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GEOLOGICAL CURATORS' GROUP

Geological collections thriving for science and society

The Geological Curators' Group (GCG) is a membership organisation founded in 1974, and a charity registered in England and Wales (no. 296050). We are affiliated to the Geological Society of London (the oldest national geological society in the world) and recognised by Arts Council England as a Subject Specialist Network (SSN). Further information can be found at www.geocurator.org.

Geological collections (rocks, minerals and fossils) are vital Earth heritage that help us understand the natural world. The Geological Curators' Group strives to connect every geological collection with appropriate resources, knowledge and skills to thrive and positively impact science and society.

We do this by:

- Supporting everyone working with and caring for geological collections of all types
- Advocating the value of expertise in the care and use of geological collections, and their importance for scientific research and education
- Connecting people, skills, information, and collections

GCG has always been a community, run by members elected from its membership. We take pride in our goals and enjoy working hard to reach them. Geological collections enrich lives and stimulate cutting edge science.

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Rocking the boat: geological collections and social change

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As experts in geological collections, we know well the important role our collections can play in engaging a wide range of people with geoscience themes, including understanding the natural environment, evidencing climate change and encouraging young people to consider STEM careers. In the context of increasing social inequality, exacerbated by the COVID-19 pandemic, we should also consider how our geological collections can address social challenges such as inequality and low social mobility. By developing a good understanding of our audiences and carefully targeting our activities and resources, we can use our public engagement work to contribute to outcomes directly relating to specific audience needs. Using examples from the work of the Sedgwick Museum and the University of Cambridge Museums, I demonstrate how a strategic approach can better align with wider social priorities and strengthen advocacy for our collections. This paper was originally given as a presentation at the Geological Curators' Group AGM in November 2020.

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Introduction: public engagement with geoscience in the time of COVID-19

As we begin to understand the wider impacts of the COVID-19 global pandemic, this is a crucial time to be thinking carefully about how the public engages with our geological collections. Substantial pressures on public funding, already felt across the museums sector, are likely to further shine a spotlight on our work in museums and universities, making it all the more urgent that we can demonstrate and articulate the broad benefits that public interaction with geological collections can bring.

I use the term 'public engagement' to encompass all types of interaction with public audiences, including museum visitors, school pupils, teachers, visitors to fossil festivals, local geology club members and more. I prefer 'public engagement' over 'outreach' as it emphasises two-way interaction and encompasses a wide variety of settings and approaches, including digital engagement as well as face-to-face activity. I also include work with schools and teachers in this definition: schools and teachers play a key role in addressing social inequality, while the challenges of home learning during lockdown have emphasised the crossover between family activities and schools learning.

In this article, I use two case studies from the work of the Sedgwick Museum and the University of Cambridge Museums to demonstrate how some of the work is framed and prioritised, but I hope that the principles I outline here for high-quality, strategic and respectful public engagement can be applied more widely and in different contexts.

Using data to focus resource: the Cambridge context

Perceptions of Cambridge as a wealthy, privileged city belie considerable levels of deprivation. Parts of the city and wider Cambridge region rank amongst the most deprived in England, according to UK government data on the Indices of Multiple Deprivation (IMD; King and Leeman 2019). Even within the city, stark levels of inequality exist. For example, IMD data indicates life expectancy for a person living in a more deprived ward of the city is, on average, 10 years less than someone living less than two miles away in a less deprived ward. These sorts of inequalities led the Centre for Cities to call Cambridge 'the most unequal city in the UK' (Centre for Cities 2018).

Social mobility is defined as 'breaking the link between an individual's parental background and their opportunities to reach their full potential in terms of income and occupation' (The Boston Consulting Group and The Sutton Trust 2017). Social mobility varies geographically: in some places, growing up poor is highly likely to negatively impact life chances, while elsewhere the negative impact is far less. The Social Mobility and Child Poverty Commission (2016) specifically mentioned Cambridge and the East of England region as performing relatively poorly in terms of social mobility: a young person growing up poor in Cambridge will have very limited opportunities to reach their potential.

The reports quoted above refer to the pre-pandemic context. Evidence is growing of the COVID-19 pandemic's exacerbating impacts on deprivation, isolation, mental health, well-being and social inequality (Blundell *et al.* 2020) and its disproportion¬ate impacts on, for example, Black people and those of Pakistani and Bangladeshi heritage. How, then, can our geological public engagement address the challenges of society? How might we contribute to addressing rising levels of social inequality, or increasing discrimination and marginalisation? How might we address the lack of opportunities faced by many young people, especially from disadvantaged backgrounds, or the lack of opportunities for people with disabilities, or the social isolation faced by many older people? With worryingly-high levels of poor mental health, particularly among young people, how can our work contribute to a solution? Can we, in our geological public engagement work, ensure we are contributing to addressing these societal challenges, rather than maintaining or exacerbating them?

Datasets such as the IMD (which draws together a range of measures of relative deprivation, including income, employment, education, health, access to housing and services, experience of crime and quality of living environment) and POLAR (which maps how likely young people are to participate in higher education) can help museums and collections to understand the context in which they are operating. High socio-economic background, university-level educational attainment and a professional occupation are still the most reliable predictors of high levels of engagement and participation in a wide range of cultural activities, including museums (Neelands *et al.* 2015). People living in more deprived areas are less likely to access cultural opportunities such as museums or to travel to events; contributing factors include the costs involved, poor access to travel links and negative perceptions of the welcome they will receive. Without a strategic, targeted approach, we will continue to serve audiences who are predominantly scientifically and/or culturally confident: those who would choose to visit a museum, or take part in a fossil festival, for example. This is not to say we should discontinue working with such audiences, but we should ensure that we are actively addressing the barriers that prevent many people engaging with our collections and target individuals and communities who are facing particular disadvantage.

For the University of Cambridge Museums, analysis of these datasets coupled with an understanding of current visitors derived from postcode data has enabled the museums to identify which parts of the city and region are experiencing the greatest deprivation and social inequality and to focus resources accordingly. This includes targeting schools and community groups in these areas and working with groups and agencies who are similarly targeting their work and/or already have established links. It informs marketing strategies, especially for free family programmes, and enables decision-making about, for example, which community festivals can be supported.

How do people benefit from our public engagement?

As geological educators in museums, universities and other organisations, we deliver a wide range of activities that have the potential to impact positively on social mobility if targeted appropriately. Supporting, enhancing and enriching school learning improves school attainment; targeting it at those schools and pupils who face the greatest disadvantages will therefore have a greater impact on social mobility. Opportunities to develop 'soft' skills such as confidence and resilience through extra-curricular activities can particularly benefit young people from lower income backgrounds. Programmes that support young people through key educational transitions, in particular the move from primary to secondary school, contribute to building self-esteem and self-identity.

Meaningful training and work experience placements offer insights into employment and encourage STEM career pathways. They can contribute to a wider aspiration-raising beyond science-specific outcomes. The types of work environments we can offer, for example, at museums and universities, are unfamiliar to many pupils, and so positive time spent in them can build confidence to explore other career opportunities as well. Inequality of attainment is established even before the age of 5, so high-quality pre-school activities can help to build early cognitive skills and help to reduce disadvantage when children start school. Public engagement activities play a key role in health and well-being for adults as well as young people and particularly for older people who may be experiencing decreased mobility, poorer health and social isolation. A growing body of evidence supports a social prescribing approach, recognising the benefits of social and learning opportunities in enhancing mental and physical health.

Through the University of Cambridge Museums consortium, the Sedgwick Museum participates in a wide range of programmes that address the challenges outlined above. The Strategic Schools Initiative has built long-standing and sustainable partnerships with a small number of schools identified as being in areas of deprivation and low participation in higher education. The communities they serve experience significant logistical, financial and attitudinal barriers to accessing the museums. Through these partnerships, the University of Cambridge Museums establishes long-term relationships with schools, their governing bodies, teachers, pupils and wider communities. Collaboratively-designed programmes combine nuanced local understanding of need with evidence for what works, resulting in interventions with a higher likelihood of positively impacting young people's outcomes (Stearn and Hide in press). Other programmes involve partnerships with local health and social care providers, while Children's Centres and social welfare charities similarly ensure that programmes meet the needs of the people who participate.

One of the consequences of social inequality is unequal access to the natural environment. Access decreases as marginalisation and deprivation increase, so economic and social barriers prevent many people from having opportunities to feel at home in nature. Our geological collections and museums can be a stepping stone to enable people to engage with the outdoors and to make their own connections with nature. This might be by encouraging them to go fossil hunting, look at their local building materials or to better understand the natural landscape around them. By enabling individuals to understand and explore our environment, our work with geological collections also contributes to raising awareness of, and addressing, global challenges such as climate change, biodiversity loss, habitat destruction and the challenges of natural resource extraction. As stewards of geological collections, we are well-versed in the arguments for the importance of our collections in enabling research in these areas and we can play a key role in helping people to understand the issues, the importance of geoheritage and geological collections, ensuring they care enough to want do something about them.

Public engagement can be hard work, and many of us do it in addition to other roles and activities; it is often carried out on shoe-string budgets and limited resources. The satisfaction of experiencing positive and enthusiastic responses is a genuine and important motivation for many of us putting our hard-pressed time, energy and resources into public engagement. It is important to recognise that, despite this, the primary reason for carrying out public engagement should always be about its impact on others. An audience-focused approach means that the reasons and intended outcomes when planning activities ensures that they are tailored to best deliver those outcomes.

The examples that follow demonstrate how, albeit modestly, the Museum's activities can be planned and framed in the context of social inequality. They both involve targeting particular groups of people who may be facing disadvantage or discrimination and working intensively with a small number of people to achieve outcomes.

Case study 1: Community Cabinet

This ongoing programme, led by the Sedgwick Museum's Exhibitions Coordinator Rob Theodore, enables the Museum to work with individuals and small groups in a targeted way, while also visibly demonstrating to our public audiences the Museum's commitment to inclusion. Display cases in the heart of the Museum, the 'Community Cabinet', host a changing series of displays co-curated with individuals or small groups of members of the public working together with Museum staff and focusing on their particular interests or specialisms. The last six years have seen five community-led displays of rocks and fossils co-curated by both younger and older people with a range of backgrounds and geological knowledge.

For the most recent iteration of the Community

Cabinet, in August 2019, the Museum collaborated with Cambridge City Council's Children and Young People's Participation Service (ChYpPS), through the University of Cambridge Museums and with the support of Communities Officer Karen Thomas. ChYpPS runs regular school holiday play events at recreation grounds across the City. They prioritise wards in the City where the levels of deprivation are highest, where free leisure and learning activities can have the greatest impact. Rob delivered a series of free recreation ground drop-in 'RockChYpPS' fossil identification workshops during the summer holidays. 48 young people participated in the recreation ground activities, and 12 followed up by bringing fossils and rocks for identification into the Museum. Seven of those young people loaned objects for display, working with Rob to write labels for their finds, which varied from local gravel finds to holiday souvenirs. The young people themselves then helped to install a display of their rocks and fossils in the Museum. All brought their families to see their work, with some families visiting the Museum for the first time.

One of our gallery volunteers, Elliot Cowie is an enthusiastic and knowledgeable fossil collector who has also collaborated with Rob to create a Community Cabinet display of his finds. Elliot's labels articulate how fossils are important to him as a young person with an Autistic spectrum diagnosis, and we hope this visibility enables other visitors who may have a similar diagnosis to feel at home in the Museum.

While we have not yet had the opportunity to formally evaluate the quantitative impact of the Community Cabinet on visitors, feedback from participants and their families has been very positive, "*My ultimate goal is to become a palaeontologist and I hope my volunteering will help me along this path.*"; *"thank you for giving [my son] the opportunity to show your many visitors Matthew's absolute passion for geology"; "Even though I had no experience in curating, I felt well supported by museum staff and had a really enjoyable time creating my display*". This latter quote is from Alex Mattin, at the time a local sixth-form student who has since gone on to study geology at Leeds University.

Most recently, Rob has been working with two young people with Black British heritage to develop the next Community Cabinet display based on their own fossil finds from both the UK and Kenya. While the project has necessarily been paused during lockdown, we look forward to opening this display in 2021.

Many people who face discrimination or disadvantage feel alienated by museums, seeing them as 'not for them'. By prioritising participation by people who might otherwise have experienced barriers to engaging with the museum, we emphasise the value that we place on their contributions and enable them to tell stories about rocks and fossils that contrast with the more traditional narratives seen elsewhere in the Museum. The collaborative approach used in developing the displays provides a way for members of the public to gain insights into the behind-the-scenes work of the museum, to build their knowledge and workplace experience and to feel part of the Museum team. The Community Cabinet displays intend to send a clear message to our public audiences that we value diverse perspectives and strive to be an inclusive Museum.

Case study 2: Portals to the World

Portals to the World is an established programme for people living with a dementia diagnosis or cognitive impairment and their care partners, initiated at the Fitzwilliam Museum and now extended to include other University of Cambridge Museums including the Sedgwick Museum. Now in its tenth year, the programme promotes familiarity, confidence and trust in the museums, emphasises ability over disability and provides opportunities for people to learn, share and experience respite together. Essential to the programme is the contribution of partner organisation Dementia Compass, who brings extensive experience and understanding of the needs and priorities of people with cognitive impairment and their families and provide training for staff involved in delivering the sessions. An alumni programme enables people who have already participated in a programme to maintain their relationship with the museums.

Pre-pandemic sessions took place in the museums comprising a short talk from a member of museum staff focusing on a particular area of interest, followed by a handling session and/or creative activity. For the Sedgwick Museum, in July 2020, Learning Coordinator Nicola Skipper worked with Fitzwilliam Museum colleagues to develop a format that worked online. She delivered a short talk to 13 participants about the dinosaur/bird transition, showcasing the work of Cambridge researcher Daniel Field on the late Jurassic 'Wonderchicken' fossil, which prompted a lively discussion with participants about a range of subjects including evolution, feathers and palaeoart. An experienced artist educator, Nathan Huxtable from the Fitzwilliam Museum, then led a feather-printing creative activity designed so that participants could do it at home.

This project demonstrates how, even with the restrictions of lockdown, a good understanding of the needs and priorities of audiences can ensure that museums can deliver meaningful activities to people who may be among those who are most socially isolated. Partnering with organisations that have relevant expertise and are already engaged with potential recipients ensures that the programmes reach those who will benefit most and that they are delivered effectively and respectfully.

Maximising the social impact of public engagement: considerations

Feedback from participants in the two projects outlined above demonstrates how these programmes have brought positive benefits to the individuals involved. By targeting our efforts on individuals who are facing substantial disadvantage, we can ensure that this work has wider social benefits as well. To this end, I recommend some considerations to ensure the social benefits of geological public engagement:

- Understand who the people are who will benefit the most, and how to reach them, using your own and others' data to help with this. Visitor research, government and local authority datasets and information from local agencies can all help to build up a local and regional picture.
- Listen to audiences to understand their needs and priorities, and respond to those identified priorities. Provide them with opportunities to shape and contribute to the programme so that it is relevant and engaging.
- Seek out expertise: There is a huge wealth of helpful experience to draw on, some published, much of it in the minds of experienced practitioners. Consult and collaborate with people and organisations that can help you reach your audiences more effectively
- Make it sustainable and long-term: build meaningful partnerships and ensure you have the resources and the motivations to continue working over a longer period.

Measured purely in terms of participant numbers, the outcomes from this approach to public engagement may be relatively modest. However, by ensuring that public engagement is planned and focused so as to be as much about the strategic long-term impacts as the number of people who took part, our work has much greater value in addressing the challenges faced by society rather than passively endorsing existing inequalities.

Advocacy

Speaking the language of social impact and articulating the benefits of our work in these terms enables us to align ourselves with wider political and economic concerns, especially if we can do this in terms of our own local or regional context. By demonstrating relevance, we are better able to reach beyond the cohort of organisations and individuals who might have an interest in geological collections, to gain wider recognition and support for what we do.

Case studies demonstrating the social impact of geological public engagement can be powerful advocacy tools amongst stakeholders including universities, local authorities and funding bodies. For some young people, seeing a dinosaur on a school trip to a museum might be the only geological engagement they have in their lifetime. We have the opportunity to make sure that for those young people, that engagement leads to lasting and sustained benefits for them and for wider society.

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Conservation and photogrammetry of subfossil Quaternary walrus (*Odobenus rosmarus*) from the Bay of Fundy, Canada

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We describe a simple, inexpensive approach to the conservation and preservation of the subfossil cranium and tusks of a Quaternary (c. 2,900–12,800 years BP) walrus (*Odobenus rosmarus*) dredged from salt water. Ideally, wet specimens should be kept immersed in seawater until the treatment process is initiated. Regardless, it is critical that specimens not be permitted to dry out prior to desalination. Desalination was accomplished by gradually replacing sea water with fresh tap water, followed by controlled, slow drying over more than 530 days. Spalling was restricted to the tusks and occurred mainly between days 293–300, requiring surface consolidation with a dilute polyvinylacetate solution. The specimens were sufficiently stabilized for geology collections storage following the 591-day process. The use of photogrammetry to produce a 3D digital image of the partial walrus cranium with tusks permitted us to minimize the necessity of future handling and conservation and to preserve details of overall morphology and meristics useful for both research and public exhibition.

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Introduction

As the ice retreated from eastern Canada at the close of the Wisconsin glaciation, populations of walrus (*Odobenus rosmarus*) occupied the emerging shoreline and shore-fast ice (Miller 1990; Dyke *et al.* 1999). By the Millville-Dungarvon phase of the Wisconsin glaciation, about 12,700 years BP, southern and southeastern New Brunswick was probably ice-free (Miller 1990; Shaw *et al.* 2006). The last relict populations of walrus disappeared from Maritime Canada at the close of the 18th century, hunted to extirpation by early European colonisers (Naughton 2012; Curley *et al.* 2019). As recently as 1904, noted New Brunswick naturalist, William Francis Ganong, was able to recover walrus bones, including crania replete with musket ball holes, from the shoreline of Miscou Island in northern New Brunswick (Ganong 1904, 1906). Only rarely have extralimital walrus wandered into the region since (Kingsley 1998; Naughton 2012; Curley *et al.* 2019). Nonetheless, in the past decades, Quaternary walrus crania and tusks have been regularly dredged from the floor of the Bay of Fundy (Miller 1990, 1997; Figure 1), and are occasionally also washed from Quaternary marine sediments that outcrop along shorelines due to erosion.

Unfortunately, untreated subfossil walrus bones, and particularly tusks, quickly deteriorate once removed from the marine environment. Here we describe a simple approach to the conservation and preservation of subfossil walrus crania and tusks dredged from salt water that maintains integrity while also leaving specimens housed in museum geology collections suitable for research and exhibition. This methodology may also prove useful in ensuring the preservation of other subfossil vertebrate osteologi-

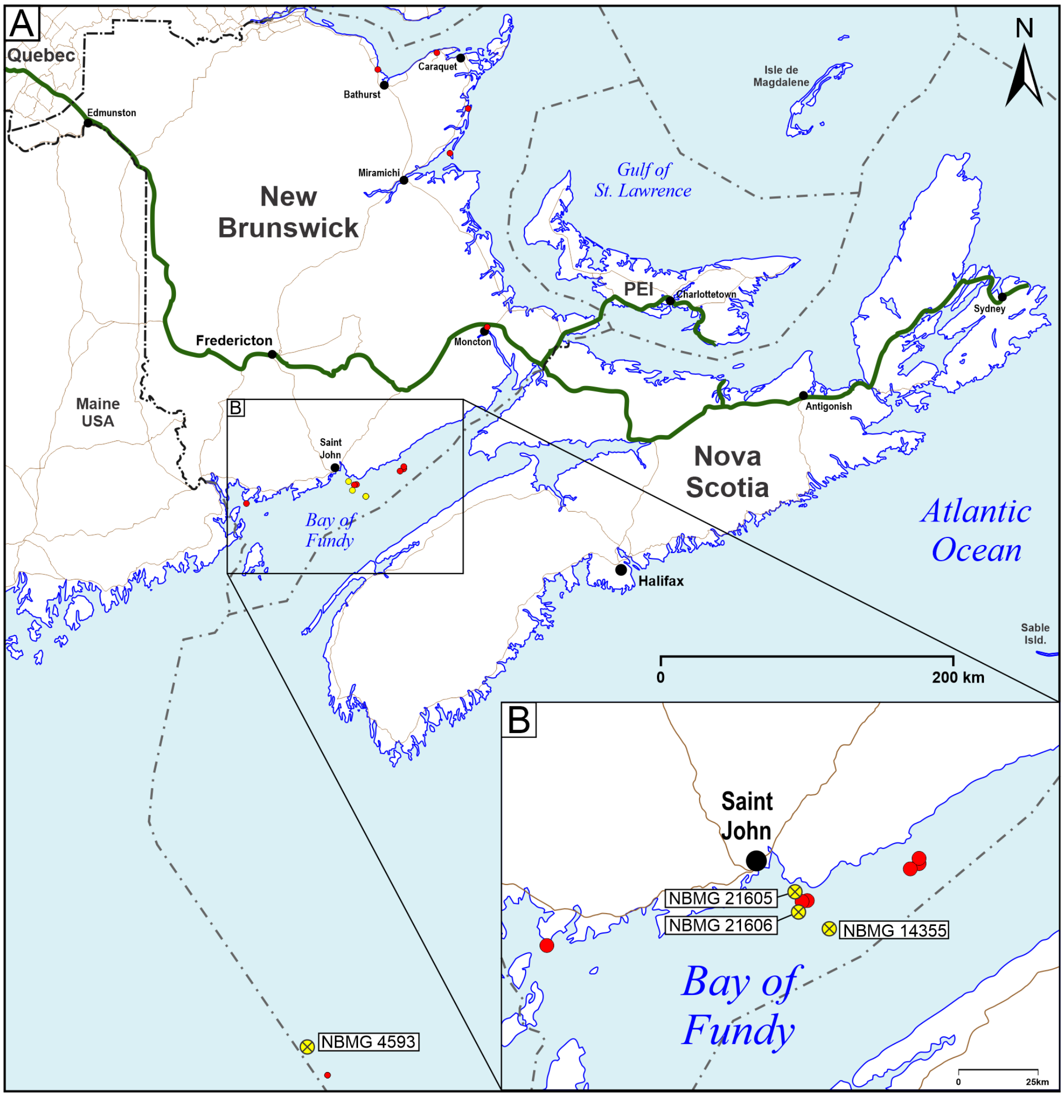

Figure 1. A) Maritime Canada showing sites of collection of semi-fossil walrus remains housed in the New Brunswick Museum geological collection, including B) the location of Bay of Fundy specimens reported here. Individual specimens identified include those conserved (NBMG 21205, NBMG 21206) and those illustrating conservation issues (NBMG 4593, NBMG 14355) and reported on in the text.

cal elements retrieved from marine waters. We also demonstrate the utility of photogrammetry in producing a 3D image that permitted us to minimize the necessity of future handling and conservation, and to preserve details of overall morphology and meristics useful for both research and public exhibition.

