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Preparation of asphalt-preserved fossils: Solvent selection and improved preparation technique with a focus on Rancho La Brea, California, USA

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ABSTRACT

Developing efficient preparation techniques is essential in augmenting paleontological collections. Preparation practices for asphalt-preserved fossil specimens are specialized, not widely known, and poorly documented. Here we describe the results of a comparative investigation into preparation materials and methods from the lagerstätte Rancho La Brea in Los Angeles, California: the first comprehensive technical report regarding asphaltic fossil preparation. Degreasing solvents are required to remove asphaltic sediments from fossils. We evaluated the efficacy of six solvents, AeroTron™-100, 2-butoxyethanol, (+)-limonene, Ecolink™ 1171, Novec™ 73DE, and 1-bromopropane, based upon the following criteria: health and safety, ease of surface asphaltic matrix removal, resources used, changes in color and mass, odor, and fossil integrity. Post-preparation effects on specimen integrity were assessed, with asphalt exudation, surface damage, visible deterioration, and surface appearance determined as indicators of degradation over time. Two solvent application methods, soaking (complete immersion) and manual (targeted matrix application), were compared. According to these results, successful solvents for asphaltic preparation are degreasers with a vapor pressure ranging from 100–300 mmHg, with Novec™ 73DE as the preferred solvent from this study. Manual preparation had less negative impacts on specimen integrity than soaking. Morphologically complex fossils (canid crania) were included to compare soaking versus manual preparation techniques with the best performing solvents. Manually prepared crania retained supportive internal matrix and had less fragmentation, leading to improved specimen stability when compared to soaked crania. These results are not only applicable to Rancho La Brea but can also be considered for other asphaltic localities globally.

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GLOSSARY

Asphalt: a thick and viscous liquid that is a naturally occurring byproduct of crude oil

Canid: a mammal of the dog family

Damaged areas: Cracks or fractures present in fossil specimens due to preservation conditions

Degreasing solvent: A chemical that dissolves heavy oils and greases such as asphalt

Femur: Upper thigh bone

Hazardous material: A material that can cause damage to human health or the environment

Integrity: Condition of being whole, stable, and/or unbroken

Matrix: The sedimentary material surrounding fossils

Metapodial: A long bone in hands and feet between the wrist/ankle and fingers/toes

Morphology: The shape and form of bones

Permineralization: A type of fossilization caused by water-carried mineral deposition into spaces in an organism

Preparation: The process of exposing fossil features from matrix and ensuring long term stability

Residual: Anything remaining after the original material has been removed

Tar Pit: An informal general term for a fossil deposit created by asphalt

Unfused sutures: Spaces between cranial bones that are closely enmeshed but remain separated during early life, eventually bonding together during an animal's life

Vertebra: Bone in the spinal column (backbone)

INTRODUCTION

Rancho La Brea (RLB) is a Late Pleistocene fossil locality in Los Angeles, California that has yielded over 3 million specimens (Friscia et al., 2008). The locality sits above the Salt Lake Oilfield, where Miocene-aged hydrocarbons migrated upwards from the Puente Formation reservoir during the late Quaternary (Critelli et al., 1995). The geological context at RLB comprises a series of asphaltic deposits containing fossil material in a matrix of alluvial gravels, sands, silts, and clays from the Santa Monica Mountains (Woodard and Marcus, 1973). These deposits are periodically infiltrated with liquid asphalt that entraps organisms, preserving biological material such as bones, mollusk shells, arthropod chitin, and botanical remains (Stock and Harris, 1992).

The majority of curated RLB fossils are bones of large mammals and birds (Stock and Harris, 1992). Permineralization, a common method of fossilization, is typically absent at RLB because oily asphalt prevents water-mediated mineral deposition. Due to the nature of asphaltic preservation, the process of removing asphalt and liberating fossils from encasing matrix presents challenges (Rice et al., 2015). Traditional mechanical preparation techniques (e.g., air scribes) have limited application. The asphalt obscures the visual distinction between bone and sediment, matrix tends to curl instead of flaking off, vibrations from the tool expand pre-existing cracks, and there are often an abundance of smaller fossils embedded in the surrounding sediment that can be damaged. Chemical preparation with degreasing solvents is the most effective approach; solvents dissolve hardened asphalt, allowing for the removal of matrix with minimal mechanical effort. As knowledge of chemical hazards and legal restrictions evolved, different degreasing solvents have been introduced over the decades at RLB. In the 1910s, heated kerosene was used to remove the asphaltic matrix (Shaw, 1982). 1,1,1-trichloroethane was adopted in 1969, although by the late 1990s it was phased out for 1-bromopropane (nPB) due to human health concerns and environmental impacts (Rice et al., 2015). Historically, fossils were prepared through soaking, a practice in which the specimen is completely submerged in solvent (Figure 1). Soaking dissolves asphalt to the saturation point of the solvent, separating asphalt-bound unconsolidated sediments and typically removing all matrix from the bone. No archived preparation documents exist, and formal investigations comparing preparation outcomes were never conducted. The lack of preparation data limits conclusions about past solvent effects on fossil bone. However, common conditions that are observed in historically prepared fossils in the collection include warping, cracking, crumbling, and asphalt exudation.

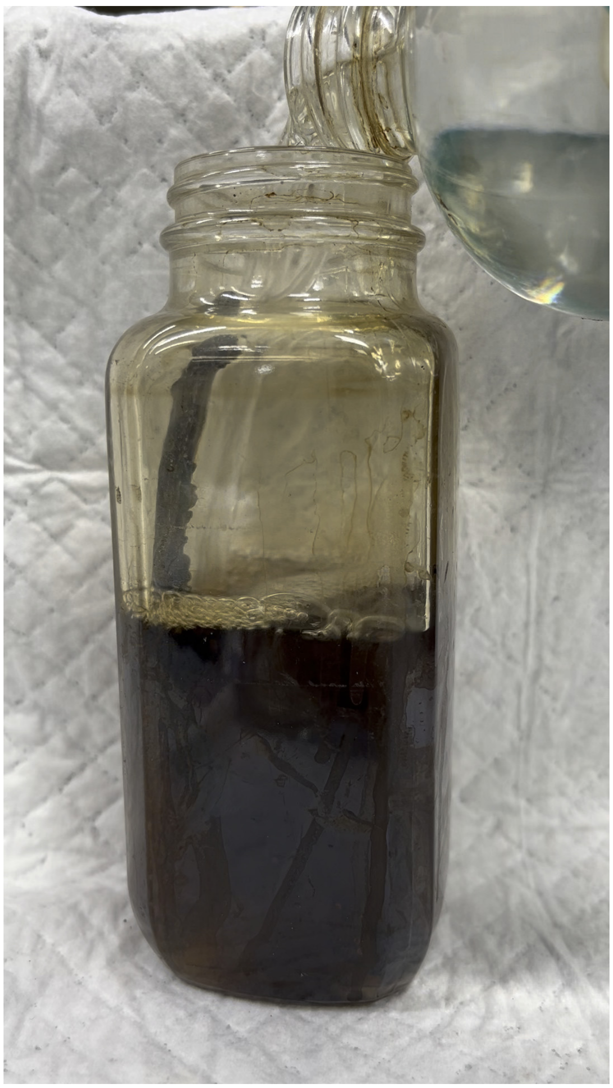

FIGURE 1. The soaking process of a rib of *Aenocyon dirus* (LACMP23-46765) with 200 mL Novec 73DE (to see animation https://palaeo-electronica.org/content/2025/5500-asphaltic-preparation-methods.

In 2017 it was well established that RLB preparation consisted of soaking fossils in ambient temperature nPB. Specimens were submerged in sealed glass containers of nPB and left to soak for ~16 hours in a designated chemical room with extraction ventilation. Fossils and their associated matrix material were decanted through a 0.85 mm mesh screen and lightly rinsed with unused nPB to remove liquefied asphalt and separate matrix. Subsequently, the fossils were left to dry and off-gas overnight. Specimens were then transferred to the lab for post-soaking preparation related to any residual re-solidified asphalt remains.

While this technique was effective in removing matrix and exposing morphological features with minimal mechanical effort, there were several concerns. The California Division of Occupational Safety and Health permissible exposure limit (Cal/OSHA PEL) of nPB is 5 parts per million (ppm), requiring greater engineering controls (such as ventilation) and more stringent personal protective equipment (PPE), especially when working with the volumes of solvent used in soaking at RLB. Additionally, several negative fossil impacts were observed with nPB soaking. In certain cases, internal asphalt migrated to the surface in a process colloquially termed “oozing” or exudation, which could continue indefinitely and be difficult to mitigate. The supportive internal matrix was indiscriminately removed during soaking, often fragmenting and separating specimens at sutures and cracks. Soaked fossils also presented concerning signs of bone dehydration, warping or cracking of thin bones (e.g., dental alveoli, avifauna material, and mammal scapulae), disassociation of intracranial osteology (e.g., nasal turbinates and auditory ossicles), and a loss of taphonomic indicators (e.g., geological and depositional context). These concerns prompted this study of alternative solvents and a more controlled preparation method, as considerations of fossil integrity are a guiding force when adopting new methods and materials (Rodrigues et al., 2023).

Solvent Selection

The ideal nPB replacement solvent would promptly dissolve asphalt to soften matrix, minimize impacts to fossil material, leave no residue, and be readily workable (safe to handle, liquid at ambient temperature, with low viscosity and surface tension for wettability). Solvents with more working restrictions than nPB, such as increased health and safety concerns, were not considered in order to avoid creating the additional conse-

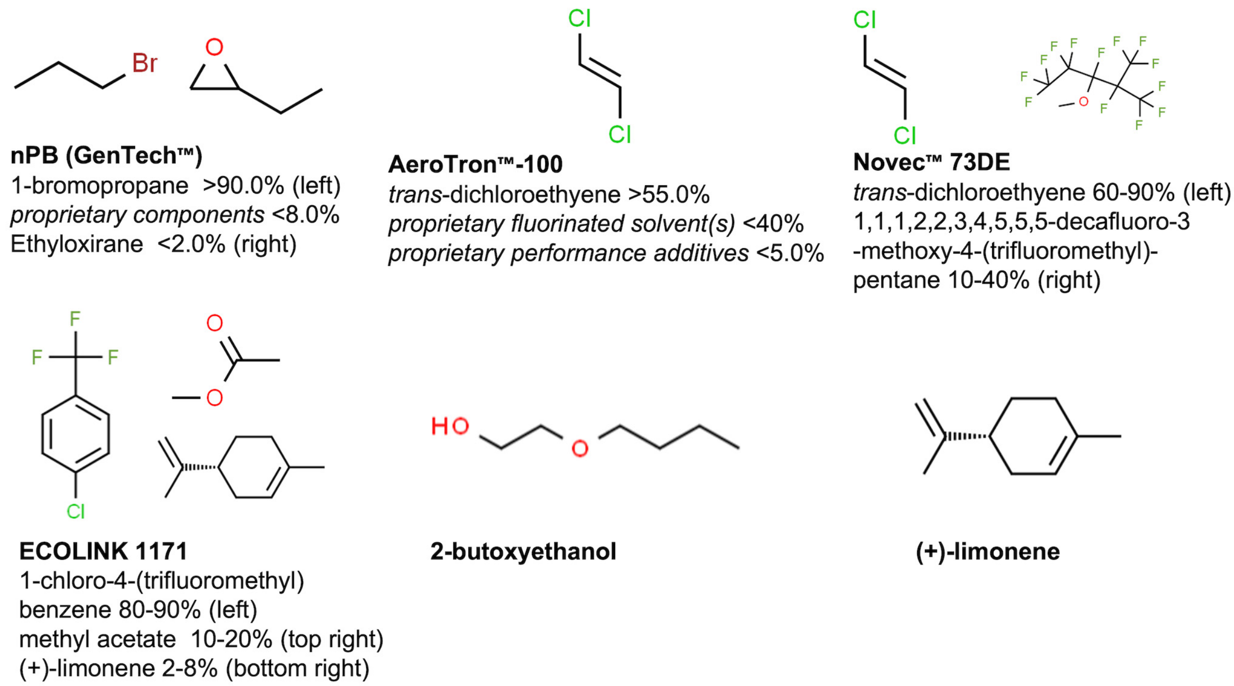

FIGURE 2. Chemical structures of solvents used in the experiment. Trade name in bold, with chemical nomenclature for each below. Undisclosed proprietary components are listed in italics.

quences of only focusing on cost and performance (Tickner et al., 2019).

