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MURALS, STONE, AND ROCK ART

Stuck like glue: Wood tar as a medieval stone adhesive

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Abstract
This study outlines a medieval stone repair technique involving wood tar. In the process of condition assessment, an unusual adhesive was identified used for repairs and indents on Stavanger Cathedral, a medieval Norwegian soapstone structure. Based on appearance and context, an initial hypothesis was formulated that tar may have been used as a historic repair method. This hypothesis was subsequently tested and confirmed through analysis. Samples of the adhesive were investigated using light microscopy, scanning electron microscopy with energy-dispersive spectroscopy, Fourier-transform infrared spectroscopy and gas chromatography–mass spectrometry. The material was radiocarbon dated and the date found to coincide with the reconstruction of the choir following a fire in the latter quarter of the 13th century. Several hundred findings of tar repairs have so far been identified on the cathedral, indicating comprehensive use of tar as a medieval adhesive for soapstone. These findings have implications for the development of an alternative conservation adhesive based on traditional materials.

INTRODUCTION

During routine condition assessment of Stavanger Cathedral, a medieval Norwegian soapstone building, a glossy and brittle black/brownish mass identified as an adhesive was observed between some stone joints on the façade. The analysis and investigation of this historic adhesive and repair method for soapstone will be outlined in this paper, and the implications for the use of this material as an adhesive will be considered.

A team of conservators, masons, stone carvers and researchers at the Museum of Archaeology in Stavanger are currently involved in a large ten-year restoration project on Stavanger Cathedral. Located in south-western Norway, Stavanger Cathedral has been in continuous use since its foundation in the Middle Ages and is Norway's best-preserved and most authentic stone cathedral, having undergone limited alteration over the past 900 years. An episcopal seat was established in Stavanger in 1125 CE, and this date is generally taken as the year the cathedral was founded, though the building was likely constructed in the first quarter of the 12th century (Stige 2013). The ongoing restoration project, funded by the municipality, is due to be completed by 2025 in time for the city and cathedral's 900th anniversary.

Stavanger Cathedral was constructed out of rubble stone for the underlying masonry and soapstone for the ashlar, decorative portals, window surrounds and sculptures. The cathedral consists of a combination of a Romanesque nave and Gothic choir. It was built on a modest scale, with a length of 65 metres, and has no transept. The nave includes two side aisles separated by arcades. These are formed by solid columns and arches topped with arcade capitals. A fire in 1272, recorded in the Icelandic *Annales Regii* (Storm 1888, 139), resulted in a subsequent Gothic building phase. This included the construction of a vestibule and a western entrance portal facing the fjord. In addition, the original Romanesque choir was replaced and two flanking towers raised at either end of the highly decorated east façade, which in medieval times would have faced the main road into Stavanger (Figure 1). Two smaller turrets form a transition between the Romanesque nave and the later Gothic choir. The choir's south portal is also known as the bishop's entrance and is elaborately decorated, repeating motifs found on the east façade. A number of carved heads are found inside the choir and on the façades. The choir's vaulted ceiling consists of five ribbed vaults, while the windows on the north and south façades consist of double-lancet windows topped by geometric tracery.

RESTORATION HISTORY

Figure 1. Stavanger Cathedral, as seen from southeast. Photo: Terje Tveit, Museum of Archaeology, UiS

Despite having changed minimally during the course of its lifetime, Stavanger Cathedral has not been exempted from change, having undergone several restoration schemes during the past few centuries. The first significant documented restoration phase took place during the 1860s–1870s under the leadership of the architect von der Lippe (Schjelderup 2008). During this restoration period, the originally narrow arch between the nave and choir was widened significantly, and a new roof was constructed over the nave. A large portion of the Renaissance inventory was removed, leaving only several epitaphs and the pulpit. The lime mortar joints were replaced with cement, and the majority of the medieval soapstone surfaces were dressed back or mechanically removed. The rubble stone walls were given a coating of cement. Stone carving work was also undertaken, with replacement of numerous soapstone profiles and carved elements. In addition, metal pins or cramps were used liberally during stone repairs, which would have consequences for future preservation.