Deterioration of Quaternary tusk and bone in the marine environment - defining the problem

Walrus remains discussed here are composed of two main regions of the skull: the snout, comprised of the premaxilla, maxilla and nasal bone, and the tusks (Kastelein and Gerrits 1990). Walrus tusks (canine teeth) are essentially cylinders that have evolved to resist lateral stress (Locke 2008). The cementum, a soft derivative of the enamel layer and a minor peripheral component, overlays a main core of dentin. Visible in the dentin, short-period incremental lines assumed to represent daily pulses of mineralization contribute to large-scale growth layer groups (GLGs) deposited annually. These GLGs have been widely used to estimate the age of marine mammals (Scheffer and Myrick 1980; Waugh *et al.* 2018). In structure and composition, the dentin of tusks has been likened to reinforced concrete. Typically, dentin is composed of a matrix of particles 5–20 µm in diameter in a ground substance containing dentinal tubules about 5 µm in diameter. These are spaced about 10–20 µm apart and arranged in sheets that form microlaminae along the length of the tusk

(Locke 2008). Uniquely, the tip of a walrus tusk is solid for about 20 cm, after which the pulp cavity fills with pearl-like concretions (60–80% at the base), rather than with the uninterrupted layer of dentin commonly found in other tusked mammals (Locke 2008). Although these concretions lack dentinal tubules, they are embedded in a tubule-dense matrix. It has been hypothesized that this core of dentin spheres, set in a matrix and sheathed in a cylinder of dentin, may minimize fracture planes (Locke 2008). However, GLGs and microlaminae presumably provide potential fracture points in once water-saturated tusks. Our own observations indicate that bone exposed to the saline environment is less susceptible (although not immune) to spalling than tusks. The work of Dirrigl *et al.* (2020), based on bird bones placed in experimental conditions that simulate saline lakes, suggests that increased mineralization and hardening of saltwater-saturated bone, as well as the lower density of bone versus tusks, may account for this.

Consequently, subfossil Quaternary walrus tusks quickly deteriorate upon removal from the marine environment. Unfortunately, standard guidelines for the curation of geological materials appear to overlook the issues of dealing with water-saturated subfossil bone and tusks retrieved from saltwaters (Brunton *et al.* 1985; Collins 1995; Green 2001). Although little consideration has been given to the conservation of subfossil bone retrieved from saltwater, the conservation of bone, ivory and antler collected from water-saturated environments has received more attention (Botfeldt and Richter 1998; Larkin and Makridou 1999; Grant 2007; López-Polín 2012; Barrón-Ortiz *et al.* 2018; Decrée *et al.* 2018).

Several methodological approaches have been pursued, the most frequent being solvent-drying, and controlled air-drying. Solvent-drying is time efficient but requires large amounts of ethyl alcohol and proper facilities (fume hood, flammable storage, etc.). Also, how the approach effects DNA extraction, microscopic surface topography and stable isotope analysis is poorly understood (Barrón-Ortiz *et al.* 2018). Paraloid B72 at 25% (V/W) with acetone has been used successfully for the conservation of subfossil ivory (Larkin and Makridou 1999). Although the process is reported to be reversible and may not hinder future biochemical studies, the impact of re-

Figure 2. A) A badly fractured semi-fossil walrus tusk (NBMG 14355), the result of drying without desalination, collected in 2007, and B) a tusk showing exfoliation and cracking in spite of consolidation with shellac (NBMG 4593), collected and prepared in 1969. Both specimens dredged from coastal New Brunswick, Canada.

movable solvents on the topography or biochemistry of the exterior layer is unclear (López-Polín 2012). Controlled air-drying is cost effective but requires a commitment of time that may range from days to several months (Barrón-Ortiz *et al.* 2018). Barrón-Ortiz *et al.* (2018) found controlled air-drying to be the most successful for late Quaternary bone from freshwater. Regardless of approach, a curatorial balance that preserves the potential for future scientific studies (radiometric dating, biochemistry, osteological studies) with gross morphology and opportunity for public exhibition, is generally the goal (López-Polín 2012, 2015).

Examination of degraded walrus tusks in the New Brunswick Museum collection show cracking and spalling along a variety of fracture planes (NBMG 14355; Figure 2A). Exposure to subaerial conditions can lead to the precipitation of salt in the pore spaces, fissures and cracks of the bone or tusk, resulting in cracking and spalling. Previous attempts to consolidate tusks retrieved from Bay of Fundy sea floor sediments by coating tusks in shellac were of limited effectiveness in preventing cracking and spalling and left specimens unsuitable for exhibition (NBMG 4593; Figure 2B). These efforts were undertaken prior to deposit in the New Brunswick Museum collection and were likely unsuccessful due to inadequate desalination and lack of penetration of the consolidant. Although Day and Miller (1989) described a successful process for conserving subfossil walrus tusk, the methodology, which used the acrylic emulsion Rhoplex AC-33, was invasive, expensive and left specimens unsuitable for radiocarbon dating (Johnson 1994). We therefore sought to develop an approach that was less invasive and produced specimens useful for both research and exhibition.

Specimen description

A partial cranium with tusks and molars *in situ* and a single tusk from a second individual were both recovered from about 73 m water depth, 9 km off the coast of southern New Brunswick in February and March 2019 (Figure 1). Because the specimens were collected within a few weeks of each other and communication with the collectors (scallop dragger crews) ensured neither specimen was permitted to dry out prior to delivery to the museum, they were treated simultaneously and have a shared conservation record. Although dating and other analysis has yet to be undertaken on these specimens, similar examples in the New Brunswick Museum (NBM) collection from the Bay of Fundy area have been previously radiocarbon dated at 2,900–12,800 years BP (Miller 1997).

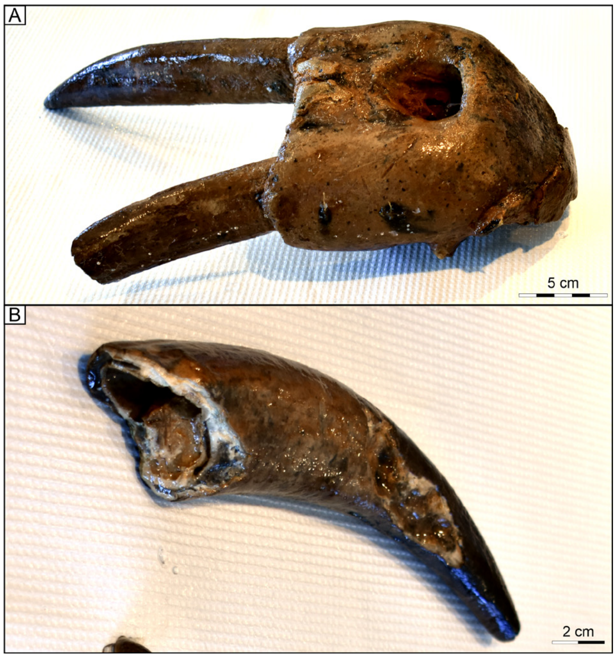

Figure 3. Semi-fossil walrus, A) NBMG 21605 and B) NBMG 21606, dredged from the Bay of Fundy, New Brunswick, following removal of bottom detritus but prior to desalination and conservation treatment. Note that specimens remain water saturated.

NBMG 21605 (Figure 3A) consists of the front portion of an adult walrus cranium with tusks of approximate overall dimensions 37 cm h x 23 cm w x 18 cm d. At collection, the specimen was water-saturated, encrusted with some barnacles and molluscs and supported algal growth. Tusks were secure in the sockets and solid with no significant spalling. Bone was discoloured grey-black. NBMG 21606 (Figure 3B) is a single, solid, darkly discoloured, proper left tusk of overall dimensions 30.5 cm l x 8 cm w x 4 cm d, with proximal end broken and much of the original surface cementum lost.

Treatment procedure

Desalination

Ideally, wet specimens should be kept immersed in seawater until the treatment process is initiated. Regardless, it is critical that specimens not be permitted to dry out. The first phase of preparation involves desalination of specimens at ambient room temperature in an immersion bath desalination tank. Specimens were immersed together in approximately

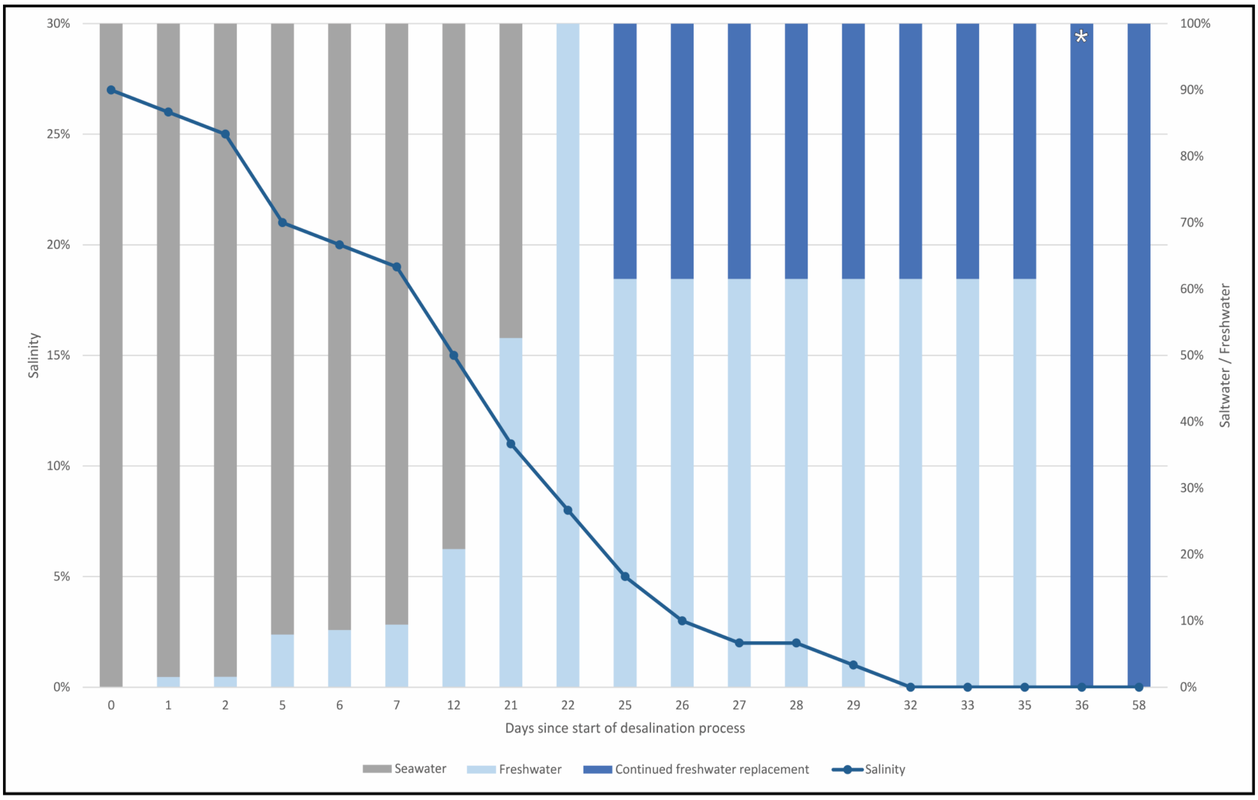

Figure 4. Decrease in salinity over time in semi-fossil walrus desalination tank. Vertical bars show change-over from seawater to freshwater. Asterisk marks point at which tank was cleaned and water replaced.

13 litres of fresh seawater, with water volume held constant as seawater was gradually replaced with fresh tap water. Tap was selected over other options (deionized, distilled) because the specimens were already contaminated with seawater and bottom sediments, obviating any advantages to deionized or distilled water. There was also concern that deionized water could potentially leach minerals from the walrus bone and tusk. The municipal tap water we had access to was chlorinated, which we felt should help limit fungal growth, and of course it was readily available at no cost. Change-over with fresh tap water occurred at 1–5-day intervals over a period of 37 days. Change-over volumes ranged from 0.2–5 litres, with the change-over volume gradually increasing over 26 days as the tolerance of the specimens to freshwater was tested. Salinity was monitored throughout using a VEE-GEE handheld refractometer. By day 22 a full change to freshwater had been accomplished, although due to salts continuing to leach from the specimens, it was a further 10 days before salinity had dropped to 0% (Figure 4). Two further changes, each of about 40% of the immersion bath volume, followed the first recording of 0% salinity. At day 37 the specimens were briefly removed from the immersion bath and placed on damp terry towelling and loosely draped with plastic sheeting to discourage evaporation. The tank was emptied and the interior thoroughly cleaned to remove fungal growth and sediment. The specimens were gently but thoroughly rinsed under running water, the tank refilled with 13 litres of freshwater and the specimens again immersed. A further complete change-over of freshwater took place 21 days later. Regular monitoring of salinity following these changeovers demonstrated that salinity remained at 0%.

Controlled, slow, drying

Both specimens were removed from the desalination tank 60 days following first immersion to begin the second phase, a controlled, slow, drying process. A lab-soaker-covered Coroplast® (an extruded virgin polypropylene manufactured for archival applications) support was placed inside a large zip-closure polyethylene bag. The specimens were set on Ethafoam® (an archival-quality polyethylene) support stilts to permit air flow across the underside of each specimen, and acrylic frame spacer bars were arranged to tent the polyethylene bag over the specimens, preventing direct contact between the plastic and the specimens (Figure 5). A 250 ml beaker containing ethanol-soaked cotton wool was introduced

Figure 5. Chamber used to accomplish controlled, slow, drying of semi-fossil walrus cranium and tusk. A) Shows drying chamber in operation with thermo-hygrometer in place, while B) illustrates acrylic frame prior to tenting and C) shows lab tubing added to zip enclosure to facilitate the drying process.

to the enclosure to reduce the risk of fungal growth during drying. A piece of 1 cm diameter lab tubing was added to the zip closure to increase ventilation after we found humidity remained consistently high during the first few days. Relative humidity was monitored with a REED LM-81 HT handheld thermo-hygrometer, and changes in mass were recorded at weekly or biweekly intervals on an Ohaus Valor2000W electronic balance. Over the following 224 days, humidity in the chamber dropped from 95.0% to 59.3%, and weight of the cranium was reduced from 2610.7 g to 2398.5 g (~8% reduction) and the tusk from 511.7 g to 476.3 g (~7% reduction). A further 239 days of slow drying followed, at which time relative humidity in the chamber had dropped to 49.0% and the weight of the cranium was reduced to 2378.0 g and the tusk to 449.1 g. Following 532 days of slow drying, active treatment was deemed complete with the cranium, and tusk weights stabilized at 2370.4 g (~9 % reduction overall) and 446.3 g (~13 % reduction overall), respectively (Figure 6).

Consolidation

Our hope had been that through slow, controlled drying we could avoid the need to apply a consolidant to the specimens. Unfortunately, at day 292 surface spalling became evident in the drying chamber on NBMG 21606 (single tusk, Figure 7A) and 8 days later on the tusks of NBMG 21605 (cranium; Figure 6, Figure 8A). Therefore, before spalling advanced any further, detailed photography of both specimens was undertaken to record as much information as possible, with a view to later photogrammetry (see below). Despite great care, handling during photography significantly increased the amount of surface loss from tusks. With the continuation of significant spalling over the following 3 days, a decision was made to apply a dilute solution of Jade 403® polyvinylacetate consolidant (25 ml PVA: 10 ml distilled water) to NBMG 21606 on day 295. Although Jade 403 has been found to fail Oddy tests (American Institute of Conservation 2021), in this instance we considered it to be of low risk. Jade 403 is a water-based consolidant, is less toxic than solvent-based consolidants, is easily applied with artist's brushes and was readily available to us in what was considered an emergency. We also note that in our experience, dried Jade 403 has a high resistance to yellowing, even in the presence of UV light. With spalling also observed on the tusks of NBMG 21605, the application of consolidant was extended to this specimen on day 302. Most spalled fragments were relatively small (<0.1 cm^2–1 cm^2), although one larger piece (~4.5 x 2 cm) spalled from the anterior surface of the proper right tusk of NBMG 21605. Figure 6 shows spalling that appeared to be associated with a significant decline in mass as well as an abrupt drop in relative humidity in the chamber (the latter the result of a building HVAC malfunction). Spalled fragments that could not be repositioned with certainty were not reattached or consolidated but were set aside with the specimens for potential use in later radiocarbon dating. No spalling of bone occurred during the process and none from the maxillary teeth of NBMG 21605. Dilution with distilled water enhanced penetration of Jade 403 into the cracks and allowed application of a very thin base coating. Jade 403 has the advantage of being pH neutral and

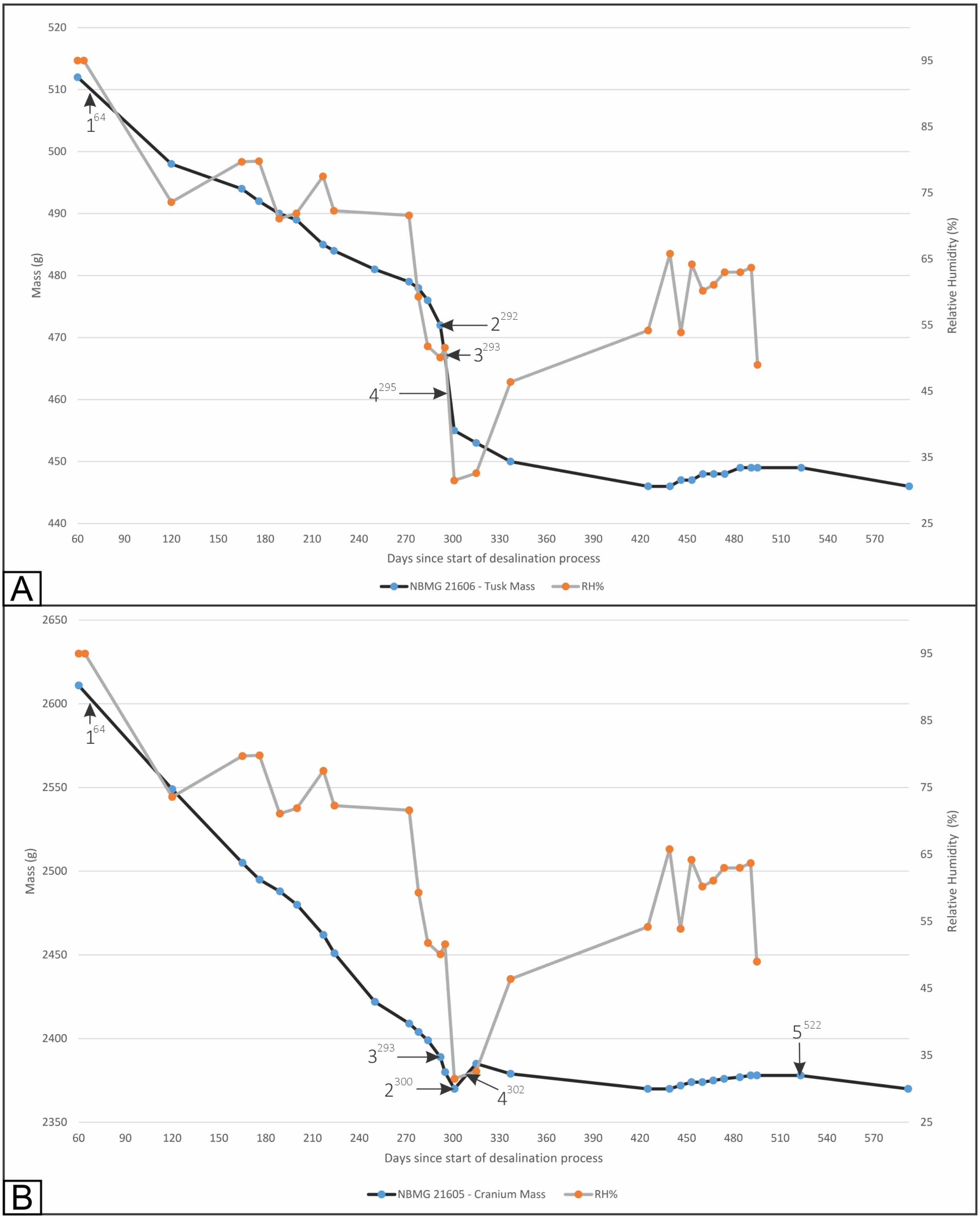

Figure 6. Decrease in semi-fossil walrus mass over time in drying chamber. A) Tusk NBMG 21606. B) Cranium NBMG 21605. Numbers mark events as follows: 1) addition of ventilation tube to chamber, 2) first spalling occurs, 3) photogrammetry images taken, 4) consolidation, 5) spot consolidation. Superscripts show days since start of desalination.

drying to a colourless, low-sheen, relatively flexible film. Some audible cracking was noted during the consolidation process of both specimens, but no surface actively spalled during treatment. Where spalled pieces could be reattached, dilute Jade 403 was applied as a sealant on the interior surface of the shard, followed by full strength Jade 403 as an adhesive. The re-adhered fragments were dried under

Figure 7. Semi-fossil walrus tusk (NBMG 21606) showing spalling A) during slow, controlled, drying following desalination, including small fragments, B) the same specimen during consolidation and reconstruction, C) with weights and a mylar shield in place and D) the fully consolidated and reconstructed tusk.

light weights for several hours (Figure 7B). Once secure, the top surface of the shard was painted with a thin coat of dilute Jade 403 and left to dry under a fan on a low setting (Figure 7C, 8B), after which specimens were returned to the humidity chamber for continuation of the slow drying process. No significant spalling of the single tusk was observed after day 300 (Figure 7C) although some minor spot consolidation of the cranial tusks was carried out at day 522 (Figure 6B). Long-term storage preparation for these specimens involved fabrication of a custom-made supporting mount of Ethafoam®, polyester quilt batting, Tyvek® (Figure 9A; a flashspun, high-density material produced from polyethylene fibers), unbleached cotton twill tapes, all within a custom-made Neutracor® acid-free cardboard box (Figure 9B). This was then placed in a metal cabinet equipped with an elastomeric door seal. The storage mount and multi-layer containerization are critical elements in the long-term preservation of these specimens in the museum geological collection. The storage mount provides even support along the entire contour, minimizes the risk of damage due to abrasion and vibration, and provides a high degree of buffering against the damaging effects of fluctuating temperature and relative humidity in the storage environment.

