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A History of Fossil Collecting and Preparation Techniques

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INTRODUCTION

The aim of this review is to show that techniques have evolved in parallel with and in response to requests for information about vertebrate fossils. The progress of and changes in collecting and laboratory methods have helped historically to provide morphological evidence that either agreed with or confounded theories of the day. In the field, expeditions go to wherever the rocks might yield vertebrates that could provide evidence for evolution or that might reveal links between the major vertebrate classes. In the laboratory, preparation bares these bones – almost invariably skulls – in order to obtain answers to questions of taxonomy, evolution, and related problems. The results of the expeditions – their faunal lists and the taxonomic descriptions and revised classifications – are self-evident in any palaeontology library, but the methods and techniques employed in the laboratory to obtain information are seldom clear and sometimes not even mentioned! Vertebrate palaeontology must be one of the few "sciences" where the techniques used to establish the facts appear to be of little consequence.

Probably the first publications to deal with early techniques are F. A. Bather's *Preparation and Preservation of Fossils* (1908) and A. Hermann's review *Modern Laboratory Methods in Vertebrate Palaeontology* (1909). These publications appear to have resulted from recognition that a preparator (a term apparently first used in North America) should have certain attributes and no longer needed to have a background of coal mining, quarrying, or stonemasonry. Firstly, a thorough knowledge of vertebrate anatomy was required. Secondly, gifts of unusual manual dexterity and patience were needed; these, coupled with an innovative mind, made the adaptation or development of mechanical or chemical techniques possible. Thirdly, the preparator, ing the anatomy of muscles in this book, Stensen went on to mention fossils. The reviewer stated:

> . . . that those and divers other substances, found in the Earth, are parts of the Bodies of Animals, and endeavours to prove, that sorts of Earth may be sediments of water, and such bodies, the parts of Animals carried down together with those sediments and in progress of time reduced to a stony hardness.

At this point in the review a note was added:

> This subject Mr Hook hath also discoursed of. . . in several of his publick Lectures. . . about Two years since in Gresham College. . . where he hath not only shown the Origins of these Glossoptrae, but of all other curiously figur'd Stones. . . of which the curious may shortly receive a further Account.

This note may have been written by Hooke himself—he was the curator of experiments at the Royal Society—and it suggests that Hooke was not only upset that his own ideas on the origin of fossils had been preempted by Stensen's book but that he also wanted to show that he had prior claim to the idea through "his publick Lecture."

While Hooke (1665) had been involved with a microscopical study of fossils, Stensen, who had been trained as a physiologist, had traveled to Italy via Montpelier. There, in the winter of 1665–1666, he met with Martin Lister and John Ray, neither of whom totally accepted Hooke's heretical ideas about fossil origins. It is possible that Stensen's interest in this topic was initiated by debate with Lister and Ray. Upon arriving in Florence, he had the opportunity—denied to Hooke at that time—of examining vertebrate fossils for himself, for skulls of fossil horse *Equus stenonis* were on exhibition at the Montevarchi Museum.

Perhaps because of the controversy started by Hooke's lectures and Stensen's book, the curious in England, noting Hooke's lack of material, were busy collecting vertebrate fossils toward the end of the 17th century and writing to the Royal Society about their discoveries. In 1668, while sinking a well for his new house, John Somner of Chartham, Kent ". . . turned up a parcel of strange and monstrous bones, some whole, some broken, together with four teeth, perfect and sound, but in a manner petrified and turned to stone."

These teeth, described and figured in 1669, and part of the skull still exist in the British Museum (Natural History) [BM(NH)] collections and, although first thought to be hippopotamus remains, were later correctly described by Grew in his catalogue (one of the first) of the *Natural and Artificial Rarities Belonging to the Royal Society* (1681) as rhinoceros teeth. Another tooth "of a sea animal" was also figured by Grew (and Hooke) and, although it has no history, appears to have been brought into Britain, for it resembles teeth of Miocene proboscideans from France; this is also in the BM(NH) collections.

The first figure to be published of a fossil reptile bone, probably belonging to the carnivorous dinosaur *Megalosaurus*, appeared in Robert Plot's *The Natural History of Oxfordshire* (1676). Plot, who mentioned Somner's "hippopotamus," had difficulty in assigning his bone to any large animal then known. Consequently, he had to rely upon legend and described it as the petrified lower end of a giant's thigh bone. Later, the bone was named (enter Linnaeus) and transferred to another part of the giant's anatomy as *Scrotum humanum* by Brooks (1763).

Thomas Molyneaux published a description of Irish "Elk" horns in the Transactions (1697). He also gave a lengthy account of his reasons, mainly religious, for believing that a live elk must still live somewhere in the unexplored world as, for him, it could not have become extinct.