The second restoration phase occurred during the early 20th century and concentrated on the interior, largely undoing von der Lippe's neo-Romantic and neo-Gothic contributions to the inventory (Schjelderup 2008). The building archaeologist Gerhard Fischer was engaged in the late 1930s and initiated the replacement of the cement coating on the rubble stone walls with a thinner plaster, in addition to undertaking extensive building archaeological investigations. Nevertheless, cement was still used as a mortar during this period. Fischer's archaeological research between 1939 and 1942, precipitated by the threat of war, was complemented by his wife Dorothea Platou's detailed measurements, which formed the basis for accurate drawings of the cathedral (Fischer 1964). On the east façade, new stained-glass windows were inserted during the 1950s, while a set of four sculptures were made for empty niches in the 1960s.

During the late 1980s and then again more extensively during the 1990s, Nidaros Cathedral restoration workshop (NDR) was engaged to undertake repairs on the soapstone exterior of the cathedral's choir. This partial restoration involved new carving and indents, as well as the use of a two-component polyester adhesive for repairs. In addition, lead sheeting was applied on some exposed profiles and surfaces as a protective measure. A few types of soapstone were used by NDR during that period, some of which have since proven unsuitable, as they only withstood weathering for thirty years before requiring replacement in the current restoration project due to extensive deterioration.

The current restoration project began in 2014, led by the architects Schjelderup and Gram, and is financed by the municipality as part of the preparations for the city's 900-year anniversary in 2025. The Museum of Archaeology is one of the subcontractors within this large project, with responsibility for all of the work on the soapstone exterior and interior. In this capacity, the project conservators have undertaken a condition assessment and proposed a range of conservation and restoration treatments with the aim of preserving the structure, authenticity and integrity of the building for the foreseeable future. As the cathedral is automatically protected by the Cultural Heritage Act, any interventions on the cathedral must be approved in advance by the Norwegian Directorate for Cultural Heritage. Cement mortar is being removed from all of the joints as part of the process due to moisture problems and resultant stone deterioration, and joints are instead being pointed with traditional slaked lime mortar. The use of iron pins during the earlier restoration schemes has resulted in corrosion and resultant rust fractures within the surrounding stone, often leading to the need for replacement. Deteriorated soapstone ashlars, mouldings, profiles and decorative stones are being replaced with new soapstone indents where necessary.

Figure 2. Medieval stone repair on Stavanger Cathedral. Photo: Bettina Ebert, Museum of Archaeology, UiS

AN UNUSUAL HISTORIC STONE REPAIR

During a recent condition assessment of the cathedral façades, an unusual attachment method for a stone indent was uncovered by the conservators (Figure 2). The stone in question was located in the window tracery in one of the bays on the south façade of the choir (Figure 3). The adhesive used on this indent was revealed because the stone had come loose during removal of the cement mortar from the surrounding joints as part of the repointing process. The method of attachment consisted of a black adhesive layer, a sample of which was taken for investigation. This adhesive sample has formed the basis of the current study. The black material had been neatly applied in an even layer a few millimetres in thickness, with a small