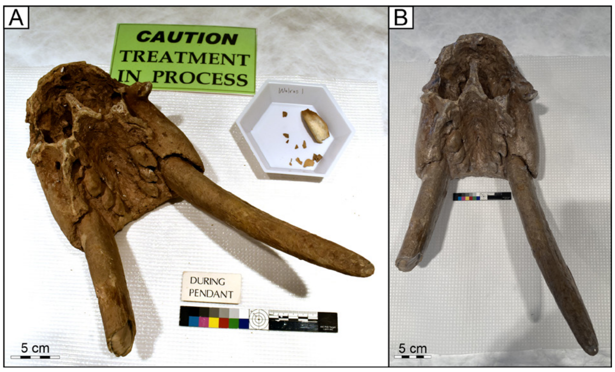

Figure 8. Semi-fossil walrus skull following A) desalination and B) after consolidation. Note that there has been very little change in the colour of the specimens as a result of treatment.

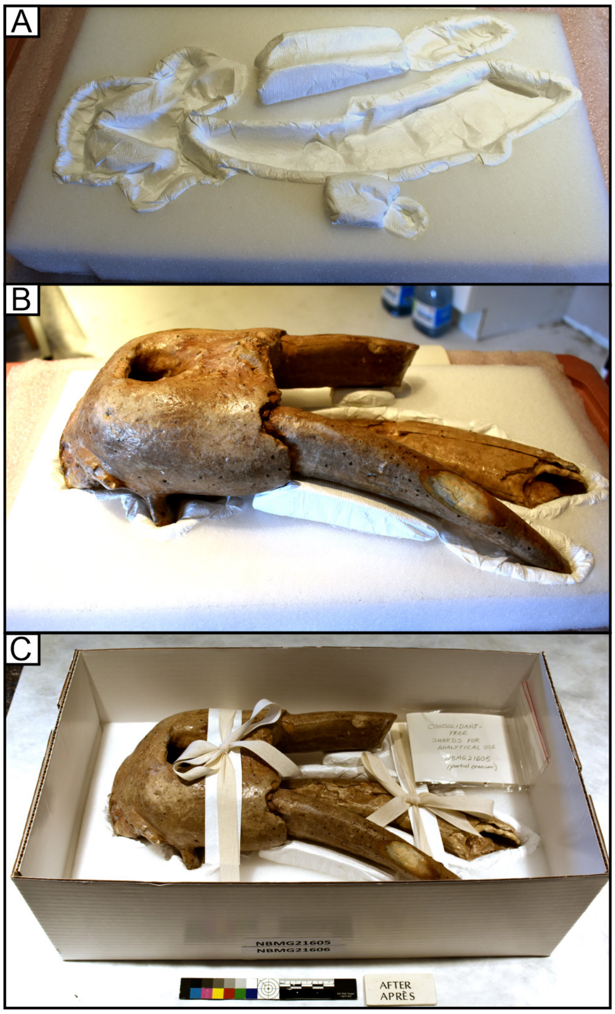

Figure 9. Desalinated and consolidated semi-fossil walrus cranium (NBMG 20605) and tusk (NBMG 20606), showing supporting mount, (A), specimens positioned on supporting mounts, (B), and mount and specimens in an acid free box, (C) for long-term storage. The box is also housed within a steel cabinet to reduce exposure to any rapid environmental changes.

Preparation of a 3D image from the preserved Quaternary walrus cranium

Photogrammetry is a non-destructive method that uses multiple photographs taken from different orientations to digitize a three-dimensional object that may be found in the field or within a museum collection. The technology to digitally replicate museum artifacts has existed for decades, however only in the past 10 years has computer hardware and easy-to-use software enabled it to become practical for smaller museums without substantial investment (Apollonio *et al.* 2021). Photogrammetry techniques have been widely applied to various fields of research in zoology (Muñoz-Muñoz *et al.* 2016), palaeontology (White *et al.* 2013; Mallison and Wings 2014; Bates *et al.* 2016; Schlüter 2016; Hamm *et al.* 2018)

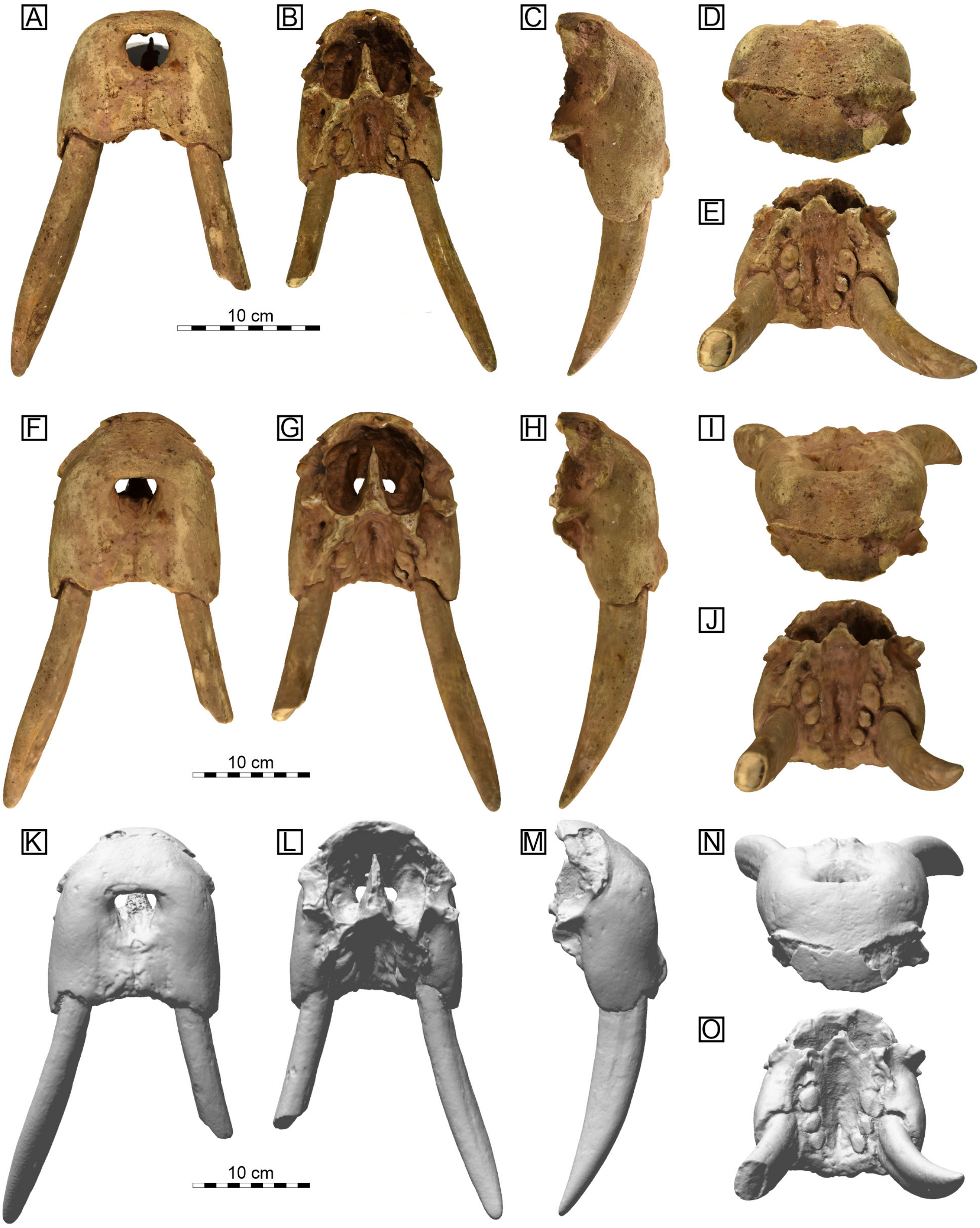

Figure 10. Orthographically projected images of the fully conserved semi-fossil walrus cranium showing natural colour and texture (A-J), contrasted with grey-shaded surface structure only (K-0). The 3D model can be rotated 360 degrees and lit from any orientation.

and archaeology (Bennett *et al.* 2013; Magnani *et al.* 2020). Entire geological outcrops and field sites can be photographed in detail (e.g. Klein *et al.* 2016) to digitally preserve paleontological or archaeological features (e.g. Themistocleous *et al.* 2015; Magnani *et al.* 2020).

Whether 3D images are obtained by photogrammetry or laser scanning technology, their availability allows museums to interact with the public in novel ways, as well as with remote researchers. In some cases, artifacts that have been lost or destroyed, for example by ongoing erosion in the field, have been recreated from historical photos using photogrammetry and 3D-printing technology (e.g. Falkingham *et al.* 2014).

Multiple studies have been published outlining techniques and best practice for generating photogrammetry models of museum artifacts (e.g. Breithaupt and Matthews 2001; Matthews *et al.* 2006; Falkingham 2012; Mallison and Wings 2014; Matthews *et al.* 2016; Hamm *et al.* 2018; Nocerino *et al.* 2020; Otero *et al.* 2020; Apollonio *et al.* 2021). Our approach followed methods similar to those cited above. Although both specimens were photographed and data for photogrammetry 3D digitization was collected, only the partial cranium (NBMG 20605) is rendered here (Figure 10). The 3D digital image preserved detail of overall morphology and colour of the original specimen in an orthographic digital model that can be 3D-printed, digitally transferred to researchers, and can be digitally measured with accuracy, without the effect of camera perspective distortion. It also minimizes future handling of the original specimen.

The walrus cranium was placed, with colour calibration and metric scales, on a white, fabric-covered surface and illuminated from multiple angles using two LED work lamps of 2500 lumens each (single tripod) and eight incandescent lamps (two units) outfitted with diffusers of 2700 lumens each. Illumination from multiple angles aims to eliminate as many shadows from the fossil surface as possible and must remain fixed through the photo collection process. A Nikon D3400 digital SLR camera fitted with an 18–55 mm lens was used to capture digital images of the walrus cranium and associated tusks. The lens zoom factor remained fixed while 391 images of the skull were captured with at least 50% overlap between successive images. Image were taken at 5–10° intervals radially around the entire specimen. Images were also taken perpendicular to the skull while circling the specimen at multiple elevations (at ~0°, ~15°, ~45°, ~85° and 90°), relative to the horizontal plane (Figure 11). The process was repeated for the ventral side of the cranium, ensuring sufficient overlap in photos to connect both dorsal and ventral surfaces of the specimen.

Exchangeable Image File data was reviewed manually for the 391 digital images to ensure that the

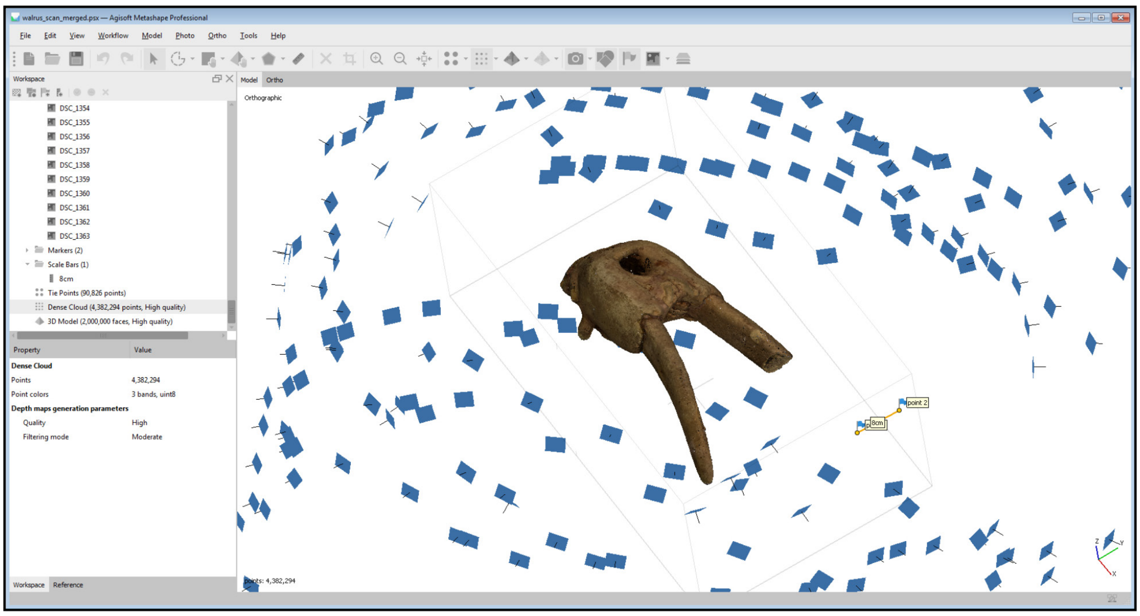

Figure 11. Screenshot showing the positions of images used to produce the 3D image of a semi-fossil walrus cranium. Blue rectangles illustrate the camera viewing plane for a subset of an original 391 images originally captured for the photogrammetry process.

lens zoom factors, image contrast, exposure and image focus were optimal with the review, producing a subset of 160 images for inclusion into the photogrammetry rendering process. Images were processed with Agisoft Photoscan/Metashape software (https://www.agisoft.com) on a 4-core Intel i7 computer with 16 MB of RAM and a 2 GB NVidia GTX 760 graphics card with CUDA support, now a modest configuration. After manually removing background clutter, processing produced a dense point cloud with approximately 4 million points and a mesh surface with 2 million polygons. Each side of the cranium was processed separately into a point cloud and then merged before mesh generation. Some areas of overlap, especially those recessed and receiving reduced lighting, such as the interior of the nares, required manual point-cloud editing. Even with manual trimming there remained some visible geometric noise in these locations in the final 3D image. Nonetheless, most areas have sub-millimetre positional accuracy.

Once rendered, the resulting 3D digital image illustrates the original colour, texture, shape and size of the walrus cranium and can be exported as an orthographically projected image (Figure 11). The digital 3D image can be analyzed for various metrics and visualized using secondary software such as MeshLab (https://www.meshlab.net) and CloudCompare (https://www.danielgm.net/cc/). As useful as a digital representation of the original may be, it does not, of course, document internal microstructural, or biochemical or mineralogical details. Nevertheless, 3D images can augment the original and can increasingly be employed to enhance the value and versatility of geological collections of even modest means.

Conclusion

It is critical that subfossil bone and tusk retrieved from marine waters not be permitted to dry out prior to desalination. Our hope was that through a slow drying process following desalination, we could avoid applying consolidant to the specimens. Although this proved not to be the case, spalling was confined entirely to tusks and no spalling of bone occurred. Further testing, perhaps with the use of a humidity dome that would permit highly controlled slow-drying, may reduce spalling of tusks, but we remain sceptical that spalling can be eliminated entirely, especially over the long-term. While we observed a correlation between spalling and a building HVAC malfunction (also coincident with a reduction in specimen mass), extent of the impact of this malfunction remains uncertain. Many museums contend with inadequate climate-control and the challenges it presents. Anticipating this and incorporating such challenges into methodology is probably wise. We were able to avoid immersion consolidation, which would have been far more invasive and clearly irreversible. Our approach proved to be simple and inexpensive and was reasonably successful in maintaining specimen integrity. Johnson (1994) noted increasing concerns about how conservation treatments of bone might influence—or prevent—further analyses. Those concerns have only grown, and we set aside spalled, unconsolidated material for this purpose. Although cured Jade 403 is hydroscopic and can in theory be removed mechanically in perpetuity following the application of water, in reality, it is effectively an irreversible treatment. However, consolidant appeared to penetrate the walrus crania only several millimetres, leaving open the option of coring bone for later radiocarbon or isotope analysis. Finally, although no substitute for further analyses, photogrammetry also allowed us to prepare a 3D image of one of the specimens, thereby minimizing the necessity for future handling and conservation and preserving details of overall morphology and meristics useful for both research and public exhibition.

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The importance of correct mineral identification for the determination of appropriate specimen storage conditions in geological museum collections

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Many minerals are susceptible to environmental conditions; for example, several sulfates are prone to dehydration under low relative humidity. As such, the appropriate storage conditions required by minerals are species-specific. In an example presented here, stalactitic specimens previously thought to have been melanterite (a hydrated iron sulfate) from the South Wales Coalfield in the collections at National Museum Cardiff (NMC) were recently identified as being dominated by magnesium and aluminium sulfate species of various hydration states. The presence of epsomite in the majority of the analysed specimens indicates that it, rather than melanterite, was likely the initial predominant phase of the stalactites. Whilst the stability limits of hydrated iron sulfates markedly differ compared to those of magnesium and aluminium, all will dehydrate if stored under low relative humidity, as evidenced in the example provided here. Specimen storage in fluctuating and low relative humidity environments resulted in the dehydration of the magnesium and aluminium sulfates to lesser hydrated sulfates, and consequently resulted in partial loss of the original specimens. As storage environments affect long-term preservation and appropriate storage conditions for minerals are species-specific, the accurate identification of mineral specimens is imperative for the determination of appropriate storage conditions.

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Introduction

Beyond a small group of mineral curators and geological conservators, chemical deterioration of mineral specimens is an underestimated problem in geological collections, but its consequences may—and often do—result in the damage or loss of scientifically important material (*cf*. Fothergill 2001; Robb *et al.* 2013; Baars and Horak 2018). The potential for deterioration of mineral species is related to their occasionally very narrow stability limits and frequently caused by inappropriate environmental conditions in storage areas. This is further complicated by species-specific storage requirements (Table 1). For example, hydrated sulfates generally require greater relative humidity (RH) conditions than sulfides (the latter of which generally require <50% RH, *q.v.* Howie 1992), thus the optimum storage conditions for both mineral groups are largely mutually exclusive. Whilst the dehydration process may sometimes be reversible (*cf.* cuprian melanterite–cuprian siderotil; Peterson and Grant 2005), the physical integrity of the geological specimen is usually lost on dehydration, resulting in a loss of specimen value.

Examples of minerals susceptible to deterioration include many hydrated sulfates, particularly those containing iron. These sulfates may be formed under high RH conditions from sulfides such as pyrite by a combination of oxidation, hydration and dehydration reactions (Jerz and Rimstidt 2003) and are prone to dehydration when stored in lower relative humidity conditions (*cf.* Chipera and Vaniman 2007). Dehydration may also occur during transportation (*i.e.*, from collection site to the museum) or analysis (Hyde *et al.* 2011; Chou *et al.* 2013).

Dehydration results in the mineral's alteration into

Mineral Species (Initial)		Mineral Species (Product)		Temp. [°C]	Relative Humidity [%]	Reference
Melanterite	$FeSO_4 \cdot 7H_2O$	Rozenite	$FeSO_4 4H_2O$	20	58	Chou *et al.* 2002
Rozenite	$FeSO_4 \cdot 4H_2O$	Szomolnokite	$FeSO_4 \cdot H_2O$	20	11	Waller 1992
Epsomite	$MgSO_4 \cdot 7H_2O$	Hexahydrite	$MgSO_4 \cdot 6H_2O$	20	48	Chou and Seal 2003
Hexahydrite	$MgSO_4 \cdot 6H_2O$	Kieserite	$MgSO_4 \cdot H_2O$	20	43	Chou and Seal 2003
Tschermigite	$NH_4Al(SO_4)_2(SO_4)_2 \cdot 12H_2O$	Godovikovite	$(NH_4)Al(SO_4)_2$	25	7	Waller 1992
Alum-(Na)	$NaAl(SO_4)_2 \cdot 12H_2O$	Tamarugite	$NaAl(SO_4)_2 \cdot 6H_2O$	20	86	Waller 1992

Table 1. The conditions at which some sulfates undergo a transition in hydration state emphasise that favourable storage conditions for many minerals are species-specific.

chemically similar species of lower hydration states. Depending on the ambient conditions, melanterite ($FeSO_4 \cdot 7H_2O$) may convert to szomolnokite ($FeSO_4 \cdot H_2O$), rozenite ($FeSO_4 \cdot 4H_2O$) or siderotil ($FeSO_4 \cdot 5H_2O$). Rozenite will form when the copper content of melanterite is below 1.2%; above this threshold, siderotil is the resultant product (Ehlers and Stiles 1965: p. 1458). Peterson and Grant (2005) observed that the rate of melanterite dehydration is dependent on relative humidity: the rate of dehydration increases if the RH is decreased but decreases at a constant relative humidity. Such phase transitions cause irreversible damage to the original specimen. Conversely, under the correct storage conditions, polyhydrated sulfate specimens may be preserved with full chemical integrity for many years. Experiments at NMC (Tom Cotterell and Amanda Valentine-Baars, pers. comm. 2020) demonstrated that freshly collected melanterite stored at a temperature of around 8°C and high (>70%) relative humidity retains its integrity even after twelve years.