Five industrial solvents widely used for degreasing purposes were selected: AeroTron™-100, Novec™ 73DE, Ecolink™ 1171, 2-butoxyethanol, and (+)-limonene (Figure 2). AeroTron™-100 and Novec™ 73DE are listed as nPB replacements that are proprietary industrial blends from Reliance and 3M, respectively, based on *trans*-1, 2-dichloroethylene and fluorocarbons. Ecolink's proprietary blend, Ecolink™ 1171, and 2-butoxyethanol are used in art conservation and were suggested by an independent art conservator. A natural derivative of orange oil, (+)-limonene, has a history of use in RLB excavations for cleaning metal tools used in asphalt removal. The investigated solvents could all be used safely, provided that adherence to prescribed health and safety measures, such as working at ventilated stations and wearing proper PPE, were followed. All of the tested solvents had Cal/OSHA PELs higher than nPB (5 ppm), decreasing health and safety concerns for prolonged use. AeroTron™-100, Ecolink™ 1171, and Novec™ 73DE all have a Cal/OSHA PEL of 200 ppm, while 2-butoxyethanol and (+)-limonene do not have Cal/OSHA listed PELs.

The selected solvents provide a range of chemical properties that facilitate the identification of useful qualities for asphaltic fossil preparation (Table 1). Most degreasing solvents have a low viscosity and surface tension to allow the solvent to penetrate complex morphology and effectively remove oils from surfaces (Kanegsberg, 1998). The investigated solvents have high vapor densities, which assists in limiting exposure to fumes while working. Three of the solvents, AeroTron™-100, Novec™ 73DE, and nPB, are halogenated vapor degreasing solvents that are designed to perform in the vapor phase to saturate and remove greases and oils in vapor degreasing machines. These solvents have low residues (<10 ppm), with Novec™ 73DE as the lowest (0 ppm) from the study group (Reliance Specialty Products, Inc., 2015, 2017; 3M™, 2023). Ecolink™ 1171, 2-butoxyethanol, and (+)-limonene are used as liquid hand-wipe or spray grease removers and are classed as low volatile organic compound emitters. Ecolink™ 1171 has no quantified residue amount listed but is advertised as leaving no residue (ECOLINK, 2024). 2-butoxyethanol has a ≤ 200 ppm residue after evaporation in product specification testing (ThermoFisher Scientific, 2024). (+)-limonene leaves slight residues, showing an affinity for hydrocarbon polymers in testing (LeMay, 1993). Volatility, as expressed through vapor pressure, ranges from 15.8 mmHg for 2-butoxyethanol to

TABLE 1. Summary of source, typical industrial use, and chemical properties for all solvents tested. (a) mmHg at 25° C, (b) centipoise/second at 25° C, (c) dyn/cm at 25° C, (d) air = 1. Asterisks (*) are values at 20° C, nd is not determined, and nl is not listed. All chemical properties are from SDS and technical data provided by the manufacturer.

Name	Source	Typical Use	Vapor pressure (mmHg)	Viscosity (cP)	Surface tension (dyn/cm)	Relative vapor density (air = 1)	Residue	Cal/O SHA PEL
AeroTron™-100	Reliance	vapor degreaser	395.2	0.49	19.5	5.2	<10 ppm	200 ppm
Novec™ 73DE	3M	vapor degreaser, liquid degreaser	263*	0.384	19.9	5.2	0 ppm	200 ppm
Ecolink™ 1171	Ecolink	liquid degreaser	44.1*	nd	nd	>5	nd	200 ppm
2-butoxyethanol	Consolidated Chemical & Solvents	solvent for varnishes, lacquers, etc.	0.874	2.9	27.4	4	nd	nl
(+)-limonene	Various, 99-100%	liquid degreaser	1.98	0.85	26	4.7	nd	nl
1-bromopropane	Reliance	nPB vapor degreaser	134	0.5	26.1	4.3	<10 ppm	5 ppm

395.2 mmHg for AeroTron™-100. Vapor pressure is positively correlated with volatility (Mackay and van Wesenbeeck, 2014) and, for fossil preparation, influences the working time of the solvent and the potential for residues in porous osteological material.

Preparation Techniques

An alternative technique, manual preparation, was developed to mitigate the negative impacts of soaking on fossils. The focus of manual preparation is to remove surface matrix that impedes visibility of morphological features, while retaining internal asphalt and matrix for structural stability. Rather than soaking the entire fossil in solvent, manual preparation uses modest volumes of solvent applied to targeted areas with hand tools (Figure 3). This technique enables preparators to better manage the process of removing matrix from a specimen, providing more spatial and temporal control than soaking.

Overview of Investigations

Two parallel studies evaluated the impacts of these alternative solvents and methods: (1) solvent and (2) cranial preparation investigations. By running in tandem, results could be compiled more efficiently and allow for broader conclusions. The solvent investigation tested the matrix removal efficacy and compared the impacts to fossil condition in response to these six solvents with both soaking and manual preparation techniques. Common and representative taxa and elements at RLB were used to investigate impacts on bones representing differing densities and forms: avian femora, canid metapodials, and canid vertebrae. Avian bones are hollow with thin cortical bone and a delicate internal trabecular network compared to the more solid and dense bone structure of mammals. Canid metapodials are relatively sturdy fossils with simple morphology that typically have less surface matrix to remove. Whereas canid vertebrae have complex shapes and foramina, offering insights into the applicability of manual preparation for a range of fossil forms. To further investigate the feasibility of manual preparation on morphologically complex and delicate fossils, canid crania were manually prepared and compared to previously soaked fossils. Soaking is particularly damaging to crania; noted impacts include loss of intracranial osteology

FIGURE 3. The manual preparation of an Aves synsacrum (LACMP23-45449) at 8x speed (to see animation https://palaeo-electronica.org/content/2025/5500-asphaltic-preparation-methods).

and supportive matrix in braincase and nasals, as well as fragmentation and separation between unfused sutures and damaged areas. Crania are regularly studied and handled, emphasizing the need for preparation methods that preserve and stabilize fragile morphological features.

METHODS AND MATERIALS

Preparation Materials and Techniques

Health and Safety. All work with chemicals was conducted following protocols based upon safety data sheets and Cal/OSHA requirements. Personal protective equipment (PPE) included lab coats, safety glasses, and nitrile or neoprene gloves. All small volume (<60 mL) solvent work was performed with extraction ventilation. For large volumes of solvent (>60mL), work was performed in a designated chemical room with a full-face respirator (Honeywell, North® 7600) and appropriate organic vapor cartridges (Honeywell, North® Multi-Gas/P100 75SCP100L).

Manual Preparation. Manual preparation prioritizes retention of internal matrix through the targeted application of small volumes of solvent (Figure 4). Hand tools, used with solvents and Paraloid B72, included: 6.2 cm bamboo toothpicks (Kitchen Essential), double tipped cotton swabs (SEGMINISMART), 4.5” orange wood manicure sticks (BTYMS), synthetic filament paint brushes (Royal & Langnickel, Golden Taklon Round Brushes), 7.5 mL polyethylene bulb droppers (McMasterCarr, 7029T1), and polyurethane foam swabs (McMaster-Carr, small round tip: 6111T2, conical round tip: 6111T3, large round tip: 7074T55) (Figure 5). All fossils were prepared under a Vision Luxo Wave LED 3.5D magnifier in front of extraction ventilation using small aliquots of solvent (20–60 mL).

For large areas of matrix (>2 cm wide and >1 cm deep), 1–5 mL of solvent were applied using a bulb dropper to soften the asphaltic matrix. Matrix was liberated through nudging with a solvent-saturated foam swab or applying gentle force parallel to the bone surface with wooden tools. For smaller areas of matrix, gentle nudging or brushing with solvent-dipped foam swabs and paint brushes was used to soften and remove matrix. Final detail work used foam swabs, cotton swabs, paint brushes, and toothpicks to clear asphalt and remaining matrix. Once the desired asphalt and asphaltic matrix was removed, residual clay and silt were cleaned using foam swabs, cotton swabs, and paint brushes with ambient temperature tap water.

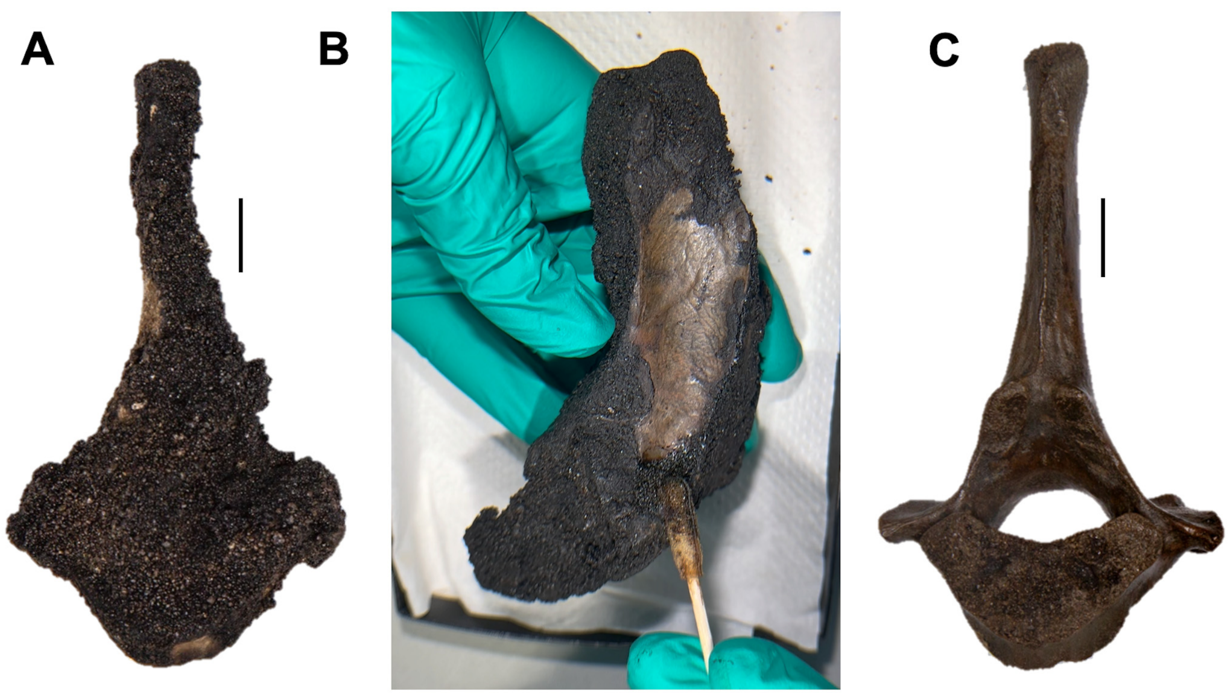

FIGURE 4. Manual preparation example with a thoracic vertebra of a juvenile *Aenocyon dirus* (LACMP23-38126). Scale bars are 1 cm. A) Before preparation, B) Example of manual preparation techniques on an Aves synsacrum (LACMP23-45449), using a foam swab on targeted area of matrix, C) After manual preparation.

