974 TO 2017)

Starting in the 1970s, and even more so during the 1980s and 90s, interest in dinosaurs surged again, and with it also the awareness of the importance of historical expeditions and collections. Regarding Howe Quarry, this led to the relocation of the site, complete excavation by the SMA, and the first scientific studies (mostly based on SMA material). Additionally, efforts were undertaken at the AMNH to salvage the neglected historical collection.

Two expeditions from other institutions returned to Howe Quarry since the AMNH-Sinclair Dinosaur Expedition. The first was a field trip of paleontologists Peter Dodson, Anna K. Behrensmeyer, Robert Bakker, and John S. McIntosh, with Vicki Rowntree and Dawn Dodson in July 1974. They intended to study general Morrison Formation taphonomy (Dodson et al., 1980), but also recovered a sauropod fibula (YPM VP.007448; Michelis, 2004) and some fragments (YPM VP.061301; D. Brinkman, personal commun., 2020) at Howe Quarry. A second real excavation campaign was organized by the SMA in 1990 and 1991, when they recovered 400 to 500 additional elements, including cranial and postcranial bones, teeth, skin impressions, and footprints. These finds led to a number of scientific publications (e.g., Brinkmann and Siber, 1992; Czerkas, 1992, 1994; Lockley et al., 1998; Ayer, 2000; Michelis, 2004; Tschopp and Mateus, 2013a, 2013b). Upon complete exploitation of the Howe Quarry bonebed in 1991, the SMA crew discovered several additional sites on the Howe Ranch (e.g., Howe-Stephens Quarry, Howe-Scott Quarry, Spring Hill Quarry) and continued excavations on the property until 2003. Additionally, the SMA also discovered the Big Al Site just outside the private property on BLM land (Chure and Loewen, 2020), but all these newly discovered sites are from different stratigraphic levels than the historic Howe Quarry, and should not be confused with it. For instance, *Allosaurus jimmadseni* MOR 693 (nicknamed Big Al), the specimen that gave the Big Al Site its name, was not found in Howe Quarry, contrary to what was stated by Chure and Loewen (2020: 2, 4, fig. 2).

Salvaging (1990 to 2017)

In 1990, water damage and a reassessment of space needs required that all the crates at AMNH had to be moved. However, because some of them had collapsed and telescoped into each other, they also had to be repacked. M.A.N., Mick Ellison (AMNH), Ed Heck (now an AMNH volunteer), and James Clark (now at George Washington University, Washington DC)

FIGURE 17. One of the 15 crates repacked in 1990. Several original crates were combined in one, and their numbers were marked on the repacked crate. Where possible, distinct crate contents were separated from each other by a sheet of plastic or cardboard (see arrow). Styrofoam chips were used for providing some protection.

spent 10–20 days moving the fragments from the damaged crates into new ones, which were filled with Styrofoam peanuts for protection. In some cases, several of the damaged crates were put together into a single new crate, separated with a sheet of plastic or some cardboard (fig. 17). Where legible, the number of the original crates (from the 1934 and other expeditions) was written on the outside of the new crates, but some of the collapsed crates had already been repacked after the fire, so those were either not marked with a number at all or the number on them did not correspond to the original crate number. In fact, one crate was supposed to include the original crate number 193 (fig. 17), but only 144 crates were built and sent to New York in 1934. It is possible that this was a transcription error of "1934," as the year of collection was generally marked on the original crates along with the crate number. No note was found in this crate that would have added any information when we opened it in 2020, and the few preserved original jackets did not provide enough information to further identify that second crate based on the field numbers and the historic list of crate contents. In 1990, the contents of the collapsed crates filled 15 new crates, which contained the contents of up to three damaged crates each. Some of these repacked crates have yet to be opened, so an exact number of telescoped crates that were repacked in 1992 is not yet available, but we estimate it to have been 25 to 30. Sadly, several of the specimens were discarded during this repacking phase as they were damaged beyond repair and crumbled when moved, or were so contaminated and chewed by rodents that they were unsalvageable. This amounted to at least 15% of the remaining collection (M.A.N., personal obs.).

Thirty-four old crates that were still intact were moved to another storage area for 10 years or so, until they were opened between 2003 and 2006 by one of us (C.M.), Jeanne Kelley (then Preparation Lab Supervisor at AMNH), and volunteer Ryan Kellas. Their contents were moved into 29 cabinets in the vertebrate paleontology collections of the AMNH. Photographs were taken from the opened crates and the drawers after moving, as well as additional photographs of particularly interesting details (fig. 18). Many of the bones in the crates were severely damaged. A few elements from these crates were prepared after that (see below), others were left untouched until summer 2017.

FIGURE 18. Documentation procedure during the rehousing project between 2003 and 2006. Photographs were taken of the crates before unpacking, and of the drawers once rehoused. Interesting details (like the horse teeth, which clearly cannot be from Howe Quarry; such complex tooth crowns evolved much later than the Late Jurassic) were photographed as well.

FIGURE 19. Specimens from the three different localities found mingled after the various repacking episodes. Note the different coloration as well as breakage patterns indicating different diagenetic history. The paper labels with the four-digit numbers mark the cabinet, where they were housed pre-2017.

Some of the crates opened by C.M. turned out to be from Brown's 1937 "AMNH-Sinclair expedition," which took place in southern Wyoming, in the Upper Cretaceous Mesa Verde Formation close to Rock Springs, and included shorter trips to Colorado and New Mexico (B. Brown, unpublished field notes, AMNH VPA-38). Probably due to the fire in the yard (see above), some of the elements from the various sites have been mingled during the recrating. In some drawers, there are both dark, nearly black, and well-mineralized bones (which fit to the usual preservation at Howe Quarry) and whitish, weakly mineralized bones in a more consolidated, gray matrix, some of which included Cenozoic mammal bones and teeth. Material from a third site, with reddish to dark gray bones in an extremely consolidated dark matrix, was present as well (fig. 19). Luckily, the preservation modes, and color of the bones and the sediment were all very distinctive, so that they could all be distinguished fairly easily.

Fifteen Howe Quarry specimens bear numbers between AMNH FARB 30070 and 30901, indicating that they were either prepared or recataloged sometime in the 1990s (AMNH FARB 30070 and 30071) and 2000s (specimens cataloged with numbers between AMNH FARB 30783 and 30901; not all of these numbers represent Howe Quarry specimens). These include a quadrate and another possible skull bone fragment (AMNH FARB 30070) that were found close to the braincase AMNH FARB 7535, and therefore likely belong to the same individual (which was tentatively referred to *Barosaurus* sp. by Tschopp et al., 2015). The same catalog number was erroneously associated with a series of hadrosaur toe bones and one tyrannosaur phalanx at some point, although those had actually already been cataloged as AMNH FARB 30078 previously (this happened because the handwritten "8" looked like a 0 with a slash through it; C.M., personal obs. 2010). A partial tail (AMNH FARB 30071) was also found close to the braincase and associated neck of AMNH FARB 7535, but probably because association of both the tail and the neck and skull to a single individual was considered impossible, both the quadrate and the tail were recataloged. Whereas we agree that the tail cannot be confidently associated with the neck, the quadrate probably can (see also Tschopp et al., 2015). Unless it can be clearly shown that a number applied to a specimen has never been used in any publication, completely changing specimen numbers is generally not done in order to avoid future confusion (however, see discussion below on specimens comprising more than one individual). In cases like this quadrate, which are already apt to cause some confusion, very clear notes about the history and decisions regarding numbering are added to the records of the specimens in question in the AMNH Paleontology Database. In preparation style, both of these recataloged specimens resemble the ones prepared in the 1930s.

Additional specimens from partial jackets were prepared in 2002, but remained uncataloged (6 ribs, 1 chevron, 2 distal fibulae) at the time. These specimens are associated with printed preparation reports (which are stored with the bones in the collections) identifying the preparator as Robert L. Evander, a former preparator in the Department of Vertebrate Paleontology. Evander mostly used Devcon 5-minute Epoxy to join fractures. A distal fibula (no field number preserved) was first consolidated with Paraloid B-72, before joining breaks with Devcon 5-minute epoxy. Another distal, left fibula (field number 121) was recently found to be a near-perfect mirrored element of the right fibula recovered from the adjacent section 120 and cataloged as AMNH FARB 30875, so the same catalog number was given to the left fibula. One specimen (a distal rib, field number 193) initially seemed to be the distal part of a proximal rib from section 193, which had already been cataloged as AMNH FARB 30786, but the near-perfect match between the two elements was apparent only because a part of the distal shaft of the cataloged rib head had been removed to make histological thin sections. Once we 3D-printed the missing (thin-sectioned) piece (which was 3D-scanned before sectioning), and rearticulated it with the original rib, the proximal and distal portions did not match anymore. However, the combination of them having been found in the same section of the quarry, being from the same side of the body, and having comparable sizes and shape makes a convincing case that these are two ribs from a single individual skeleton, so the uncataloged distal rib was cataloged as AMNH FARB 30786 in early 2020. In addition, two scapulae initially included in that same catalog number were clearly from a different individual based on their very small size. Because the rib had already been published in an extended abstract (Moretti et al., 2018), the two scapulae were later recataloged as AMNH FARB 33672.