In the NMC collection, the consequences of deterioration of polyhydrated sulfates in the mineral store are most noticeable in a suite of melanterite specimens from Wales and other locations. These minerals, alongside other geological collections, had been stored in oak cabinets in the museum basement since the early 1920s. No monitoring of environmental conditions was undertaken in those early years, but it is likely that relative humidity fluctuated between very low (due to the presence of winter heating) and very high (due to periodic flooding events in the basement relating to fluctuating groundwater levels). In 1989, the Mineral Collection was relocated to a purpose-built, temperature-controlled mineral store. However, the temperature control was intermittent due to episodic technical faults of the in-room recirculating chiller, resulting in dramatic periodic fluctuations of temperature and RH until the mineral store was connected to the museum's central air handling plant in 2016, following which environmental fluctuations were greatly decreased.

Analysis and Results

Two specimens of crumbling, powdery white stalactites—held in the Mineral Collection at NMC since their donation in 1926 by T. G. Cotsworth and labelled as "Melanterite, stalactitic" from Deep Navigation Colliery, Treharris—were analysed in 2019 using powder X-ray diffraction (PXRD) to determine whether any melanterite remained.

One specimen, NMW 26.151.GR.1.1-4 (Figure 1A), is comprised of four relatively small stalactites. The second specimen is also recorded as NMW 26.151.GR– (Figure 1B), but is missing the last digit of the accession number on its label, due to it being scorched by the acid derived from the deteriorating specimen. NMW 26.151.GR– may have once been one or several stalactites but is now in a number of fragments and has deteriorated to a substantial quantity of white powder.

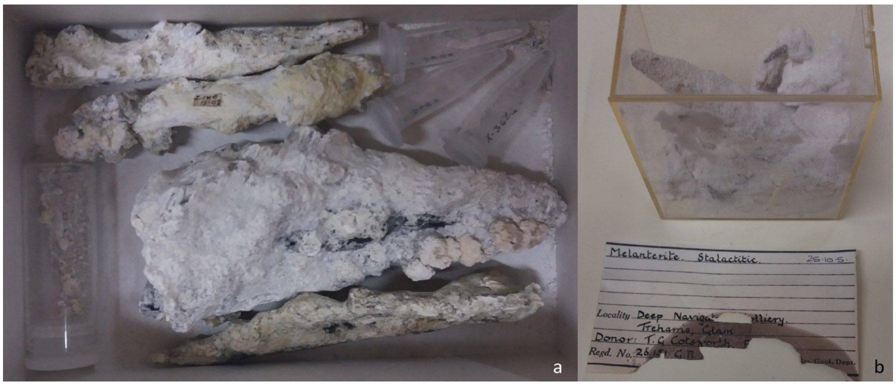

Figure 1. Stalactitic specimens analysed during this study. A) NMW 26.151.GR.1.1-4. B) NMW 26.151.GR-.

Powdered samples were taken from both specimens. A small quantity of the powdered efflorescence was removed from inconspicuous external locations of NMW 26.151.GR.1.1, 1.3 and 1.4. to determine if there were any compositional variations among the stalactites. The loose powder shed by NMW 26.151. GR– was used for analysis, following the assumption that the specimen was originally collected as a single item. No internal core samples were taken due to curatorial advice and the NMW Collection Sampling Procedure: core sampling would have resulted in unnecessary additional damage to the physical integrity of the specimens.

Samples were then further ground by hand in an agate mortar to produce a consistent particle size. A PANalytical X'Pert-Pro X-ray diffractometer with a Cu anode was used to continuously scan rotating powdered samples at 40kV and 30mA. Spectra were acquired over the range of 5–70°2Θ, with each step (0.02°) being scanned for 38 seconds.

The samples from NMW 26.151.GR.1.1, 1.3 and 1.4 were identified as primarily hexahydrite ($MgSO_4 \cdot 6H_2O$) and epsomite ($MgSO_4 \cdot 7H_2O$). No iron minerals were detected. Additionally, each sample contained a hydrated, aluminium-bearing sulfate (Table 2); jurbanite ($Al(SO_4)(OH) \cdot 5H_2O$) (Figure 2), pickeringite ($MgAl_2(SO_4)_4 \cdot 22H_2O$), and tschermigite ($NH_4Al(SO_4)_2(SO_4)_2 \cdot 12H_2O$), respectively. NMW 26.151.GR– was determined to have a slightly different composition of kieserite ($MgSO_4 \cdot H_2O$), hexahydrite and tamarugite ($NaAl(SO_4)_2 \cdot 6H_2O$).

Discussion

Jurbanite

One of the minerals detected by the PXRD analysis, jurbanite, took the authors by surprise. It is a rare mineral with only a few confirmed natural occurrences (Anonymous 2021). At the type location (San Manuel Mine, Arizona, USA), jurbanite was discovered as a "post-min[ing] stalactitic material deposited on lagging and overhead pipes" (Anthony and McLean 1976: p. 1) in association with epsomite, hexahydrite, pickeringite, starkeyite ($MgSO_4 \cdot 4H_2O$), and a hydrated ammonium and iron sulfate. This assemblage is strikingly similar to that of the NMC specimens from Deep Navigation Colliery. Jurbanite, however, has not been previously reported to occur in Britain and Ireland (Tindle 2008). Thus, it is uncertain at present whether the jurbanite in our sample occurred as a primary phase pre-collection or represents a dehydration product formed post-accession in the NMC Mineral Collection. This was a similar concern for the type specimen (Anthony and McLean 1976). Further analysis is required to better ascertain when the jurbanite formed.

Lack of Iron

Because samples were taken externally, the possibility remains that the compositions of the cores of the stalactites differ from those of the powders analysed. Perhaps a higher hydrated state has been preserved in the centre. Equally, there could be entirely different compounds within the specimens' bulk. Further analysis is required to confirm the cores' compositions.

However, as the exteriors of all the specimens analysed did not contain any iron-bearing minerals, it is equally feasible that the whole of the original stalactites may never have contained any significant quantities of iron and thus were likely never melanterite. Alternatively, this may be related to the sulfide oxidation mechanism, where sulfur is oxidised by the oxygen from molecular water (Usher *et al.* 2004). Sulfate formation is mediated by ferric cations (Fe^{3+}),

Specimen Accession Number	XRD Sample ID Number	Minerals Detected	Formulae of Detected Minerals
NMW 26.151.GR.1.1	NMW X-3656	• hexahydrite • epsomite • jurbanite	• $MgSO_4 \cdot 6H_2O$ • $MgSO_4 \cdot 7H_2O$ • $Al(SO_4)(OH) \cdot 5H_2O$
NMW 26.151.GR.1.3	NMW X-3686	• hexahydrite • epsomite • pickeringite (minor)	• $MgSO_4 \cdot 6H_2O$ • $MgSO_4 \cdot 7H_2O$ • $MgAl_2(SO_4)_4 \cdot 22H_2O$
NMW 26.151.GR.1.4	NMW X-3687	• hexahydrite • epsomite • tschermigite	• $MgSO_4 \cdot 6H_2O$ • $MgSO_4 \cdot 7H_2O$ • $NH_4Al(SO_4)_2(SO_4)_2 \cdot 12H_2O$
NMW 26.151.GR-	NMW X-3684	• kieserite • hexahydrite • tamarugite	• $MgSO_4 \cdot H_2O$ • $MgSO_4 \cdot 6H_2O$ • $NaAl(SO_4)_2 \cdot 6H_2O$

Table 2. X-ray diffraction results for the samples analysed during this study detected a variety of sulfates.

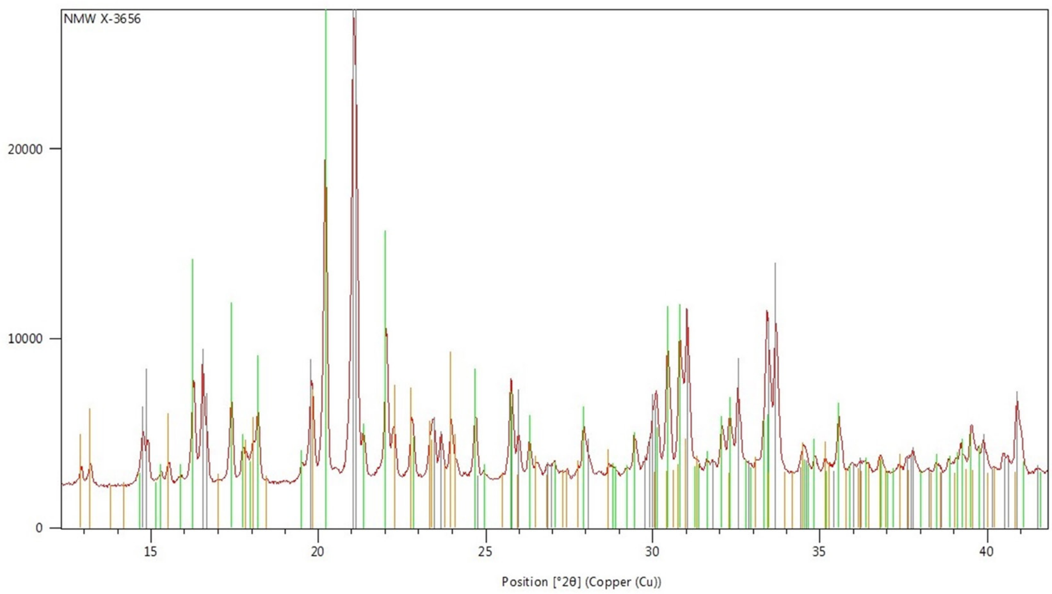

Figure 2. X-ray diffraction spectrum of sample NMW X-3656 from specimen NMW 26.151.GR.1.1, depicting peaks attributable to hexahydrite (green), epsomite (grey), and jurbanite (orange).

which are known to act as an oxidant on cathodic sites (Jerz and Rimstidt 2003). The presence of Fe^{3+} promotes iron sulfide decay; Fe^{3+} oxidises pyrite at faster rates than oxygen (McKibben and Barnes 1986; Williamson and Rimstidt 1994), but the resulting sulfates products do not necessarily contain iron (*cf.* Rouchon *et al.* 2012).

A separate study performed by Cotterell in 2009, in which he described two other specimens of post-mining efflorescence from Deep Navigation Colliery, provides evidence that the post-mining assemblage at Deep Navigation Colliery may not contain much, if any, iron, but rather is comprised largely of magnesium, aluminium and sodium minerals. Cotterell (2009) analysed specimens from Deep Navigation Colliery by powder X-ray diffraction (PXRD), scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). Specimen NMW 26.151.GR.4, originally registered as alunogen, consisted of several fragments of matted aggregate fibres and was determined to be primarily composed of pickeringite with minor surface alteration to yellow epsomite and possibly also tamarugite. Similarly, specimen NMW 27.128.GR.2—registered as epsomite and precisely provenanced to the Two-Feet-Nine Seam—was identified as massive opaque white epsomite with colourless crystallised tschermigite. These results provide further support that the original identification of specimens NMW 26.151.GR.1.1-4 and NMW 26.151.GR.– (analysed as part of this present study) was likely incorrect.

The presence of lower magnesium hydrates—kieserite and hexahydrite, in our samples—suggests that significant dehydration has occurred to these stalactites. A likely precursor is epsomite, which is present in residual quantities in both the NMC samples and the jurbanite type specimen. Chou and Seal (2003) described the process of dehydration from epsomite to hexahydrite and kieserite. This complex series of reactions depends on various conditional variables, which may be summarised briefly as follows: at 20°C and 48% RH, epsomite begins to transition to hexahydrite, which in turn alters to kieserite at 43% RH.

For a period of more than 25 years, the Mineral Store at NMC was serviced by a recirculating in-room chiller unit which was prone to mechanical defects. Consequently, conditions fluctuated between 20–27°C and 30–62% RH. Epsomite alteration is entirely feasible under such conditions (and under the conditions that may have occurred unrecorded during the previous 70 years of the specimens' lifetimes). In March 2016, the Mineral Store at NMC was connected to the central museum air conditioning system, which provided the opportunity for improved environmental control and a filtered fresh air supply; temperature is now maintained at 21±2°C and RH at a stable 40±5%. These conditions were selected to improve the storage conditions for a large collection of sulfide minerals, because a previous risk assessment suggested that RH conditions inappropriate for the preservation of sulfides was one of the largest risks to the Mineral Collection at NMC (Baars 2016). However, this did not improve conditions for all mineral species, most notably the polyhydrated sulfates which are subject to the work undertaken by this present study.

Although requiring specific temperature and RH conditions, epsomite is stable across a broader range of RH than melanterite (Chou *et al.* 2013). Had the original specimen from Deep Navigation Colliery contained melanterite, it is very likely that it would have dehydrated into rozenite given the historically inappropriate conditions in the NMC mineral storerooms. In that sense, the historically uncontrolled environmental conditions in the Mineral Store were not conducive to the preservation of *either* iron or magnesium sulfates.

The provision of appropriate environmental conditions, with the aim of improving the preservation of collection items, is accepted as an important component of collections care in modern museums. This should also extend to geological collections (and partly does, at least in some instances, such as pyritic specimens; *q.v.* Howie 1978; Larkin 2011). We make the case here that this principle needs to be considered more widely in geological collections and that an accurate identification of mineral specimens held in museums is a crucial element of decisions on appropriate storage conditions. The authors are currently researching further information required for making storage and display decisions for minerals, and our findings will be published shortly.

Summary

PXRD analysis of specimens from the Two-Feet-Nine Seam in the North Pit at Deep Navigation Colliery and stored at National Museum Cardiff, originally thought to be melanterite, did not contain any iron minerals but rather various magnesium and aluminium sulfates. The Two-Feet-Nine Seam in the North Pit at Deep Navigation Colliery was cut at a depth of 623 m and is now permanently inaccessible (Cotterell 2009), meaning that pre-existing specimens of post-mining efflorescence are a precious, irreplaceable resource which require careful conservation. This entails an understanding of the storage requirements for various individual mineral species and a precise knowledge of a specimen's mineralogical composition to ensure storage under appropriate environmental conditions. Decisions on suitable storage conditions, which should be provided as soon as possible after acquisition, are informed by mineral stability parameters. The stability limits of hydrated iron sulfates differ markedly from those of magnesium and aluminium sulfates, implicating different storage conditions according to chemical composition. Hence, the correct identification of mineral specimens is an important step in preventing damage caused by incorrect storage environments.

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Mechanical and chemical preparation techniques applied to Frasnian Cephalopods from Lompret (Belgium)

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When embarking on a preparation project it is essential to consider a variety of techniques. A combination of different mechanical and chemical treatments may be necessary, even within the same formation. This article explores this principle using a case study of large accumulations of Frasnian cephalopods collected between 2015 and 2021 from the active quarry of Lompret near Chimay (province of Hainaut, Belgium). The quarry comprises strata that can be linked to the Kellwasser event, an important mass-extinction event near the Frasnian–Famennian boundary. Several of the lithological entities from this quarry require specific approaches in terms of preparation. This article will explicitly focus on preparation techniques applied to cephalopods. This informative and diverse group of macro-organisms can contribute to a better understanding of marine environmental changes during an ecological crisis. A thorough preparation of all the collected specimens from this specific location is required, as this peculiar fauna is in desperate need of a taxonomic review. We will demonstrate to what extents the uses of potassium hydroxide (KOH) and Rewoquat® W 3690 PG as solvents have proven to be particularly effective in dissolving clay-rich sediments during preparation.

Hellemond, A., Houben, K., Tolisz, N., Nolis, K., De Bock, F. and Van Uytfanghe, S. 2021. Mechanical and chemical preparation techniques applied to Frasnian cephalopods from Lompret (Belgium). *Geological Curator* **11** (5): 361-374.

Geological framework

In order to understand the environment in which these Frasnian cephalopods were deposited, we should first provide a larger picture of the present-day context in which they are encountered. Looking at the quarry of Lompret (N 50°04'14.0", E 4°23'08.0"), we observe that the lithology is dominated by mud- and limestones from the Late Frasnian (around 372.2 ± 1.6 Ma; Gradstein *et al.* 2020). The oldest deposits belong to the Grands Breux Formation (GBR) consisting of hard limestones that make up the vast majority of the quarry. On top of that, we have the Neuville Formation (NEU) as defined by the National Commission for Stratigraphy of Belgium (NCSB). The NEU consists of dense nodular shales with few inferior nodular and argillaceous limestone beds (*cf.* Tsien 1975; Coen and Coen-Aubert 1976; Bultynck *et al.* 1987; Boulvain *et al.* 1993). These strata were deposited in an open marine environment North of the Rheic Ocean (Gatley 1983; Wynants *et al.* 2018). The layers have been diagenetically transformed during the Variscan orogeny of the Rheno-Hercynian basin (Figure 1A, B), which makes the present outcrop tectonically deformed.

Other important lithological entities include the black shales belonging to the Matagne Formation (MAT). These fine, dark, greenish-brown to pitch-black shales, with generally a few dark limestone beds in the lowermost part, are very recognisable and have been studied for more than 150 years (Gosselet 1871). The black shales are linked to anoxic conditions and were also deposited in deep water (Sartenaer 1974; Mottequin and Poty 2016). The macrofauna consists of small bivalves, brachiopods and cephalopods, often coated with a thin layer of pyrite (Maillieux 1939). This particular formation, located between the Lower and Upper Kellwasser event, is synonymous with a profound change in

Figure 1. Overview of the Lompret quarry in July 2016. The Formations of Neuville and Matagne lie folded against the grey massive limestones of the Grands Breux Formation in the northern part of the quarry.

facies and associated fauna. It marks the transition from a reef-dominated environment to an anoxic setting defined by mass extinctions and ecological turnovers (Mottequin and Poty 2016).

Though the description of both formations provides us with seemingly adequate lithological information, we must bear in mind that a vast spectrum of strata with slightly variable lithological properties can occur within these formations. On the current geological map of Wallonia (57/7-8 - 1:25.000) the difference between the Neuville and Matagne Formations in Lompret is problematic to such an extent that they are grouped together in the "NM complex" (Marion and Barchy 1999). In this framework, additional biostratigraphical controls could help to further distinguish both formations in the future. Macrofossils such as cephalopods could turn out to be a suitable group for stratigraphical differentiation. The faunal variation in cephalopods from Lompret might encourage grouping similar species or morphologically similar specimens together. However, we suggest grouping specimens based on lithological properties, rather than biological (systematic) criteria (Figure 2). This storage method will not only prove helpful during preparation, but will also facilitate future cyclostratigraphic (sequential) research, during which lithological matching is of fundamental importance.

Cephalopod fauna

The Lompret quarry yields large numbers of well-preserved corals, sponges, brachiopods, bivalves, crinoids, conodonts, ostracods, graptolites, trilobites, placoderms, sharks and other classic reef (building) organisms (Houben and Hellemond 2016). In the past five years, a few papers on the well-preserved fauna from the Lompret quarry provided additional insights into the unique faunas of the Matagne and Neuville Formations (Gouwy and Goolaerts 2015; Houben and Hellemond 2016; Houben *et al.* 2020). Cephalopods are among the previously overlooked taxa and are rarely included within (private) collections. Solely based on these collections, they may seem underrepresented in the fossil fauna because they are difficult to distinguish from the often oddly shaped nodular limestone concretions in the field. Around 85 years after the first cephalopod review by Dr. Hans von Matern (1931), a palaeontologist from Frankfurt am Main, new material can be gathered systematically and in large numbers.

The cephalopod fauna from Lompret consists of two important subclasses, the Ammonoidea Zittel, 1884 and Nautiloidea Agassiz, 1847. The Ammonoidea are represented by a few genera of goniatites, of which the genus *Manticoceras* Hyatt, 1884 is by far the most common. The Nautiloidea are represented by a few

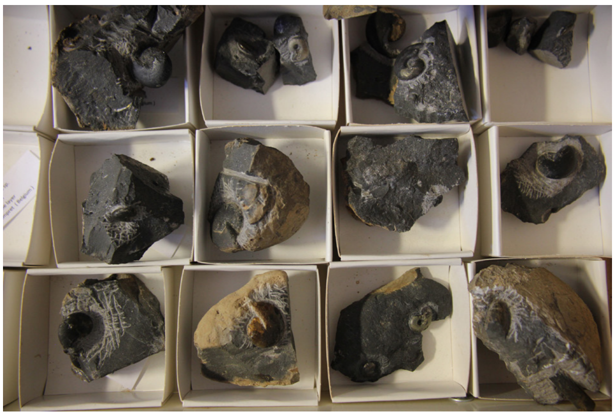


Figure 2. Instead of systematically grouping similar species together, we chose to set up a stratigraphical collection to facilitate future research and help us during the preparation process.

genera of orthocone (straight-coned) organisms belonging to the orders of the Bactritoidea (Shimansky, 1951) and the Orthoceratoidea (Zhuravleva, 1994). Other cyrtochonic (curved) Nautiloidae belong to the order of the Oncocerida (Flower and Kummel Jr., 1950). The observed genera include: *Tornoceras* Hyatt, 1884; *Crickites* Wedekind, 1913; *Manticoceras* Hyatt, 1884; *Trimanticoceras* House, 1977; *Carinoceras* Ljaschenko, 1957; *Beloceras* Hyatt, 1884 and *Bactrites* Sandberger, 1843. Regarding the Belgian Frasnian cephalopod fauna, there is an abundance of outdated literature, resulting in difficult taxonomic identification. The variety and concentration of cephalopods collected over the past five years will hopefully serve as a solid base upon which a refined classification can be established.