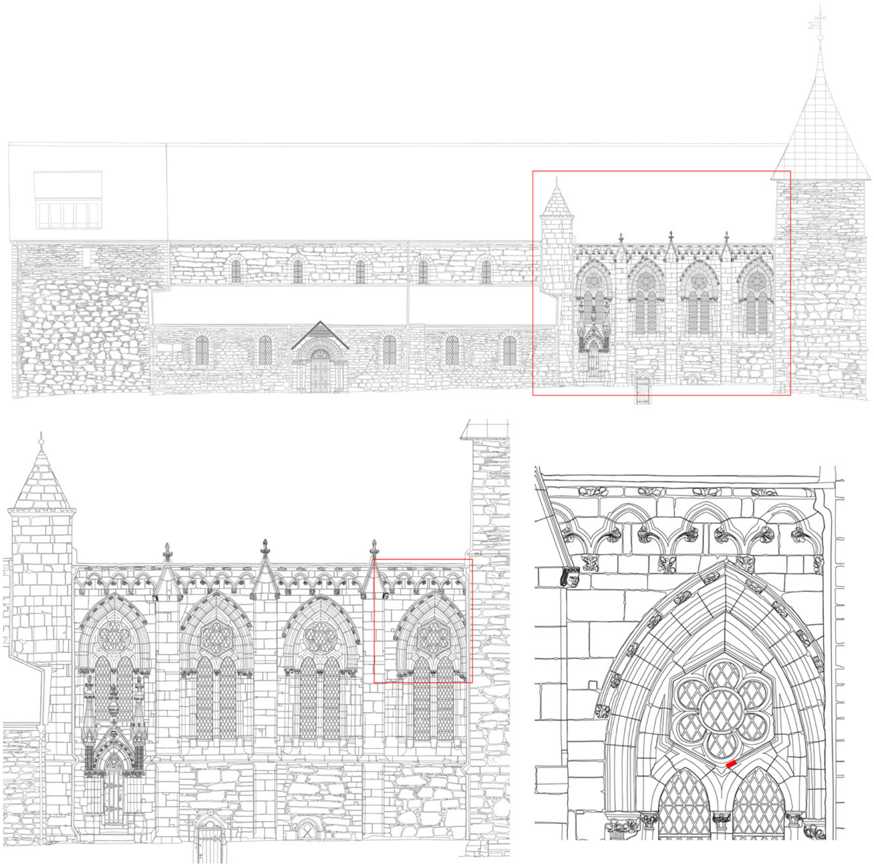

Figure 3. Location of the analysed indent with tar on the south façade of the choir, Stavanger Cathedral. Illustration: Museum of Archaeology, UiS

adhesive-free gap around all edges of the indent (Figure 4). The indent itself consists of two curved profiles within the hexagonal mouldings around the hexafoil window tracery.

Where the adhesive had been in contact with the surrounding stone, the blackish material was discoloured grey from the minerals in the soapstone, while the adhesive itself varied in colour from black to dark brown, with some reddish inclusions (Figure 5a). Wrinkling was observed in isolated areas. The nature and context of the find led to an initial hypothesis being formulated that it could be a historic tar-based repair. Since such repair methods had hitherto not been recorded on site, it was decided to develop a small research project around the topic.

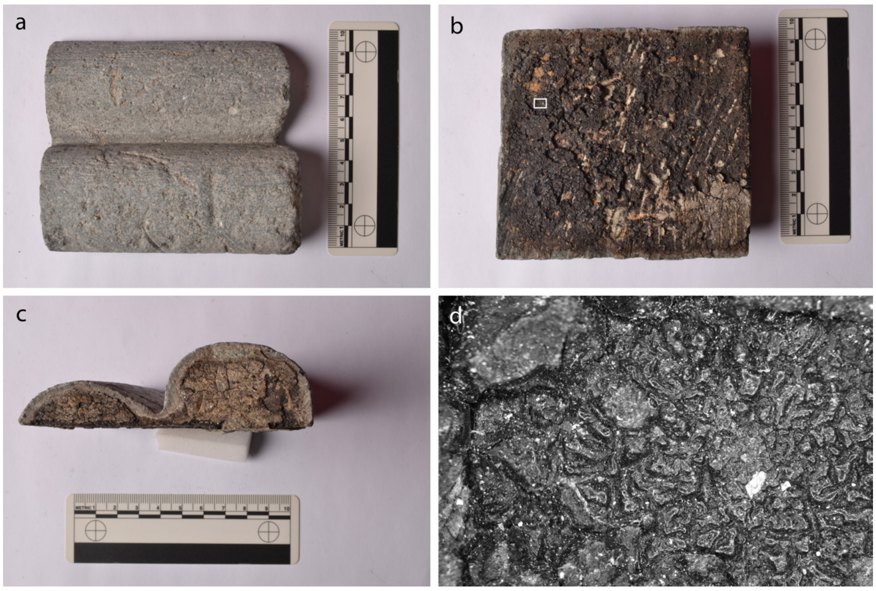

Figure 4. Soapstone indent with tar. Sample seen from (a) top, (b) bottom and (c) side, and a (d) detail of the adhesive layer seen in (b). Photos: Bettina Ebert, Museum of Archaeology, UiS