In a third preparation effort after the 1930s and 2002, several specimens were prepared and cataloged between 2009 and 2012 (these specimens bear numbers between AMNH FARB 30783 and 30901). In some cases, these are associated with printed photographs documenting the bones while still in the original jackets, which are stored in the collections together with the specimens (fig. 20). Few of the photographs show the field number

FIGURE 20. Photographic record of the curation history of a scapula (AMNH FARB 33672). Photographs of original crate 11 (upper left; from 1934) before unpacking in October 2004, the contents of the crate (upper right), details of the jacket once opened (lower left), and the entire scapula after preparation in the 2000s, in its form-fitted plaster support (lower right). Both the right and left scapula of the same individual were found in section 193, the scapula shown on the right could be from either of the two jackets marked with a red asterisk in the lower left. Both of these small scapulae were recataloged during the current conservation program as they were obviously not from the same individual as two large ribs cataloged as AMNH FARB 30786 in the past.

on the jacket, but the latter can be found on photographs taken from the crates when opened between 2003 and 2006 (see above), which show that most of them came out of the original 1934 crate 11, one of the few crates that had remained pristine until then. The field number was noted on the specimen tags and the bones were labeled directly with both the field and the catalog numbers. The preparators (volunteers Jim Klausen and Steve Cohen) and time of preparation and cataloging of these specimens were recorded in the collection database. The specimens have their small breaks joined with a transparent, glossy adhesive, probably epoxy, and the large fractures with a white or greenish material, which likely represents some type of paste epoxy. The field and catalog numbers were written on labels adhered to the bone following a method outlined by Davidson et al. (2006), where a layer of Paraloid B-72 is covered with white paint, the number is written onto the paint with a black archival pen, and the entire label is covered and sealed with a second layer of Paraloid B-72. Catalog numbers were attributed to the specimens based on their field number (e.g., all the jackets prepared with field number 193 were cataloged as AMNH FARB 30786). This third episode of preparation produced 12 newly cataloged specimens and a total of 30 bones, which belong to at least 10 individual skeletons (probably more; fig. 21). As with the cataloged specimens in the 1930s, a few of these new catalog numbers initially included bones from several distinct individual skeletons, some of

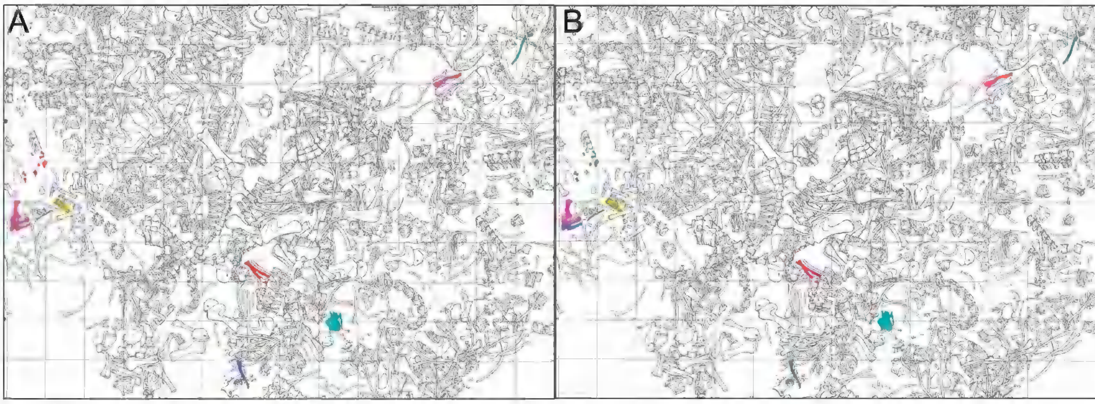

FIGURE 21. Portion of the quarry map with **A,** specimens cataloged in 2000s versus **B,** individual skeletons represented within those cataloged specimens. Some material was subsequently recataloged to better represent the actual association of the bones and their referral to single individuals (e.g., the small scapulae in the center right, see also fig. 20).

which were recataloged during the recent conservation project, and the history of cataloging is recorded in the collection database.

A number of bones from the Howe Quarry were molded and cast at some point in time. Casts were apparently made of the tibia of AMNH FARB 3030 as can be recognized by silicone marks on the bone (fig. 14), but no records exist of this in the database or in other departmental documents. The skull and neck of AMNH FARB 7530 was cast to create a small, composite skeleton of a "baby *Barosaurus*" for the spectacular exhibit of the rearing *Barosaurus* protecting its offspring from an approaching *Allosaurus* in the main entrance of the museum. According to the FARB collection database, at least parts of AMNH FARB 7535 were molded and cast as well, but it remains unclear for what purpose.

RECENT CONSERVATION PROJECT (SINCE 2017)

State of Conservation before the Project

At the beginning of the project, an inventory was made by E.T., C.M., and Jacopo Moretti (then a Master's candidate at the University of Modena and Reggio Emilia, Italy, on an internship at AMNH), to check collection records for accuracy, and add details for the uncataloged specimens from Howe Quarry, where possible. In total, there were 37 cataloged specimens, only two of which were identified to genus, whereas the others had higher-taxon identifications noted in the database (e.g., Sauropoda, Dinosauria). Thirty-three cataloged specimens had associated field numbers, but only 19 of those were noted in the database. Data associated with the cataloged specimens included their taxonomy, if a cast of the specimen was produced, locality, horizon, names of the collectors, year of collection, field number, description of contents, and storage location. Apart from the cataloged specimens, unprepared, putative Howe Quarry material was housed in 15 repacked crates from the 1990s, plus 29 collection cabinets resulting from the rehousing project between 2003 and 2006, and five large plaster jackets

FIGURE 22. Purported Howe Quarry jackets that were found to be from the 1937 expeditions due to crate markings and the fact that section 8 in the Howe Quarry map did not include any bones. Photographs by C.M., October 2004.

(AMNH FARB collection database, 2017). The first inventory included a detailed assessment of the 29 cabinets with the unprepared material rehoused between 2003 and 2006. Such an assessment was necessary to identify which cabinets included specimens from the crates that held specimens from several localities and were combined after part of them burned in the yard. Of the initial number of 29 cabinets with putative, unprepared Howe Quarry material, 21 were found to house actual Howe Quarry material, whereas the other eight did not. Thanks to this assessment, we also realized that at least two of the separately stored, putative Howe Quarry jackets were from some other historical expedition; the numbers on the jackets (8) were lower than the lowest section number on the Howe Quarry map (9) and photographs taken of the original crate confirmed they were from the 1937 expedition (fig. 22).

The state of preservation of the bones in these cabinets varied substantially. Some cabinets housed nicely preserved, complete plaster jackets, on which the field numbers could be recognized easily. Other jackets were damaged, and the field numbers were only partly present, completely broken away, or had become illegible. Many of the original jackets were entirely broken, and their contents were spread over the drawers as bone fragments of greatly varying sizes (fig. 18). One cabinet held three plastic garbage bags filled with minute bone and other fragments. Based on this, we decided to begin the project with the cabinets with the best-preserved jackets and largest fragments.

In order to process the unprepared material efficiently, the drawers from the cabinets were moved to the Vertebrate Paleontology laboratory, one cabinet at the time. Thus, the risk of disassociation of the bones with their home in the collections was minimized. Also, doing so facilitated a first round of matching fragments.

Volunteer Program

A volunteer program was set in place to move the project forward. Many of the tasks were fairly easy and did not require any previous experience or extensive training. These included the various steps in preparation and conservation (see below), finding fits, documentation, and curatorial tasks such as creating housing and the physical numbering of the newly prepared and cataloged specimens. Prospective volunteers were first shown around the lab to explain the entire project and the various tasks that would need additional help. If they were interested in the project, we tried to find the best-fitting task for each volunteer, and provided specific training for this task. If, at some point, a volunteer wanted to fulfill additional tasks, or if some other task required more help at a particular point in time, training was provided for the new technique.

Since July 2017, 14 volunteers were involved with the project at different times and for different durations. These are (in alphabetical order): Wayne Callahan, Pedro Galindo, David Geiger, Fanny Guex, Ed Heck, Bruce Javors, Roberto Lei, Ayo Lewis, David Ludwig, Juan Martinez, Wayne Mones, Jacopo Moretti, Enrica Sarotto, and Danqing Zhu. Supervision was shared between E.T., C.M., and AMNH Department of Vertebrate Paleontology Preparators Amy Davidson and Verne Lee. Three to five volunteers were generally active during the same time period, and up to a maximum of four volunteers could work in the lab contemporaneously

FIGURE 23. Water filtering system to reduce further contamination of the bones during rinsing, developed and installed by A. Davidson. Photographs by A. Davidson.

without interfering with each other. However, most volunteers came in on a specific day during the week for about three to five hours, so mostly, only one or two volunteers were present at any specific time. Seven volunteers mainly assisted in preparation and conservation (Galindo, Guex, Heck, Martinez, Ludwig, Lei, Sarotto), four with documentation (Javors, Lewis, Moretti, Zhu), and three with curatorial tasks (Callahan, Geiger, Mones).

Laboratory Conditions

Humidity in the lab is 20%–30%, as measured by a standard humidity indicator card. Temperature is 24°–27° C. The dry, warm conditions speed the evaporation of the acetone and ethanol, helping the used adhesives and consolidants (Paraloid B-72 and Butvar B-76; see Preparation) to harden to the point where it can resist rinsing with water, but probably not soaking.

New York City tap water has a high percentage of chlorine. Given that Howe Quarry has been known to produce soft-tissue impressions (Brown, 1935a; Czerkas, 1992), we installed a water filter so potential contamination that could influence future geochemical analyses could be avoided. The filter used was an Inline Catalytic Carbon Garden Hose Filter from Ideal H_2O – Premium Water Filtration Systems, which purifies up to 8000 gallons of water, and which we applied directly to the tap. By using a flexible Loc-Line modular hose system we redirected the flow back into the sink while saving as much desk space as possible (fig. 23).

FIGURE 24. Restoration of field numbers under the microscope: microscope setup with plaster jacket (left) and close-up of number on jacket (right). The original ink has sometimes faded, and the number can be damaged. Restoration is done after gentle, dry cleaning, enhancing the original ink until a clear outline could be seen. Photographs by A. Davidson.