The vast concentration and diversity of cephalopods in Lompret, makes them an interesting study subject. Specific layers containing dozens of individuals buried in close proximity to each other can serve as proxies for marking environmental changes (Figure 3). Combined with auxiliary biological markers (both micro- and macrofossils), they also allow for statistical and biostratigraphical analysis to some extent (Korn 1996). Cephalopods inhabited an undisputable part of the Frasnian ecosystem, but in Lompret they remain a fairly understudied group of organisms despite their mass occurrence in specific layers. A careful preparation will help to facilitate future taxonomic studies, revealing certain anatomical details which might otherwise pass unnoticed.

Mechanical preparation

It is important that each specimen is prepared following a procedure suited to the distinct layer or bedding in which it was found. Thus, it is beneficial to physically separate fossils from different strata before undertaking any preparation. Prior to any mechanical or chemical manipulation, one should ensure that every specimen block is cut to a manageable size and cleaned as thoroughly as possible with water. Most of the downsizing should be done in the quarry using a cordless angle (disk) grinder equipped with diamond encrusted discs (Figure 4A). The mechanical preparation of medium- to very hard limestones requires the use of tools, each with their own benefits and weaknesses that need to be taken into account according to the purpose of the preparation (e.g. study, conservation or exhibition). From all available mechanical techniques (air abrasion, pneumatic percussion, manual removal, etc.) we would recommend the use of a traditional pneumatic pen as a first intervention for the reasons listed below. Although air abrasion removes the risks of unwanted fractures due to the vibration we find in pneumatic tools, it nevertheless involves significant risk in removing the very top material of the fossil once matrix elements are no longer in its way. This is especially critical when preparing fossils in which matrix- and specimen hardness are very similar, or when visual distinction between these layers is problematic. Air-scribing, when used properly, has the advantage of splitting matrix off at the very surface of the specimen along its natural separation from surrounding sediment, especially suited to the naturally spiral-shaped features of goniatites. Of course, a possible successive use of first pneumatic then abrasive preparation, if affordable, should be left to the judgement of every preparator (Figure 4B). Here, we used a Wegner (W224) pen, driven by a 25 L (whisper/silent) compressor generating between 7–8 bars of pressure. For the cephalopods of Lompret, we used a maximum of 36.000 bpm to chip away at the hard limestone.

Figure 3. **In situ** *detail of one of the rich layers containing multiple cephalopods. This entity, informally known as the 'middle limestone layer', was exposed in 2017.*

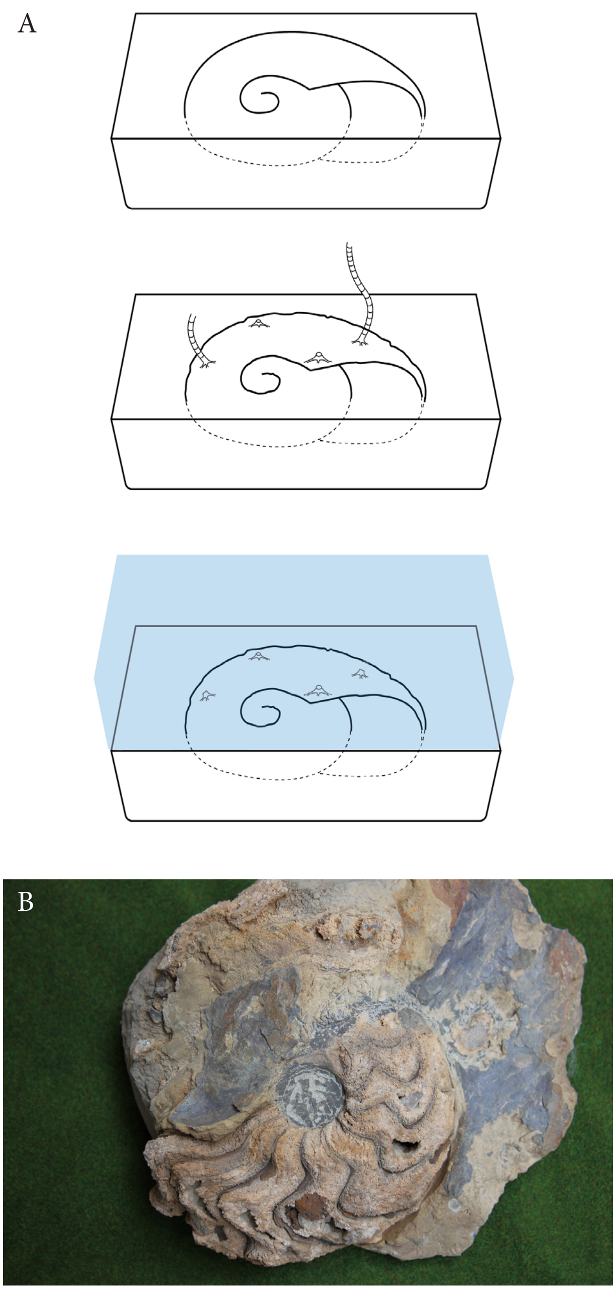
Most of the cephalopods found within or alongside the nodular concretions, especially the goniatites, have two sides with different modes of preservation. Taphonomic conditions often produce one weathered side, exposed prior to burial, and another, more intact side, covered by the original seafloor sediment (Figure 5A). The soft and mostly eroded side is related to thermal, diagenetic or taphonomical alterations linked to the mudstone (clay-rich) beddings (Figure 5B). Hard carbonate beddings, or nodular concretions in general, assure a better state

*Figure 4. Mechanical preparation. A) In-situ cutting of cephalopods from their original bedding, using a battery powered disk grinder. B) Traditional mechanical preparation using an air scribe with tungsten needle at 36,000 beats per minute. C) Covering up the striations left by the air scribe, using a rotating multi-tool with cylindrical shaped aluminium oxide (Al2O3) grinding stone head. D) Example of a grinded matrix around several cephalopods from the BLL (*c.* 4 inches). E) A large (*c.* 6 inches) but broken* Manticoceras *sp. goniatite, cut and polished dorso-ventrally to study the anatomical and taphonomical features hidden inside the shell. F) A multi-tool bristle steel brush is used to polish a pyrite coated* Tornoceras *goniatite. G) A fully polished* Tornoceras *sp. goniatite with visible sutures (*c.* 0.6 inches).*

of preservation. It is therefore tempting to consider only preparing the soft side of each specimen, but since preservation is significantly better on the harder side, it is preferential to prepare that side using an air scribe, as stated above.

The discovery of several cephalopods in close proximity within the same layer does not imply they are found in parallel orientation to the original bedding plane. In particular, the smaller goniatites within the nodules (concretions) are often not found parallel to the original bedding plane. These 'strange positions' often result in breaks through the fossil when cutting the limestone nodule in half. Very rarely, lucky splits result in some remarkably preserved calcified shells (Figure 6). The "unlucky splits", which resulted in broken specimens, were initially glued together using Araldite AW 2101, an irreversible fast-setting

A



B

Figure 5. *A, Taphonomic process visualising the cause of dissimilar preservation in goniatites from Lompret. B, Backside of a* Manticoceras *sp. goniatite. This partially prepared specimen is representative for the state of preservation characterizing the majority of all cephalopods from Lompret.*

epoxy resin with hardener (HW2951), before switching to a reversible transparent adhesive (Locktite SG-3 precision), when the decision was made that this collection should become an important study collection. After adhering the nodules together, we started preparing them with the air scribe.

After carefully finishing all preparations using the air scribe, we removed the striated marks left behind by the pneumatic pen. To do this, we used a Dremel™ multi-tool equipped with a conical or cylindrical aluminium oxide (Al_2O_3) grinding stone head (Figure 4C). The use of this tool should be carefully considered before applying it close to the fossil(s). Alternatively, a Chicago Pneumatic CP9361 air scribe can be used in a circular motion, which allows for better control. The use of an air abrasion tool might also be considered in this case, but this was not used due to budget restrictions. Grinding away the surrounding matrix results in a smooth and polished look (Figure 4D). This might be advantageous because it makes the fossil stand out from its supporting bed, but consequently also alters the original look and lithological texture of the matrix. Without the proper accompanying documentation describing the original lithology, a visual link to the original matrix or stratigraphical entity will become difficult. The absence of any visual access to the original matrix on all specimens may highly hinder specific types of future research.

In some cases, the carbonate cement of the limestone (micrite) is tightly bound to the fossil, making separation difficult during preparation. In our

Figure 6. A nice example of a Manticoceras *sp., which was fortunate enough to come out of its concretion whole. Diameter: 9 cm.*

case, we noted that this was the case with goniatites from certain beds. This poor separation sometimes concealed a bad state of preservation. If this was the case, we would no longer try to preserve the fossil in its initial state but opted for a more dissective approach by adhering any displaced parts together and cutting the assembled cephalopod in half dorso-ventrally. This granted us visual access to the specimen's inner features (Figure 4E). Especially for the orthocones, this could help us to determine the orientation of the siphuncle, which is taxonomically informative. In order to observe the position of the siphuncle, it is recommended to cut the orthocones diagonally. The cutting of the cephalopods was done with the aid of a water-cooled table-top (bridge) saw with a diamond blade 35 cm in diameter. Only 10% of the total amount of collected cephalopods were cut in this manner as a result of poor preservation of the outer shells. Non-destructive methods such as (micro)CT scanning might achieve similar results, but given the mass occurrence of cephalopods in this deposit, we opted for physical separation.

Optional mechanical interventions to further reveal visual features such as the use of brass or steel brushes have shown some satisfactory results on pyrite-coated goniatites from the Matagne formation, although one could object that gentle air abrasion might be a less intrusive and lower risk equivalent. A simple manual brass brush was used to brush delicate specimens, but for larger specimens we used a Dremel™ multi-tool ½" (12.7 mm) bristle steel brush to superficially polish the pyrite-coated goniatites. This (temporarily) accentuated the gold colour and septa of the cephalopods for photographic purposes (Figure 4F-G). When using the bristle steel brush, we advise wearing safety goggles and, if possible, pre-setting the base of the brush in resin (where it connects to the hub). This way, ejected strands are prevented from flying off during brushing. The efficiency of the costlier air abrasion techniques on the Lompret cephalopods will be assessed in future preparation projects.

Chemical preparation

Keeping in mind that most of the cephalopods, especially the goniatites, are difficult to spot in the field, a chemical preparation can help to accentuate fossils from their matrix. In the course of the past five years, different chemical compounds have been tried for this purpose. Here we would like to emphasize that a detailed record of all applied chemical products and preparation techniques should be logged in the collection database under each specimen number. Traces of certain molecules will show up in future geochemical research and might interfere with the scope of an ulterior restoration or future investigation.

Rewoquat®

A popular and relatively modern product used for chemical preparation is Rewoquat® W 3690 PG (Jarochowska *et al.* 2013). This chemical compound was initially used as an industrial fabric softener (Krüger 1994), but its value has been recognised as a powerful agent for fossil preparation since the 1980s (Riegraf 1985). The use of Rewoquat® has also been popular in Germany, where it was used as a product to dissolve marly and clay-rich sediments (Lierl 1992). Over the years it established a solid use amongst fossil collectors, and different approaches and techniques using Rewoquat® can be found on online fora and regional paleontological journals. The product has since become a household name in paleontological preparation and can be bought in pre-made solutions, distributed by shops specialising in fossil preparation materials.

Rewoquat® W 3690 PG is a 1-methyl-2-noroleyl-3-oleic acid amidoethyl imidazolinium methosulfate with 24% polyglycol and a pH ranging between 4.0–5.5. The original formula works as a cationic hydrophilic softener. It is viscous and has a distinct yellow, transparent colour. It is useful as a coupler and co-emulsifier for cationic formulations. Within the framework of fossil preparation, it is commonly sold as a 5% solution in isopropyl alcohol (IPA - 2-propanol). The solution works as a surfactant, and it can be re-used several times. We strongly advise reading the Material Safety Data Sheet (MSDS) before using it. We would also like to specifically point out that the imidazole component is highly toxic and corrosive.

The use of Rewoquat® on the calcified mudstones of Lompret was highly effective. Promising results have already been demonstrated on several taxa of Silurian and Devonian microfossils, where it proved an excellent and fast working solvent for phyllosilicate minerals compared to caustic potash (Jarochowska *et al.* 2013). Instead of erasing important morphological and anatomical features, Rewoquat® seems to spare the often weathered and vulnerable cephalopod shells and their associated epibiont fauna, such as crinoid-anchoring parts (holdfasts) and corals (Figure 7).

Our method of applying Rewoquat® to the cephalopods of Lompret is fairly straightforward. We first started by placing the mechanically-prepared specimen in a sealable container. We then applied the Rewoquat® on the clay-rich surface of the cephalopod with a paintbrush, or poured Rewoquat® at the base of the recipient. We subsequently placed the cephalopod in the box and, depending on its morphology or lithological properties, decided to submerge it fully or only face down on the side being treated (Figure 8A). We also applied Rewoquat® on any required area by using a small brush, syringe or transfer beral pipette (Figure 8B). This reduced the amount of Rewoquat used. This treatment should be performed in a ventilated space at normal room temperature or, as recommended by safety standards, under a closed chemical fume hood. After closing the box, we let specimens rest for 5–7 days, monitoring the process on a daily basis. On the last day, we carefully removed the Rewoquat® from the specimen and transferred the fossil to a tray where it was rinsed with isopropyl alcohol for 7 days (Figure 8C). In the second stage of the rinsing process, we washed our specimens with warm water and a toothbrush. As a surfactant, Rewoquat® can easily be reused, so we filtered the leftover product from the box with several sieves or a separating funnel to save for a second application (Figure 8D). The mixture of leftover Rewoquat®, isopropyl alcohol, water and dissolved sediment was collected and stored in a closed jar. The jar could be disposed of in a chemical waste container.

Potassium hydroxide

Potassium hydroxide (KOH), or caustic potash, is a strong base frequently used in fossil preparation. The characteristic white flakes have a pH ranging between 10–13 and are widely available. The use of KOH requires a series of precautions prior to any handling. We strongly recommend reading and carefully following the MSDS instructions before attempting any preparation. Nitrile disposable gloves, tweezers and safety goggles are mandatory, as well as protective clothing and a safe working place under a fume hood. The violent reaction of KOH with water can cause severe skin and respiratory irritations. Potassium hydroxide should therefore be stored in a

Figure 7. Some of the typical epibionts we encounter on the cephalopods illustrate that they served as a basis upon which other organisms could grow for some time.

controlled environment free of water, metal and acids. Its corrosive nature and heat generation during a reaction can cause glassware to break and will react with H_2O particles in the air.

The majority of the large cephalopods from Lompret were treated with 99% KOH flakes (not pellets). For safety reasons, we worked inside a PVC (polyvinyl chloride) container which could be closed. Within the container, a PVC bag served as a reaction vessel in which to place the specimen, with the side requiring treatment facing upwards. We used a spray bottle with a pump atomiser to moisten the surface of the specimen (Figure 9A). Next, we carefully placed the KOH flakes on the wet surface with a pair of PVC-coated tweezers (Figure 9B). We recommend that areas with more matrix receive more KOH flakes. Once the surface was sufficiently covered in flakes, we used our spray bottle to moisten the KOH flakes. One should avoid aiming directly at the flakes, but rather spray just above them, allowing the dispersed water particles to gently mist down on the KOH (Figure 9C). We advise then closing both the PVC bag and the container. Keeping the fossil and chemicals contained at room temperature is saf-

Figure 8. Chemical preparation – Rewoquat. A) Submerging a small specimen in a jar filled with Rewoquat® W 3690 PG. We let our specimen rest between 5-7 days. Plate 2B: Applying Rewoquat® with the help of a transfer (beral) pipette. C) After the Rewoquat® treatment, we rinse our specimen with 2-propanol (isopropyl alcohol) for 1-2 days and afterwards wash it with water and a pH neutral detergent. D) Re-using the used Rewoquat® through a sieve and a separating funnel. E) Using a 1:1 linseed oil and turpentine solution to deepen the contrast of a goniatite. F) (left) The goniatite treated with linseed oil and turpentine (right) An orthocone treated with a polyvinyl acetate (Paraloid B72). Notice the reflections that occur as a result of the treatment. A coating with Butvar B-76 might be a better alternative against the reflection.

er and will greatly accelerate their reaction time. We recommend checking the contents of the bag two hours into the process. When the water from the spray and present in the pores of the matrix breaks the KOH ion bond, the solvated ions (K^+ and OH^-) endothermically react within their aqueous environment (1). This may cause the flakes to move during the reaction (Figure 9D), so we advise repositioning the displaced flakes using a pair of tweezers or adding additional flakes after two hours.

$$KOH\ (s) \longrightarrow K^+\ (aq) + OH^-\ (aq)$$

Potassium hydroxide (KOH) will break the ion bond when confronted with H_2O, resulting in an aqueous potassium ion and an aqueous hydroxide ion.

This procedure works particularly well for goniatites, whose relatively flat shells act like a table upon which the KOH can be placed. For conical fossils, such as our orthocones, the positioning of the flakes (and keeping them in place) can be more difficult. We used vacuum seal bags as described by Vercammen (2020). These transparent bags allowed us to monitor the position of the flakes and equally distribute them across the surface (Figure 9E). The time needed to complete a KOH treatment varies for each specimen; we suggest monitoring the treatment every 4–6 hours.

After leaving the fossils in their bags and containers overnight, we then started carefully brushing off the dissolved sediment. One should use large amounts of water to rinse the fossils. Brushes should be of plastic (polymers), not metal. During the cleaning, always wear safety goggles and protective clothing and make sure to protect your skin and face from ejected droplets at all times. Following the safety guidelines, both

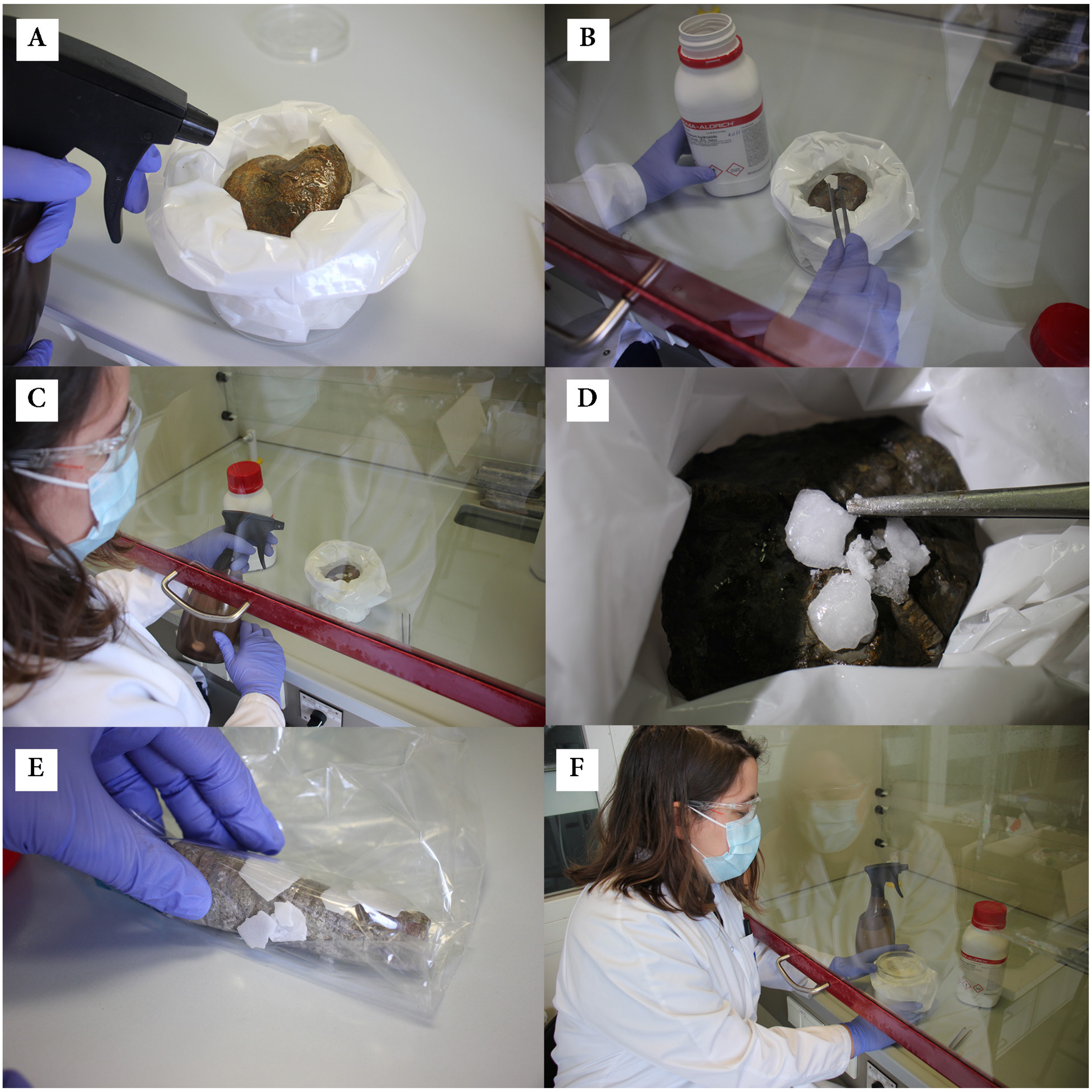


Figure 9. Chemical preparation – potassium hydroxide (KOH). A) Moisturising the specimen within a PVC bag on top of a Pyrex® jar. B) Carefully placing potassium hydroxide (KOH) flakes on the specimen using a pair of tweezers. Plate 3C: Spraying water above the specimen, allowing the mist to gently drizzle over the flakes. D) 2 hours into the preparation, we check our reaction vessel to see replace the KOH flakes who moved during the chemical reaction. E) Preparing a three-dimensional orthocone by using a vacuum seal bag. F) Safety clothing and precautions used when working with potassium hydroxide under a fume hood.

the treatment and the rinsing should be performed under a fume hood (Figure 9F). We submerged the brushed specimens in water that was replaced every 2–3 hours over a 12-hour span in order prevent any remaining KOH from reacting with the fossil in the future.

