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Short communication

A new amber Lagerstätte from the Lower Cretaceous of Japan

Aya Kubota [a,1,*], Ryo Taniguchi [b], Yoshinori Hikida [c], Yasuhiro Iba [d]

[a] Research Institute for Geo-Resources and Environment, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba 305-8567, Japan
[b] School of Biological Sciences, University of Edinburgh, EH9 3BF, UK
[c] Nakagawa Museum of Natural History, 28-9 Yasukawa, Nakagawa Town, Nakagawa District, Hokkaido 098-2626, Japan
[d] Department of Earth and Planetary Sciences, Hokkaido University, N10W8, Kita-ku, Sapporo 060-0810, Japan

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ABSTRACT

During the Early Cretaceous, terrestrial ecosystems underwent a critical transition driven by the emergence and diversification of angiosperms. Amber-rich deposits from this period are crucial for understanding the diversity, interactions, and evolution of terrestrial biota. However, their occurrences are limited both geographically and stratigraphically. Here, we report a new amber Lagerstätte from the upper Aptian (116–114 Ma) in northern Hokkaido, Japan. The abundant amber occurs within deep-sea deposits and is rich in bio-inclusions: arthropods (hymenopterans, mites), fungi, and plant remains (tracheids, stellate hairs, pollen grains), with submicron-scale morphological details. This is the first report of fossiliferous amber-rich deposits from the Aptian in Asia. It is also recognized as one of the older amber-rich localities with bio-inclusions following those in northeastern Italy (Carnian, Upper Triassic), the Levantine area (Tithonian, Upper Jurassic; Barremian), Austria (Hauterivian), the United Kingdom (lower Barremian), and southern Congo (upper Aptian). This finding fills a paleobiogeographical gap in fossil record and provides anatomical and ecological insights into a critical interval marked by the rise of modern-type forest ecosystems.

1. Introduction

A Fossil-Lagerstätte (Seilacher, 1970) is a deposit yielding abundant or exceptionally well-preserved fossil assemblages, serving as crucial geological records for the evolutionary history of life. Discovering such deposits holds great potential to enhance our understanding of extinct taxa and their ecologies significantly. Amber, which is fossilized resin, is a form of Lagerstätte that rapidly hardens after exuding from trees, trapping small organisms such as arthropods and fungi (e.g., Martínez-Delclòs et al., 2004). These soft-bodied organisms lacking biomineralized tissues are generally lost through decay, compaction, or transport under normal sedimentary conditions. Once entombed in amber, however, they are shielded from oxidation and pressure, ensuring that their three-dimensional structures remain completely preserved for hundreds of millions of years. This remarkable preservation has substantially contributed to our knowledge of the taxonomy, morphology, and ecology of terrestrial micro- and meso-biota throughout Earth's history.

The Early Cretaceous was the initial phase of the transformative period in terrestrial ecosystems, characterized by the rise of angiosperms (Peris and Condamine, 2024). Amber bio-inclusions provide critical insights into the forest biota and their co-evolution, such as pollination of angiosperms by insects, during this noteworthy period (Grimaldi et al., 2019). Despite these advantages, amber-rich deposits with bio-inclusions from the Lower Cretaceous are limited to specific ages and regions (Rasnitsyn et al., 2016; Delclòs et al., 2023). Here, we report a new amber-bearing site from the upper Aptian, Lower Cretaceous in northern Hokkaido, Japan (Fig. 1). This deposit yields abundant amber with exceptionally preserved inclusions (Figs. 2, 3), highlighting its significance as a newly recognized Lagerstätte.

* Corresponding author.
E-mail addresses: akubota@omu.ac.jp (A. Kubota), v1rtanig@ed.ac.uk (R. Taniguchi), nmhikida@coral.ocn.ne.jp (Y. Hikida), iba@sci.hokudai.ac.jp (Y. Iba).
[1] Present address: Department of Geosciences, Graduate School of Science, Osaka Metropolitan University, 3-3-138, Sumiyoshi-ku, Osaka 558-8585, Japan

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Fig. 1. Location of Nakagawa amber site, Shimonakagawa Quarry, Nakagawa, Hokkaido, northern Japan (44.827722, 142.112528). A. Paleomap in the Early Cretaceous showing the position of the locality in Japan. Early Cretaceous paleomap is modified from Iba et al. (2011). B. Locality map showing the Nakagawa area. C. Outcrop photograph of the Shimonakagawa Quarry.