Robert Hooke, with more fossils available than he had had 32 years earlier, was quick to use Molyneaux's discovery in a lecture to the Royal Society in May, 1697, entitled "Of Animal Substances Found Buried." This lecture, published posthumously as *A Discourse of Earthquakes* (1705), not only ridiculed the Flood theory of fossil origins but offered proof against it and also showed that Hooke believed in extinction and the change of species as well as in changes of climate through geological time, for instance:

> . . .that there have been in former times of the world, divers species of creatures, that are now quite lost, and no more of them surviving upon any part of the earth (page 435).

> . . .and 'tis not unlikely also but that there may be divers new kinds now, which have not been from the beginning (page 291).

> I would desire them to consider. . . that this very land of England and Portland, did at a certain time for some ages past, lie within the torrid zone (page 343).

> . . .and to me it seems very absurd to conclude, that from the beginning things have continued in the same state that we now find them, since we find everything to change and vary in our own remembrance (page 450).

Hooke and Stensen established the guidelines for future discoveries, theories, and arguments about fossil vertebrates. Hooke's realization that species had become extinct and his implication that geological time was much longer than had been believed possibly derived from his mathematical training. His remark that "we find everything to change and vary" set the scene for events during the next hundred years.

THE 18TH CENTURY: EXPLORING AND REVOLUTION

Owing to the conflict in Europe during the early 1700's, few important events concerning vertebrate fossils were recorded. The effects of that war spilled over into the New World where, in 1739, Baron de Longueuil, while claiming most of America directly south of the Great Lakes for France, came across some mastodon bones and teeth near the Ohio River valley; these fossils were destined for the Cabinet du Roi of Louis XV at Versailles. The Ohio valley Indians may have regarded the bone localities as sacred, and local skirmishes with encroaching fossil collectors made the area hazardous. In 1766, George Morgan and George Croghan, deputy on Indian Affairs, were able to collect from the "big salt licking place." Their collection of mastodon bones and teeth was divided; one lot was sent to London to Earl Shelborne, who was sympathetic to the American cause, and the other went to Benjamin Franklin. Less than twenty years later, these two were to negotiate the position of the frontier between America and Canada.

Hunter, a London obstetrician, described and figured a jaw from Shelborne's lot in the Royal Society Transactions (1768), and this is now in the BM(NH). Hunter sought the opinion of ivory dealers in London; after cutting and polishing a tusk, they declared that it was "true elephant ivory." Despite this excellent evidence and possibly because the opinions of both Daubenton and Buffon in Paris were similar (they had examined de Longueuil's specimens and had also "mammoth" teeth from Siberia available), Hunter contrarily concluded that they were not elephant teeth but were of some carnivorous "*animal incognitum*." Franklin did not share this opinion and sent a tooth to d'Auteroche in Paris, commenting that an animal with such large tusks was "too bulky to have the Activity for pursuing and taking Prey."

In 1769, the year in which Cuvier was born, the artist Charles Peale returned to Maryland after two years in London and served as a war artist in Washington's army. He became interested in a project to draw bones sent to a Dr. Morgan by his brother George Morgan, the same individual who had collected on the Ohio 1766 expedition. On seeing these bones, Peale became eager to establish a museum of natural curiosities in Philadelphia as an alternative method of making his living. As Franklin had just returned from London with the peace treaty, the time was not only ripe to celebrate the birth of the Republic but also its first museum—with an entrance charge! Peale opened his museum to the public in about 1786, but interest eventually waned;

toward the end of the century, its contents were incorporated into the collections of the American Philosophical Society.

COMPARATIVE ANATOMY: EXCAVATIONS AND TECHNIQUES

By applying the laws of comparative anatomy to the relics of extinct races of animals. . . , we make an important step in advance of all preceding philosophies. . .

–Richard Owen (1860)

During the period of the evolution of America's first natural history museum, the Cabinet du Roi and the Royal Garden and Zoo had become the Museum National d'Histoire Naturelle of Revolutionary France and George Cuvier had joined its Anatomy department in 1795. In the same year, the Revolutionary Army had laid siege to the town of Maastricht, Holland, and the general in charge had orders to seize the 4-foot-long jaw that had been found in 1770 amongst the city's chalk caverns. The offer of 600 bottles of the best wine encouraged the French troops to locate the specimen quickly.

This fossil, believed to be either a crocodile or a giant lizard (in fact, a mosasaur), was sent to Paris along with other military booty from the natural history collection of the Hague. Cuvier was therefore fortunate in having an unrivaled collection of both recent and fossil animals available with which to rapidly pursue his ideas on comparative anatomy. He published a figure (1799) that compared a mammoth jaw from Siberia with that of an Indian elephant and remarked (much as Hooke had done a hundred years earlier) that certain animals had become extinct.

Quarrymen, in 1770, manoeuvring a block of chalk containing the jaw of a Dutch mosasaur.

in the role of conservator, ought to be able to think several decades ahead in order to ensure that the materials used in the work should, at best, be totally stable in a museum environment. Finally, for work in the field, the preparator should have knowledge of both geology and sedimentology so that the best methods of discovering fossils and then removing them from various rock types could be used.