Although it may be tempting to neutralise KOH with mild acids like vinegar (5–8% acetic acid solution) or HCl (hydrochloric acid), we strongly discourage the use of acids for neutralising strong bases, even if they are diluted. Occurring reactions could result in the formation of orthosilicic acid, which would permanently damage. This also applies when using excessive amounts of KOH on your specimen, resulting in a white grey patina. Always make sure to use plenty of water to rinse your fossils after treatment. The residual KOH and sediment solution should be heavily diluted and disposed of in a chemical waste container.

Stone deepener and Paraloid® B72

Certain industrial products called 'stone deepeners' are designed to be used on polished stones and tiles or to enhance their colour and appearance. They can also be applied on fossils for photographic purposes, increasing the visibility of certain anatomical details. For mineralogical specimens, linseed oil is often used as a biological alternative to remove unwanted scratches or deepen the colour of specimens. On the calcified cephalopods from Lompret, this could also be applied to intensify the white calcified septa of certain specimens.

We used a commercial stone deepener, HMK S748 Stain Protection - Premium Color (made by the German company Moeller; Möller-Chemie GmbH), on some of our cephalopods. This solvent-based oleophobic impregnator is biodegradable and easily absorbed by the cephalopods from Lompret (Figure 8E). As the exact composition of this product is not known to us, we recommend applying it only to specimens whose sole purpose is photographic or educational display. Moreover, it contains highly flammable silane, silicone and unspecified petroleum derivatives, which should never be used in combination with a KOH treatment. In spite of the positive aesthetic results in this case, we advise against the use of stone deepener as a conservational practice. For enhancing the colours on the specimens, we first suggest experimenting with modern imaging techniques before resorting to stone deepeners.

To coat the small pyritised gephuroceratid cephalopods from the Matagne Formation, we used Paraloid® B72. Paraloid® is an acrylic resin based on methacrylate-ethyl methacrylate, applied in a 15% solution with acetone. This coating helps protect the specimen from oxygen and moisture in the atmosphere, reducing oxidation and possible pyrite decay. We left a number of specimens uncoated in order to monitor whether pyrite turns out to be unstable over time; thus far the pyrite on the uncoated specimens has not changed. The Paraloid® acrylate serves two purposes: first, it consolidates fragile suture lines and prevents chambers from falling apart. It also acts as a stone deepener, accentuating the calcified shell of our cephalopods. Preparators should decide whether this serves the intervention's purposes, as it also covers the specimen with a thick and reflective coating (Figure 8F).

A lithological approach

States of preservation of the cephalopod fauna varies widely across the Neuville and Matagne Formations (NM) in the quarry. The following overview will focus on specific strata exposed in the quarry, as well as provide an overview of the cephalopod faunae and respective preparation techniques we recommend. The names used here are informal and have been applied to different strata within the grouped Matagne-Neuville Formation outcrop over the years. They should not be regarded as part of any official lithostratigraphical classification recognised by the National Commission for Stratigraphy Belgium (NCSB).

Black 'anoxic' shales

The strata on the northern part of the quarry are dominated by black anoxic shales (mudstones), which are classified as the Matagne Formation (Wynants *et al.* 2018). Within this formation, there are some nodular concretions that contain small pyritized ammonoids belonging to the genera T*ornoceras* Hyatt, 1884; *Crickites* Wedekind, 1913; *Manticoceras* Hyatt, 1884 and *Bactrites* Sandberger, 1843. Preparing them may require magnification, as the diameter of some genera does not exceed 2.5 cm. In the field, we applied a primary coat of Paraloid® B72 to secure fragile specimens for transport. The small, pyritised cephalopods from the black shales are generally covered in softer mudstone (shale) which can be removed mechanically with an air scribe or scraper hand tool. A final clean-up with a Dremel™ multi-tool equipped with a soft steel brush produces excellent results and brings out the shiny pyrite coating. Depending on the fragility of the specimen, we applied Paraloid® B72 or Mowilith® (a polyvinyl acetate) in an attempt to reduce the potential for oxidation of the pyrite coating. Butvar® B-76 was not used but might also be an appropriate alternative, as it is more resistant to warmer storage conditions and is not as reflective as Paraloid® B72.

The black anoxic shales also contain many small fossils, such as anaptychi (Figure 10). We also found large nodules with cephalopods up to 41 cm in diameter. The only way to begin preparing these large nodules is with hammer and chisel. Next, mechanical preparation can be carried out using a pneumatic pen (air scribe). The relative hardness of these concretions did not obstruct the mechanical separation of the fossil from its matrix and gave satisfactory results.

Bottom limestone layer (BLL)

This particular stratum is around 5 cm thick and encloses a considerable number of juvenile cephalopods. We predominantly observed orthocones and small goniatites mostly less than 2.5 cm in diameter. Similar to previous layers, we also found most of the specimens preserved on the top of this layer covered in claystone. The preservation was often poor, but, during preparation, favourable results were obtained by using the air scribe to remove the limestone. A final treatment with Rewoquat® also proved successful at removing excess claystone. From a taphonomic perspective, the BLL is an interesting case-study on the mass mortality of juvenile individuals.

Middle limestone layer (MLL)

This particular layer yielded an important concentration of large goniatites. The MLL has a thickness of approximately 7.5 cm and contains adult goniatites of the genus *Manticoceras*. Some of these specimens can reach a diameter of 13 cm. Many of the cephalopods found on the top of this layer are covered in (calcareous) mudstone. The preparation of this mudstone is quite straightforward and can easily be achieved with an air scribe and finished with a chemical treatment of Rewoquat® W 3690 PG. Unfortunately, the majority of the cephalopods in this layer are often heavily eroded on one side.

On the solid limestone side, we observed that the cephalopod shells had often experienced intense recrystallisation, making it difficult to separate the fossil shell from the hard matrix. During manual preparation, this resulted many broken specimens. Some of these specimens could not be further prepared, so we decided to glue them back together, cut them in half and polish them to reveal their inner anatomical features.

Top limestone layer (TLL)

The TLL is one of the more understudied cephalopod-bearing layers. This thick limestone bed (20–25 cm) near the MLL was almost impossible to take apart with traditional field equipment. The few collected specimens were mostly found ex situ after explosives were used to blast this layer. We found that most of the specimens in this layer were entirely covered in limestone (micrite).

Other strata

Throughout the rest of the quarry we observed cephalopods in the grey-blue limestones of the Grands Breux Formation. Most of these were cross-sections embedded in massive limestone boulders that were nearly impossible to remove. Compared to the Neuville and Matagne Formation, their presence in the Grands Breux Formation is rare. As a result of their heavy compaction, we were not able to retrieve any three-dimensional specimens (Figure 11).

Figure 10. Fossilised anaptychi are often overlooked as part of the cephalopod fauna. Their often bivalve-like appearance leaves them neglected in the field.

Discussion

Comparing the previously discussed solvents, no single option gave decisive results. Based on our experience within the framework of the cephalopod fauna from Lompret, we feel that both products have their own advantages and disadvantages. As we have adopted a very individual approach for each specimen, we have chosen to give an overview of both products based on their different properties (*cf.* Table 1). We hope that this allows our colleagues to experiment more confidently with both solvents, thus reducing the risk of damaging or irreversibly altering the chemical composition of the specimens.

We did not use both products on the same specimen in this study, because we obtained satisfactory results with a combination of mechanical and chemical preparatory methods, as mentioned above. In addition, we do not recommend combining several chemical compounds, as they may interfere with each other if the rinsing phase is not performed properly. Our advice for potential experimentations combining both products would be to focus on an extensive rinsing phase and allow for a sufficient time lapse of at least a few weeks between the use of both products.

Conclusions

When dealing with the preparation of fossils, it is of primary importance to examine the matrix surrounding the specimen(s). Trained preparators value a preliminary assessment of the involved lithologies by first submitting sterile fragments to chemical or mechanical preparation and/or conservation techniques. They will then monitor and keep a record of variations in order to choose the most appropriate technique, depending on whether the specimen needs to be sampled, anatomically exposed or preserved. Prior to any kind of preparation, a thorough knowledge of the physical, chemical or mineralogical properties of a matrix will undoubtedly reduce errors and save time spent on the preparation of the specimen.

Over a five-year span, approximately 450 cephalopods were collected from different strata within the Neuville and Matagne Formations of the Lompret quarry. Most specimens possess a (calcareous) mudstone side and a hard limestone side. The latter offers a challenge for the preparation of the cephalopods. It is important to adopt an individual approach for each specimen in order to obtain the best results. A combination of both mechanical and chemical preparatory methods is recommended, especially for the larger cephalopods.

90% of all cephalopods from Lompret survived three-dimensional preparation without breaking. The remaining 10% of specimens were adhered together and used for cross sectional study by cutting them in half and polishing the cut surface. In doing this, we rehabilitated partially damaged finds into useful specimens for future research or educational display, allowing for the observation of anatomical details and the identification of internal diagnostic features.

Our mechanical preparation techniques were quite traditional, involving a pneumatic pen (air scribe) and reversible adhesives. Sandblasting was not applied in this setting but will be the focus of future projects. For chemical treatments, we would, before all else, recommend the use of Rewoquat® W 3690 PG and only a switch to potassium hydroxide if results with previous chemicals are not satisfactory. Additional use of (semi-)permanent stone deepeners or linseed oil are not mandatory but can enhance certain anatomical features for exhibition purposes. However, in the framework of scientific research we advise using polynomial texture mapping to enhance the contrast of digital photographs, rather than applying physical coatings to specimens (Hammer and Spocova 2013). The untreated and pyrite coated cephalopods have proved fairly stable over the course of five years, but continuous monitoring will be necessary. The same goes for the storage conditions, for which pyrite coated specimens were packed in acid-free paper to avoid acid aerosols

Figure 11. Cross-section of an unidentified orthocone embedded in the compact limestone of the Grand Breux Formation.

	Potassium hydroxide (KOH)	Rewoquat® W 3690 PG
Price	Low	Medium-high
Re-usability	None	Yes
Reactivity	Very high	Medium
Toxicity	Very high	Medium-high
Corrosiveness	High	Medium
Efficiency	Aggressive	Good
Preparation time	3 days	4–5 days
Not Compatible with	Stone deepener	NA
Dissolves the fossil and/or epibionts	Sometimes*	No
Use of water / acetone for rinsing	High	Medium
Safety material requirements	High	Some

Table 1: Comparing different features of Caustic potash (KOH) and Rewoquat® W 3690 as compounds in chemical preparation. *Only when the concentration exceeds more than 1 flake per cm²

from interacting with other specimens. Future X-ray micro-computed tomography analysis, following the method described by Allington-Jones *et al.* (2020), might help us determine if the delicate pyrite-coated cephalopods or the rare and fragile anaptychi present any signs of pyrite decay in the long term under certain conditions.

In 2022, a public exhibition at the Musée du Marbre in Rance (Sivry, Province of Hainaut) will display a large part of the cephalopod collection from the Lompret quarry within a geological, mineralogical and palaeoecological framework. This public outreach program will help increase awareness of the Lompret cephalopod fauna as an important paleontological study collection.

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A brief history of natural history museums in the Ottoman Empire

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Natural history collections and museums made their appearance in the Ottoman in late 19th century through various attempts to build collections through field excursions, donations and exchanges among researchers, individuals and institutions around the world. Among them, the Imperial Medical School of the Ottoman Empire, schools of the American Board of Commissioners for Foreign Missions (ABCFM) and other American educational groups and French colleges stand out with their vast collections from various parts of the Ottoman Empire and beyond. While these museums were created and built by eminent curators and researchers, a considerable amount of work was carried out by uncredited staff and the students. The history of these museums was often obscured by catastrophic events such as the great fires in Istanbul, the passing of the curators and other administrators and, particularly, the devastating effects of the First World War. However, long-lasting commercial science objects networks and the establishment of global natural history collections and museums are still operational today, supported by scientific exchange between other countries and the Ottoman Empire during the 19th and early 20th centuries. Drawing an outline of the history of the natural history collections of the Ottoman Empire can shed light on the evolution of both the naturalistic movement within the Ottoman society and an embryonic scientific network around the Middle East and the rest of the world.

Göçmengil, G. 2021. A brief history of natural history museums in the Ottoman Empire. *Geological Curator* **11** (5): 375–384.

Introduction

Natural history museums and collections in the Ottoman Empire were first established for educational purposes, particularly in the fields of medicine, pharmacy, zoology, geology and biology, during the first half of the 19th century. In the second half of the 19th century, substantial collections were created in colleges of missionary establishments and schools of the *millets*, religious communities of the Empire.

This overdue outline of the most prominent natural history collections in the Ottoman Empire from the 1830s to 1923, when the Turkish Republic was founded, is representative of small-scale networks of learning, scientific thought and commercial interaction between global cultures and the Ottoman world. Within the scope of this paper, I specifically present and discuss the efforts of three different institutions and organizations that have built rich and enduring natural history museums, including the Imperial Medical School, the French Catholic schools in Istanbul, the American Board of Commissioners for Foreign Missions (ABCFM) and American teachers in Istanbul and Anatolia. The full list of museums included can be found in Table 1. Insight into the historical development of these museums (and their collections) and tracking down the location of the vestiges of these collections can shed light on different historical scientific networks at play and how these contributed to the understanding of the evolution and biodiversity in the Ottoman Empire and beyond. Many collections have been lost, but some are preserved in the museums of schools and herbaria in Turkey and around the world (Austria, Switzerland, England) and are, fortunately, still accessible.

Table 1 (over page). Natural history collections and museums in the Ottoman period particularly existed before the establishment of the Turkish Republic (1923). Many more natural history museum and collections existed in the Ottoman Empire, but, within the scope of this brief review article, I only list and discuss the well-studied examples.

Table 1.

Organization that created the collections / museums	Name of the museum	Lifetime of the collections / museums
Ottoman Sultanate	The Natural History Museum of the Imperial Medical School in Istanbul	1839–1874?
American Board of Commissioners for Foreign Missions	Museum of Anatolia College, Merzifon (Merzifoun)	1913–1938
American Board of Commissioners for Foreign Missions	Central Turkey College Aintab, Mary A. Dickinson Museum	?–1924?
Independent American Teachers	Robert College (Istanbul) Natural History Museum	1869–?
French "Frères"	Saint-Joseph Kadıköy Natural Science Museum/Center	1910–ongoing

The Natural History Museum of the Imperial Medical School in Istanbul: Early attempts at natural history museum establishment (1839–1874?)

The oldest known natural history museum in the Ottoman Empire already existed in a cosmopolitan context. It was established at the Imperial Medical School, a military educational institution located at the Galata Sérai, Istanbul, sometime between 1839 and 1846. The museum was called Numunehane-i Mekteb-i Tıbbiye-yi Şahane (*Musée d'Histoire naturelle de l'Ecole impériale de Médecine de Constantinople*). The school itself was founded in 1839 by Austrian doctor Karl Ambros (Charles Ambroise) Bernard (1808–1844) at the behest of Sultan Mahmud II. Together with his colleagues and students, such as the botanist Salih Efendi (1816–1895), Bernard collected and organised the nuclei of the museum until he succumbed to cholera himself (Günergun and Baytop 1998). Sultan Abdülmecit then commissioned the Austrian botanist and pharmacist Friedrich Wilhelm Noë (1798–1858; Baytop 2012a), who continued to expand the collection with botanical and geological specimens from Salih Efendi's botanical studies, as well as from materials obtained from the travelers and envoys. Information about the first-known museum collection was given in the travelogues of Charles Macfarlane and John Mason. (Macfarlane 1853; Mason 1860; Ülman 2017). Mason's detailed description highlights both the conditions of the collection and the scientific network that contributed to the museum's collection. According to Mason, one of the notable contributors was the school's medical doctor Constantin Carathéodory (1802–1879), whose undated trip to Egypt returned shells from the Red Sea and Nile and reptilians, insects and petrified woods from the environs of Cairo collected by medical doctor Clot Bey (Antoine Barthelemy Clot, 1793–1868). In addition, M. Schevertzbach (or Schwartzbach, reputedly a Swiss natural scientist) went on an expedition that covered Smyrna (present-day Izmir), Cyprus, Central and Eastern Anatolia and the Middle East, possibly before 1848. The French naturalist Auguste Viquesnel, sent to Turkey by the French Government in 1847, contributed new samples to the school's museum. In 1848, a fire in Beyoğlu (Péra) destroyed the buildings of the medical school along with a major part of the collection (Baytop 2000), which left Noë striving to make up for this loss until his death (Çelik 2019; 2020). After a long hiatus, Hungarian-Austrian medical doctor and naturalist Karl Eduard Hammerschmidt (1800–1874) was appointed in 1870 to rebuild the museum from the remnants. An article published in the *Gazette médicale d'Orient* in 1872 documents the material that survived the fire and the new collections Hammerschmidt succeeded in providing (Günergun 2010).

Dr. Hammerschmidt was a prominent figure in science and politics during his time (Figure 1). After emigrating to the Ottoman Empire, he changed his name and embraced Islam, becoming known as Colonel Abdullah Bey, the Hungarian (Macarlı Miralay Abdullah Bey). He first served as a medical doctor in Ottoman military hospitals and was then appointed as a professor to the Imperial Medical School. He was known particularly for his work on entomology and geology (Şengör 2010). He collect-

Figure 1. Portrait of Karl Eduard Hammerschmidt (1800–1874).

ed, acquired and exchanged many geological, entomological and zoological specimens, microscopes, sample preparation kits and reference books on natural sciences from the Imperial Natural History Museum (*K.k. Naturhistorisches Hofmuseum*) of Vienna. He acquired mineral and fossil specimens from mineralogist Gustav Tschermak von Seysenegg, geologist Franz Ritter von Hauer, and many botanical and entomological specimens, specimens of quadrupeds and birds from different individuals and institutions (Günergun 2010; 2019; Çelik 2020). He is one of the first to mention the long-term conservation problems of specimens due to humidity, specifically with insects, and the quality of the cabinets in terms of museology in the Ottoman Empire in his article in the *Gazette médicale d'Orient* (Abdullah B. 1872).

Geological samples at the Imperial Medical School museum under the curation of the Hammerschmidt include trachytes from Hungary, coal samples from Austria and a large range of Devonian fossil samples from Istanbul Palaeozoic sequence (up to 5000 samples). Although the collection was lost during the beginning of the 20th century, duplicates of the collection (especially Devonian samples) had been sent to the Natural History Museum of Vienna, and some portion of them is still hosted there.

Natural history collections and museums established at the ABCFM and other American Schools

Starting in the 1820s, American missionary groups established different institutions within the Ottoman Empire. The majority were protestant missionaries sent by the ABCFM. Over the years, these institutions became endowed with well-staffed schools and began to reform their curricula from religious studies to social, mathematical and natural sciences in order to reflect a modern, pragmatic outlook and to attract more students with broader curriculae (Alan 2008; Göçmengil 2019; İleri 2019a, b). Presented here are the most remarkable collections and museums established within the Museum of Anatolia College of Merzifon (also known as Merzifoun, Marsovan), the Central Turkey College at Aintab (Antep, Gaziantep) and Robert College of Istanbul.

Museum of Anatolia College, Merzifon (Merzifoun, 1913–1938)

The Anatolia College was founded in 1886 by the ABCFM at Merzifon. The founder of the school, Dr. Charles Chapin Tracy (1838–1917), philanthropist and naturalist, was the longest-serving member of the school. He was the first person to gather a modest fossil collection around the city of Amasya (now northern Turkey), which became the core of the museum collection. Over the years, the collection grew with the addition of specimens by college professor Dr. Edward Riggs and his students. C.C. Tracy sent many of the graduates of the college to Europe and the USA to gain a better education in the various social and natural sciences, and return to become future teachers at the college. Among them, Johannes Jakob (John) Manissandjian (Ohannes/Hovhannes Agop Manisacıyan, 1862–1942) was the driving force for the teaching and research of natural sciences in the College. J. J. Manissandjian was the son of German-Armenian parents and developed an interest in natural sciences at a young age in Merzifon (Empty Fields Exhibition Brochure 2016). He attracted the attention of the German entomologist and natural history dealer Otto Staudinger (Staudinger 1879; Etker and Göçmengil 2020). Beginning in his teenage years, J. J. Manissadjian became both an amateur natural scientist and collector.