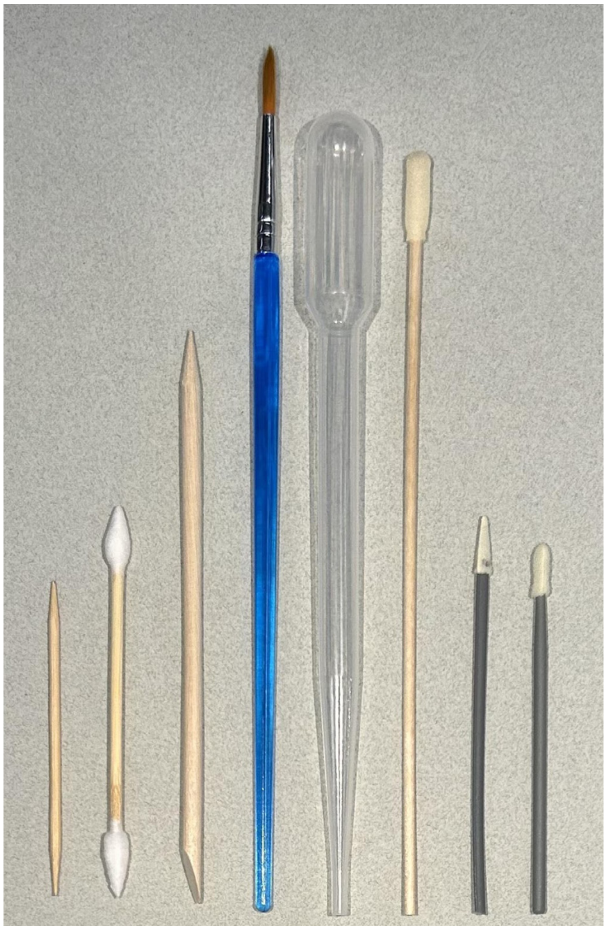

FIGURE 5. Hand tools used in preparation, from left to right: bamboo toothpicks, double tipped cotton swabs, wood manicure sticks, synthetic filament paint brushes, polyethylene bulb droppers, and polyurethane foam swabs.

After water preparation, metapodials, vertebrae and femora did not receive Paraloid B72 because it was desirable to observe uninhibited long-term effects of solvents on bone in response to ambient conditions like those in RLB collections. Cranial specimens were consolidated and repaired using Paraloid B72 (Talas, TFK028003) in acetone (Klean Strip) after solvent and water manual preparation.

Crania are oft-studied fossils, and the importance of preserving features was prioritized over long-term impact analysis. Cracks, fragile areas, and exposed matrix were consolidated using very thin (1:20 w/v) and thin (1:5 w/v) Paraloid B72 adhesive solutions (Davidson and Brown, 2012). Medium (3:4 w/w) and thick (1:1 w/w) Paraloid B72 solutions were used to repair specimens (Davidson and Brown, 2012). Paraloid B72 was applied with 60mL polypropylene dropper bottles (Grainger 6FAR5). After an overnight rest to allow Paraloid B72 to cure, excess Paraloid B72 was removed using paint brushes and foam swabs with acetone. For crania requiring additional support, archival Kozo paper (Talas, Uso Mino Thin 12 gsm TPB077001, Uso Mino 15 gsm TPB076001, and Hon Mino 30 gsm TPB168001) was used in concert with Paraloid B72 over breaks with limited contact area or areas requiring greater structural stabilization (Artal-Isbrand, 2018). Kozo paper was torn to fray edges, which offers more sustainable bonding. These frayed pieces were then positioned over the target area, after which thin Paraloid B72 was applied with a dropper bottle or paint brush until the paper was saturated. Foam swabs and paint brushes dipped in acetone were pressed into and rolled over the paper to ensure strong contact between the paper and bone.

Photography. All specimen photography was performed using a Canon EOS 6D camera with a Canon MP-E 65 mm 1–5x macro zoom full frame lens under fluorescent ambient lighting and two OttLite GX7911 lights on either side of the specimen. Six pre-determined angles (anterior, posterior, dorsal, ventral, left lateral, and right lateral) were photographed to ensure consistency of follow up imaging. Sandbags, pins, and clay blocks were used to support specimens as needed.

Solvent Investigation

Specimen Selection. Avian femora (n=12), canid metapodials *(Aenocyon dirus* n=12), and canid vertebrae *(A. dirus* n=12; *Canis latrans*, n=10; Canidae indet. n=2) were selected from a single deposit, Project 23 Deposit 14 (P23-14), to demonstrate solvent effects on various bone densities and structures. P23-14 had a high fossil output providing access to large quantities of unprepared material within specific taxa while presenting consistency regarding geological context such as asphalt saturation, sediment grain size, and taphonomic influences. Unprepared specimens were selected, to the greatest degree possible, to have similar amounts of asphaltic matrix coating and comparable specimen condition (i.e., unbroken, uncracked, and robust) to ensure consistency in matrix coverage and fossil integrity. For each solvent, two study groups were formed to compare soaking and manual preparation. Each group consisted of one avian femur, one canid metapodial, and two canid vertebrae.

Soaking Preparation. Specimens were soaked in ~250 mL of solvent for 24 hours, then drained over a 0.85 mm wire mesh screen and off-gassed over-

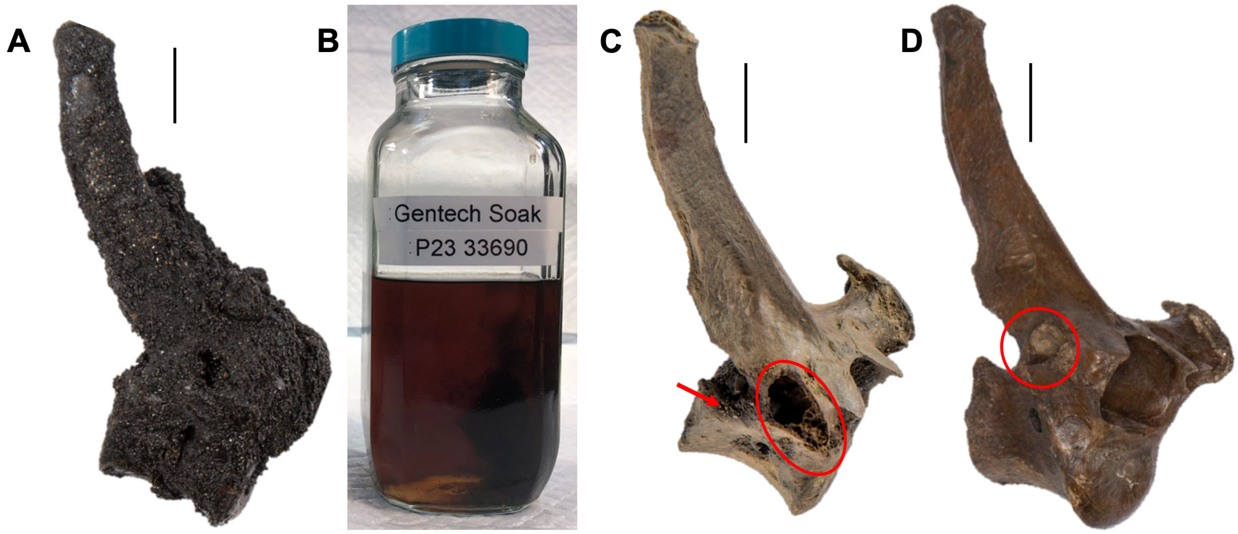

FIGURE 6. Soaked preparation example with a thoracic vertebra of *Canis latrans* (LACMP23-33690). Scale bars are 1 cm. A) Before preparation, B) Submerged in solvent, C) After soaking and off-gassing, D) After removing residual matrix with hand tools. The red arrow points to a spot of residual matrix present after soaking, and the red ovals highlight an exposed cavity that lost supportive interior matrix after soaking.

night in a designated chemical room with ventilation. Remnant matrix and exuded asphalt on specimens were removed by hand with foam swabs, cotton swabs, toothpicks, and paint brushes and the designated solvent, followed by ambient temperature water preparation (Figure 6).

Data Collection and Assessment. Preparation resources including the number of tools required was summed, and active work time was tracked and averaged by solvent and treatment method, excluding 24-hour soaking intervals. Photographs and observations of odor, color, mass, and fossil integrity were taken prior to treatment, during preparation, and monthly thereafter for a 9-month period to document potential long-term effects of solvent on specimens post-preparation. All visual assessments except for those regarding color were made with a Vision Luxo Wave LED 3.5D magnifier.

Odor: Lingering odors were understood to be indicators of solvent residue on the fossil. A single observer performed an olfactory test by holding fossils approximately 3 cm away from their nose and breathing normally for up to 5 seconds. All specimens were assessed monthly for the intensity of solvent odor only, ignoring the scents of asphalt and bone. Odor was coded in a range from no odor to very strong.

Color: Fossils from RLB show a range of colors and patterning. These changes in colors or patterning might indicate continued solvent action after preparation. Fossils were photographed and compared against Munsell soil color charts (Munsell Color, 2010). Notes were made about color distribution and pattern.

Mass: Specimens were weighed to gain insight into possible responses to ambient conditions or other effects based on solvents used. Masses were taken with an Ohaus CS2000 scale and an Escali Alimento digital scale. Each fossil was weighed three times on each of the scales to account for inconsistencies. Weights were averaged from each resulting mass.

Fossil Integrity: Surface appearance and damage were noted and photographed after preparation to create a baseline for monitoring changes over time. Reference photographs facilitated observations of damage sustained during preparation and over the 9-month observation period. Long-term effects included exuding asphalt (oozing) as an indication of unstable internal asphalt. Such instability of internal asphalt is undesirable for the permanent storage and care of fossil materials, reducing internal structural support, and leading to cracks and breakage. Cracking, crumbling, and dehydration or flaking bone were all considered to be visible indications of fossil degradation over time. These losses in fossil integrity have been previously observed in specimens housed within the RLB collection. All signs of structural change were noted and photographed.