These themes were developed by Camp and Hannah (1937) and more recently by Hotton (1965), Rixon (1976), and Croucher and Woolley (1982). In addition, papers describing variations of techniques have appeared in the journal *Der Präparator* (in West Germany) and in the *News Bulletin* of the Society of Vertebrate Paleontology (in the United States).

Studies of fossils – and therefore the techniques used to give substance to such research – can be divided into three periods:

- The first – extending from the mid-17th century, when fossils were first shown to be related to the nature of the rocks that contained them, to 1795, when George Cuvier joined the Museum National d'Histoire Naturelle – is characterized by arguments about geological time, the Flood, and the collection of specimens for "cabinets of natural history."
- The second – 1795 until 1859 – began with Cuvier developing his ideas of comparative anatomy and ended with the publication of the *Origin of Species*. This period appears to have been the most revolutionary politically, industrially, and palaeontologically.
- The third – extending from 1859 to the present – is marked by institutional funding of expeditions to search for fossil ancestors and the development of palaeontological laboratories within the institutions.

The history of collecting that follows begins with two 17th-century scientists, an anatomist and a physicist, forming the idea that fossils might be the remains of extinct animals preserved long before the Flood.

COLLECTING: FACT OR FLOOD

That our collections are imperfect is admitted by everyone.
– Charles Darwin

In 1667, the Transactions of the Royal Society carried a review of a book by the Dane Niels Stensen entitled *A Specimen of the Elements of Myology*, which had just been published in Florence. After describ-

Cuvier's work was encouraged by the publications of another comparative anatomist, Dr. Caspar Wistar, in America. Wistar, an Edinburgh medical graduate, had become interested in fossil vertebrates through Thomas Jefferson, who was president of the American Philosophical Society, for which Wistar served as curator. Jefferson maintained that fossils could not be extinct animals and invoked Indian legends to suggest that unknown beasts lived in the unexplored interior of America. Jefferson read a paper (1799) concerning New Jersey bones that he believed to be those of a lion (they are of a sloth), the "megalonyx." Wistar described and figured these bones, *Megalonyx jeffersoni*, the same year and, despite the lack of comparative material in Philadelphia, was able to conclude that the articulation of the foot bones of the animal enable it "to turn its claws under its soal of its feet. . .the animal did not walk on its toes."

The first recorded excavation for vertebrate fossils in the United States took place in 1801. The mastodon bones that were collected are significant for several reasons. First – through Wistar – the American Philosophical Society gave $500 to the Peale family, thereby enabling the failed museum entrepreneur Charles Peale to supervise

Excavating and draining swampy ground in Orange County, New York in 1801 to recover the remains of the Peale mastodon. The Peale family are holding a drawing of the bones while men inside the wheel *wearily supply the power to lift the water laden buckets.*

the excavation, hire labor, and construct what must be the largest device ever used in the history of vertebrate fossil collecting. The fossils had been found in swampy ground; because of seepage and wet weather, a huge water-removing wheel was made. Secondly, one skeleton went on show in the American Philosophical Society's rooms and later in Independence Hall; the other skeleton was shipped to London and was shown in Pall Mall in 1802. Thirdly, the artistic Peale family – Rembrandt, Titian, and Charles – produced many drawings of the bones, and some of these were sent to Cuvier *prior* to his 1806 paper on the American "Mastodonte."

Although Rudwick (1972) stated that Cuvier's reconstruction of this mastodon was "a spectacularly successful result of his anatomical methods," it was in fact simply the result of the drawings and information that Cuvier had received from "his favourite American correspondents," the Peale family.

Cuvier may have actually been the first person to describe a laboratory technique. In his description (1804) of a nearly complete marsupial skeleton discovered in the quarries near Paris that were the source of *le gypse* (plaster of Paris), which has since become such an important collecting material, Cuvier described how he actually prepared the specimen:

> "Je creusai avec precaution, au moyen d'une fine pointe d'acier, et j'eus la satisfaction de mettre a decouvert toute cette portion anterieure du bassin . . . (page 286).*

It seems likely that Cuvier recognized the historical significance of this operation, for it was carried out "en presence de quelques personnes" to whom he had predicted the scientific result. Later, Cuvier asked his brother's secretary to undertake some preparation, and Monsieur Laurillard became Cuvier's technician and draftsman.