Unpacking

Unpacking mostly involved removing bones and fragments from original plaster jackets. Additionally, in early 2020, a project was started to open the 15 remaining wooden crates that were repacked in 1990.

The original plaster jackets were marked with field numbers that indicated the number of the section on the quarry map from where these bones were removed. These field numbers were applied mostly with black paint. In some cases, the numbers faded or became covered with additional layers of plaster during the excavation or dust, dirt, and mold in the collections. The dust could be cleaned using brushes, and additional layers of plaster could be removed carefully with small scrapers and spatulae. Cleaning with water damaged the original ink used, therefore faded numbers had to be cleaned very carefully below the microscope to detect traces of ink and restore them (fig. 24). Restoration of these numbers was crucial to track as many bones as possible on the original quarry map, and potentially recognize elements belonging to a single skeleton. In many cases, the jackets were damaged, so that only a part of the number was preserved. However, by going through all the possible squares in the grid, looking for the bones preserved, we were often able to identify the correct one.

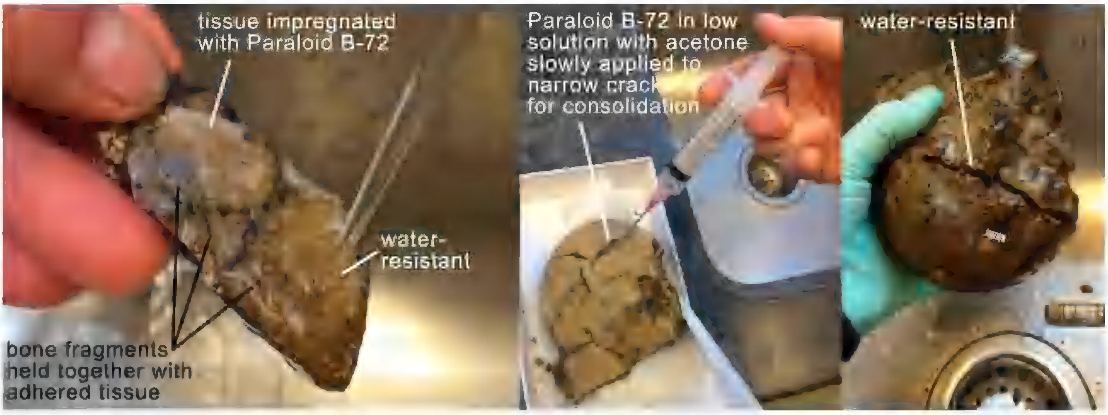

FIGURE 25. Restoration and consolidation of small fragments using Paraloid B-72. Small fragments can be held together with impregnated tissue (left), whereas small cracks can be consolidated with highly diluted Paraloid slowly applied with a syringe (center). Both techniques leave the specimen water-resistant (right). Photographs by A. Davidson.

The plaster and burlap had often become so weak and brittle that they could easily be broken or picked off by hand and with minimal application of force, easing separation from the bones. Where this was not possible, we used scissors, knives, and/or Dremel tools to cut through the plaster and burlap.

Some bones were packed in wool or cotton and wrapped with newspaper. Whereas the strings to keep them together were generally still in good condition, the newspaper was brittle (fig. 7). In some cases, there was limited mold growth. Where possible, we tried to keep the newspaper intact, at least the portions with the date and the name of the newspaper.

Most bones in the original jackets and newspaper packages were moderately to heavily fragmented, but often still in connection. This likely resulted from the extensively cracked state in which they were discovered as shown by some of the photos from 1934. Most of the bones had been consolidated and coated with shellac in the field in 1934 (Brown, 1935a; Bird, 1985), but this apparently was not enough to withstand the many decades of time in inappropriate storage conditions. For example, the coating was observed to flake off the bones either spontaneously, or upon gentle scratching with a scalpel, a shellac issue that has been known for some time (e.g., Brothwell, 1993; Linares Soriano and Carrascosa Moliner, 2016). Also, in some instances, the coating has turned somewhat violet in color; it is unclear what caused this kind of discoloration.

When unpacking the original plaster jacket, most of the bones required immediate stabilization due to the extensive cracking. In heavily fractured parts, we stabilized the fragments by covering them with tissue paper impregnated with Paraloid B-72 in an approximately 20% solution of acetone, applied from nail polish containers with the incorporated small brush (fig. 25), or directly with pipettes. After drying, the tissue coating was also resistant to washing with water. Slightly less complex damage was stabilized and preliminarily consolidated by applying the same solution with a syringe into visible narrow cracks (following Davidson and Alderson, 2009; Roubach et al., 2014; fig. 25). Wide cracks were stabilized with a mixture of pulverized sediment and a Paraloid B-72 solution in acetone or ethanol, adapting the viscosity to fit the width and depth

FIGURE 26. Mixture of pulverized sediment with highly diluted Paraloid B-72 (left) creates a strong gap filler for larger cracks (right), without adding extraneous filler material. It also remains soluble in acetone (center) and can be removed mechanically. Photographs by A. Davidson.

of the cracks needing stabilization (fig. 26), a technique that has been developed by Davidson (2009). The stabilized bones were left to set overnight to become strong enough to handle. The sediment was taken from the original Howe Quarry material, and ground with a glass mortar in a ceramic bowl. This material can be dissolved again in acetone, or removed mechanically, with a needle, air scribe, or grinder. Once stabilized, the bone was extracted from the package or jacket.

In early 2020, E.T. and C.M. started to open the repacked crates from the 1990s with volunteers Martinez and Sarotto. In order to do this systematically, the crates were marked with letters from A to O based on their position in the collections. Following the protocol developed for the 2003–2006 rehousing project by C.M., we photographed each crate from the outside, started to clear the bones from the covering Styrofoam chips, took a second photograph from the contents within the crate (where two or three crates were repacked into a single crate, this shot was taken for every distinguishable layer), and moved the bone fragments into drawers lined with a thin layer of ethafoam. A final photograph was taken of the complete drawer (fig. 27). In addition to the previous workflow, we separated the bones into vertebrae, ribs, and appendicular bones (preferably each of them in separate drawers, space allowing) and attempted to find matches among the fragments. Preserved original plaster jackets were put into their own drawers, because their contents were not always clearly identifiable. Fragments that belonged to a single bone were stored together in specimen trays and marked with red pencil where the fit was not evident due to a complex fracture pattern. The contents of the drawers were noted in a spreadsheet, and notes were added to the drawers themselves to facilitate future preparation and conservation endeavors. These handwritten notes were later replaced with printed labels, using archival ink and paper so they would survive long-term storage if necessary.

Rinsing

Numerous fragments in the cabinets with the rehoused material from 2003–2006 were disassociated from any jacket, often without any obvious connection to other fragments. These

FIGURE 27. Recent rehousing efforts of 1990s crates and accompanying documentation. The repacked crate is photographed from the outside (A) and inside (B) before unpacking, and the drawers are photographed before moving them into the collection cabinets (C-E). Original crate (or "box") numbers were noted on the repacked crate (A), and where two or more original crates were transferred into a single repacked crate, the contents of the original crates were separated with cardboard or plastic (B). During the recent rehousing, notes are included in the drawers (C-E) to facilitate future efforts in finding matches, and fragments that were already realized to belong to a single bone are stored together in trays.

were often very dusty, so that a first step in the initial preparation workflow involved rinsing and brushing. Varying brush resistance was created by cutting the bristles to various lengths. When soaking the fragment for some time in water, and then brushing it under flowing water with a relatively hard brush, we could also remove some of the more silty sediment from the bone. The initial aim here was to clear the fractured surface, so that it would be easier to find a match. However, one of our volunteers, Galindo, later realized that the color, texture, and distribution of the sediment on the bone provided additional clues for finding a match, so the work could be done more efficiently with no soaking and less rinsing. Distinct breakage patterns in the sediment even helped to identify different bones that were initially found articulated, and were likely taken up as a block, with several bones in a single plaster jacket. Moreover, it later turned out that some of the "sediment" attached to the bones actually represents pre-

FIGURE 28. The articulated partial pes AMNH FARB 33152 (left) was photographed before disarticulation. Close-up of paper label applied to one element (right) indicates number of collection cabinet (1063), field number (#164), and bone ID (PHP II-2). PHP II-2 refers to the second phalanx of the second digit of the pes. The paper label is adhered and sealed with Paraloid B-72 in 20% acetone and withstands rinsing with water.

served soft tissue (Tschopp et al., 2019a), so the change in the workflow also saved those occurrences from destruction.

Labeling

Initially, in order to keep the association with the original crates as much as possible, we planned to label every single fragment with its crate number, where available. However, this proved to be impossible, because the numbers of many of the original crates faded through time and could not be restored during repacking of some crates in 1990 and the subsequent opening of the rest in the 2000s. Also, many of these crates did not have a number at all and were apparently repacked after the incident in the yard. This early repacking after the incident also means that any number written on those repacked crates did not necessarily correspond to the original crate numbers from 1934. Therefore, we instead opted to label the fragments with the number of the cabinet where they were stored (numbers ranging from 1041 to 1076, as well as 727 and 728 for material rehoused between 2003 and 2006, and 513 to 521 for the material rehoused since the beginning of 2020; fig. 19). Where

FIGURE 29. Section of map (left) with two new ischia (right) assigned to historic specimen AMNH FARB 7533. The ischia (green arrows) were identified thanks to the field numbers #196 and #197 which were visible on the remains of the original plaster jackets recovered during the recent conservation project. The ischia are shown in lateral view, acetabular surface toward the top. Photography by B. Javors.

we had a field number (only in cases in which the fragments were still associated with at least part of the original plaster jacket), we added the field number to the label using the symbol # in front of the two- to three-digit number of the square where they were found (e.g., #156). Where possible and reasonable in terms of available space on the bone, we added a label with our identification of the bone (e.g., "php I-1, R" for a right, proximal, pedal phalanx of the first digit; fig. 28). A key was produced to explain and illustrate these different types of labels, and the independent numbering systems, with the aim to help researchers studying the material in future understand and interpret the undertaken conservation work (see supplementary material at doi.org/10.5531/sd.sp.42).