Cranial Preparation Investigation

Specimen Selection. Canids are abundant in RLB and are good representatives for typical cranial preparation. Specimens were selected to create study groups for manual and soaking preparation. For the manually prepared group, 11 unprepared crania of *Canis latrans* and *Aenocyon dirus* from various deposits were prepared according to the manual preparation technique described above. These crania were selected from Pit 91 (n=1) and Project 23 Deposits 9 (n=5), 13 (n=2), and 14 (n=3) to determine the efficacy of the solvent on various matrix compositions. The pre-preparation condition of the selected fossils presented a variety of preservational conditions, from intact and complete, to partial, to crania excavated in multiple fragments (Figure 7). The first set of crania in this group were prepared with nPB (n=4, three *A. dirus* and one *C. latrans)* and later crania were prepared with Novec 73DE (n=7, six *A. dirus* and one *C. latrans)* once it was identified as the preferred preparation solvent. Specimens were photographed before and after preparation as described above.

The RLB curated collection contains previously prepared nPB soaked crania from P23 Deposits 1 and 9, excavated using the same techniques as employed with Deposits 13 and 14. Thirteen cataloged canid crania (five *Canis latrans* and eight *Aenocyon dirus)* were selected to form the soaked comparative group, to avoid unnecessarily soaking unprepared crania. Although no archived preparation data was available for these specimens, the general procedure at the time (2010s) was to submerge a specimen in nPB for several hours. The cranium was taken out, and if excessive matrix remained adhered to the specimen, it was re-submerged. Once the majority of the matrix was liberated, the specimen were rinsed with nPB and allowed to off-gas. Any remnant matrix was removed with hand tools and nPB. Fragments were repaired and consolidated with polyvinyl acetate (white glue). In 2016, attempts were made to remove the white glue with water and hand tools, followed by consolidation and repair with Paraloid B72 in acetone as described above. White glue has a long history of use in preparation but it is not an archival material; it chemically crosslinks, becoming brittle, unstable, and less reversible.

Data Collection and Assessment. The resources required to manually prepare a specimen were recorded. Labor was quantified by tracking manual preparation time. Solvent use was determined by measuring volume before and after preparation periods in a 50 mL graduated cylinder.

With such a small sample size, nPB versus Novec 73DE impacts on crania were not assessed in the same approach as with the solvent investigation. It is difficult to distinguish between taphonomic effects, damage during preparation, and post-preparation impacts on previously soaked fossils due to the lack of pre- and post-preparation photos and archived data. Soaked crania were also prepared and stored for over a decade before this

FIGURE 7. Crania manual preparation. Scale bars are 2 cm. A) Before (top) and after (bottom) preparation of a cranium of *Canis latrans* LACMP23-41926. B) Before (top) and after (bottom) preparation of a cranium of *Aenocyon dirus* LACMP23-41940.

study. Additionally, the initial repairs made with white glue and its subsequent removal and replacement with Paraloid B72 could have caused damage unrelated to preparation. Assessments were primarily based upon fragmentation and internal matrix retention in response to these factors.

Fragmentation was assessed by counting the number of repairs on prepared crania, with zero indicating that none were required. Fossils sustain damage during preservation, excavation, and preparation. To account for the unknown effects of taphonomy and excavation on soaked fossils, manually prepared specimens demonstrating a range of pre-preparation preservational states were selected. The fragmentation count represents all three sources of breakage; a difference between the average number of fragments per specimen for soaked and manually prepared fossils can therefore be attributed to preparation as specimens originated from similar deposits and were excavated with similar techniques.

Matrix retention is almost entirely related to preparation, with minor impacts from excavation technique or taphonomy. During asphaltic preservation, soft tissues decay while asphalt and matrix infiltrate cavities. Excavation techniques at RLB for deposits Project 23 and Pit 91 emphasize removing intact specimens and maintaining a preservative matrix layer to protect fossils during transport and storage. Removal of matrix adhering to bone, and especially in cavities, occurs almost exclusively during preparation.

Internal matrix was considered retained if it covered the cavity at the surface. Cavities were classed into four groups: major cavities, dental alveoli, foramina, and non-morphological cavities. Major cavities were nasal, braincase, and choanae. Matrix retention in dental alveoli was only analyzed in complete toothless sockets, excluding sockets with teeth, re-absorbed sockets, and partial sockets. Incomplete alveoli and foramina were included in non-morphological cavities, as in many instances, an area of wear or breakage spread over multiple foramina or alveoli. Non-morphological cavities were those areas that exposed the internal matrix or osteological morphology.

Bone conditions of warping, cracking, and dehydration were also recorded, although these conditions are less easily attributed to preparation than fragmentation and internal matrix retention. These bone conditions can occur taphonomically, during preparation, or during extended periods of storage without the support of archival adhesive and relevant conservation efforts. Warping was counted as individual areas of uplifted or depressed bone with displacement > 1 mm. Cracks were counted per cranial bone and tooth, with < 1 mm of separation classed as moderate and ≥ 1 mm as severe. Individual cracks were counted multiple times if they crossed multiple bones (e.g., if a crack transversed the right premaxilla to the right maxilla). Dehydration was observed as dry, flaky bone textures and counted per cranial bone and dental alveolus.

RESULTS

Solvent Investigation

As with any introduction of new chemicals into a collection, it was important to ascertain not only the solvents' usability for asphaltic matrix removal, but to assess impacts to the specimens both immediately post-preparation, as well as in the long term. Observations over a 9-month assessment period provided insights into the potential long-term effects of these solvents on fossil bone.

Ease of Surface Asphaltic Matrix Removal. For all solvents used in this study, matrix was more readily liberated from soaked fossils than those in the manual preparation groups. Ease of matrix removal was observed to be correlated with solvent volatility. During soaking trials the lower volatility solvents including Ecolink™ 1171, 2-butoxyethanol, and (+)-limonene required longer intervals to dissolve asphalt than the more volatile AeroTron™-100, Novec™ 73DE and nPB (Figure 8). These low volatility solvents dissolved asphalt slowly, taking several seconds to minutes to turn brown. Solvents with higher volatilities (>100 mmHg) such as AeroTron™-100, Novec™ 73DE and nPB immediately turned dark brown to black when solvent was added in soaking trials, indicating rapid asphalt dissolution. These observations were echoed in manual preparation; specimens treated with Ecolink™ 1171, 2-butoxyethanol, and (+)-limonene required a greater degree of mechanical effort to remove matrix since the asphalt did not dissolve as readily. Due to their slow evaporation, specimens became over-saturated, slippery and difficult to handle with care (Table 2). Novec™ 73DE and nPB both removed asphaltic matrix readily, with low mechanical effort. Novec™ 73DE did not penetrate as deeply into the matrix as nPB, allowing for greater control around fragmented sections of bone and preventing disassociation. However, Aerotron™-100 (395.2 mmHg) evaporated too quickly to soften matrix effectively, indicating

FIGURE 8. In-progress specimen soaking examples, approximately five minutes after submersion and backlit with lamps to highlight color and translucency, demonstrating the relative efficacy of each solvent to dissolve asphalt. From left to right, nPB (Gentech), AeroTron™-100, Novec™ 73DE, Ecolink™ 1171, 2-butoxyethanol (Butyl Cellosolve), (+)-limonene.

that it is beyond the desirable volatility range (Table 2).

Resources. Determining the budgetary impacts of labor and materials when investigating new techniques aids in assessing the feasibility of their adoption. The duration of preparation was averaged for each solvent and treatment. With all solvents except nPB, manually prepared specimens required approximately twice the time than soaked fossils, averaging around 1 hour for soaking and 2 hours for manual preparation (Table 2). The most notable difference was observed with nPB which only required 0.5 hours when soaked but an average of 3.6 hours when prepared manually.

Soaked fossils required fewer tools than those that were manually prepared because most of the encasing matrix was released during submersion. AeroTron™-100 required 67 tools after soaking and 92 during manual preparation. Novec™ 73DE used 55 tools after soaking and 183 tools to manually remove matrix. Ecolink™ 1171, 2-butoxyethanol, and (+)-limonene each used nearly the same number of tools for both soaking (115, 110, 100) and manual (223, 220, 218) preparation. The greatest difference between soaking (33) and manual (162) preparation tool use was seen from nPB.

TABLE 2. Ease of surface asphaltic matrix removal and average preparation time by solvent and treatment method.

Name	Method	Ease (Mechanical Effort)	Average Time (minutes)
AeroTron™-100	Soak	Low	65
	Manual	Moderate	121
Novec™ 73DE	Soak	Low	68
	Manual	Moderate	164
Ecolink™ 1171	Soak	High	77
	Manual	High	145
2-butoxyethanol	Soak	High	61
	Manual	High	130
(+)-limonene	Soak	High	72
	Manual	High	123
1-bromopropane	Soak	Low	31
	Manual	Low	218

Preparation Observations. Surface Damage: No damage was incurred by specimens treated with Novec™ 73DE or 2-butoxyethanol (Figure 9A-B, Table 3). AeroTron™-100 has a high evaporation rate resulting in minor surface scratches of four specimens due to the mechanical force required to remove matrix (Figure 9C, Table 3). Four fossils prepared with Ecolink™ 1171 resulted in minor scratches due to the slick nature of the solvent coating (Figure 9D, Table 3). Only one fossil sustained damage during treatment with nPB when a small flake of cortical bone chipped away with a stubborn piece of matrix (Figure 9E, Table 3). Three fossils treated with (+)-limonene sustained damage during preparation (Table 3). Two fossils had minor scratches and, in one instance, water applied to exposed cancellous bone resulting in a pulpy, gritty paste (Figure 9F).