A surge of interest in palaeontology and geology in England at the beginning of the 19th century came from a practical "middle class" and eventually rivaled that of the aristocratic investigators of the "king" of science – astronomy. In 1811, one year after Mary Anning had found the first articulated ichthyosaur skeleton at Lyme Regis, Henry de la Beche, a gentlemen cadet, was thrown out of the Royal Military College (McCarthy, 1977). De la Beche moved to Lyme Regis and collaborated with Mary Anning and other geologists in gathering specimens both at Lyme and elsewhere in Britain. After a European tour and meetings with eminent geologists, he published a description of

*I scraped away carefully using a sharp steel probe and had the satisfaction of uncovering the entire front part of the pelvis.

a plesiosaur with Conybeare (1821), believing it to form a link between crocodiles and the new ichthyosaurs. Subsequently, de la Beche became the geologist of the Trigonometrical Survey of Great Britain in 1831 and – amid Devonian mapping controversies with Murchison, Sedgwick, and Lyell – he declared that he was just a geological observer and that "preconceived opinions" should be separated from facts. This philosophy led him to publish *How to Observe – Geology* (1836), which seems to be the first publication to describe a field technique. In the section concerned with organic remains, de la Beche alluded to Cuvier's work stating:

> . . . organic remains are thus sometimes as beautifully perfect as if prepared for the purposes of instruction by the comparative anatomist.

He then described the techniques that he himself must have developed. He said that remains:

> . . . should be carefully wrapped in paper, the locality having been written on a strip of paper and enclosed with the specimen; or a particular mark may be made on the specimen, or enclosed strip of paper, which shall correspond with a similar mark in the observer's field-book (page 249).

Having set down the first rules of recording field data, de la Beche then presented his ideas on collecting vertebrates:

> When the structure of the fossil is delicate, it is not desirable to endeavour to extract it from the rock on the spot; on the contrary, the observer should then strive to detach so much of the rock, no matter whether the portion be great or small (page 250).

This second rule, like his first, is not always carried out today, and too many vertebrate specimens have suffered because collectors often prepare the fossil in the field. De la Beche, however, did recognize that fish or saurian remains posed special collecting problems. To overcome these he suggested:

> . . . it may even be desirable to go to the expense of preparing plaster of Paris on the spot, and cover the fossil. . . . By this process the exposed part of the skeleton becomes set in a block . . . ; so that by working carefully beneath it and the fossil in the friable rock, the skeleton is eventually on the surface of plaster of Paris, from which it may eventually be freed (page 251).

Other collectors were not as inclined as de la Beche to get dirty, and they bought – or were given – vertebrates from the many quarries then operated to supply materials for Britain's expanding industry and population.

Buckland obtained the dinosaur *Megalosaurus*, which he described (1824), from the Stonesfield roofing-slate quarries in this way. Gideon Mantell's opinion of quarrymen must have varied. In 1824, he described the teeth of another dinosaur, *Iguanodon*, which his wife had apparently picked up from locally quarried Sussex roadstone metal. Several years later in 1832, when "accidentally visiting the quarry," Mantell noticed a block of calciferous grit that had been broken up by quarrymen and thrown upon the road, "as it was not supposed to contain anything interesting." After directing that the portions should be collected and sent to his residence, Mantell eventually cemented the fragments together and chiseled off the grit to expose bones he later named as the herbivorous dinosaur *Hylaeosaurus*. His thoughts on quarrymen when he learned that workers at Bensted's quarry in Kent had actually blasted a specimen of *Iguanodon* out of the quarry face are also unrecorded. The hole for the blasting powder can still be seen in the block containing these bones now stored in the BM(NH). At least Richard Owen must have been thankful to those unknown quarrymen whose efforts provided him with the material that became "founder members" of his order Dinosauria.

Meanwhile, in August, 1833, another collector, Charles Darwin, had arrived in South America. At Punta Alta, Argentina, he found remains of the Megalonyx, the Scelidotherium and *Mylodon darwinii*. These animals, described by Owen in the *Zoology of the Voyage of the Beagle* (1840), were deposited in the Royal College of Surgeons, London. More importantly, their discovery was to influence Darwin so much that in his *Origin* (1859) he wrote:

> When I found in La Plata the tooth of a horse embedded with the remains of Mastodon, Megatherium, Toxodon, and other extinct monsters, which all co-existed with still living shells at a very late geological period, I was filled with astonishment. . .

Horses, Darwin's friend T. H. Huxley, and the New World were to become important in the years following the publication of *Origin of Species*.

BETTER TECHNIQUES AND ANCESTOR HUNTING

> *Yet to-day's neo-Darwinian theory, with all its faults,*
> *is still the best we have.*
> — Colin Patterson (1978)

William Davies of the British Museum was sent down to Ilford, Essex, in 1863 to collect a mammoth skull complete with tusks. His equipment was contained in a "one horse spring van" and consisted of a bundle of splines, a box full of hay and tow, and a hundredweight of plaster. Davies developed two important variations on de la Beche's original technique. First, he covered the tusks with "whitey brown paper" onto which he then laid the plaster of Paris. As additional support, he then had soft iron bars bent to the shape of the tusks; these were then covered with plaster also. Having formed the top of a cocoon, he then sawed through the base of the tusks to separate them from the skull; he then had six men lift the mass "swathed with bandages of canvas, hay and cord, like a mummy" into his van. The skull was removed in a similar manner, and this specimen can still be examined in the collections of the BM(NH).