The paper labels adhered to the bones were either printed with archival ink or handwritten with archival pens on archival paper. The labels were applied on a clean portion of the bone surface, where available. They were cut on the long sides and ripped by hand on the short side to increase the strength of attachment through the exposed paper fibers. In order to best adhere to an irregular surface, we crumpled the label to make it more flexible. We first applied a layer of Paraloid B-72 (20% in acetone) with a nail polish brush, adhered the label, and covered it with a second layer of Paraloid as protection. Labels adhered and protected like this also withstood rinsing with water (fig. 28).

Puzzle

Some of the crates included bones from at least two to three sites, as recognized by the matrix, labeling of the plaster jackets, and color and preservation of the bones (fig. 19). This mingling complicated the reassembling of separated fragments, because on top of recognizing the bones themselves, we also had to separate elements from different quarries. The bones from Howe Quarry are generally well preserved and of a dark, almost black color. The sediment is

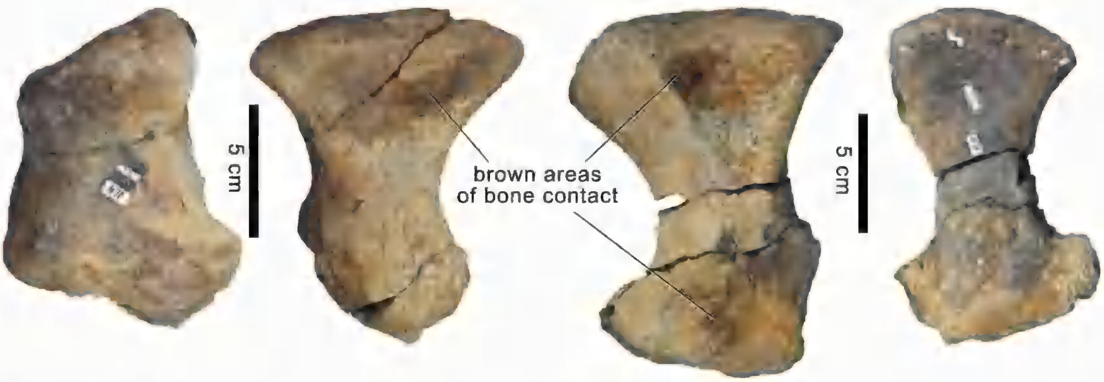

FIGURE 30. Brown marks in areas where bones were in contact during fossilization. The marks allowed identification of articulated bones, as in this case metatarsals I and II from the pes AMNH FARB 33304. The metatarsals are shown in dorsal and lateral view (metatarsal I; left), and medial and dorsal view (metatarsal II; right). Photographs by B. Javors.

rather muddy, relatively soft, and mostly gray to green. Elements from other sites have a yellow color and are relatively light and soft, within a very hard matrix that also preserves marine fossils. A third site is indicated by large blocks of very hard sediment, packed in only one to two layers of burlap and plaster, and numbered with a one- or two-digit number, separated by a hyphen. At Howe Quarry, jackets were numbered only with the number of the square they were found in (Bird, 1985) and sometimes with an added letter (often "X"), which indicated that the bone was taken up in at least two pieces (figs 20, 24).

After having identified the Howe specimens, we conducted three rounds of finding matches. The first round was made with only the fragments from a single cabinet, assuming that at least some spatial context of fragments of a single bone was preserved during the recrating of the specimens after the fire and the telescoping of the original crates in storage. Subsequently, we separated the elements into axial versus appendicular bones, and (where possible) identified them even further to facilitate the second step of the puzzle (as was done in the Bristol Dinosaur Project; Viegas and Benton, 2014). During this phase, we combined fragments from different cabinets on tables in the lab, and indeed found matching pieces that were initially stored in different cabinets and hence also in different crates before the rehousing (see Salvaging). Finally, we attempted to identify bones that belong to a single skeleton. The elements that were preserved in their original plaster jackets could be retraced on Bird's quarry map, which led to the identification of some elements being part of specimens that had already been prepared and cataloged previously (e.g., two ischia that were found articulated with the sacrum AMNH FARB 7533; fig. 29). Bones or bone fragments that were not

FIGURE 31. Bones recovered disassociated in the collections but found to have been articulated in the field. Two caudal vertebrae are interpreted as two adjacent elements in a series based on their size, general shape, and matching deformation and sediment breakage pattern of the joint articular surface. The metacarpal and the phalanx are interpreted to be from a single manus because they were recovered from the same cabinet, they match in size, and have a very similar color that is slightly different from most of the other Howe Quarry bones in that drawer, indicating that they were initially articulated and packed in the same plaster jacket. Photographs by B. Javors.


1044
1043
1043
0 5 10 mm

associated with original plaster jackets were more difficult to attribute to a specific skeleton. Often, elements from the same skeletal region and of compatible size to pertain to a single skeleton were found in the same cabinets or even drawers, suggesting that they derived from a single, deteriorated plaster jacket. However, unambiguous attribution was almost never possible. In rare cases, bones that were preserved articulated bore dark brown marks where the two articulating elements were in contact (fig. 30). These marks allowed us to attribute several metapodials to their respective manus or pes, for instance. In some vertebrae, distinctive cracks in the sediment adhering to the articular surfaces and a comparable extent of deformation allowed us to identify sequential elements of a vertebral column (fig. 31). Finally, some bones found together in a single cabinet were encased in a thin layer of matrix with a distinct color rarely observed in other Howe specimens, so the likelihood that they were originally from a single skeleton was fairly high (fig. 31).

Bone fragments found to be part of a single bone were stored in specimen boxes and the fitting surfaces were marked with a red or green color pencil to facilitate reassembling the pieces later (see Preparation). Also, once several bones of a single skeleton were identified as belonging together, those elements were kept in cardboard specimen boxes, and finally put into collection housings (see Curation).

Preparation

Bones preserved in articulation within an original jacket that were intended to be disarticulated were documented with photographs before taking them apart and cleaning and preparing them separately (fig. 28). Association with the other bones was also recorded in a spreadsheet, and on paper tags kept with the bones themselves. Since several people would often work on the same material at different times, clear communication about association of bones and/or fragments was crucial.

Preparation was minimal and done mechanically. The rinsing was generally only done with fragments that were preserved disassociated from their original plaster jackets. Before the discovery that the adhering sediment was helpful in finding fits (in early 2018) and could in fact represent soft tissue in some instances (in early 2019), some bones were partially prepared using needles, scalpels, and air scribes. Air abrasion was attempted on a few elements in December 2018 under guidance of Mike Eklund, but the time investment to find the correct combination of air pressure and type and amount of abrasive powder to efficiently prepare the bones was deemed too high. In one specimen of three articulated caudal vertebrae in a jacket (AMNH FARB 33158), separation of the sediment from the bones was nearly perfect, leaving only a thin layer of matrix with a slightly orange hue on the bones themselves. In order to have the dark bone stand out from the grayish sediment, we started to clean that thin orange layer from the bones using ethanol on a piece of cloth (similar to a technique used on a fossil turtle in Spain; Roubach et al., 2014). However, once we analyzed the specimen under UV, the cleaned surface did not react to UV excitation, whereas much of the bones covered with the orange layer did (fig. 32), indicating potential preservation of some kind of soft tissue, which had been