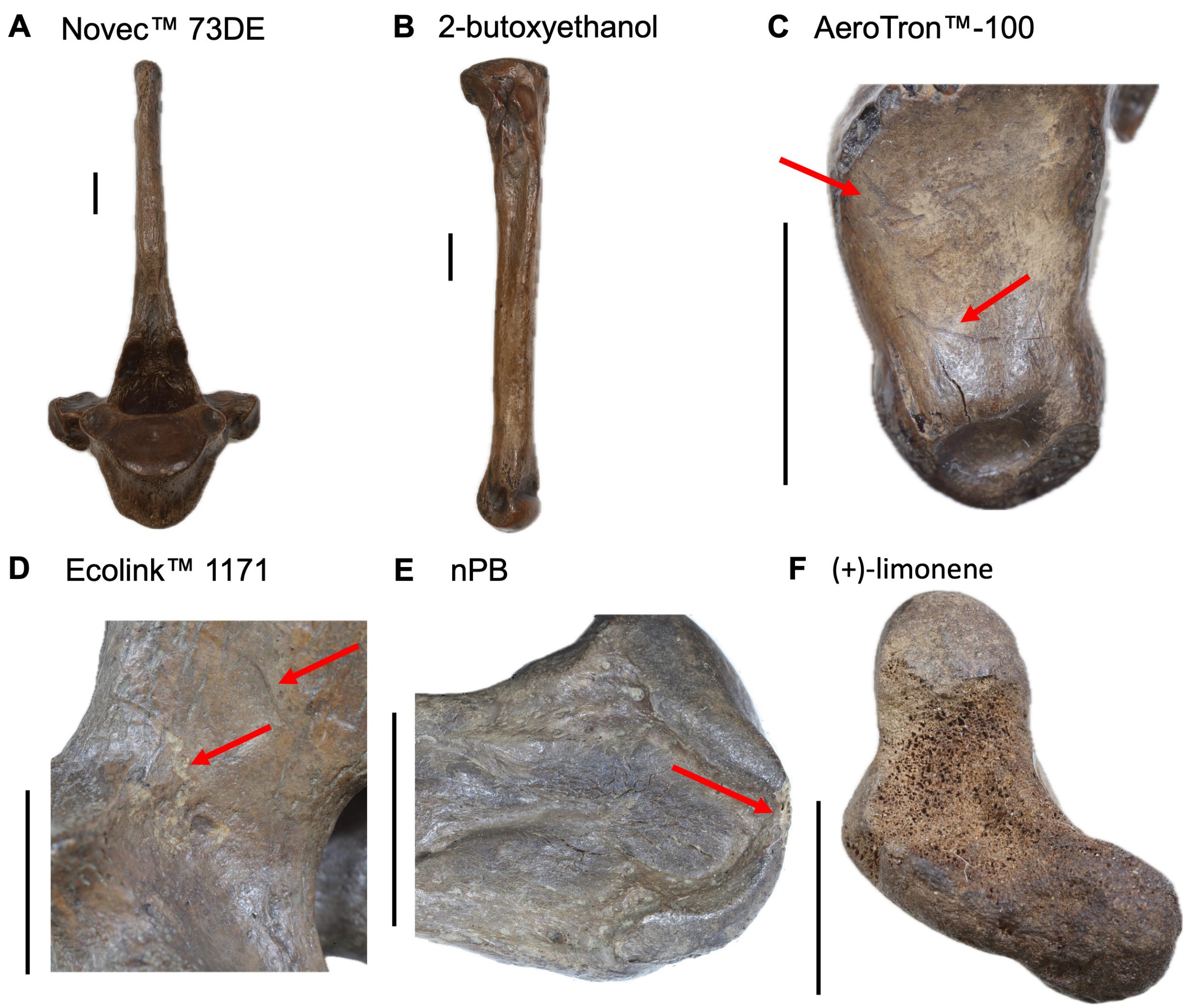

FIGURE 9. Surface damage examples. Scale bars are 1 cm. A) Thoracic vertebra of *Aenocyon dirus* LACMP23-38125 and B) Metapodial of *A. dirus* LACMP23-38116 with no damage. C) Aves femur LACMP23-34952 and D) Thoracic vertebra of *A. dirus* LACMP23-38128 with scratches (red arrows). E) Metapodial of *A. dirus* LACMP23-33686 with a chip (red arrow). F) Aves femur LACMP23-34955 with exposed and degraded cancellous bone.

Surface Appearance: Novec™ 73DE left fossils with a natural shine that did not appear to be the effect of any solvent residue (Figure 10A, Table 3). Fossils prepared with AeroTron™-100 exhibited inconsistent quality of their appearance (Table 3). AeroTron™-100 soaked specimens appeared more dried out than those from the manual treatment group, with cracks primarily occurring in dehydrated areas (Figure 10B). Specimens treated with nPB had a dehydrated appearance, especially in damaged areas (Figure 10C, Table 3). Fossils treated with Ecolink™ 1171 and (+)-limonene became dark, glossy, and dehydrated at damaged areas (Figure 10D-E, Table 3). A similar dark, oily, plastic-like appearance, and wet-seeming asphalt visible in cancellous bone, were noted for fossils that underwent preparation with 2-butoxyethanol (Figure 10F, Table 3).

Long-term Observations. Odor: By the end of the 9-month assessment, specimens treated with AeroTron™-100 had a weak odor, whereas Novec™ 73DE and nPB presented no noticeable solvent odors. Ecolink™ 1171, 2-butoxyethanol, and (+)-limonene retained odors which raised concerns about fossil conservation and integrity over time (Table 3). Persistent odor implied that solvent remained present on specimens. The porosity of the osteological material, coupled with odor and surface residues suggests that low volatility solvents are not viable for consideration of replacement solvents.

TABLE 3. Summary of solvent effects after preparation and long-term observations.

Name	Preparation Observations: Surface Damage (# of Fossils)	Preparation Observations: Surface Appearance	Long-term Observations: Odor	Color	Mass	Asphalt Exudation	Visible Degradation
AeroTron™-100	4	Inconsistent	Weak	No change	No change	Minor	None
Novec™ 73DE	1	Excellent	None	No change	No change	Minor	None
Ecolink™ 1171	4	Glossy, dried-out at damaged areas, dark	Moderate	No change	No change	Moderate	Minor
2-butoxyethanol	0	Dark, oily, plastic-like	Strong	No change	No change	Minor	None
(+)-limonene	3	Glossy, dried-out at damaged areas	Strong	No change	No change	Major	Significant
1-bromopropane	1	Dried-out at damaged areas	Weak	No change	No change	Moderate	None

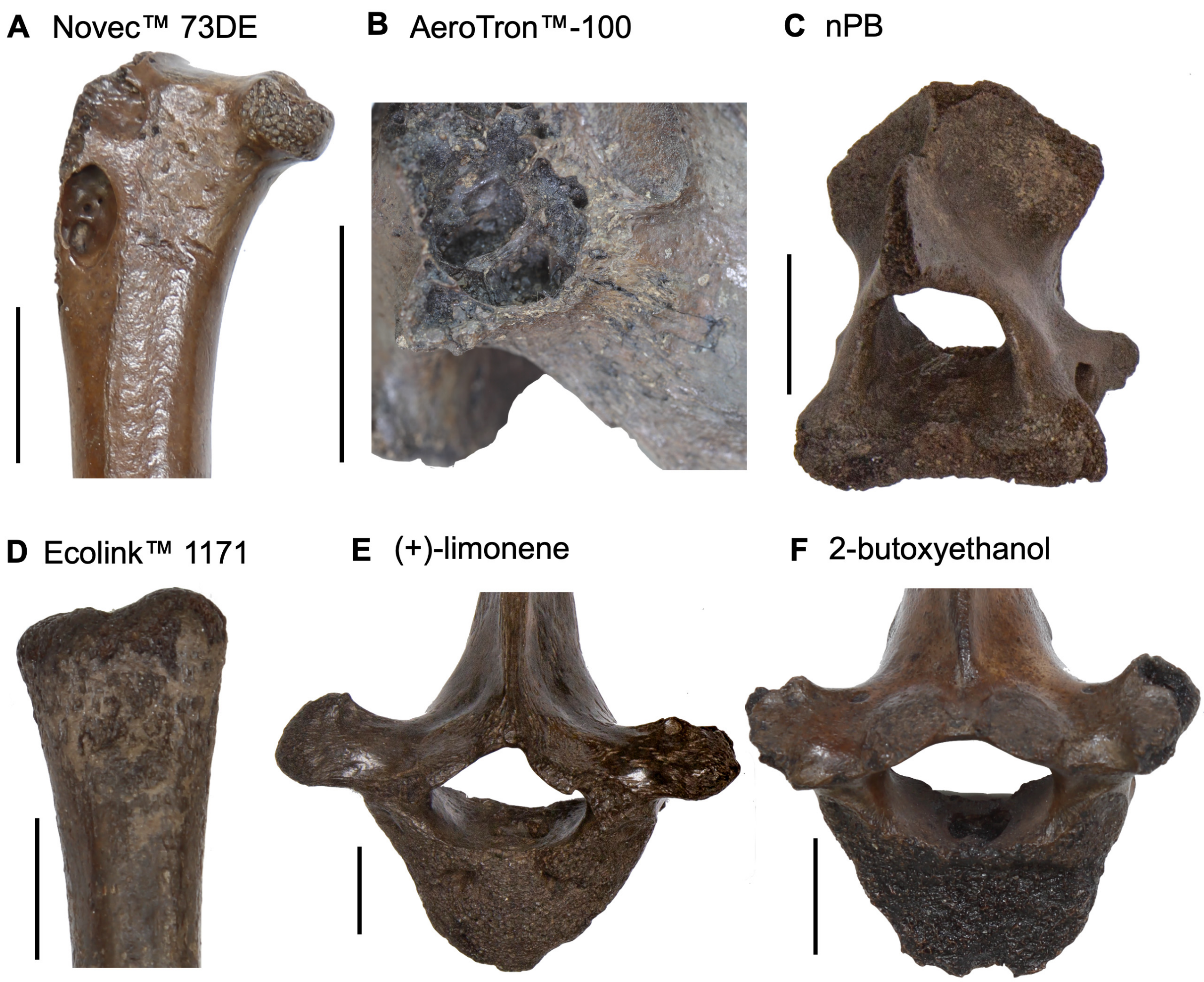

FIGURE 10. Surface appearance examples. Scale bars are 1 cm. A) Stable cancellous bone and natural shine in Aves femur LACMP23-34948. B) Soaked thoracic vertebra of *Aenocyon dirus* LACMP23-38120 and C) Cervical vertebra of *Canis latrans* LACMP23-34944 with dehydrated cancellous bone. D) Metapodial of *A. dirus* LACMP23-34932 with dehydrated end. E) Thoracic vertebra of *A. dirus* LACMP23-38123 with dark glossy exterior. F) Thoracic vertebra of *A. dirus* LACMP23-38129 with wet-seeming asphalt in cancellous bone.

Color: While some changes in color patterning were observed over nine months in a small number of specimens, changes were not significant enough for color to be considered a useful criterion for solvent performance in this investigation (Table 3).

Mass: No significant differences in masses were observed; therefore, mass was determined to be of minimal use when selecting a preferred solvent (Table 3). It is possible that specimen masses fluctuated within the scale error of +/-1g and that more sensitive equipment could have identified changes in response to external factors (e.g., ambient humidity).