However, Davies did make mistakes and – unlike other collectors – was not averse to describing them (1876). In 1874, he was sent to the Swindon Brick and Tile Company's Kimmeridge clay pits to collect "many large bones." He discovered that the bones of a "huge dragon" were contained in a large septarian nodule occurring some 9 feet below the edge of the pit. The nodule was "8 feet in its longest and 6 feet in its shortest diameter" and to "raise it entire with such appliances as we had was impossible." Before deciding on any special plan, Davies had a trench cut around the nodule and "a workman was then instructed to insert his pick beneath and try to slightly raise the mass." Cracks then appeared, and Davies became hopeful that the nodule might be removed in large blocks. Unfortunately, while lifting an 18-inch square mass:

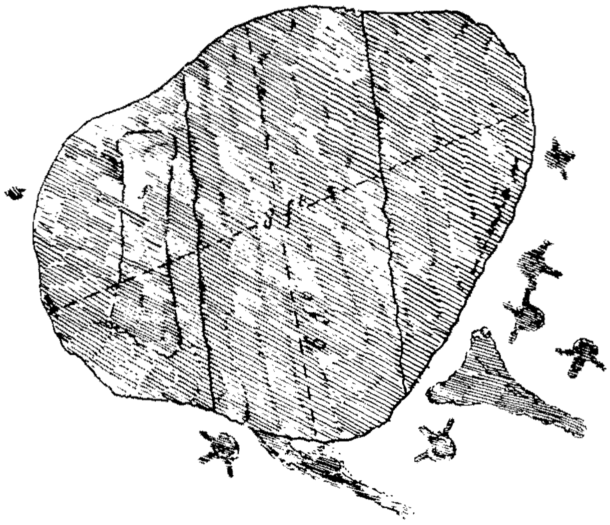
> It fell from our hands in many pieces by its own weight, and its enclosed bone was found to be wet, rotten and crumbling.

Davies persevered, and many small blocks were lifted and numbered, then:

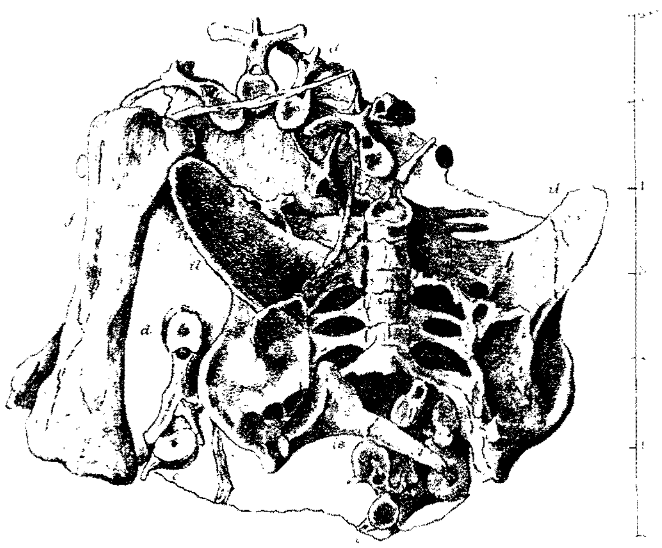
> ...the exhumation being completed, the whole mass, packed in many cases...weighing nearly three tons, was forwarded to the British Museum.

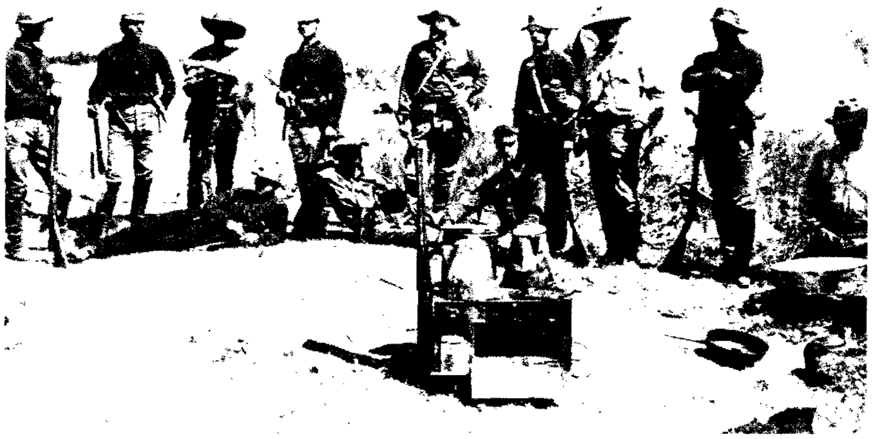
Eventually, the pieces were stuck together and the bones, when prepared by "Mr Barlow, the mason attached to the Geological Department," proved to be the sacral region of a dinosaur described by Owen (1875) as *Omosaurus armatus*.

In America, Professor O. C. Marsh and ten students left New Haven on the first scientific expedition to the West by Yale College in 1870.