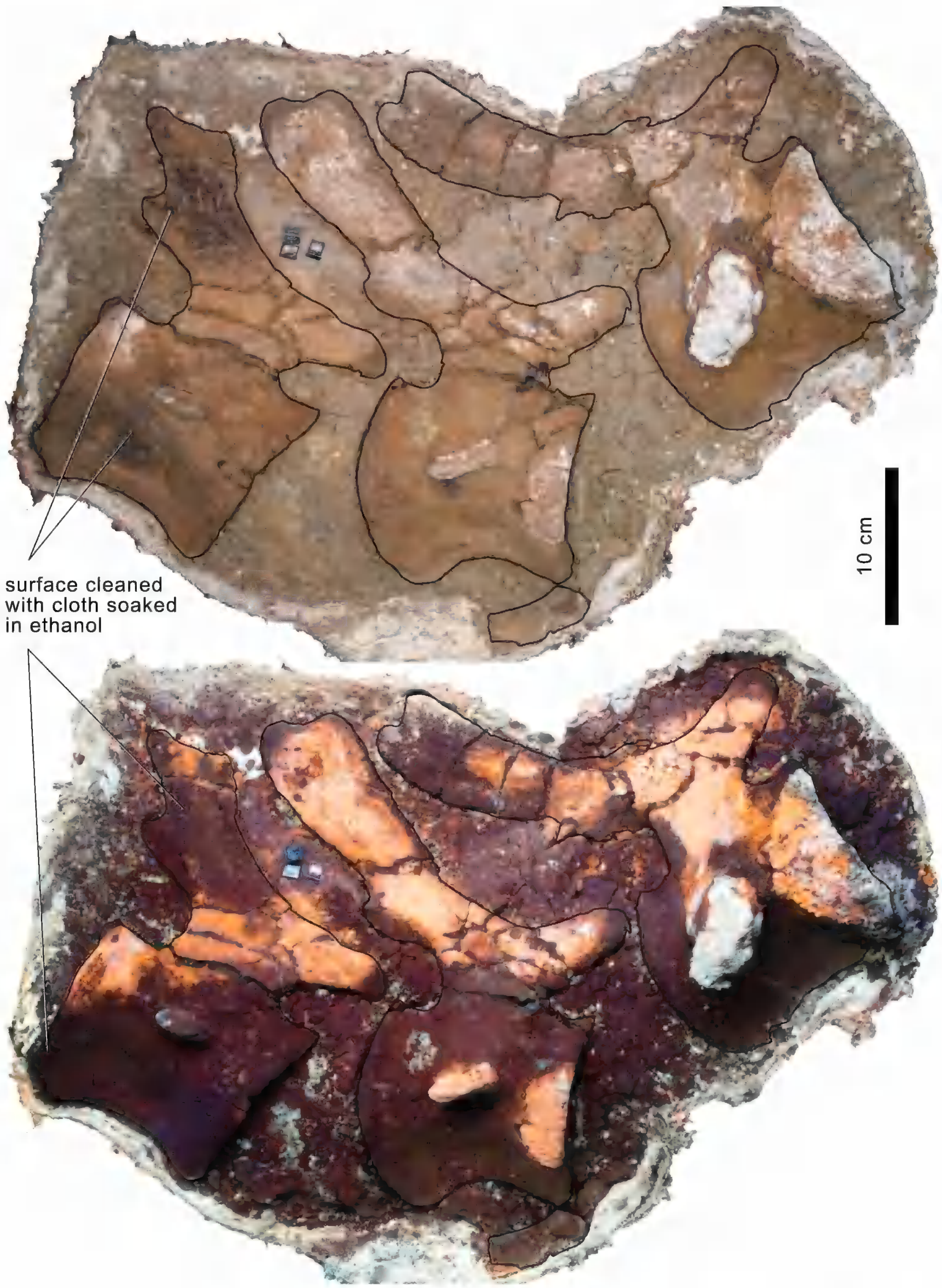

FIGURE 32. Caudal vertebrae AMNH FARB 33158 under normal (above) and UV light (below). The photograph under UV light was taken under combined UV-A, B, and C wavelengths, with an orange filter (see Eklund et al., 2018 for more details). The outlines of the three vertebrae and the chevron are highlighted in black. Note the cleaned bone surface and its distinct reaction to UV compared to portions that remain covered with a thin layer of sediment. The reaction indicates potential preservation of soft tissue. Photographs by M. Eklund.

cleaned off with the ethanol. Once we learned about the potential presence of soft tissue, we almost completely restricted preparation to fracture surfaces, where gypsum crystals and other adjoining matrix created loose fits and hindered proper application of Paraloid B-72 in order to adhere matching fragments.

We opted to adhere matching fragments as extensively as possible, because the risk of losing the association of fragments in future due to moving specimens for collection and research purposes would be too high. Adhesion was mostly done using Paraloid B-72 in a 50% solution with acetone (following Koob, 1986; Davidson and Alderson, 2009; Davidson and Brown, 2012; Russell and Strilisky, 2016). On large fractured surfaces, we generally first applied a weaker solution, or pure acetone or ethanol to the fractured surfaces, which would facilitate penetration of the bone by the 50% solution through capillary action. Although penetration is generally not recommended because it is not easily reversible and could potentially impact the original geochemistry of the bone (Davidson and Alderson, 2009; Schulp et al., 2013), some penetration is welcome in cases of large sauropod bones, because these glued pieces will have to bear considerable weight if they have to be handled for research or other reasons. In order to increase adhesion in these cases, we pulled apart and rejoined fragments repeatedly to more equally distribute the adhesive across the fractured surface and develop tack, following Koob (1986) and Davidson and Brown (2012). Smaller fragments with near-perfect fits were adhered with a 20% solution of Paraloid B-72 in acetone or ethanol.

Given the potential for preserved soft tissue with specific geochemistries, consolidation of the bones was limited as much as possible so as to avoid interference with future scientific analyses (Davidson and Alderson, 2009). However, in some cases, consolidation was necessary, and was generally done with Butvar B-76 in a 20% ethanol solution (or less frequently acetone). Cases where this procedure was necessary included bones whose external surfaces were flaking off or whose numerous minute cracks were destabilizing them. Butvar B-76 was used in these cases because it does not produce a shiny surface when dry. Application of such a liquid consolidant to a strongly fractured bone initially increases the risk of destabilization while capillary forces pull the consolidant into the cracks. A stable support is therefore necessary for much of the drying process (Russell and Strilisky, 2016), to avoid the disintegration of the fossil. For this purpose, the bone fragment was put on a support (e.g., sand box or bags, or a custom-made support with heavy duty aluminum foil) before the procedure, which would hold it in place while the consolidant was drying (at least 24 hours, preferably more).

In large, heavy bones (mostly appendicular bones like tibiae and fibulae), adhering all the broken surfaces was sometimes impractical, and it was not guaranteed that the adhesive would be able to withstand the heavy weight of the complete bone. Also, some of these

FIGURE 33. Ulna (AMNH FARB 33667; field number #155), housed in two pieces. We chose to keep the ulna in two parts because it will be easier to handle for curatorial purposes, and this way it fits in a drawer. The fractured surfaces (see cross section) were partially freed from adhering gypsum crystals using needles, and then consolidated with Butvar B-76, which makes the surface look slightly wet, but avoids gloss. The layer of Butvar will protect the surfaces when the two pieces are joined to take pictures or measurements for research purposes (see complete ulna; break where pieces are joined indicated with arrows). Photographs by B. Javors (cross section and complete ulna) and E.T. (ulna in ethafoam housing).


10 cm
bone surface
needle marks
gypsum crystals
5 cm

elements would be too large to be stored in a drawer of a collection cabinet. In these cases, we opted to keep bones in two or three parts that could be stored safely in one drawer (fig. 33). However, because broken pieces will have to be assembled for measurement or other analyses for research purposes by visiting scientists in future, the fractured surfaces had to be protected from damage through bone-to-bone contact. In order to do so, these surfaces were covered with a thin layer of Butvar B-76 (to avoid gloss) in a 20% solution (or less, for more penetration), which was applied using pipettes and wipes to evenly distribute the adhesive across the surfaces.

Documentation

Once prepared, and before going back to their home in the collections, the elements were documented using photography, measurements, and in some cases 3D scanning. Photography was done with the help of Ellison, Nicole Wong, Eklund, and volunteer Javors. Various cameras were used to produce images in the six cardinal views, where possible. Some heavy and/or fragile elements could be feasibly photographed only in a limited amount of views.

Some elements (in particular specimens where associated soft tissue was expected) were documented using the Progressive Photonics workflow established by Eklund et al. (2018). This workflow consists of 17+ photographs taken under normal frontal and oblique lighting, polarized light, and UV light with three different wavelengths (UV A, B, and C) separately and again with the three wavelengths combined, both with and without an orange filter that subtracts some of the excess blue in the original photograph. These photos were saved as digital negatives (DNG files), and were not modified in any way with photo-editing software in order to preserve the original metadata of the camera settings and color range of the reaction of the various materials to UV excitation. Photographs taken under UV light, in particular, also helped to understand details of the excavation and preparation history of some elements, such as the coating and consolidation of historic specimens (fig. 13; see also Baeza et al., 2016).

Measurements were taken with a caliper and/or tape measure. These followed standard measurements and protocols used in sauropod research and/or phylogenetic matrices (see e.g., Hatcher, 1901, 1903; Riggs, 1903; Janensch, 1961; Bonnan, 2001; Wilhite, 2003; Upchurch et al., 2004; McIntosh, 2005; Curry Rogers, 2009; Sekiya, 2011; Mocho et al., 2014; Royo-Torres et al., 2014; Poropat et al., 2015; Tschopp et al., 2015, 2019b; Carballido et al., 2017; Tschopp and Mateus, 2017; Mannion et al., 2017, 2019). In many cases, complete measurements were impossible because of the incompleteness of the bones themselves. Here, measurements were taken to represent the maximally preserved dimension, or measurements of one complete half were doubled to estimate total transverse width in bilaterally symmetrical elements. The measurements are stored in a spreadsheet with comments indicating issues due to incompleteness.

Bones chosen for subsequent study including potentially destructive sampling (e.g., histology) were 3D scanned, using a surface scanner or a CT scanner. However, since this report is restricted to the preparation and conservation project and the 3D scans are mainly for research purposes, and not simply documentation, details on these techniques and the devices will be given in the respective research papers.

A spreadsheet was produced with the aim to list every bone recovered or recorded at the quarry. A first list was compiled based on Bird's final quarry map, which was subsequently annotated and completed using the original field drawings in the archives of the AMNH Research Library (AMNH DR 202), and information gleaned from the recent preparation and conservation project. The spreadsheet records: (1) the section(s) of the quarry where the bone was recovered, (2) what kind of bone it is, (3) what number the plaster jacket was marked with, (4) the possible original crates in which it was packed (it was often impossible to identify the exact crate), (5) the catalog number attached to this bone, (6) whether the bone is drawn on the compiled map, (7) spatial relationships of the bone with others in cases when several bones of the same kind were recovered from a single section, or when the single bone was part of an articulated skeleton, (8) any field notes associated with a particular bone, (9) historical photos on which the bone can be identified, (10) whether the bone was present and identified at AMNH, (11) where it was located pre-2017 and currently, (12) when and by whom it was prepared, photographed, measured, and 3D scanned (and how), (13) whether the bone was sampled for histology and/or geochemistry, and (14) who created the housing and applied the catalog numbers to the bone. Where known, taxonomy was noted, as well as in how many pieces the element is preserved, and also any other comment deemed interesting was added. Finally, if the bone was mentioned in some scientific publication, references to those are listed as well.