Asphalt Exudation: Internal asphaltic matrix stability is indicated by a lack of asphalt exudation. AeroTron™-100, 2-butoxyethanol, and Novec™ 73DE out-performed other solvents by leading to only minor asphalt exudation after preparation (Figure 11A-C, Table 3). Ecolink™ 1171 and nPB showed moderate instances of asphalt exudation which stabilized within the assessment period (Figure 11D-E, Table 3). Two specimens treated with (+)-limonene, one from each

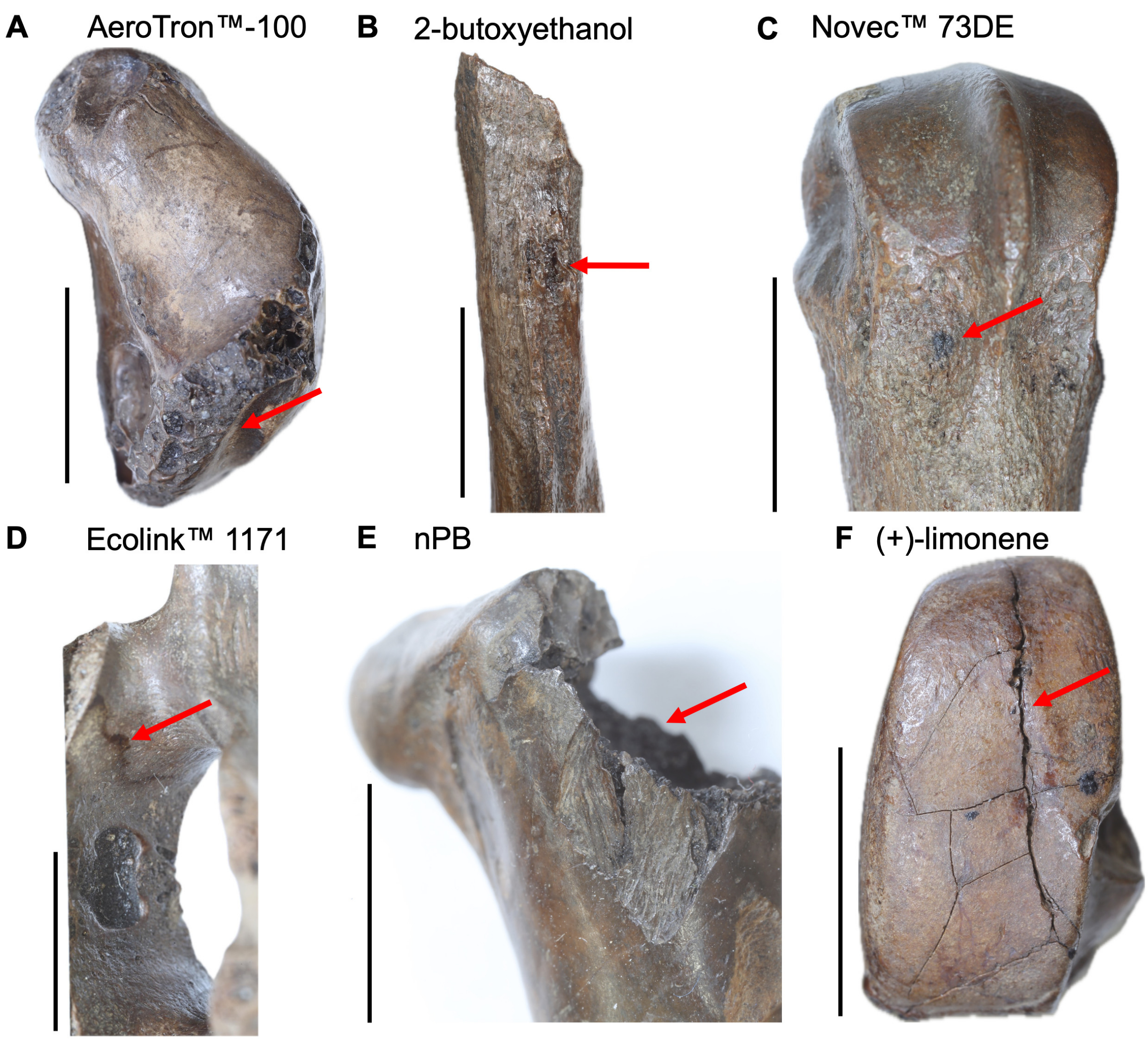

FIGURE 11. Exudation examples, with red arrows indicating exposed asphalt. Scale bars are 1 cm. A) Aves femur LACMP23-34952, B) Thoracic vertebra of *Aenocyon dirus* LACMP23-38129 and C) Metapodial of *A. dirus* LACMP23-34936 showed minor signs of asphalt exudation that stabilized within the first month after treatment. D) Thoracic vertebra of *A. dirus* LACMP23-38124 and E) Aves femur LACMP23-34956 had moderate instances of asphalt exudation which stabilized by the end of the assessment period. F) Metapodial of *A. dirus* LACMP23-34942 revealed possible continued asphalt instability throughout the study.

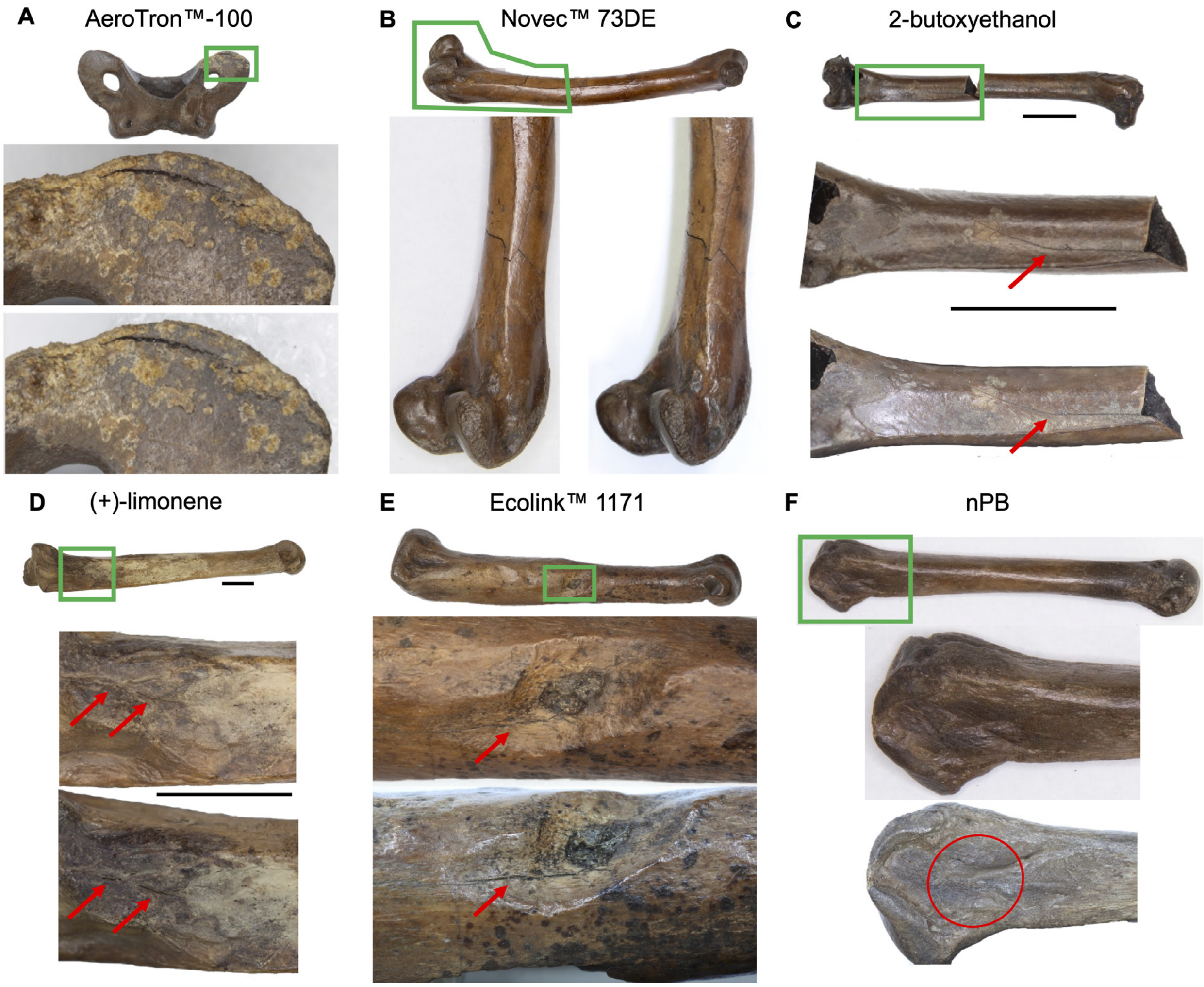

FIGURE 12. Visible degradation examples. Top is the overall specimen with green box highlighting inset areas, middle is inset after preparation, and bottom is inset after nine months. Red arrows and circles highlight changes. Scale bars are 1 cm. A) Cervical vertebra of *Canis latrans* LACMP23-38114, B) Aves femur LACMP23-38330 and C) Aves femur LACMP23-34951 with no change in original cracks. D) Metapodial of *Aenocyon dirus* LACMP23-38118 with crack growth and new cracks. E) Metapodial of *A. dirus* LACMP23-34934 with crack growth and continued asphalt exudation. F) Metapodial of *A. dirus* LACMP23-33686 with new cracks.

treatment group, showed signs of possible asphalt instability nine months after preparation (Figure 11F, Table 3).

Visible Degradation: Three treatment groups showed no change in fossil integrity over time: AeroTron™-100, Novec™ 73DE, and 2-butoxyethanol (Figure 12A-C, Table 3). Specimens treated with (+)-limonene had crumbling cancellous bone, some with liquid asphalt visible, and cracks with frayed edges (Figure 12D, Table 3). Ecolink™ 1171 and nPB specimens were prone to crack expansion (Figure 12E-F, Table 3). During monthly assessments, crack expansion, flaking and warping predominantly were observed to coincide with seasonal temperature and humidity shifts. The building envelope at RLB is minimal with regard to temperature and humidity controls. Specimens were stored in an open-topped plastic bin on a shelf with overhead protection but an open front, mimicking storage conditions within the collection space. Greatest changes in fossil integrity were noted to coincide with periods of increased humidity.

Cranial Preparation Investigation

Resources. To ensure that the benefits of manual preparation outweighed preparation gridlock, time and resources were compiled (Table 4). Crania averaged 30 hours (range of 13.2–63.7 hours) to

TABLE 4. Crania manual preparation time and solvent volume. All specimen numbers are prefixed by LACM. Crania are classed as complete (majority of cranium present), anterior (frontals, parietals, and occipitals missing), or posterior (premaxillae, maxillae, and palatines missing). Abbreviation nr indicates not recorded.

Specimen #	Taxa	Crania	Deposit	Solvent	Preparation time (hr)	Preparation solvent (mL)
P23-41921	*A. dirus*	posterior	P23-13	Novec 73DE	25.1	208
P23-41926	*C. latrans*	complete	P23-13	nPB	44.6	nr
P23-41929	*A. dirus*	posterior	P23-9	nPB	17.8	480
P23-41930	*A. dirus*	complete	P23-9	nPB	nr	nr
P23-41931	*A. dirus*	complete	P23-9	Novec 73DE	26.3	nr
P23-41932	*A. dirus*	complete	P23-9	Novec 73DE	50.4	510
P23-41936	*A. dirus*	anterior	P23-14	Novec 73DE	13.6	225
P23-41937	*A. dirus*	posterior	P23-14	Novec 73DE	16.5	306
P23-41940	*A. dirus*	complete	P23-14	nPB	63.7	750
P23-42371	*C. latrans*	complete	P23-9	Novec 73DE	28.6	306
R66366	*A. dirus*	posterior	Pit 91	Novec 73DE	13.2	161

fully prepare manually with an average of 370 mL of solvent (ranging from 151–750 mL). Direct time and solvent volume comparisons with soaked specimens was not possible due to a lack of archived preparation data. Inferring from recent historical practice, submerging crania used multiple liters of solvent per specimen, requiring a specialized workspace, increased PPE, and respirator-certified staff. The lower solvent requirement for manual preparation was determined to reduce chemical hazards related to large quantities of solvent, as well as costs related to solvent procurement, storage, and disposal. Manual preparation is a viable technique because it does not considerably extend preparation time and reduces solvent requirements.