ANALYTICAL METHODS

A range of analytical methods were selected to characterise the organic and inorganic content of the historical adhesive sample. (1) Light microscopy with a Nikon SMZ25 was used to obtain the first detailed overview of a cross-section through the sample. (2) Fourier transform infrared (FTIR) spectroscopy was utilised to provide an initial confirmation of the organic content, for which a Bruker Alpha FTIR spectrometer with Platinum ATR (attenuated total internal reflectance) accessory was used. (3) Gas chromatography–mass spectrometry (GC–MS) was subsequently employed to characterise the organic content present in several samples. (4) The age of the adhesive was investigated to determine which restoration phase the repairs may be linked to. Radiocarbon dating was undertaken at the ^{14}CHRONO Centre at Queens University Belfast. (5) Scanning electron microscopy (SEM) was used to study inorganic material present in the sample, for which a Zeiss Supra VP35 scanning electron microscope, equipped with an energy-dispersive spectroscopy (EDS) system and a backscatter electron (BSE) detector, was used. The sample was sputter-coated with copper, and analyses were performed at an acceleration voltage of 20 kV.

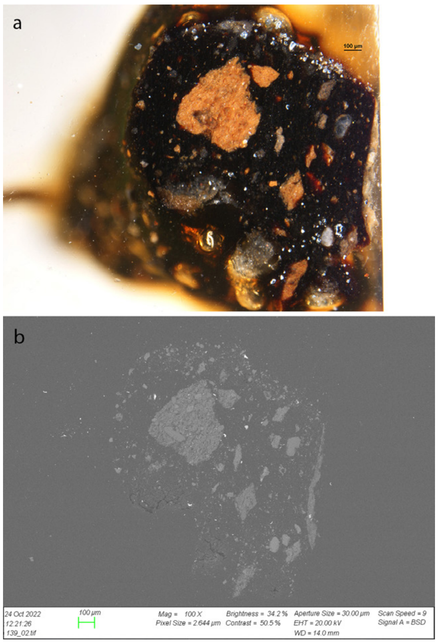

Figure 5. Cross-section of a tar sample viewed by (a) light microscope and (b) SEM–BSE. Photos: Bettina Ebert, Museum of Archaeology, UiS

INTERPRETATION OF RESULTS

The material appears to consist of an adhesive or binder, possibly with additives or bulking agents. FTIR confirmed the initial hypothesis of an organic resinous material. This was then followed up with GC–MS to characterise the organic components in the adhesive sample. The adhesive was identified as consisting of wood tar and possibly some pine resin, with a smaller proportion of beeswax (Stern 2021, Mazurek 2022). The tar was identified as of pine origin due to the presence of unique marker compounds typical for Pinaceae. Retene is one such marker compound that forms as a result of thermal degradation of resinous softwood, while dehydroabietic acids and a range of other resin acids are indicative of Pinaceae origin. Given that pine tar and pine resin are derived from the same material yet processed in differing ways, the two products have numerous shared marker compounds. Thus, whether diterpenoid markers detected in the samples are related to pine tar or pine resin or a combination of both is very difficult to determine. Consequently, the next steps will involve comparison of the historic material with a range of reference samples with known proportions of pine tar, pine resin and beeswax.

Following the identification of the organic content, radiocarbon dating was employed to determine the calibrated age of the adhesive sample. There is 95 percent probability that the pine tree from which the wood tar was derived dated to between 1044 and 1213 cal AD (2σ, IntCal20) (^{14}CHRONO Centre 2021). This early-medieval dating correlates well with construction of the Gothic choir after the city fire in 1272. Assuming that 100- to 200-year-old pine stumps were used for tar production, the wood tar adhesive could potentially have been applied to the indent for repair during the construction of the new choir in the late 13th century.

The inorganic content in the wood tar sample includes minerals and small pieces of bedrock (Figure 5). The SEM–EDS analyses show elemental peaks for iron, chromium, nickel, phosphorus, sulfur, silicon, calcium and aluminium. These peaks may be associated with soapstone debris. However, at this stage it cannot be excluded that the grains originate from other bedrocks as well. It is not clear whether the grains have been added for a special purpose or if they were incorporated during the adhesive process, or a combination of both.

IMPLICATIONS

The use of wood tar as an adhesive for architectural stone structures is hitherto undocumented. Historically, stone buildings have been repaired through the replacement of deteriorated or damaged stone with new stone, or the use of smaller indents, wherein only the deteriorated portion of a larger stone is replaced or pieced in (see also Griswold and Uricheck 1998, and Geological Society 1999, 405). Mortars, cements and adhesives have been used, often in conjunction with metal rods, to hold such indents in position. In more recent times, a range of adhesives have been employed for the gluing of stone, though again mostly in relation to stone sculptures or smaller monuments rather than in the built heritage sector. Adhesives used in the conservation of sculptural and architectural stone include, amongst others, shellac, wax, animal glue, mortars, plasters, cements, epoxy, polyester resins, acrylic resins and polyvinyl acetates (Griswold and Uricheck 1998, Podany et al. 2001, Jorjani et al. 2009).