Given the collection's history, many bones prepared now could not be identified on the quarry map, because they were not associated with their original plaster jacket, and section numbers were not written directly on the bone during the excavation. These newly prepared bones could therefore not be associated with an entry in the above spreadsheet, which was based on the quarry map itself. Hence, a second spreadsheet was created with the same columns for the elements for which the quarry section was unknown or that could not be unambiguously identified because several bones of the same type were recovered in a single section. Given that specimens were probably historically cataloged based on the jacket in which they were packed (see above), a third spreadsheet had to be created listing individual skeletons, and which part of what catalog number constituted a single individual skeleton. Ideally, the AMNH Division of Paleontology prefers to give a single specimen number to a single organism, but the paleohistory and postexcavation history of Howe Quarry make this especially challenging. Finally, the cataloged sauropod specimens are continuously added to the Morrison Formation Sauropod Consensus (Tschopp et al., 2019c), which is a freely available online spreadsheet of sauropod specimens from the Morrison Formation in museum collections worldwide. All these spreadsheets are a work in progress but are available from the first author upon request. Their structure and content is also further explained in the keys available as supplementary materials (doi.org/10.5531/sd.sp.42).

FIGURE 34. Creation of plaster supports for safe storage in collection. A cervical vertebra (AMNH FARB 33153) was prepared in its original jacket (upper left) and stabilized using Paraloid B-72 mixed with pulverized sediment for large cracks. A sheet of plastic is used as a separator (upper right), and to protect the specimen from increased humidity after application of wet toilet paper (lower left) and medical plaster bandages (lower right). The toilet paper serves as padding, whereas the plaster provides the necessary stability. Photographs by A. Davidson.

Curation

New form-fitted plaster jackets were created for bones that, due to an increased risk of damage caused by their own weight, could not be supported uniformly on a flat surface. These jackets were made with plaster bandages on wet toilet-paper padding, with a plastic sheet as separator to avoid wetting the specimen (fig. 34). Original jackets were reinforced if necessary, or, if still well preserved and stable, kept as is.

Collections housings for newly prepared Howe Quarry specimens vary depending on the size of the element. Even though nearly all the bones are from sauropods, most of the bones the project has so far dealt with are shorter than our collection drawers so we are able to house them in the controlled environment of closed cabinets. A few elements that would not have fit in a drawer when completely reconstructed were kept in two or three separate pieces. In cases where the broken surfaces were not a perfect match for each other, paper labels were adhered to the bone to indicate how the different fragments articulate (see keys in supplementary material: doi.org/10.5531/sd.sp.42).

The larger bones, particularly long bones and vertebrae, are especially prone to breakage compared to the generally compact smaller bones, and thus require extra support. Beds are crafted for these bones by carving a well that is shaped like the bone's footprint into a plank of ethafoam and lining it with polyester batting for cushioning overlain by a Tyvek sheet to provide a smooth surface that will not snag the specimen (see also Vila et al., 2014). This Tyvek sheet is secured to the ethafoam base by pushing its entire loose edge into an encircling slot cut just outside the perimeter of the well. Securing it in this way removes the need for any adhesives that might prove nonarchival in the future. Hand slots are provided for easy access to the most sensible places to lift the specimen out of its bed. In cases where the correct position in which to return a bone once it has been removed from its bed is ambiguous or easily forgotten, photos of the specimen in its bed are attached to the bed. A paper label attached to the bed also provides information concerning the identification of the bones, taxonomy, provenance, and field number. When several bones of a single specimen are identified, where feasible, a single bed was crafted for all of them, in order to physically maintain the association of the bones in the collections as well. In such a case, paper labels are printed with archival ink on archival paper, in addition to the photo, to be as specific as possible concerning which bone belongs where in the mount. The photo and the paper labels are put into Mylar sleeves that are slightly wider than the labels, and attached to the bed by folding the empty edges of the Mylar sleeves and pushing them into slots cut into the ethafoam (fig. 35).

The smaller compact bones, generally hand and foot bones, are housed in archival cardboard specimen trays lined with thin sheets of ethafoam. If several elements or fragments are housed in a single tray enough room is provided so that the individual pieces do not touch and measures are taken to mitigate rolling.

Cataloging

Some newly prepared specimens were cataloged as part of historic specimens (e.g., the two ischia of AMNH FARB 7533) or of specimens that were prepared more recently (but still before the recent project started). We opted to do so in cases where attribution to a single skeleton was completely unambiguous based on the location in the quarry map (i.e., the bones were articulated), or where an origin from a single skeleton was highly likely due to general vicinity in the quarry and fitting size and shape. (For instance, a second rib now cataloged with the rib AMNH FARB 30786, both from section 193, is of such a similar size and shape that at some point we were convinced they were two parts of a single rib, separated by a short gap. This resulted to be incorrect once an additional piece was found that clearly articulated with the proximal portion, but not with the distal portion; see above). New catalog numbers were created when specimens had to be scanned or otherwise sampled for research purposes (e.g., for histology; Moretti et al., 2018), and to elements that were associated with field numbers in areas of the quarry where no other specimen has been cataloged in the past.

FIGURE 35. Ethafoam bed for partial pes AMNH FARB 33152, with photograph and paper labels indicating which bone goes where, locality, taxonomy, and other information. Bones are housed in beds filled with cushioned batting and lined with Tyvek. Labels with basic data are preserved in Mylar sleeves. Photograph and labels clearly indicate which bone belongs in which cavity. Catalog numbers are painted in white on the dark surface, between two layers of Paraloid B-72, which remains transparent, so that the bone surface remains visible.

FIGURE 36. The right ischium of AMNH FARB 7533 in its ethafoam bed with the piece of the original plaster jacket that preserves the field number. This field number is also adhered to the bone itself on a paper label. Additional fragments for which we could not find their fit are housed in a plastic box. Photograph by B. Javors.

Some bones were recataloged, because they were included in specimen numbers that comprised bones from more than one individual. In cases like this, the original number remained for some part of the bones in question and parts deemed from other individuals or taxa were assigned new catalog numbers. This is considered less problematic than the kind of number changing described above (see Salvaging) because of the priority AMNH ideally places on having one specimen number per individual organism and because something remains that carries the original number. Again, very clear notes about these changes were then added to the AMNH Paleontology Database.

Physical numbering of the newly cataloged bones during the current project generally followed the paraloid-number-paraloid technique used with the bones prepared between 2005 and 2012 (see Salvaging), with the exception that we tried to avoid the use of the white paint as a background for the black number. Instead, on sufficiently light surfaces of the bone or the sediment, the black number is easily distinguishable without background, and on darker surfaces, white paint numbering was used an alternative to the white paint layer (fig. 35). In so doing, a minimal amount of the specimen's surface is covered with paint and inaccessible for morphological analysis.

Conservation of Nonpaleontological Objects

Occasionally, numbered fragments of jackets or fragments of newspapers are preserved as well. Jacket fragments that bear field numbers were treated in the same way as fragile fossil bone and housed with the contents of their jacket (fig. 36). Newspapers, often crumpled and always extremely brittle, were relaxed using increased local humidity followed by encapsulation in Mylar sheets. A photographic record of these typographical data is also kept.

FIGURE 37. Ischium AMNH FARB 33157 (field number 303), reconstructed from more than 50 small to large fragments, mostly by volunteers (Pedro Galindo, Enrica Sarotto, and Fanny Guex in this case). The relatively thin acetabular portion (toward the top) was much more damaged than the relatively stout shaft, as can be seen by the pattern of fragmentation.

We kept sediment samples from several jackets. These sediment samples are stored together with the bones they were associated with in the plaster jacket. The sediment samples bear the same specimen numbers as the bones, if those are cataloged, and come from various locations within the quarry.

Current State of Howe Quarry Collection (2020)

Since the beginning of the recent conservation project, we estimate to have cleaned and minimally prepared (where necessary) fragments that number in the low thousands. An exact number is impossible to provide due to the large number of very small fragments. Of these, hundreds were found to be various parts of single bones and have been glued to reconstruct the bones as much as possible. Some of the larger bones consist of 50+ fragments that were pieced back together by the lead author, preparators, and volunteers during several hundred hours of work (fig. 37). Every so often, fragments and bones recovered from the cabinets and crates during the recent project were found to be part of specimens that had been prepared previously, so that significant additional material is now available for study, and more information on several historic specimens is preserved than what was known before (not only anatomical information, but also data concerning attribution of bones from different catalog numbers to individual skeletons).

All the material from the 21 cabinets with specimens rehoused between 2003 and 2006 was reassessed, and seven of the 15 repacked crates from the 1990s were opened and their contents transferred into collection cabinets. From the newly prepared material, 529 elements could be identified as to what type of bone they represent. Of these, 141 are associated with field numbers, i.e., their location in the quarry is known, and attribution to individual skeletons can be assessed. An additional 82 jackets and packages with associated field numbers are present among the material transferred from the crates that were repacked in the 1990s into collection cabinets in early 2020. To date, 47 specimens were cataloged and/or recataloged during the recent conservation project. This amount of work could not have been done without the dedication and numerous work hours of the volunteers.

Termination and Future Prospects

The conservation and preparation part of the Howe Quarry Project was greatly reduced due to limited funding and termination of E.T.'s postdoctoral fellowship at AMNH in April 2020. Without E.T.'s active, onsite lead and supervision of the project, the project could not be continued at the same scale. Therefore, cataloged and documented bones had to be brought back to the collections, and measures had to be taken to prepare the uncataloged, prepared material for its move back to the collections as well. Uncataloged material was brought back to its original collection storage, which was noted on the paper labels adhered to the fragments in an early step during preparation (see above). Cataloged material was moved into new, empty cabinets. This entire process was developed and planned in collaboration with Ruth O'Leary (the division's Director of Collections, Archives, and Preparation).