Manissadjian collected diverse sets of geological (Pia 1913), botanical (Freyn 1894) and entomological (Morton 1916) specimens and sent to them various museums, collectors and companies (Empty Fields Exhibition Brochure 2016). He also worked as a consultant for researchers who wanted to collect specimens from various parts of Anatolia (Morton 1916). As the natural science collection expanded, specific parts of the collection were handled by Manissadjian and Henry Chester Tracy, who served as a taxidermist in the college from around 1898 to 1900. Manissadjian and other college staff acquired a wide range of specimens from Central and Eastern Anatolia, Syria, Lebanon and Russia (Museum Catalogue as it came from Merzifon 1939; SALT Research Archive). The expansion of entomology, botany, geology and mammal sections necessitated a larger space for conservation and exhibition purposes. To fulfill the requirements of a natural history museum and also maintain the extensive natural science collection of the college, construction on a museum-library building was launched in 1910 (Figure 2A) and inaugurated by the end of 1913 (Annual Report for Marsovan Station 1912–1913; Figure 2B).

In 1914, the museum contained some 7,000 botanical and animal samples, 2,500 entomological samples, 1,000 fossils, 900 minerals, 50 mollusks and 40 big mammal samples (McGrew 2015). The museum was open for two days a week and attracted as many as 100 daily visitors. Unfortunately, the growing unrest of World War I put the museum on hold around 1915–1916. Some members of the non-Muslim community and the school staff were deported or perished, and the school premises were used as a military base (Maksudyan 2013). Manissadjian remained with the German Colony in Amasya and returned to the museum in 1917 for a year to compose a catalog of the collection. The catalog itself is an important testament to both Manissadjian's scientific approach and the collective effort that helped the museum collection flourish (Museum Catalog as it came from Merzifon 1939). The catalog mentions the exchange of specimens particularly among the researchers from Germany, Istanbul (with the botanist Georges Vincent Aznavour [Jorj Vensan Aznavur], 1861–1920) and another ABCFM school in Talas, Kayseri (teacher R. Wingate; Empty Fields Exhibition Brochure 2016; Göçmengil 2019).

Shortly after completing the Museum Catalog, Manissadjian first went to Istanbul and then emigrated to the USA and lost contact with his museum. Following the foundation of the Turkish Republic (1923), the College transformed into a girls' vocational school and maintained its educational function until 1938. In these years, the museum was still open for the public and attracted the attention of visitors in the vicinity (Etker and Göçmengil 2020). Around 1938, the school closed due to financial problems, and museum holdings were transported to the Tarsus American College, another ABCFM school in southern Turkey. A portion of the herbarium collection was sent to the Ankara University

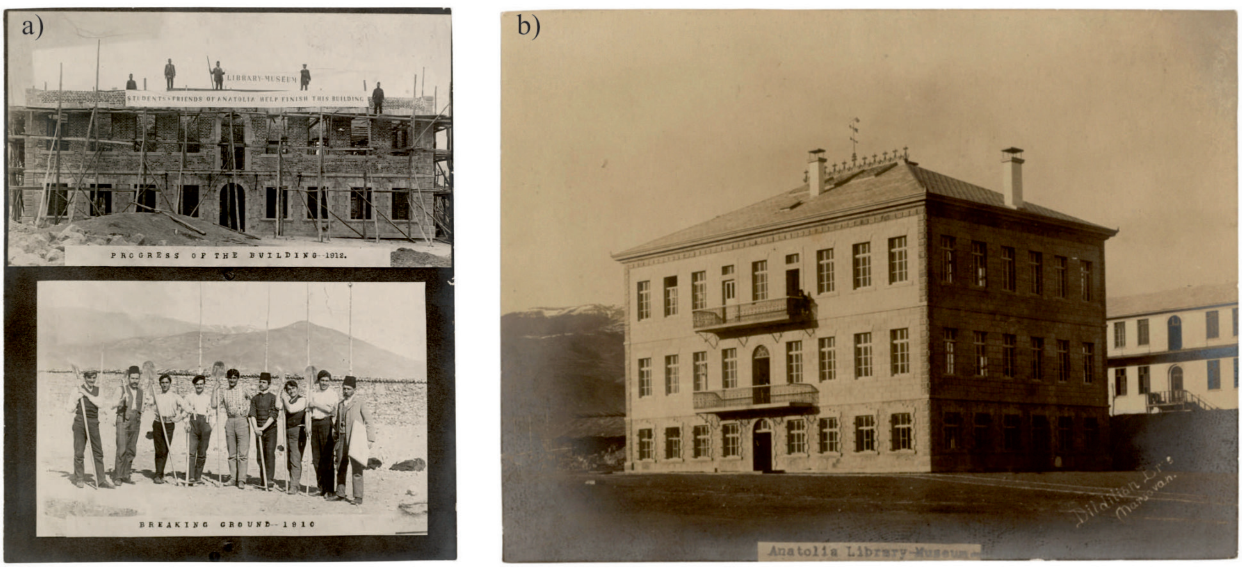

Figure 2. A) Construction phases of the library-museum building in Anatolia College Merzifon. B) The final version of the museum-library building in 1914.

Faculty of Sciences Herbarium.

A major portion of the collection hosted at Tarsus American College was forwarded to Robert College of Istanbul after the 1960s without any traceable documentation. The remainder of the collection has been recently reclassified at the Tarsus American College and is currently being exhibited in the newly established Natural Sciences Research Center located in the historical Sadık Pasha mansion (Göçmengil 2019).

The remaining part of the collection at the Tarsus American College contains fossil fishes from Beirut, ammonites and belemnites from Turkey and Pelecypoda, Gastropoda, Sigilaria, Graptolites and Mollusca fossils from Germany and Vienna. Interestingly, the catalogue of the museum shows the existence of Ichthyosaurus foot and head fossils from Holzmaden, Germany and various different fossils (Museum Catalogue as it came from Merzifon 1939; SALT Research Archive). Various common mineral and rock associations such as main silicate groups and common magmatic-metamorphic and sedimentary still existed in Tarsus that were collected primarily from Turkey, Germany and Switzerland (Göçmengil 2019).

Central Turkey College Aintab, Mary A. Dickinson Museum (?–1924?)

Central Turkey College was established at Aintab (Antep, present day Gaziantep) in 1875. The college had a similar structure to the other Anatolia College in Merzifon, with educational and health facilities, including a medical school, as outlined in the yearly reports (Catalogue of Central Turkey College at Aintab 1901). The college possibly hosted one of the rare natural history museums that bears the name of a woman, the naturalist Mary A. Dickinson (1829–1902), a largely unacknowledged collector from Romeo, MI, who gave her valuable herbarium collection to the college. The museum holdings included a wide range of specimens of sea-algae and California plants, the herbarium collection by Mrs. Fany P. Shepherd (1856–1920) from Syria, specimens gathered from European and American woods and marine animals that were given by Herr Pfarrer Sarasin-Forcart from Basel, Switzerland. Crystallography models and minerals arrived from the USA, geological specimens were acquired from Yellowstone Park and the Mississippi Valley, fossils and limestone specimens were collected from the Antep region of present-day Turkey and Mexican objects of curiosity were donated by Mr. Elmer Shepard.

Unfortunately, details of the collection, beyond what is recorded above, have been poorly recorded or lost due to the devastating effects of World War I. There is no indication that the geological samples survived after this time interval. The college closed in 1924, and the collection most likely did not last beyond that time period. Alçıtepe and Alçıtepe (2019) suggested that the only surviving traces of the collection were found in the American University of Beirut (AUB).

Robert College Natural History Museum (1869–?)

Robert College was founded in Istanbul in 1863 by Rev. Cyrus Hamlin (1811–1900) with the donation of Mr. Christopher R. Robert (1802–1872). Although they had a strong relationship with ABCFM institutions and schools, they had no formal connection with them. According to the 1878–1879 school catalogs, the museum consisted of geological and mineral specimens together with an ornithology collection (Sakarya 1979; Akyıldırım 2006; İleri 2019a). Through the years, the museum collections grew with further additions, and a rich herbarium collection was contributed by the botanist Georges Vincent Aznavour (Jorj Vensan Aznavur; Baytop 2012b; Aksoy 2018) together with Dr. George E. Post. Aznavour was a key figure in collecting botanical specimens in and around Anatolia and Istanbul. Dr. George E. Post, who worked in the Syrian Protestant College, Beirut, AUB, collected many botanical specimens from Syria, Palestine and the *Sinai Peninsula*. Dr. Bertram van Dyke Post*, the son of* Dr. George E. Post, was appointed as a new teacher and museum curator to the school in 1904. Together with Angele Yemedijian, they curated, preserved and classified the collection (Aksoy 2018; İleri 2019a).

Various animal specimens were added to the museum collection, including invertebrates, wild boar and butterfly collections from China and Java, seabirds, sea-snakes, leopards, pelican, hippopotamus, amphibians, birds and a large herbarium collection consisting of 13,000 specimens (İleri 2019a). In the annual reports of the College (1912–1913), curator Bertram van Dyke Post described new additions and documented a new exhibition covering different mammal and bird species (İleri 2019a).

The museum survived World War I and continued to grow during the early years of the Turkish Republic. The museum drew interest from various college and high school students throughout Istanbul and Turkey and inspired its visitors (İleri 2019a). According to Baytop (2002) and Sakınç (2013), Dr. Bertram van Dyke Post bought Georges Vincent Aznavour's herbarium collection from Aznavour's inheritors and donated it to the Geneva Herbarium (Switzerland) when he retired in 1940. Other school staff and museum curators cared for the remaining collection for many years (Aksoy 2018). Eventually, the collection was split and the majority of it was sent to the Natural Sciences Centre of Saint-Joseph Kadıköy in Istanbul some time before 2010 without a record of transfer information (Göçmengil 2019).

According to Akyıldırım (2006), 180 specimens of Gastropoda and Bivalvia species from Turkey and adjacent regions, 75 fish samples belonging to Chondrichthyes and Osteichthyes classes collected between 1892–1893 in the Bosphorus, together with unclassified mineral, rock and fossil specimens from Anatolia and adjacent regions still exist in the museum at the present-day Robert College. However, the surviving collection has not been thoroughly explored and should be evaluated with care in the future.

Collections at the French colleges of Istanbul

Saint-Joseph Kadıköy Natural Science Museum/Center (1910–ongoing)

Saint-Joseph High School (Lycée Français Privé Saint-Joseph d'Istanbul) was founded in 1870 as a part of the Lasallien schools around the world. The Natural Sciences Museum of the College (*Musée des Sciences Naturelles du Collège*) was founded around 1910 by the frères Possesseur Jean (1867–1946, surnamed Jean des Bêtes) and Paromont-Felix, who were already collecting entomological and geological samples before the establishment of the museum. Apart from these two frères, other teachers contributed to the emergence of the museum collection, such as frère Felix (butterflies), frère Pasteur (sea shells), frère Fructueux (mineralogy), frère Onésime (fish and eggs), and frère Honeste (botany) (Şentürk 1998).

Frère Jean was the instrumental in the formation of the museum and collected and made several exchanges with dealers from Vienna and Berlin (Şentürk 1998). During his time in Istanbul, he collected throughout the city and guided the interest of the frères at Anatolian colleges towards natural science studies and specimen collection. With the permission of the Ottoman Sultan, animals from the Bosphorus area were hunted and prepared at the museum, resulting in excellent bird and mammal collections, among others. The museum also contained a rich herbarium collection of specimens primarily collected from Istanbul and environs. The herbarium collection started in 1905 by frères Jean Marius Reynaud, Pasteur Luis and Idinaël Simon (Sakınç 2013). From the 1970–1990s, the museum did not receive proper conservation and nearly lost its rich collections. From 2000–2010, the collection was re-organized and curated, mainly by the staff of the Saint-Joseph high school, researchers from Istanbul Technical University Geology Department (Mehmet Sakınç, Vecihi Gürkan), a botanist (Necmi Aksoy) and a taxidermist (Xavier Filoreau). Collections opened to public as a natural history center in 2010. The currently museum holds the one and only proper natural history collection in Istanbul that can be visited by the public at the Natural Sciences Centre (Doğa Bilimleri Merkezi) of Saint-Joseph Kadıköy, Istanbul (Figure 3).

Currently, 4000 mineral and rock specimens from France, Turkey, Germany, England and various places from Europe are hosted in the museum. Common rock units and gem-quality samples belonging to silicates, native elements, oxides, sulfates and haloids groups are currently exhibited in the museum space. In addition, up to 500 hundred fossil vertebrates (including primates), echinoderms, brachiopods, ammonites, trilobites, graptolites and Palaeozoic plant fossils are hosted in the museum and collected from mostly France, as well as some from Turkey, Germany and the USA. The Natural Sciences Centre of Saint-Joseph Kadıköy may well contain the only intact and well-documented natural history collection in Turkey.

Apart from the Saint-Joseph high school, other French colleges such as Saint-Benoît also possessed prominent herbarium collections (Akyıldırım, 2006). However, these and similar institutions belonging to Armenian and Greek minorities kept their natural history collections private due to lack of funding, staff and exhibition space.

In sum, the Imperial Medical School, an Ottoman military educational institution, the American

Board (ABCFM) colleges, American schools and French colleges were the main institutions in which important natural history collections were created in the 19th century Ottoman Empire. To these are now added the natural history collection of the Darüşşafaka, an Istanbul-based Ottoman high school aiming to educate Muslim orphans (Günergun 2019) and the Getronagan Armenian High School (*est.* 1886) in Istanbul. Traces and remnants of these collections survive today. Darüşşafaka in particular contains a rich Palaeozoic fossil collection, mostly collected from Germany, that still under investigation. In the following section, I will briefly discuss the exchange of scientific thought and specimens between eminent curators in the Ottoman Empire and the rest of the world in an attempt to highlight the importance of these institutions at the transition from 19th to 20th centuries.

Discussion: Exchange of scientific ideas and objects in the 19th and early 20th centuries

Since the 16th century, travelers, diplomats, researchers and geographers have visited the Ottoman Empire, driven by an interest in natural sciences. Interactions between these inquisitive foreigners and the knowledgeable Ottomans improved understanding of the Ottoman landscape, resources and populace (Ihsanoglu 2004, 2019; Martykánová *et al.* 2010; Shefer-Mossensohn 2015; Yalçınkaya 2015; Küçük 2020). Many travellers in Ottoman lands acquired various objects to take with them back to Europe, Russia and the USA. Among them, botanical specimens were of particular interest (Salzman 2000; Erik and Tarıkahya 2004; Todd *et al.* 2018) and were exploited as both commercial and scientific assets. In addition to the botanical specimens, live animals also captured the interest of some travellers. Local actors exhibited wild animals in a kind of zoo called *Arslanhane* (literally "lionhouse", ménagerie) within close proximity of the Ottoman Palace (Günergun 2006). However, these creatures were also kept for personal glory, gifts to the other diplomats and countries and for entertainment (Sunar 2018). It was not until the 19th century that the major portion of zoological specimens were valued seriously as scientific and educational objects.

Figure 3. Exhibition hall of the Saint Joseph Natural Sciences Centre (Photograph by Gönenç Göçmengil).

Even though the establishment of the natural history collections / museums began sometime in the first half of the 19th century, natural sciences education was only available to a small portion of the population enrolled in colleges like the Imperial Medical School and, later, the French, American, Armenian and Greek schools, together with the *Darüşşafaka* high school, a number of Ottoman state high schools (*Rüşdiyes*) and the *Darülfünun* / University (irregularly before 1900 and regularly after). A major portion of natural science objects were collected with a mind for their commercial and medicinal values. Considering the various natural science relationships fostered by Noë and Hammerschmidt, it may be that these early collectors were attempting to build and compete with the other natural history museums in Europe. The close relationship of Hammerschmidt with scientists, such as Pierre de Tchihatcheff (1808–1890), and Austrian naturalists facilitated the exchange of scientific entities and natural objects with institutions outside the Ottoman Empire (Şengör 2010). Both Noë and Hammerschmidt encountered many people and students while collecting natural history samples on field expeditions, but the lack of personal narratives of these people limits the interpretations that can be made about the extent to which their contributions were understood by society at large despite their impact on the scientific literature.

Even though the direct relationships between museum collections and the public was limited, naturalistic modes of thought were often experienced through publications dealing with evolution and the creation of the Earth by important naturalists such as Jean-Baptiste Lamarck, Charles Darwin, Ernst Haeckel and Eduart Hartmann (Figure 4; Erguvanlı 1978). These ideas were critically discussed by Ottoman intellectuals in journals, newspapers and books throughout the second half of the 19th century and the beginning of the 20th century (Alkan 2009). Besides the natural sciences books written by Karl Eduard Hammerschmidt and a translation of the natural sciences book of Nérée Boubée (*Géologie Populaire à la Portée de Tout le Monde Appliquée à l'Agriculture et à l'Industrie*, 1833) into Ottoman Turkish that were extensively used in natural science education, the impact of these resources on society are poorly investigated (Şengör 2009–2010). Dr. Hüseyin Remzi (1839?–1896), the successor of Hammerschmidt in the Imperial Medical School, also wrote various books on the natural sciences (*İlm-i Mevalid-i Selase* is the best-known) and established the core of the natural sciences collection in the Darüşşafaka high school (Istanbul), which is still under investigation (Günergun 2019).

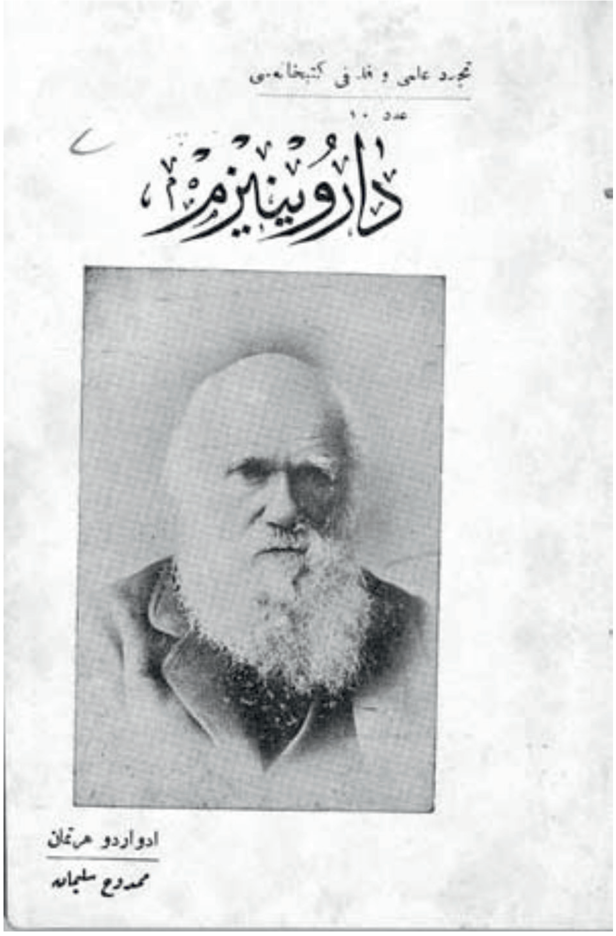

Figure 4. Front cover of the translation of the book Eduart Hartmann "Wahrheit und Irrthum im Darwinismus" by Ottoman intellectual Memduh Süleyman, published in 1911.

Later figures, such as J. J. Manissadjian, Georges Vincent Aznavour and the frères of Saint Joseph, Dr. Hüseyin Remzi and another poorly known figure in the natural sciences, Dr. Nazaret Daghavarian (1862–1915; curator of natural sciences collection in Getronagan Armenian high school, Istanbul) not only built the natural history collections but also acted as natural science dealers and science ambassadors in the communities in which they lived. Manissadjian gave public lectures about volcanoes and evolution around his time in Merzifon, and his lectures were met with great interest in his community (Arık 2019; Göçmengil 2019). At the Empty Fields exhibition curated by Marianna Hovhannasiyan, memoirs of the college students gave evidence of the positive effects of the museum collection: in several years, college students who visited to museum joined in efforts to establish museum collections and, later, to collect their own naturalistic objects. Similarly, the Robert College Natural History Museum guestbook, recently unearthed by İleri (2019a), shows the impact of various curators, such as father and son Post, in their naturalistic inclinations. Nevertheless, these issues beg further investigation, and different institutions such as Darülfünun (later Istanbul University), Darüşşafaka high school and French, Armenian and Greek high schools still hold poorly investigated collections (İshakoglu 1998; Akyıldırım 2006; Günergun 2019).

Conclusion

Museum collections in the Ottoman Empire reflect the scientific curiosity of curators, teachers, students and various members of prominent educational and governmental authorities and institutional networks and they represent snapshots of past biodiversity of the Anatolian region and beyond. Despite various attempts to build natural history museums during the time of the Ottoman Empire, natural history museums and collections were uniformly short-lived. A majority of these museums relied on the personal efforts of their curators, and the sudden and tragic loss of these persons due to political and military catastrophes resulted in the destruction of major portions of these collections. Despite the loss of the curators, buildings and segments of the collections, some parts of them survive at different museums, herbariums and collections hosted in Turkey, Europe and the Middle East. However, the documentation of the natural history museums in the Ottoman Empire and early Turkish Republic still has many unanswered questions, and revealing and extending personal stories might yield a better picture of the evolutionary pathways of these natural history collections.

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Digitising the historical archives of the Conservation Centre at the Natural History Museum, London

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The Conservation Centre at the Natural History Museum in London (NHM) holds a collection of approximately 18,000 archival records and documents. These historical records, which include photographs, slides, X-rays, building plans, letters, press cuttings and field maps, provide a history of fieldwork, specimen treatments and the evolution of conservation and preparation methods at the museum. This paper details a six-month project that was carried out to digitise much of these collections, making them more accessible and easier to associate with specimen records on the museum collection management system and adding to a museum-wide drive to improve accessibility through digitisation.