Wood tars, often in the form of birch bark tar and pine tar, have been used throughout prehistory and history as adhesives and coatings (Pietrzak 2012, Langejans et al. 2022 and references therein). Birch bark tar has been identified as a residue throughout Europe on ceramic vessels for repairs, decoration and as a waterproofing and caulking method as well as an adhesive on flint tools (Junkmanns 2001, Nordby 2009, Morandi et al. 2018, Niekus et al. 2019). Pine wood tar has been used in much the same manner, though its use has had a wider geographic distribution.

One of the earliest identified uses of pine tar in Norway is from the Scandinavian Early Iron Age (Nordby 2009), while pine tar pits dating to the aforementioned period and the subsequent Viking period have been excavated in Sweden (Hjulström et al. 2006). Pine tar was widely manufactured and in common use during the medieval period in Scandinavia and the Baltic regions. It has been used extensively as a protective coating on Norwegian wooden stave churches (Egenberg 2003). The situation is similar in Sweden and Finland, where the material functions as a sacrificial coating for wooden buildings and roofs constructed from wooden shingles (Källbom 2015, Lindblad et al. 2021). In addition, pine tar found popular use as a caulking material for ships, also in more recent postmedieval periods (Loewen 2005). However, the use of wood tar to attach stone indents on buildings is hitherto unknown in the literature.

Successful adhesive formulations often consist of complex mixtures that may necessitate the use of bulking agents or other additives to modify the working properties. It is possible that pine resin was added to the tar for increased plasticity or to modify the workability of the adhesive in a different manner. Much like pine tar, pine resin was readily available in medieval Scandinavia. For example, heat-treated pine resin was applied over silver leaf in early medieval Norwegian altar frontals to replicate the appearance of gold leaf (Plahter 2004, 162). Beeswax has been employed throughout human history as an additive to adhesives since its low melting temperature allows it to function as a plasticiser and counteracts brittleness (Kozowyk et al. 2016, Langejans et al. 2022). Consequently, the identification of a small proportion of beeswax in the adhesive is unsurprising and points to an awareness of the need to adjust the rheological and working properties of the end product.

Following the initial find of the adhered stone investigated in this paper, nearly 250 additional indents, stones and repairs have since been identified that employ the same method of adhesion (Figures 6–8). These repairs range in size from a few centimetres to entire stone blocks making up the vaulted choir. They have been identified on structures linked to the Gothic rebuilding of the cathedral, both on the interior and exterior, with no such evidence on the Romanesque elements. Since the investigation of these finds on Stavanger Cathedral is as yet incomplete, it may be estimated that several hundred such instances remain to be documented, before expanding the research to other medieval stone structures in the region

Figure 6. Tar used as an adhesive for large blocks of soapstone in the choir's vaulted ceiling. Arrows indicate stones adhered with tar. Photo: Bettina Ebert, Museum of Archaeology, UiS

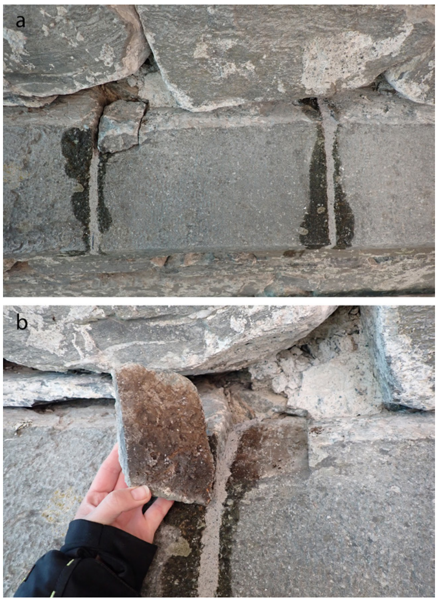

Figure 8. Indent with tar on the north tower's cornice, seen from (a) top and (b) bottom. Photo: Bettina Ebert, Museum of Archaeology, UiS