The move was severely impacted by the fact that at the time of termination of E.T.'s fellowship, New York City was one of the epicenters of the COVID-19 pandemic. None of the collections staff, postdocs, or volunteers were allowed into the museum for the last month of the duration of E.T.'s fellowship, when most of the preparations for the move were planned to take place. In order to preserve as much information and data as possible in the short remaining time before complete museum closure, we produced a detailed photographic documentation of the lab and the various specimens being worked on. These photographs were used to create detailed guides and descriptions of every specimen, so that even after a prolonged closure, people tasked with preparing the specimens for the move could follow those guidelines. In this way, we attempted to avoid as much data loss as possible resulting from such an unprecedented situation.

During the nearly three years of the Howe Quarry Project, only a little more than half the uncataloged material could be assessed. Eight additional crates of the ones repacked in 1990 remain to be opened and their content inventoried and transferred to cabinets. Of the inventoried, uncataloged material, several original jackets and packages remain intact and likely contain well-preserved bones and, potentially, soft tissue. We intend to continue the project at a small scale with the help of volunteers, who will be able to work on the preparation of these intact jackets. With the photographic documentation and compiled spreadsheets listing the Howe Quarry material and its locations in the collections, it will be possible to indicate which specimens to prepare next, and with guidance from a distance. Furthermore, we intend to apply for additional fellowships and grants for E.T. and/or other interested students and postdocs to continue the project. In the meantime, several research projects started during the Howe Quarry Project can continue and are likely to expand our knowledge of sauropod anatomy and Morrison Formation paleoecology significantly.

DISCUSSION

The Howe Quarry Project is an interesting example of how paleontological preparation and conservation is very much a process of learning by doing, and how it has improved through time since the 1930s. It also shows how collecting and preparation has been, and continues to be, affected by institutional interest and final curatorial aims, which can have very distinct requirements for preparation and thus the techniques and materials used.

Exhibition pieces are prepared differently from research specimens, and not just in paleontology (Rae, 2014). Stability and completeness are often the main concerns for display specimens, so consolidation and reconstruction of missing parts is key. Research specimens, on the other hand, should see minimal intervention and minimal addition of extrinsic materials that could impact the original chemistry or obscure morphology. Preferably, all those interventions should also be reversible, and should be noted somewhere so scientists can access all the required information to decide whether a certain methodology or analysis is applicable to a certain specimen, or whether historic interventions first must be undone (Davidson and Alderson, 2009). Although published paleontological preparation reports exist for a number of cases (e.g., Araújo et al., 2009; Roubach et al., 2014; Val et al., 2014; Viegas and Benton, 2014), they remain the exception. Whereas many of these approaches have already been developed and put in place in art, archaeology, and general natural history conservation (e.g., Koob, 1986), paleontology is often a step behind. Unfortunately, there are only limited possibilities for communication between professionals in conservation science and paleontology researchers and preparators. A couple of examples of journals dedicated to both fields are *Journal of Paleontological Techniques* and *Collection Forum*. The meetings of the Society for the Preservation of Natural History Collections and the preparator's session and table at the Annual Meetings of the Society of Vertebrate Paleontology are other opportunities for such an exchange. However, other than during these occasions, exchange of information between conservators, preparators, collection managers, and researchers is sometimes difficult, and different procedures are developed inadvertently and independently for similar challenges (Rae, 2014). Working at a natural history museum with its own conservation department definitely helped us in our recent project. We profited significantly from earlier work by our Senior Preparator Davidson, who had adapted nonpaleontological conservation methods she learned from in-house natural science collections conservators to the specific materials of our fossils (Davidson and Alderson, 2009), and—again—to the various final purposes of the specimens themselves.

Research programs and, even more, exhibition planning largely depend on the interests of museum curators. At Howe Quarry, the initial intention was to have the specimens both for research and exhibition, as can be gleaned from various sources (e.g., Brown, 1935b). However, it also appears from these same sources that exhibition was a more immediate aim. This, however, changed when Brown retired in 1941. Although the amount of neglect the Howe Quarry collection went through after Brown's retirement cannot be explained away or excused, the fact that so much of the material remained unprepared also has a positive side. This collection now can be prepared and conserved with the latest methods and materials, following the standards for preparation for research purposes. This clearly salvaged a lot of potentially crucial information especially in terms of soft-tissue preservation (Tschopp et al., 2018), of which almost no trace can now be seen associated with specimens prepared before the current conservation project started.

Skin impressions were known from Howe Quarry since the excavation (Brown, 1935a), so the preparators working on Howe Quarry specimens in the 1930s all the way to the 2000s were able to look for them, but they were not trained to identify other potential soft tissue, which was only recognized in 2018, thanks to advanced technologies (Tschopp et al., 2018, 2019a). After that, the recent conservation project was thus adapted and all people involved in it were trained to identify signs of potential soft tissue and preserve it in connection with the bone, where possible.

CONCLUSION

Historical collections such as the one from the 1934 AMNH-Sinclair Dinosaur exhibition to Howe Quarry in northern Wyoming can carry unexpected scientific value. Reassessments of these collections is time-consuming and challenging in terms of conservation and research work but can yield important results for both scientific and outreach purposes. We hope that the detailed assessment of the history of the Howe Quarry collections, and the description of the recent conservation and preparation efforts will inspire similar efforts in other historical collections. Although much of the material, as well as information on associations of single bones and entire skeletons, was lost due to neglect and the several repacking episodes that followed from accumulated problems of inappropriate storage, things like attached sediment, potential soft tissue, and other details would likely have been prepared away and discarded during earlier conservation interventions. These data, however, can provide much information on taphonomy, age of the quarry, soft-tissue anatomy, and more. We therefore do not think it is necessarily a bad thing to keep historical collections stored away, and, in fact, it may be advisable for ongoing expeditions to set aside certain jackets from the field to keep them untouched for future analyses.

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REFERENCES

Araújo, R., O. Mateus, A. Walen, and N. Christiansen. 2009. Preparation techniques applied to a stegosaurian dinosaur from Portugal. Journal of Paleontological Techniques 5: 1–23.

Ayer, J. 2000. The Howe Ranch Dinosaurs. Sauriermuseum Aathal, Aathal, Switzerland, 96 pp.

Baeza, E., S. Menéndez, A.M. Bravo, and L. Ruíz. 2016. Past preparation procedures and contemporary conservation techniques applied on a holotype (Museo Geominero, Madrid, Spain). Journal of Paleontological Techniques 15: 133–143.

Bird, R.T. 1985. Bones for Barnum Brown: adventures of a dinosaur hunter. Fort Worth: Texas Christian University Press, 225 pp.

Bonnan, M.F. 2001. The evolution and functional morphology of sauropod dinosaur locomotion. Ph.D. dissertation, Department of Biological Sciences, Northern Illinois University, Dekalb, Illinois.

Breithaupt, B.H. 1997. Howe Quarry; pp. 355–356 in P.J. Currie and K. Padian (editors), Encyclopedia of dinosaurs. San Diego, CA: Academic Press.

Brinkmann, W., and H.-J. Siber. 1992. Dinosaurier in Aathal. Sauriermuseum Aathal, Aathal, Switzerland, 37 pp.

Brothwell, D.R. 1993. Notas orientativas para la excavación y la redacción de informes sobre restos humanos. *In* Desenterrando huesos. La excavación, tratamiento y estudio de restos del esqueleto humano: 11–40. S.L. Madrid: Fondo de Cultura Economica de España.

Brown, B. 1935a. Sinclair dinosaur expedition, 1934. Natural History 36: 2–15.

Brown, B. 1935b. The American Museum-Sinclair Expedition. Natural History 35: 438.

Carballido, J. L., et al. 2017. A new giant titanosaur sheds light on body mass evolution among sauropod dinosaurs. Proceedings of the Royal Society B 284: 20171219.

Chure, D. J., and M.A. Loewen. 2020. Cranial anatomy of *Allosaurus jimmadseni*, a new species from the lower part of the Morrison Formation (Upper Jurassic) of Western North America. PeerJ 8: e7803.

Colbert, E.H. 1984. The great dinosaur hunters and their discoveries Reprint. New York: Dover Publications, 384 pp.

Curry Rogers, K.A. 2009. The postcranial osteology of *Rapetosaurus krausei* (Sauropoda: Titanosauria) from the Late Cretaceous of Madagascar. Journal of Vertebrate Paleontology 29: 1046–1086.

Czerkas, S.A. 1992. Discovery of dermal spines reveals a new look for sauropod dinosaurs. Geology 20: 1068–1070.

Czerkas, S.A. 1994. The history and interpretation of sauropod skin impressions. Gaia 10: 173–182.

Davidson, A. 2009. Temporary gap-filling to stabilize an exploded matrix for fossil preparation: the sand and Butvar B-76 technique. Journal of Vertebrate Paleontology 29 (suppl. 3): 85A.

Davidson, A., and S. Alderson. 2009. An introduction to solution and reaction adhesives for fossil preparation. *In* M.A. Brown et al., Methods in fossil preparation: proceedings of the first annual fossil preparation and collections symposium: 53–62. Petrified Forest National Park, AZ: C. Wylie et al. [Lulu.com]

Davidson, A., and G.W. Brown. 2012. ParaloidTM B-72: practical tips for the vertebrate fossil preparatory. Collection Forum 26: 99–119.

Davidson, A., S. Alderson, and M. Fox. 2006. Assembling an archival marking kit for paleontological specimens. Journal of Vertebrate Paleontology Suppl. 3: 54A.

Dingus, L., and M.A. Norell. 2010. Barnum Brown. The man who found *Tyrannosaurus Rex*. Berkeley: University of California Press, 368 pp.

Dodson, P., A.K. Behrensmeyer, R.T. Bakker, and J.S. McIntosh. 1980. Taphonomy and paleoecology of the dinosaur beds of the Jurassic Morrison Formation. Paleobiology 6: 208–232.