A field sketch (top) probably made by William Davies in 1874, showing an 8 foot wide nodule containing bones of "a huge Dragon". The block from Swindon, Wilts., was later prepared (bottom) by Caleb Barlow, a mason, and described by Richard Owen in 1875.





Probably the first photograph of the members of an expedition to collect fossil vertebrates. The Yale College team of 1870 armed with both pistols and hammers. Prof. O.C. Marsh stands fourth from right. (Photograph by courtesy of the Peabody Museum of Natural History, Yale University).

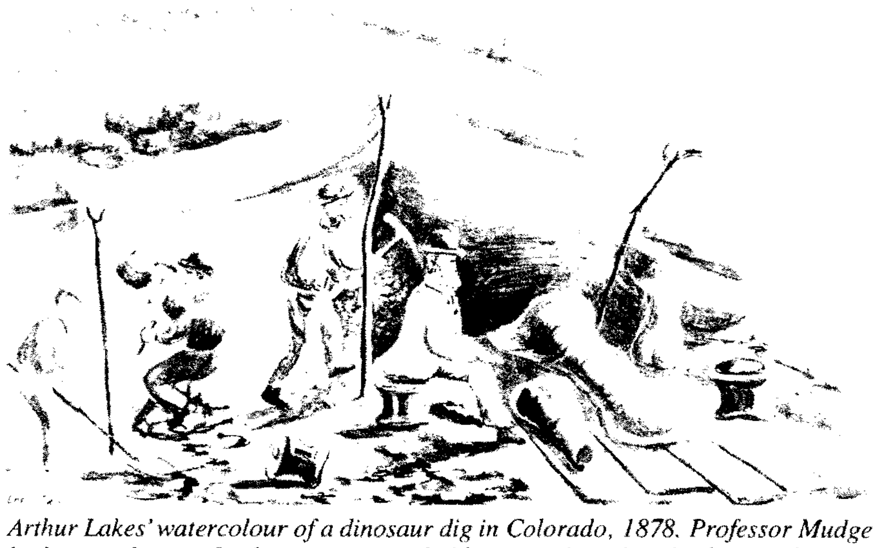
During almost six months in the field, the members of the expedition found rich fossil localities in Colorado, and bones of the toothed bird *Hesperornis* were discovered near the Smoky Hill River, Kansas. Remains of other Odontornithes were found, but extreme cold and danger from hostile Indians led to the postponement of further collecting until subsequent expeditions in 1871-1872 (Schuchert and Levine, 1944).

The method used by Marsh's collectors during the early years of dinosaur hunting was known as the "pick, rake and sack technique." Obviously, the time spent in New Haven reassembling three-dimensional jigsaw puzzles must have worried Marsh's men with the result that, by 1877, Samuel Wendell Williston reported to Marsh that he was: "wrapping fossils with strips of paper dipped in flour paste." These fossils were in fact the bones of the long-necked dinosaur *Diplodocus* from Canon City, Colorado, discovered on a dig led by Professor Mudge of Kansas. The Cope-Marsh rivalry meant that the years of 1876 and 1877 were extremely hectic for the dinosaur collectors. As a result of the Harlow and Edwards discoveries in Wyoming, Marsh sent Williston from Canon City to Como Bluff, Wyoming, and Professor Mudge to Morrison, Colorado, in order to see Arthur Lakes and his dinosaur bones. Lakes is a significant figure, for he was both an artist and apparently an innovator of technique. A watercolor of his painted in 1878 shows Professor Mudge whimsically seated on a large dinosaur vertebra while pondering the femur of *Atlantosaurus*. Later in the year when writing to Marsh, Lakes wrote:

> I have occasionally laid on a coat of plaster of Paris on the outside of the bone to preserve it whilst the rest of the rock was being jarred by the hammer.

The femur shown in his watercolor appears to have a distinct rim around it, and – with some allowance for his particular artistic style – it is my opinion that the rim is actually plaster of Paris that he had laid onto the bone. If my interpretation is correct, then this watercolor is possibly the first pictorial record of a collecting technique in use.

There is very little first-hand evidence as to the identity of the collector who first used sacking, or burlap, soaked in plaster. Charles Schuchert (1940) recorded that he saw plaster and gunnysacking cocoons arriving at Yale Peabody Museum in 1892. Earlier, at the time Williston was using flour paste and paper, Charles Sternberg



Arthur Lakes' watercolour of a dinosaur dig in Colorado, 1878. Professor Mudge looks at a femur of Atlantosaurus *probably strengthened with plaster of Paris.* (Photograph by courtesy of the Peabody Museum of Natural History, Yale University).

was boiling rice to a thick paste and soaking flour bags and burlap in it. Later in 1897, when Harry Menke was working with the American Museum excavations at Como Bluff, E. S. Riggs (1952) recorded that Jacob Wortman experienced difficulty in collecting a dinosaur from crumbling clay. Wortman told his men to mix some plaster and then poured this onto gunnysacking and this "mass was then drawn under the sacrum through a trench." Oddly, the instruction was then given to pull out the sacking, but, of course it held in place. With the realization of this technical advantage, more plaster and burlap strips were applied to the block, and after completing the cocoon, "the party declared a holiday."