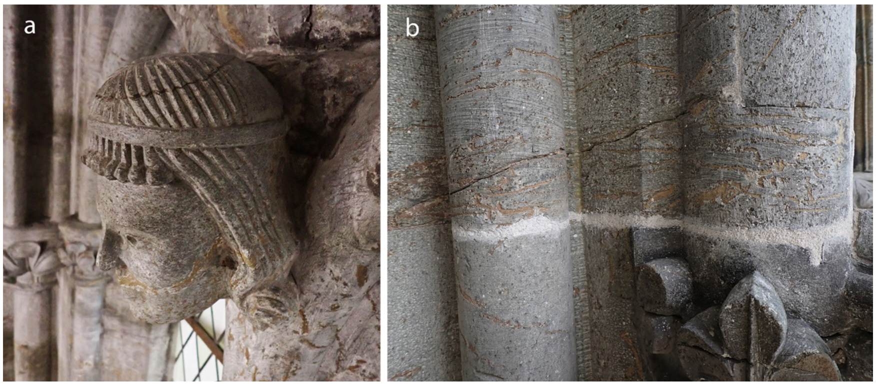

Figure 7. Use of tar to repair (a) a crack in the scalp of a sculptural head in the interior and (b) a large diagonal crack on the exterior of the choir's east façade. Photo: Bettina Ebert, Museum of Archaeology, UiS

and beyond. However, from the several hundred repairs identified so far, it is clear that tar was extensively used during the Gothic construction period as a method of repair for soapstone on Stavanger Cathedral. Due to its heterogeneous composition, one may assume that the soapstone used in construction was subject to minor damages during the carving and construction process, thus necessitating repair instead of carving an entirely new block. The technique is a unique glimpse into medieval approaches to stone repair and early restoration ethics. Given its ubiquitous presence in medieval Scandinavia as a protective material for wooden buildings and as a caulking material in shipbuilding, it seems logical that pine tar would also have been used as an adhesive in different, more unusual contexts on the western coast of Norway.

The use of wood tar for medieval indents and repairs on stone buildings offers numerous exciting avenues of research. Subsequent steps will involve mapping further evidence of the use of tar on Stavanger Cathedral and elsewhere. All documented instances of tar repairs will be subjected to detailed investigations for comparison purposes with the initial sample investigated in the current study. Further GC–MS and radiocarbon analyses are currently underway.

This project offers the possibility to develop an alternative conservation adhesive based on traditional materials and techniques as a potential replacement for the modern epoxies that are commonly used at present. To achieve this goal, the analytical results of historical tar samples will be used to replicate a tar adhesive for use in experimental archaeology. In collaboration with craftspeople engaged in traditional tar production, the historic recipe can be approximated and test blocks of soapstone adhered to demonstrate applicability of the technique. The replication will involve an experimental setup to test rheological and adhesive properties of the material. This will be combined with accelerated ageing for comparison with modern materials.

CONCLUSION

Wood tar was identified as an adhesive on numerous historical stone indents and repairs likely dated to the medieval construction period of Stavanger Cathedral. This would appear to indicate that minor adjustments and damages occurring during construction were repaired with a material in common use in Scandinavia during that period. The use of tar as a historical repair material on other stone buildings is currently unknown, but it has the potential for providing alternative methods for modern conservation/ restoration based on traditional techniques. This repair method will undergo testing through experimental archaeology as the project progresses.

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REFERENCES

^{14}CHRONO Centre. 2021. *Radiocarbon date certificate*. ^{14}CHRONO Centre, Queens University, UK.

Egenberg, I.M. 2003. *Tarring maintenance of Norwegian medieval stave churches*. Gothenburg: Acta Universitatis Gothenburgensis.

Fischer, G. 1964. *Domkirken i Stavanger: kirkebygget i middelalderen*. Oslo: Dreyer.

Geological Society. 1999. Stone repair and restoration. In *Stone: Building stone, rock fill and armourstone in construction*, ed. M. Smith, Engineering Geology Special Publications, 16(1). London: Geological Society. DOI:10.1144/GSL.ENG.1999.016.01.10.

Griswold, J. and S. Uricheck. 1998. Loss compensation methods for stone. *Journal of the American Institute for Conservation* 37(1): 89–110.