Eklund, M.J., A.K. Aase, and C.J. Bell. 2018. Progressive Photonics: Methods and applications of sequential imaging using visible and non-visible spectra to enhance data-yield and facilitate forensic interpretation of fossils. Journal of Paleontological Techniques 20: 1–36.

Foster, J.R. 2003. Paleoecological analysis of the vertebrate fauna of the Morrison Formation (Upper Jurassic), Rocky Mountain region, USA. New Mexico Museum of Natural History & Science Bulletin 23: 1–72.

Hatcher, J.B. 1901. *Diplodocus* (Marsh): its osteology, taxonomy, and probable habits, with a restoration of the skeleton. Memoirs of the Carnegie Museum 1: 1–61.

Hatcher, J.B. 1903. Osteology of *Haplocanthosaurus*, with description of a new species and remarks on the probable habits of the Sauropoda and the age and origin of the *Atlantosaurus* beds. Additional remarks on *Diplodocus*. Memoirs of the Carnegie Museum 2: 1–72.

Janensch, W. 1961. Die Gliedmassen und Gliedmassengürtel der Sauropoden der Tendaguru-Schichten. Palaeontographica-Supplementbände 7: 177–235.

Kirkland, J.I. 1987. Upper Jurassic and Cretaceous lungfish tooth plates from the Western Interior, the last dipnoan faunas of North America. Hunteria 2: 1–16.

Klein, N., A. Christian, and P.M. Sander. 2012. Histology shows that elongated neck ribs in sauropod dinosaurs are ossified tendons. Biology Letters 8: 1032–1035.

Koob, S.P. 1986. The use of Paraloid B-72 as an adhesive: its application for archaeological ceramics and other materials. Studies in Conservation 31: 7–14.

Linares Soriano, M.A., and M.B. Carrascosa Moliner. 2016. Consolidation of bone material: chromatic evolution of resins after UV accelerated aging. Journal of Paleontological Techniques 15: 46–67.

Lockley, M.G., C. Meyer, H.-J. Siber, and B. Pabst. 1998. Theropod tracks from the Howe Quarry, Morrison Formation, Wyoming. Modern Geology 23: 309–316.

Mannion, P.D., R. Allain, and O. Moine. 2017. The earliest known titanosauriform sauropod dinosaur and the evolution of Brachiosauridae. PeerJ 5: e3217.

Mannion, P.D., P. Upchurch, D. Schwarz, and O. Wings. 2019. Taxonomic affinities of the putative titanosaurs from the Late Jurassic Tendaguru Formation of Tanzania: phylogenetic and biogeographic implications for eusauropod dinosaur evolution. Zoological Journal of the Linnean Society 185: 784–909.

McIntosh, J.S. 2005. The genus *Barosaurus* Marsh (Sauropoda, Diplodocidae); pp. 38–77 in V. Tidwell and K. Carpenter (editors), Thunder-lizards: the Sauropodomorph dinosaurs. Bloomington: Indiana University Press.

Michelis, I. 2004. Taphonomie des Howe Quarry's (Morrison-Formation, Oberer Jura), Bighorn County, Wyoming, USA. Ph.D. dissertation, Institute of Palaeontology, University of Bonn, Bonn, Germany, 41 pp.

Mocho, P., R. Royo-Torres, and F. Ortega. 2014. Phylogenetic reassessment of *Lourinhasaurus alenquerensis*, a basal Macronaria (Sauropoda) from the Upper Jurassic of Portugal. Zoological Journal of the Linnean Society 170: 875–916.

Mook, C.C. 1914. The dorsal vertebrae of *Camarasaurus* Cope. Bulletin of the American Museum of Natural History 33 (17): 223–227.

Moretti, J., E. Tschopp, D.E. Barta, K. Waskow, and M.A. Norell. 2018. Histological study of sauropod dinosaur bones from the historic Upper Jurassic Howe Quarry (Wyoming, USA): determination of an age range for every specimen. Fossilia 2018: 23–25.

Norell, M.A. 2019. The world of dinosaurs: an illustrated tour. Chicago: University of Chicago Press, 256 pp.

Poropat, S.F., et al. 2015. Reassessment of the non-titanosaurian somphospondylan *Wintonotitan wattsi* (Dinosauria: Sauropoda: Titanosauriformes) from the mid-Cretaceous Winton Formation, Queensland, Australia. Papers in Palaeontology 1: 59–106.

Rae, A. 2014. Exploring the common ground between organic artifacts and natural history specimens: we share problems – can we share solutions? Journal of Paleontological Techniques 13: 101–110.

Riggs, E.S. 1903. *Brachiosaurus altithorax*, the largest known dinosaur. American Journal of Science (Series 4) 15: 299–306.

Roubach, S., B. Gómez de Soler, G. Campeny Vall-Llosera, and J.I. Morales. 2014. Preparation of a turtle fossil from the Pliocene site of Camp dels Ninots (Caldes de Malavella, Girona, Spain). Journal of Paleontological Techniques 13: 38–49.

Royo-Torres, R., et al. 2014. The anatomy, phylogenetic relationships, and stratigraphic position of the Tithonian-Berriasian Spanish sauropod dinosaur *Aragosaurus ischiaticus*. Zoological Journal of the Linnean Society 171: 623–655.

Russell, R., and B. Strilisky. 2016. Keep it together: An evaluation of the tensile strengths of three select adhesives used in fossil preparation. Collection Forum 30: 85–95.

Schulp, A. S., R. Schouten, L. Metten, A. van de Sande, and A. Bontenbal. 2013. Tracking consolidant penetration into fossil bone using neutron radiography. Netherlands Journal of Geosciences 92: 177–180.

Schwarz, D., T. Ikejiri, B.H. Breithaupt, P.M. Sander, and N. Klein. 2007. A nearly complete skeleton of an early juvenile diplodocid (Dinosauria: Sauropoda) from the Lower Morrison Formation (Late Jurassic) of north central Wyoming and its implications for early ontogeny and pneumaticity in sauropods. Historical Biology 19: 225–253.

Sekiya, T. 2011. Re-examination of *Chuanjiesaurus anaensis* (Dinosauria: Sauropoda) from the Middle Jurassic Chuanjie Formation, Lufeng County, Yunnan Province, southwest China. Memoir of the Fukui Prefectural Dinosaur Museum 10: 1–54.

Tschopp, E., and O. Mateus. 2013a. The skull and neck of a new flagellicaudatan sauropod from the Morrison Formation and its implication for the evolution and ontogeny of diplodocid dinosaurs. Journal of Systematic Palaeontology 11: 853–888.

Tschopp, E., and O. Mateus. 2013b. Clavicles, interclavicles, gastralia, and sternal ribs in sauropod dinosaurs: new reports from Diplodocidae and their morphological, functional and evolutionary implications. Journal of Anatomy 222: 321–340.

Tschopp, E., and O. Mateus. 2017. Osteology of *Galeamopus pabsti* sp. nov. (Sauropoda: Diplodocidae), with implications for neurocentral closure timing, and the cervico-dorsal transition in diplodocids. PeerJ 5: e3179.

Tschopp, E., O. Mateus, and R.B.J. Benson. 2015. A specimen-level phylogenetic analysis and taxonomic revision of Diplodocidae (Dinosauria, Sauropoda). PeerJ 3: e857.

Tschopp, E., et al. 2018. The Howe Quarry Project: after 80 years of neglect, a historic collection still provides invaluable scientific data and a great opportunity for scientific outreach. Geological Society of America Abstracts with Programs 50: 6.

Tschopp, E., J. Wiemann, F. Dela Pierre, S. Cavagna, and M.A. Norell. 2019a. Howe Quarry (Upper Jurassic Morrison Formation, western USA), a hot spot for sauropod soft tissue. Journal of Vertebrate Paleontology 2019, Program and Abstracts 2019: 207.

Tschopp, E., S.C.R. Maidment, M.C. Lamanna, and M.A. Norell. 2019b. Reassessment of a historical collection of sauropod dinosaurs from the northern Morrison Formation of Wyoming, with implications for sauropod biogeography. Bulletin of the American Museum of Natural History 437: 1–79.

Tschopp, E., et al. 2019c. The Morrison Formation sauropod consensus: A freely accessible online spreadsheet of collected sauropod specimens, their housing institutions, contents, references, localities, and other potentially useful information. PaleorXiv 1–8.

Upchurch, P., Y. Tomida, and P.M. Barrett. 2004. A new specimen of *Apatosaurus ajax* (Sauropoda: Diplodocidae) from the Morrison Formation (Upper Jurassic) of Wyoming, USA. National Science Museum Monographs 26: 1–118.

Val, S., R. García, and D. López. 2014. Preliminary results on the chemical preparation of dinosaur eggshells. Journal of Paleontological Techniques 13: 29–37.

Viegas, P. A., and M.J. Benton. 2014. Bones and sediments: part of a synergetic continuum. Journal of Paleontological Techniques 13: 50–64.

Vila, M., M. Pérez, O. Muñoz, and E. Garcia-Franquesa. 2014. Two examples of preventive conservation actions in the Museu de Ciencies Naturals de Barcelona (MCNB): inspection of specimens and substitution of packaging. Journal of Paleontological Techniques 13: 65–69.

Whitlock, J. A., K.C. Trujillo, and G.M. Hanik. 2018. Assemblage-level structure in Morrison Formation dinosaurs, Western Interior, USA. Geology of the Intermountain West 5: 9–22.

Wilhite, R. 2003. Biomechanical reconstruction of the appendicular skeleton in three North American Jurassic sauropods. Ph.D. dissertation, Department of Geology and Geophysics, Louisiana State University, Baton Rouge, Louisiana.

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