Miles, K. 2020. Digitising the historical archives of the conservation centre at the Natural History Museum, London. *Geological Curator* **11** (5): 385-391

Introduction

In July 2018, the NHM's Conservation Centre (hereafter TCC) held three filing cabinets full of historical records and images including high quality black and white photographs, Polaroid pictures, negatives, X-rays and slides, as well as documentation including condition reports, building plans, press cuttings, letters, memos and field maps. Many of the photographs are high-quality black and white images taken by the museum's dedicated photographic unit. These records provide a fascinating insight into the history of the museum, past conservation techniques, fossil preparation equipment, previous gallery displays and palaeontological excavations. They also represent a record of the progress of work in TCC through the decades. Capturing the look of a specimen can be particularly important in the field of fossil preparation, as the specimen's appearance constantly changes through the removal of matrix, subsequent repairs and restoration or chemical treatments. Due to the origins of TCC (Graham 2019), the vast majority of the records relate to palaeontological material.

Between August 2018 and February 2019, the author completed a six-month project to digitise as much of this material as possible with the aims of preserving the records, making them easier to associate with specimen records on the museum's Collection Management System (CMS) and to make them more readily accessible and available for reference. A master spreadsheet of associated metadata was also created to maximise the usefulness of the scanned images. Images and records that were deemed particularly important were boxed and transferred to the main NHM Archives. This paper will explain the digitisation process, while also discussing the changing role of the Conservation Centre through time for further context as well as highlighting a few interesting examples of images from the archives.

History of the Conservation Centre

The history of the Conservation Centre dates back to the beginning of the museum at South Kensington in 1881 (Graham 2019) as there was originally a fossil preparation facility in the basement of the Waterhouse building. This facility was known originally as the Geological Workshop, where fossil preparators (known as 'masons' at this time) carried out the mechanical removal of matrix, primarily with hammer and chisel, and undertook the moulding and casting of specimens. From the 1950s onward, this facility was renamed the Palaeontological Laboratory, and the scope of its work had expanded to include acid preparation (Toombs and Rixon 1959), some conservation work on palaeontological, mineralogical and anthropological collections, as well as work on exhibitions, excavations and, later, commercial projects.

With the addition of a new Palaeontology Building to the east side of the museum in 1977, a new facility was built to carry out these tasks, as well as environmental monitoring, named the Palaeontology Laboratory. Conservation of palaeontological material gradually became emphasised from the late 1980s onward, and the facility was later renamed the Palaeontology Conservation Unit (PCU) to reflect this. The remit of the PCU expanded significantly in 2002, when the focus shifted to providing conservation services, both preventative and remedial, across all the museum's collections. Fossil preparation remained an important part of the work undertaken, but resources became more focussed on the museum-wide provision of conservation. The latest iteration of the facility, as the Conservation Centre, happened in 2012 during a major restructure that saw TCC move from the Palaeontology Department to Core Research Laboratories.

Photography and other imaging techniques have long been in use at TCC as a means of ongoing condition monitoring, recording the stages of fossil preparation or chemical treatments and documenting important events such as fossil excavations, large specimen moves or exhibition installs. The historical archives act as a central repository for these images, some of which date back to the 1920s and perhaps earlier. Digitising these records provides insight into the evolution of conservation practices and informs the wider conservation discipline.

From the archives

Casting a giant amphibian

There are a number of records in the TCC archives relating to the historical moulding and casting of specimens. Among the contents of the cabinets were a series of old, faded notebooks in which staff had kept records of the casts they had made. One particularly noteworthy example was the cast skeleton of *Paracyclotosaurus* (NHMUK PV R 6000), a very large Triassic temnospondyl amphibian, for many years on display in what is now Hintze Hall of the museum. The only known specimen was discovered in Australia in 1910, the skeleton encased in a shattered ironstone nodule consisting of over 50 blocks. As the nodule was too hard and brittle to remove, and the fossil bone poorly preserved and in some places missing completely, the decision was made to instead remove the bone entirely and use the negative impression inside the nodule as a natural mould from which to create a cast, a Herculean feat taken on by preparator Frank Barlow.

To dissolve the bone, a 15% solution of hydrochloric acid was used, leaving a series of natural moulds. A hot-melt compound (Vinamold HMC 1026) was poured into the cavities and withdrawn when set, reproducing the shape and details of the bones. The cavities had to be cast separately in adhesive—from the adhesive impression, a waste mould was made, from which a plaster positive was produced. This was trimmed until it fit the cast of the same bone from the counterpart; the two halves were then joined together and cast in a mould, from which the final replicas were produced (Figure 1). The preparator's lengthy and complex work creating this cast is highly praised in the published description of the species: "Barlow's work [on this specimen] covered many years, and I do not know of any other man who could have done it; it was a technical triumph" (Watson 1958: p. 236).

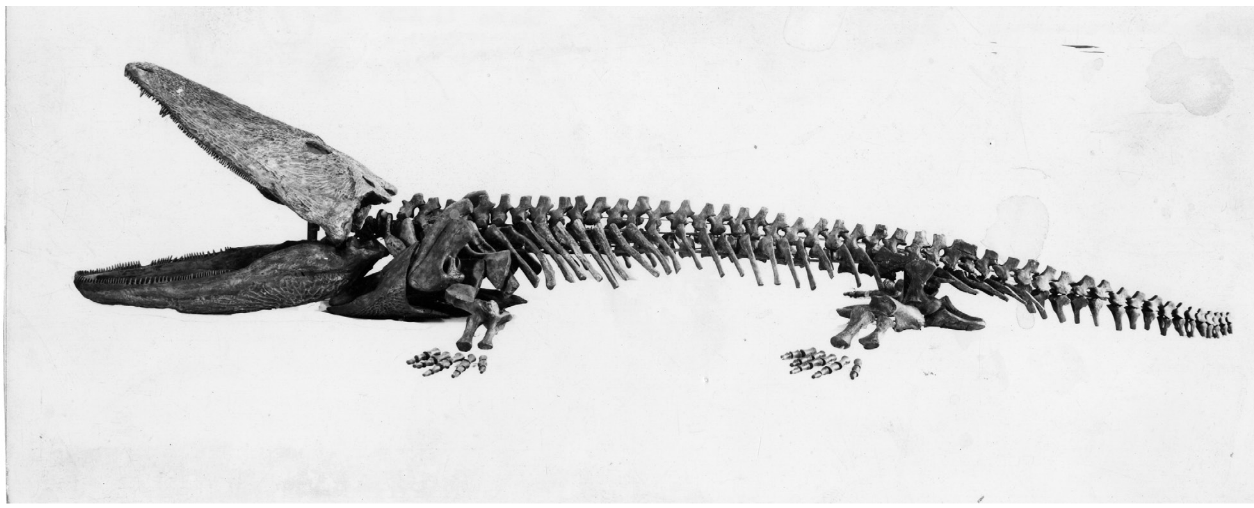

Figure 1. The 2.25-metre-long skeleton of Paracyclotosaurus*, painstakingly cast from natural moulds. Natural History Museum Archives, TCC-ARC-0826.*

Fossil preparation and conservation

While many aspects of the museum's work have changed through time, in essence, the techniques and processes of collecting and preparing fossils have remained much the same, and a palaeontology laboratory of today still shares much in common with those of the early 20th Century (Brown 2012). Materials and tools on the other hand have advanced significantly. Figure 2 shows a preparator in 1969 using a vibro-tool, which are still in use today but have been surpassed by modern pneumatic airscribes, the engineering tolerances of which allow for greater control (M. Graham, pers. comm. August 2020). The availability of adhesives and consolidants with a range of properties has also allowed for greater stabilisation of fossils (Davidson and Alderson 2009).

Figure 2. Judy Goodall preparing a fossil with a vibro-tool, 1969. Natural History Museum Archives, TCC-ARC-1702a.

Conservation practices have moved on from those depicted in the archives, with the modern Conservation Centre having a much greater focus on both specimen care and health and safety. Extraction and the use of PPE are notable additions to the everyday work of today's conservators, both notably lacking in the historical photographs. Figure 3 shows preparator Robert Parsons cleaning the *Stegodon*

Figure 3. Robert Parsons cleaning the **Stegodon** *skull, 1947. Natural History Museum Archives, TCC-ARC-1732a.*

skull (NHMUK PV M 3008) during restoration of the Fossil Mammals gallery in 1947 using a heavy duty brush; today this operation is carried out with a low-suction vacuum and a soft dusting brush of animal hair.

Mounting fossil skeletons for display has also changed relatively little, and a well-articulated specimen may find itself gracing the public galleries for more than a hundred years. Figure 4 is a print taken from a glass slide and is believed to be Louis Parsons (father of Robert) sometime between 1910 and

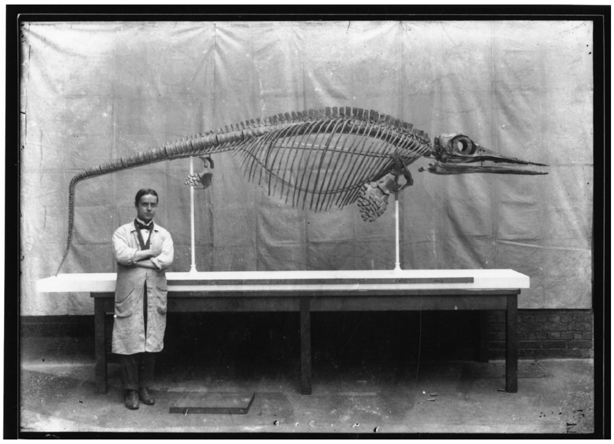

Figure 4. Louis Parsons with mounted **Ophthalmosaurus**, *date unknown but probably c. 1914. Natural History Museum Archives, TCC-ARC-1896.*

1914, years during which he restored and remounted this composite skeleton of the ichthyosaur *Ophthalmosaurus*. For more details about the early fossil preparators at the NHM (and the familial links that have often been present), see Graham (2019).

Out of the lab and into the field

The lab has been involved with fieldwork in the past, as shown by a wealth of photographs from a variety of fossil excavations. A series of images record the recovery of a plesiosaur (*Cryptoclidus*, NHMUK PV R 8621) from a quarry in Fletton, near Peterborough, in 1970. The dig attracted some publicity at the time and was visited by the crew of the long-running British television show, *Blue Peter* — presenter Peter Purves can be seen in Figure 5 crouching next to the fantastically well-preserved and nearly-complete marine reptile. The dig team included fossil preparator Ron Croucher, who was also present (along with a number of other members of lab staff) at another high-profile NHM excavation, that of the *Baryonyx* (NHMUK PV R 9951), the dinosaur collected from Ockley, Surrey, in 1983. As the most complete theropod dinosaur discovered in the UK, this was a major acquisition for the museum, and photographs relating to the recovery, preparation and casting for display of this one specimen number in the hundreds. Conservation staff assisted with the excavation of this specimen, and Ron Croucher led the preparation of the specimen and can be seen in Figure 6 with Dr. Angela Milner and Dr. Alan Charig (both dinosaur specialists at the NHM) looking at some of the prepared bones.

Figure 5. Blue Peter presenter Peter Purves (second from left) at the Fletton plesiosaur dig, 1970. Natural History Museum Archives, TCC-ARC-11790a.

Figure 6. Ron Croucher, Angela Milner and Alan Charig with Baryonyx *bones, 1986. Natural History Museum Archives, TCC-ARC-4236a.*

Moving giants

Relocating very large and heavy specimens at the museum can be a major undertaking, and one worth documenting. The museum's photography team has sometimes been on hand to capture these occasions, and the lab archives include photographic records of several such events. One example is the movement of the 350-million-year-old fossil tree to its current position on the museum's East Lawn in 1972. The tree (*Pitys withamii*), excavated from Craigleith quarry near Edinburgh in 1873, weighs an approximate 12.5 tons, so a crane was deployed for the move process (Figure 7).

The museum's iconic *Diplodocus* cast skeleton 'Dippy' (NHMUK PV R 8642) has undergone a number

Figure 7. The fossil tree being moved and positioned on the East Lawn, 1972. Natural History Museum Archives, TCC-ARC-2065.

of moves since arriving at the museum in 1905. A time-lapse film in the archives records the dinosaur being transported from the Fossil Reptiles gallery to take pride of place in the Central Hall in 1979, a position it would occupy for the next 38 years. One specimen can boast of an even longer run in this prestigious position: the taxidermic African elephant nicknamed 'George', which had pride of place in the hall for 72 years from 1907 to 1979—barring the occasional absence for specialist repairs. Figure 8 shows 'George' being transported through the main museum entrance in April 1927 to be sent to the taxidermists Rowland Ward Ltd. to remount the skin—note that the large ears have been tied back with rope, as they were too wide for the doorway (Snell and Parry 2009).

Figure 8. 'George' the elephant is manoeuvred out of the main entrance, 1927. Natural History Museum Archives, TCC-ARC-2123.

The digitisation project

Methodology

The initial phase of the project involved surveying and sorting the physical archive records to evaluate relevance and retainment and plan a project timeline. A file-naming convention was then established, with a standard prefix followed by a four-digit number; in conjunction with the master contents spreadsheet that would be updated in conjunction with the scanning process, this would allow specific images to be located quickly. Where images had written information on the reverse, both sides were scanned, with the two filenames given the suffix 'a' and 'b' to designate two sides of the same record. The workflow consisted of a rolling four days scanning records, followed by one day populating the spreadsheet with as much associated metadata as possible; fields chosen to record included media (e.g., "black and white photo"), specimen number, description of subject, names of individuals if present, description of event or process depicted, date the image was taken and date the image was scanned.

The last part of the project was a final reorganisation of the records, replacement of old or damaged storage media and the transferral of hard copies considered to be of particular historical importance to the main Museum Archives for long-term retention.

Digitisation

Some scanning trials were conducted in the preliminary stages of the project, testing different software and scanning at different resolutions to achieve a balance between high quality images and manageable file sizes; speed was also a factor, in order to maximise work done. The scanner used was an Epson Expression 1100 XL with Silverfast scanning software. The majority of images were scanned at 300 dpi, adjusted on a case-by-case basis in order to manage file sizes. The file format chosen was TIFF (Tagged Image File Format). One of the advantages of the TIFF format is that it is an uncompressed file type that features lossless compression, meaning that images can be resized without any loss of quality. TIFF files are also considered to have good longevity, as the widespread adoption of the format for scanned images means that there are a large number of programs that support TIFF files.

For the most part, minimal image correction was required—the Silverfast scanning program allows the user to make adjustments of lighting, contrast and colour balance during pre-scan. Minor cropping was occasionally required, again easily achievable during pre-scan. For the rare occasions where more intensive image correction was required—such as scans of X-rays, which needed more subtle alterations of lighting and contrast to produce a clear image—an image editing program was used (Digital Photo Professional).

In line with digitisation best practice (Horan 2013), in addition to the scanned images held on the museum server, a duplicate repository of all the scanned images has been kept on a hard drive, which has also been copied to cloud storage.

Results

By the end of the project, 4,606 individual images had been scanned, representing a complete digital record of the photographs, X-rays and negatives in the archives. The accompanying master contents spreadsheet contains as much associated metadata as could be gathered; the author is very grateful to a number of Conservation Centre and Earth Sciences staff who assisted with some of this information gathering, particularly in recognising faces of ex-museum staff.

Achieving a good quality scan of a photographic slide was deemed too time consuming (there were approximately 3,800 individual slides in the archive), so the decision was made instead to photograph them in sheets against a lightbox background. This provided a visual catalogue of what was present, accompanied by a contents list that was created to improve accessibility of the slide sheets.

During the course of the project the three filing cabinets were reduced to two, due to space being saved from the rationalising and re-organising of the contents, and disposal of some items (mostly obsolete product catalogues). In addition, eight boxes of material that were considered of most historical interest were sent to the main Museum Archives for long-term retention. Worn or damaged storage media such as slide hangers and protective sleeves were also replaced.

It is hoped that the digitisation of these records will greatly enhance their accessibility and research potential in the future. Some treatment images have already been added to the CMS to enrich specimen records, for example photographs of a specimen being recovered from the field or undergoing remedial treatment, and the ability to rapidly retrieve and view archive images has already proven beneficial. For example, the aforementioned photographs of the fossil tree move in the 1970s have been used by Conservation Centre staff to evaluate the possibility of moving the tree for a project to remodel the gardens at the NHM—the images show that the fossil extends underground by several metres and was embedded in concrete (aspects impossible to divine from surface level inspections), resulting in the decision to leave it in place. This knowledge not only saved a huge amount of time and money, but also prevented risk to the specimen itself.

Images associated with registered specimen numbers are currently being added to the CMS and through this to the NHM Data Portal (an online platform that makes research collections and data sets accessible to the public). Until then, some images will be available on request (email conservation@nhm.ac.uk).

Conclusion

Digitisation of the Conservation Centre historical archives was a necessary step in the preservation of these assets in the long-term, and will enable greater access to future users, as well as enhancing the value of specimen records. Images from TCC archives have enriched journal publications, public engagement talks, articles written for Evolve (the NHM member's magazine), blog posts and internal newsletters. Now that there is a digital repository of images to draw from, it is expected that they will be of much greater use in the future.

Many museums may have similar collections of archival records scattered across departments; digitising these records and consolidating them into a central image repository could maximise their usefulness. In addition, if records are made open access, this could have great public engagement potential (particularly the increasingly popular field of social history) and increase public interest in the sciences. While funding for such projects may not always be easy to obtain (Vollmar *et al.* 2010), it is advisable to carry out this work sooner rather than later, while the knowledge and expertise of experienced staff (who may have vital insights into the people and processes depicted) is available. Finally, digitisation mitigates risk—physical records may be vulnerable to floods, fire, 'vinegar syndrome' (Capell 2010) and general deterioration. Preserving them digitally increases the long-term survival chance of these records.

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NHM lab staff Mornington John Meade and Pat Hammond carrying out conservation work on an Edmontosaurus *specimen, 1949. Natural History Museum Archives, TCC-ARC-1772a.*

BOOK REVIEW

***Measures for Measure: Geology and the Industrial Revolution.* Mike Leeder. Published by Dunedin Academic Press Ltd, Edinburgh, 2020. UK £24.99, hardback, 272 pp. ISBN 978-1-78046-081-9.**

Measures for Measure is an organised and extensively researched approach to an extremely complex topic: How, why and to what extent did the geology of the British Isles play a role in the instigation and progressive development of the Industrial Revolution? Rather than answering this question outright in a series of narrative arguments, Leeder presents the insights and achievements of geologists, luminaries, inventors, engineers and natural philosophers of the 17th–19th centuries alongside our current interpretations of the chronological development of the Earth. In doing so, Leeder demonstrates the indisputable importance of the geology of the United Kingdom on multiple aspects of industrialisation, and we see this borne out in a series of key case-studies across the UK. This approach ultimately leaves us to decide for ourselves how geology stacks up against social, economic and political drivers of change. All of these are touched upon throughout the book but rarely in such a way as to pitch one against the other, or against geology.

Although today we perceive many disparate things as industrial, the focus of this book is the industrial revolution, the period of change that brought about industrialisation. Through the brilliant minds of the engineers who harnessed steam-power, Leeder presents coal and iron as the primary geological ingredients for industrialisation. These two materials are the dominant focus of the book—indeed "British Coal and Iron" could have been an alternative (but rather dry) title! Base metal mineralisation gets an occasional and important mention when relevant, but the mining focus is very much on the UK's once extensive collieries.

Not quite a popular science or history book, nor a purely academic publication, *Measures for Measure* sits in the gap between these two genres. The various histories presented are clear, easy to follow and told occasionally through the eyes of contemporary travellers on their various 'tours'. This inclusion allows the reader a perspective on how the industrial revolution felt at the time. Throughout the book there are significant digressions into art and poetry both from the time of the industrial revolution and later, inspired by it. It seems that not only is factual information important to Leeder, but also the less tangible feelings and emotions of those 'at the coal face' (pun intended). A subtle artistic nature underpins the book in Leeder's expansive use of the English language: I certainly learned a good word or three.

The geological portions of the book are detailed due to the complex evolution of the areas in question. The section is well-illustrated, but the extensive use of chronostratigraphic and geological terminology often without further explanation made these sections hard to follow. Being a mineralogist/geochemist, I certainly don't feel like I have done Leeder's hard work justice here, being unlikely to have extracted everything I should have from these sections on my first read through. I'm sure I will find myself returning to these parts as excellent summaries for reference.

The inclusion of the case-studies is a great way to bring the historical and geological narratives and assessments together, showing the breadth of the connections between UK geology and the social, economic, political and scientific aspects of the Industrial Revolution. There is understandably a little repetition from elsewhere in the book, but this just helps to drive the message home.

The book ends rather abruptly with no concluding remarks or comments, which may seem like a missed opportunity considering the current political importance and controversy over the continued use of fossil fuels. However, those who care to read the book carefully are left with little doubt as to Leeder's thoughts on this, and I am instead left wanting a new work exploring the role of geology in our transition to what might be the next big revolution, that of renewable energy. I can only hope that this is the next topic of interest for Leeder.

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GEOLOGICAL CURATOR

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The Geological Curator is the official journal of the Geological Curators' Group (GCG) and has been published by the GCG since its first issue in 1974. There are two issues per year: in June and December, available in both electronic and print format. The most recent content (last two years) is available to GCG members only. Funding for the publication is derived from GCG income (primarily membership fees). Issues older than two years are freely available from the GCG website (www.geocurator.org) via a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International Public Licence (CC BY-NC-ND 4.0: https://creativecommons.org/licenses/by-nc-nd/4.0/). Attribution should follow standard academic format, with the author(s) and year and link to a full reference. All accepted articles have been through peer review.

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