Soaked and Manual Comparison. Fossil condition was primarily assessed for soaked and manually prepared crania by evaluating specimen fragmentation and the presence of supportive internal matrix (Table 5). Soaked fossils had a median of 13 fragments, whereas manually prepared fossils had a median of two. Fragment ranges for both manual (0–29) and soaked (1–31) crania were similar, potentially due to shared taphonomic histories. Unfused sutures and extensive cracks that usually disassociate during soaking remained intact in manual preparation, reducing fragmentation (Figure 13).

No soaked crania retained matrix in major cavities— nasal, braincase, and choanae— while all major cavities in manually prepared crania retained matrix (Figure 14A-B, Table 5). Most soaked crania lacked matrix entirely, but six of the thirteen soaked specimens did have matrix deeper in the nasal cavity or covering the ethmoid. Nasal turbinates were partially to completely missing in all soaked crania, with one cranium completely lacking them, four only having traces around the lateral edges and six with some presence deeper in the skull (posterior to P2). One cranial specimen even lost a ~2 cm x 1cm piece of bone from inside the nasal cavity during assessment handling, highlighting the fossil's fragile condition. Manually prepared crania retained matrix in 77% of foramina, 68% of non-morphological cavities, and 99% of dental alveoli, as opposed to soaked crania with only 8% of foramina, 2% of non-morphological cavities, and 0% of dental alveoli that retained matrix (Figure 14C-F, Table 5). Manual preparation preserves internal matrix lost during soaking.

Several differences were noted in bone condition between soaked and manually prepared crania, although attribution to preparation technique is complicated by the different histories of specimen preparation at RLB. Warping was noted in six of the soaked specimens, with a range of one to three observations per crania, although definitive attribution solely to preparation is not possible. However, similar effects have been noted in fossils after soaking. These warps were observed predominantly across breaks (Figure 13A). Only one manually prepared cranium presented warps, with six observations, mostly due to damaged areas that did not disassociate during preparation (Figure 13B). While these damaged areas are offset and

TABLE 5. Cranial preparation comparison. All specimen numbers are prefixed by LACM. Crania are classed as complete (majority of cranium present), anterior (frontals, parietals, and occipitals missing), or posterior (premaxillae, maxillae, and palatines missing). Dash indicates not applicable.

Specimen #	Taxa	Crania	Deposit	Preparation Type	# fragments	% of Cavities with Retained Matrix: Major	Dental alveoli	Foramina	Non-morphological
P23-12787	*A. dirus*	complete	P23-1	soak	6	0%	0%	3%	0%
P23-17329	*C. latrans*	complete	P23-1	soak	4	0%	0%	10%	0%
P23-18908	*A. dirus*	complete	P23-1	soak	13	0%	0%	14%	0%
P23-18909	*A. dirus*	complete	P23-1	soak	15	0%	0%	7%	4%
P23-18910	*A. dirus*	complete	P23-1	soak	1	0%	0%	6%	0%
P23-18911	*A. dirus*	complete	P23-1	soak	8	0%	0%	3%	0%
P23-18912	*A. dirus*	complete	P23-1	soak	29	0%	0%	3%	0%
P23-42850	*C. latrans*	posterior	P23-9	soak	13	0%	-	40%	0%
P23-42851	*C. latrans*	posterior	P23-9	soak	16	0%	-	0%	0%
P23-5351	*C. latrans*	complete	P23-1	soak	31	0%	0%	0%	0%
P23-7388	*A. dirus*	complete	P23-1	soak	2	0%	0%	7%	5%
P23-8099	*C. latrans*	complete	P23-1	soak	6	0%	0%	29%	6%
P23-8580	*A. dirus*	complete	P23-1	soak	15	0%	0%	0%	0%
P23-41921	*A. dirus*	posterior	P23-13	manual	1	100%	-	100%	100%
P23-41926	*C. latrans*	complete	P23-13	manual	2	100%	100%	100%	100%
P23-41929	*A. dirus*	posterior	P23-9	manual	0	100%	-	100%	100%
P23-41930	*A. dirus*	complete	P23-9	manual	7	100%	100%	94%	100%
P23-41931	*A. dirus*	complete	P23-9	manual	2	100%	100%	93%	73%
P23-41932	*A. dirus*	complete	P23-9	manual	7	100%	100%	100%	100%
P23-41936	*A. dirus*	anterior	P23-14	manual	2	100%	89%	100%	100%
P23-41937	*A. dirus*	posterior	P23-14	manual	12	100%	-	100%	100%
P23-41940	*A. dirus*	complete	P23-14	manual	29	100%	100%	83%	0%
P23-42371	*C. latrans*	complete	P23-9	manual	6	100%	100%	100%	100%
R66366	*A. dirus*	posterior	Pit 91	manual	0	100%	-	100%	100%

un-aligned (thus classified as warping), the individual fragments have not changed shape, unlike the warping seen in the soaked crania. Both soaked and manually prepared specimens had a median of 20 moderate cracks per fossil, along with similar ranges (1–41 for soaked, 12–41 for manual). The commonality of moderate cracks between soaked and manually prepared crania probably relates to their shared taphonomic history. Severe cracks were more prevalent in manually prepared specimens, with a median of five and a range of 0–14, compared to a median of zero and a range of 0–6 for soaked. The reduction of severe cracks in soaked specimens might best be attributed to their increased number of fragments. Severe cracks are often held together by internal matrix prior to preparation. However, once the matrix is removed these fragments can fall apart along the crack lines. The median number of cranial bones with observed dehydration per specimen for soaked and manual crania is six, ranging 0–18 for manual and 0–17 for soaked. In soaked specimens, 49% of dental alveoli were observed with dehydration (n=213), including chipping and exfoliating bone (Figure 14A, C, E). Comparisons to manually prepared dental alveoli are complicated by the retention of matrix; only one dental alveolus was exposed in manual preparation. Overall, manual preparation reduces fragmentation and preserves internal matrix, thereby minimizing separation

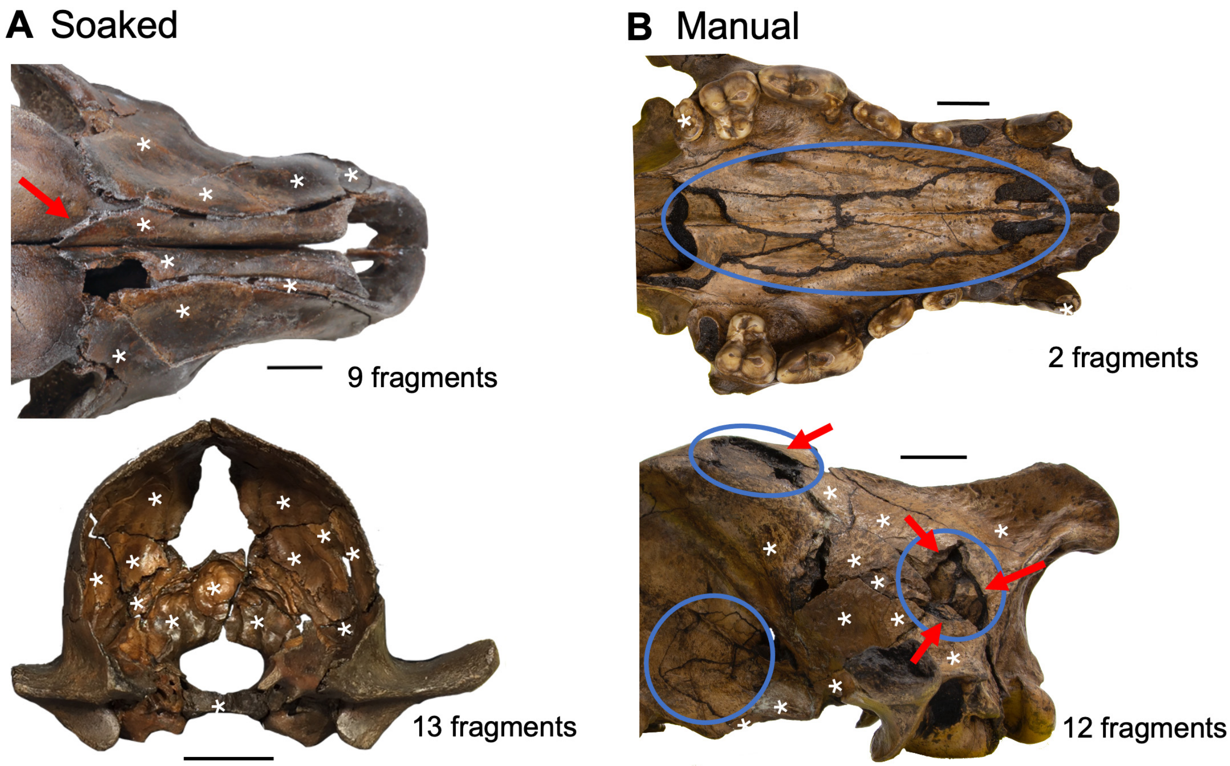

FIGURE 13. Cranial fragmentation examples. White asterisks highlight repaired fragments and blue circles highlight heavily cracked areas that did not disassociate during preparation. Red arrows highlight warping. Scale bars are 2 cm. A) Soaked specimens, top *Aenocyon dirus* LACMP23-18912 and bottom, *Canis latrans* LACMP23-42850. B) Manually prepared specimen *A. dirus* LACMP23-41940. Scale bars are 2 cm.

along cracked regions and improving overall specimen stability.

DISCUSSION

Solvent Investigation

This comparative investigation included solvents with various properties, enabling a better understanding of important factors for selecting alternative degreasing solvents. Solvent volatility, as expressed by vapor pressure, is a key consideration when selecting a degreasing agent for asphaltic matrix removal from fossil bones. Low volatility solvents such as Ecolink™ 1171 (44.1 mmHg), 2-butoxyethanol (0.874 mmHg), and (+)-limonene (1.98 mmHg) were ineffective for asphaltic fossil preparation and showed signs of continued impacts on bone stability over long-term assessments. The residues from these solvents would require a secondary rinsing agent to remove, which requires adding a step in preparation, including another chemical, which would increase time and costs. AeroTron™-100, with a vapor pressure of 395.2 mmHg, also yielded undesirable results because it evaporated too quickly to be useful in manual asphaltic matrix removal. For the purposes of manually preparing fossil material at RLB the ideal volatility ranged between 100 mmHg and 300 mmHg. Novec™ 73DE (263 mmHg) and nPB (134 mmHg) both fall within this range and were effective for preparation. However, long-term impacts for nPB prepared specimens included dehydration and crack expansion, while Novec™ 73DE specimens showed no change. Novec™ 73DE yielded the most favorable results accounting for fossil condition and health and safety. The Cal/OSHA PEL of Novec™ 73DE is 200 ppm, 40 times higher than the 5 ppm PEL for nPB, making it easier to achieve safe working conditions. Industrial hygiene surveys were conducted at RLB, and the results of air monitoring while manually preparing fossils with Novec 73DE in front of typical extraction ventilation were an exposure of 0.73 ppm, less than 1% of the Cal/OSHA PEL. From this dataset, there appears to be a balance between selecting high volatility solvents (less long-term impacts) and solvents that remain liquid long enough to be workable.