It seems to me that unlike the practice today when even skulls or limb bones are collected with the technique of reinforced plaster, during the late 19th century paste and sacking were commonly employed to collect small bones, with plaster and sacking only being utilized to form and protect blocks containing large skulls or articulated bones. Hermann (1909) alluded to these different methods and also mentioned the practice adopted by Davies in 1863 of separating the bone from the plaster and sacking by a thin layer of tissue paper.

THE 20TH CENTURY

Up until the Second World War, the materials used to harden bones in the field were invariably animal or vegetable glues. Davies (1865) used gelatine and fish or bone glues to harden his mammoth specimen. In the United States, the earlier use of thin solutions of gum arabic or acacia gum as consolidants was superseded by shellac dissolved in alcohol. The use of the hardener Celluloid produced from cellulose nitrate probably originated in Germany where it was used to consolidate specimens found in damp Eocene brown-coal deposits. The dangerous qualities of cellulose-nitrate film has led to the film industry's adoption of cellulose acetate to replace Celluloid, but commercial cellulose-nitrate glues and hardeners, known as Duco and Durofix, are still used in fieldwork today.

Developments in the petrochemical industry have helped in the collection of fragile vertebrates as well as in their conservation. In 1937, polyvinyl resins were first produced from natural and cracked petroleum gases, a process that gave the polyvinyl acetal group of which Alvar 1570, known to all palaeontologists, proved to be an excellent replacement of vertebrate and plant glues and cellulose hardeners. Alvar has been used since the 1940's but is no longer manufactured – being replaced by Butvar from the polyvinyl butyral group. Emulsions of polyvinyl acetate that are water-based are used for consolidating damp specimens.

Two advances in collecting large vertebrate bones occurred in the early 1960's. Ron Croucher of the BM(NH), while excavating the large, flat and very thin pubes of an Oxford Clay pliosaur in 1963, decided that woven glass fiber could be glued to the pubes using a viscous solution of Alvar 1570 dissolved in chloroform. Wooden splints were attached with the same solution encasing the pubes in a lightweight but strong cocoon. Once in the laboratory, it was then a simple matter to dissolve the Alvar, remove the glass fiber and splints, and proceed to prepare the specimen. A solution of Butvar in acetone has been substituted in the method used today (Croucher and Woolley, 1982).

In 1966, John Carreck of Queen Mary College, London, when faced with the task of removing a Pleistocene elephant from an Essex clay pit, experimented with polyurethane foam (Carreck and Adams, 1969). This technique, although expensive and hazardous owing to the toxic isocyanate gases given off during the foaming stage (masks need to be worn during application), can be much quicker than the conventional use of plaster and bandages. Quite recently the BM(NH) adopted this technique when collecting part of an *Iguanodon* pelvis from a clay pit in Surrey.

Finally, mention must be made of a technique apparently first used in England in the 1860's to collect micro-mammal teeth that has become

The technique first developed by Ron Croucher, B.M.(N.H.), using glass fibre strengthened with viscous Alvar to cocoon the pubes (centre) and ribs (right) of a pliosaur found at Stewartby, Beds., 1963.

widely used as an aid to bio-chronostratigraphic and taphonomic studies. The technique involves collecting large quantites of bone-bearing matrix, soaking it in water, and then screening the sludge. The history and hazards of this technique have been described by one of its main proponents, Malcolm McKenna (1962), and also by C. W. Hibbard (1949, 1975). An adaptation of this technique has been made in England when dealing with bone-bearing matrices cemented with calcium carbonate, by placing the rock in a sieve and then immersing it in dilute acetic or formic acids and sorting the residue.

LABORATORIES AND PREPARATION

At the British Museum in 1874, Richard Owen, the superintendent of the Natural History Departments (salary, £800 per annum), employed Caleb Barlow as mason in the Department of Geology (salary, £101-14-6d). Barlow's duties were the developing, modeling, casting, and mounting of the vertebrate fossils; five other masons were employed in the Department of Antiquities, where presumably they conserved rather than "created." Little is known about the facilities available in the "masons' workshop," but they could have been very similar to those of the Dinosaur Laboratory at the Carnegie Museum in Pittsburgh.

Around the turn of the century, it appears that the limitations of

The Dinosaur Laboratory at the Carnegie Museum, Pittsburgh in 1899. The bones appear to be of Diplodocus *of which a plaster skeleton was presented to the B.M.(N.H.) in 1905.*

the mason's hammer-and-chisel technique were realized, possibly arising from the fact that most institutions were changing to the new power source of electricity and new equipment had become available. (The BM(NH) had electricity in 1911.)