Hjulström, B., S. Isaksson, and A. Hennius. 2006. Organic geochemical evidence for pine tar production in middle Eastern Sweden during the Roman Iron Age. *Journal of Archaeological Science* 33(2): 283–294.

Jorjani, M., G. Wheeler, C. Riccardelli, W. Soboyejo, and N. Rahbar. 2009. An evaluation of potential adhesives for marble repair. In *Holding it all together: Ancient and modern approaches to joining, repair and consolidation*, eds. J. Ambers, C. Higgitt, L. Harrison, and D. Saunders, 143–149. London: Archetype Publications.

Junkmanns, J. 2001. *Vom „Urnenharz“ zum Birkenteer: der prähistorische Klebstoff Birkenpech*, Tugium: Jahrbuch des Staatsarchivs des Kantons Zug, des Amtes für Denkmalpflege und Archäologie, des Kantonalen Museums für Urgeschichte Zug und der Burg Zug, 17, 83–90.

Källbom, A. 2015. *Tjära på trätak*. Mariestad: Hantverkslaboratoriet.

Kozowyk, P., G. Langejans, and J. Poulis. 2016. Lap shear and impact testing of ochre and beeswax in experimental Middle Stone Age compound adhesives. *PLoS ONE* 11(3). DOI:10.1371/journal.pone.0150436.

Langejans, G., A. Aleo, S. Fajardo, and P. Kozowyk. 2022. Archaeological adhesives. In *Oxford research encyclopedia of anthropology,* 1–54. Oxford University Press. DOI:10.1093/acrefore/9780190854584.013.198.

Lindblad, L., N. Fredriksson, and A. Källbom. 2021. Challenges in pine tar production and practices for sustainable preservation of Swedish wooden heritage. In *Earthen and wood vernacular heritage and climate change*, ed. M. Dabaieh, 128–133. Lund: ICOMOS.

Loewen, B. 2005. Resinous paying materials in the French Atlantic, AD 1500–1800. History, technology, substances. *International Journal of Nautical Archaeology* 34: 238–252.

Mazurek, J. 2022. *GC/MS analysis report*. Materials characterisation report, Getty Conservation Institute, USA.

Morandi, L., S. Porta, and E. Ribechini. 2018. Evidence for birch bark tar use as an adhesive and decorative element in the early Iron Age central Italy: Technological and socioeconomic implications. *Archaeometry* 60(5): 1077–1087.

Niekus, M., P. Kozowyk, G. Langejans, D. Ngan-Tillard, H. van Keulen, J. van der Plicht, K. Cohen, W. van Wingerden, B. van Os, B. Smit, L. Amkreutz, L. Johansen, A. Verbaas, and G. Dusseldorp. 2019. Middle Paleolithic complex technology and a Neandertal tar-backed tool from the Dutch North Sea. *Proceedings of the National Academy of Sciences* 116(44): 22081–22087.

Nordby, C. 2009. Continuity or change? The use and function of birch bark tar in Norwegian Early Iron Age grave contexts. In *Holding it all together: Ancient and modern approaches to joining, repair and consolidation*, eds. J. Ambers, C. Higgitt, L. Harrison, and D. Saunders, 54–60. London: Archetype Publications.

Pietrzak, S. 2012. *Wood tar in the Dnieper and Elbe communities: VI–II millenium BC*. Baltic-Pontic Studies 17. Poznań: Adam Mickiewicz University.

Plahter, U. 2004. *Painted altar frontals of Norway 1250–1350. Volume 2: Materials and technique*. London: Archetype Publications.

Podany, J., K. Garland, W. Freeman, and J. Rogers. 2001. Paraloid B-72 as a structural adhesive and as a barrier within structural adhesive bonds: Evaluations of strength and reversibility. *Journal of the American Institute for Conservation* 40(1): 15–33.

Schjelderup, H. 2008. *Stavanger domkirke og bispekapellet – oversikt over bygningsmessige arbeider 1125–2008*. Stavanger: Stavanger kommune.

Stern, B. 2021. *GC/MS analysis report*. Materials characterisation report, University of Bradford, UK.

Stige, M. 2013. Stavanger domkirke – den menneskelige katedralen. *Stavangeren* 22(3): 53–64.

Storm, G. 1888. *Islandske Annaler Indtil 1578*. Christiania: Grøndahl & Sons.

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