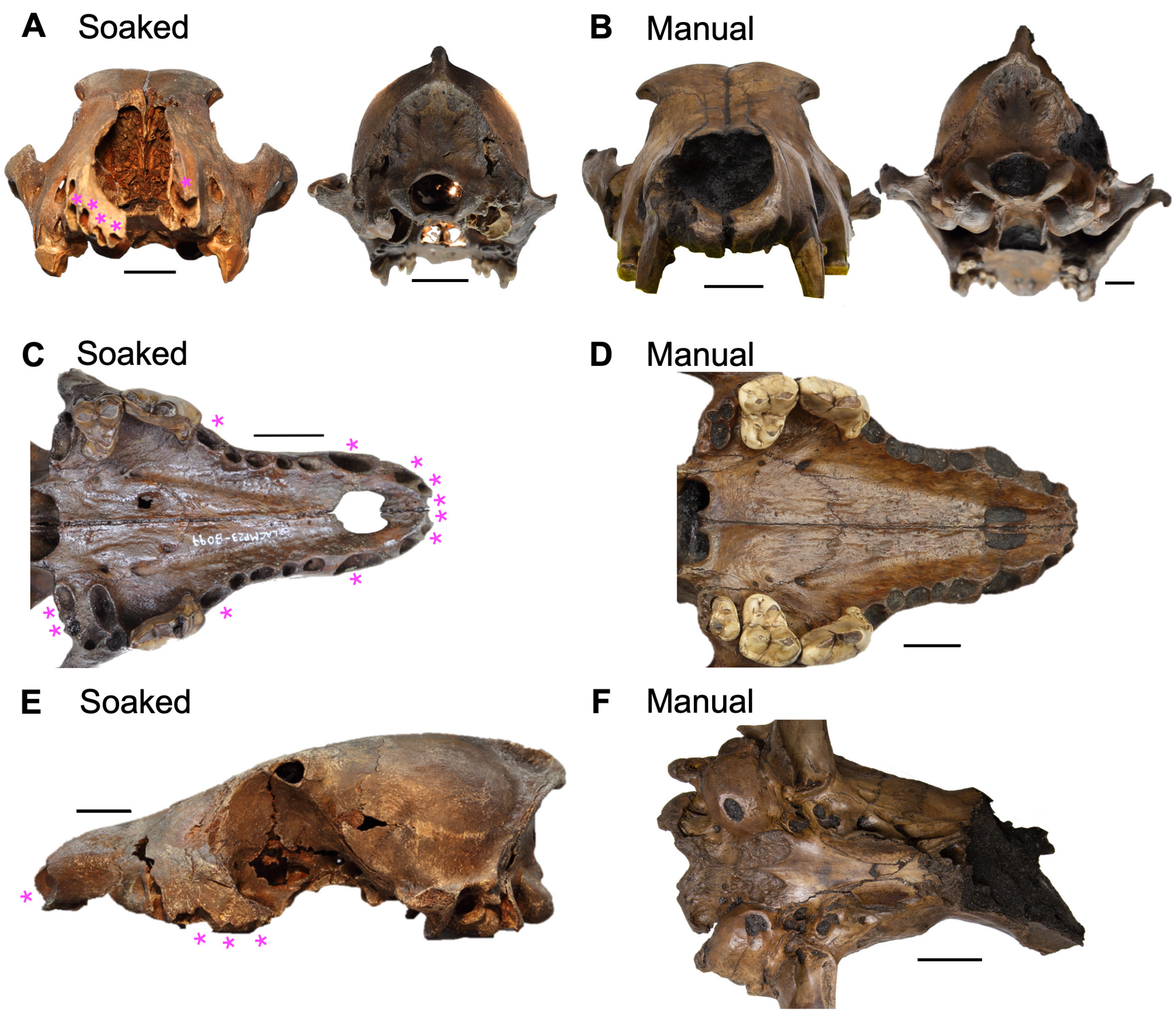

FIGURE 14. Cranial matrix retention examples. Scale bars are 2 cm. Pink asterisks highlight dehydrated dental alveoli. A) Loss of internal matrix in major cavities for left, *Aenocyon dirus* LACMP23-8580 and right, *Canis latrans* LACMP23-5351. B) Retention of internal matrix in *A. dirus* LACMP23-41940 (left) and *C. latrans* LACMP23-41926 (right). C) Loss of matrix in dental alveoli in *C. latrans* LACMP23-8099. D) *A. dirus* LACMP23-41930 with matrix retained in dental alveoli. E) Matrix lost in foramina and non-morphological cavities in *C. latrans* LACMP23-17329. F) Retained matrix in foramina and non-morphological cavities in manual *A. dirus* LACMP23-41929.

Cranial Preparation Investigation

Crania are often studied and handled for research and educational purposes, and determining best preparation practices is critical to preserve important features and stability over time. Retained internal matrix provides support to delicate morphological features such as dental alveoli, limiting the impacts of repeated stress (e.g., caliper measurements). Intracranial osteology, although not visible in manually prepared crania, is better preserved and can be visualized through CT scans (Baraga et al., 2024).

CONCLUSIONS

Since excavations began and asphaltic fossil preparation at RLB, several degreasing solvents have been used to prepare specimens. It is likely that new solvents will need to be selected in the future as material availability changes. This study developed a framework for future investigations by defining criteria for solvent selection.

Future solvent investigations at RLB will likely omit the color and mass criteria because this study found no significant change in either over time. Volatility was identified as a key factor for solvent selection because solvents with a vapor pressure between 100 mmHg and 300 mmHg were most effective for asphaltic matrix removal. Standards were set for the photographic documentation of experimental specimens. These standards were adapted into a standard operating procedure and are implemented for all new projects.

Properly evaluating a range of degreasing solvents prior to their introduction avoided a host of potential issues including cracking and flaking, undesirable odors, preparation damage related to volatility, and fossil degradation. Monthly assessments were performed to address the impacts of solvents on osteological material over time. The data collected allowed RLB to make an informed decision, which ensured that the solvent selected as a replacement for nPB would be effective in preparation and not negatively impact the collection or preparators.

Investigating a novel manual preparation technique in the solvent study explored the complementary effects of materials and techniques. Manual preparation of osteological material ameliorated negative impacts of soaking, especially for crania. The benefits, including improved fossil integrity and reducing the amount of solvent used, rectified the increased labor and resources for manual preparation. The current standards for preparation practice at RLB are the use of Novec™ 73DE and manual preparation due to their preferable outcomes. Further investigations have validated this practice as effective for preparation of fossils from other asphaltic localities, such as Tanque Loma in Ecuador and Forest Reserve in Trinidad (Potze, 2022).

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REFERENCES

3M™. 2023. Novec™ 73DE Engineered Fluid Safety Data Sheet, downloaded 16 October 2023. 3M™. https://www.3m.com/3M/en_US/p/d/b00000627/

Artal-Isbrand, P. 2018. So delicate yet so strong and versatile – the use of paper in objects conservation. Journal of the American Institute for Conservation, 57:112-126. https://doi.org/10.1080/01971360.2018.1490134

Baraga, J., Clarke, C., Morley, S. and Potze, S. 2024. The Efficacy of CT Scans for Imaging Fossils in Asphaltic Paleontological Deposits from Rancho La Brea. Geological Society of America Abstracts with Programs, 56:28-24. https://doi.org/10.1130/abs/2024AM-401638

Critelli, S., Rumelhart, P., and Ingersoll, R. 1995. Petrofacies and Provenance of the Puente Formation (Middle to Upper Miocene), Los Angeles Basin, Southern California: Implications for Rapid Uplift and Accumulation Rates. Journal of Sedimentary Research, 65:656-667. https://doi.org/10.1306/D426818F-2B26-11D7-8648000102C1865D

Davidson, A. and Brown, G. 2012. Paraloid B-72: Practical Tips for the Vertebrate Fossil Preparator. Collection Forum, 26:99-119.

ECOLINK. 2024. Ecolink 1171 Low VOC Degreasing Solvent Safety Data Sheet, downloaded 25 January 2024. ECOLINK https://ecolink.com/products/prodpages/ecolink-1171-low-voc-degreasing-solvent/.

Friscia, A.R., Van Valkenburgh, B., Spencer, L., and Harris, J. 2008. Chronology and spatial distribution of large mammal bones in Pit 91, Rancho La Brea. Palaios, 23:35-42. https://doi.org/10.2110/palo.2005.p05-143r

Kanegsberg, B. 1998. Cleaning options for degreasing & surface preparation. Plating & Surface Finishing, 85:48-51.

LeMay, J.D. 1993. Partitioning of residual D-limonene cleaner vapor among organic materials in weapons. Proceedings of the 18th Department of Energy Compatibility, Aging and Service Life Conference, Aiken, South Carolina.

Mackay, D. and van Wesenbeeck, I. 2014. Correlation of Chemical Evaporation Rate with Vapor Pressure. Environmental Science & Technology, 48:10259-10263. https://doi.org/10.1021/es5029074

Munsell Color. 2010. Munsell Soil Color Chart: Year 2000 Revised Washable Edition. Grand Rapids, Michigan, 9 pp.

Potze, S. 2022. A comparative investigation of asphaltic fossil preparation from three brea localities: California, Ecuador & Trinidad. 82nd Annual Meeting of the Society of Vertebrate Paleontology, Toronto, Ontario, Canada.

Reliance Specialty Products, Inc. 2015. GENTECH Non-Flammable Vapor Degreasing Solvent Safety Data Sheet downloaded 17 February 2015. Reliance Specialty Products, Inc. https://relspec.com/gentech-overview

Reliance Specialty Products, Inc. 2017. AeroTron Non-Flammable Precision Cleaning and Vapor Degreasing Solvent SDS downloaded 30 January 2017. Reliance Specialty Products, Inc. https://relspec.com/aerotron-100-overview

Rice, K., Sessions, A., Lai, K., and Takeuchi, G.T. 2015. New technique to remove asphalt from microfossil-rich matrix from Rancho La Brea. Natural History Museum of Los Angeles County Science Series, 42:169-174.

Rodrigues, L.S., Nyakatura, J., Zachow, S., and Israel, J.H. 2023. Design Challenges and Opportunities of Fossil Preparation Tools and Methods. Proceedings of the 20th International Conference on Culture and Computer Science: Code and Materiality, Lisbon, Portugal, p.1-10.
https://doi.org/10.1145/3623462.3623470

Shaw, C.A. 1982. Techniques Used in Excavation, Preparation, and Curation of Fossils from Rancho La Brea. Curator: The Museum Journal, 25:63-77. https://doi.org/10.1111/j.2151-6952.1982.tb00583.x

Stock, C. and Harris, J.M. 1992. Rancho La Brea, 7ed. Natural History Museum of Los Angeles County, Los Angeles.

ThermoFisher Scientific. 2024. 2-Butoxyethanol product specification, downloaded 24 January 2024. ThermoFisher Scientific. https://www.thermofisher.com/order/catalog/product/A17976.0D

Tickner, J., Jacobs, M., Malloy, T., Buck, T., Stone, A., Blake, A., and Edwards, S. 2019. Advancing Alternatives Assessment for Safer Chemical Substitution: A Research and Practice Agenda. Integrated Environmental Assessment and Management, 15:855-866. https://doi.org/10.1002/ieam.4094

Woodard, G.D. and Marcus, L.F. 1973. Rancho La Brea Fossil Deposits: A Re-Evaluation from Stratigraphic and Geological Evidence. Journal of Paleontology, 47:54-69.