E. S. Riggs introduced a commercially-made pneumatic hammer of the straight-cylinder type into the Field Columbian Museum in 1903, having adapted it to hold 6-inch-long chisels that reciprocated at around 3,000 strokes per minute. Although such a tool was merely a mechanized stone-mason's chisel, Riggs realized that he could develop dinosaur vertebrae from hard concretions with a greater degree of finesse than he had previously achieved by simply hitting them with a chisel and hammer. The following year, Henry Fairfield Osborn (1904) used a similar tool in the U.S. National Museum and—after experimenting with other equipment—reported that a sandblast machine with fine nozzles and working at 50 p.s.i. had given admirable results when used in preparation. The idea of using an abrasive powder forced through a fine-diameter nozzle by compressed air was first published by Bernard (1894); the process required that the fossil be harder than its surrounding matrix.

Therefore, by the time Hermann's paper on the modern techniques used in vertebrate palaeontology was published (1909), the three basic methods of mechanical preparation, grinding, percussion, and sandblasting had been developed.

CHEMICAL PREPARATION

Although Hermann mentioned that hydrochloric acid had been used to weaken carbonate matrices, it is Bather's paper (1908) that first records experiments with various chemicals to discover aids for preparing fossil vertebrates. Bather, primarily an invertebrate palaeontologist at the BM(NH), consulted W. F. Reid at the Society of Chemical Industry. Reid recommended the use of "hypo-acetine":

> . . . the hypo-acetine, which is the result of considerable experiment, seems to have a more equable action. This process is particularly suitable in the case of bones which, being phosphate of lime, are not so readily attacked by the acid as is the carbonate of lime matrix.

Bather gave no information on the chemical composition of hypo-acetine, nor does it appear in any modern chemical dictionary. However, there are some clues about its composition arising from the fact that Reid's principal work was concerned with explosives. Acetin, or glyceryl monoacetate, is a colorless thick liquid soluble in water and made by heating glycerol and strong acetic acid. Used for gelatinizing smokeless gunpowders and preparing dynamite, its effect on the matrix containing vertebrates seems to have resulted from the uncombined acetic acid that acetin contained as an impurity. Bather suggested that it might be possible to use other acids such as acetic, but it was not until 1946 that the first hint of the technique that was to revolutionize vertebrate palaeontology was published (White, 1946).

Previously, Bulman (1931) had been fortunate in his use of mineral acids in the preparation of the enigmatic Devonian fish *Palaeospondylus*, for the fossil itself had been coalified so that the acids had little effect. Harry Toombs found in 1938 that when he used mineral acids on a collection of ostracoderms in the BM(NH), the bones were destroyed as well as the matrix. Eventually, after establishing acid values from the literature and considerable experimentation, Toombs discovered that dilute acetic acid provided the best result. This work was halted during the Second World War, but White (1946) mentioned that a 20 percent solution of acetic acid in water had been used in preparing specimens of *Traquaraspis (Phialaspis) pococki*. In 1948, Toombs published his technique of using a rubber cement, Bostick, to hold the fragile plates during acid preparation of the matrix on the obverse side.

Arthur Rixon (1949) described his results in using dilute acetic acid on a wide range of other fossil vertebrates, including mammals found in cave breccias, and also lime-encrusted bone axes and other artifacts. Rixon also experimented with dilute formic acid on ostracoderms, obtaining equally good preparations. Collaboration with colleagues in the Department of Zoology at the BM(NH) who had been embedding anatomical specimens in resins (Purves and Martin, 1950), enabled Toombs and Rixon to adapt the earlier idea of backing a fossil with opaque rubber cement to the easier process of embedding it in the clear synthetic resin Marco. This method is referred to as the "transfer technique" (Toombs and Rixon, 1950).

In recent years, the removal of haematite from vertebrate specimens, one of the most intractable problems, has been solved by Frank Howie. The results of his use of thioglycollic acid on Miocene fish and Triassic reptiles are comparable with those produced by the acetic-acid technique, although the process is very slow (Howie, 1974).

THE FUTURE

This review has concentrated on developments in techniques that have mainly arisen in the United States and Britain. Experience has shown that specimens collected and prepared over a hundred years ago and in some cases merely ten years ago can suffer from chemical breakdown when brought into a museum environment. Workers are now collecting and preparing fossils found in Third World countries, and it must be one of the principal duties of a palaeontologist in such countries to educate his colleagues in conservation and ensure that good techniques are practiced. It is ill advised to utilize old techniques using animal and vegetable glues simply because they are inexpensive, for they will undoubtedly create problems for the future.

The Palaeontology Laboratory and the Photographic Unit at the BM(NH) are planning to produce video recordings of certain field and laboratory techniques, preparation, casting, molding, and conservation. We hope that these recordings will become available to all institutions for educational purposes, for seeing someone deal with a specimen is more useful than thousands of descriptive words.

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