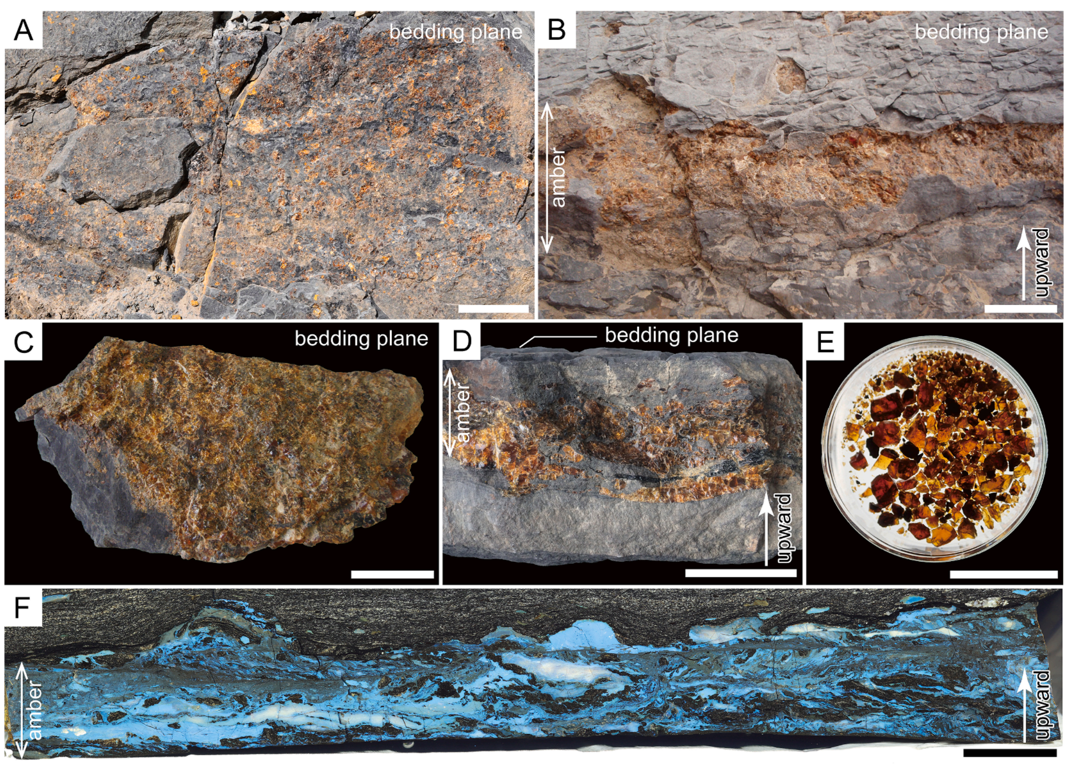

Fig. 2. The mode of occurrence of Nakagawa amber. A–B. Amber-bearing sandstone beds. A. Amber (orange to brown) and plant debris (black) concentrated on a bedding plane of sandstone beds. B. Thick amber concentration (orange and brown) in the upper part of the sandstone beds. C–D. Slab samples of the amber-bearing sandstones. E. Amber fragments extracted from rocks. F. Fluorescent tomograms showing soft-resin deformation structures of a planar amber (blue). Photographed under the UV and white lights simultaneously (image collection number: NMNSDS00047_c1_wluv365_01_0308 in the National Museum of Nature and Science, Tokyo), showing complex internal structures such as flame structures of a planar-shaped amber. Scale bars: 20 cm (A), 5 cm (B–E), 1 cm (F).

2. Geological settings

The Yezo Group (Barremian or Aptian–Maastrichtian) is a Cretaceous forearc basin deposit that developed along the eastern margin of Eurasia (Fig. 1A; e.g., Ueda, 2016). This group conformably overlies the Sorachi Group, which consists of basaltic oceanic crust and siliceous–volcanogenic sedimentary rocks, and comprises 10,000-m-thick siliciclastic deposits (Takashima et al., 2004; Ueda, 2016). The basin is estimated to be deposited at 35°–45°N (e.g., Takashima et al., 2004) and covers an area of about 200 km (West-East direction) by 1,400 km (North-South direction) (Ando, 2003). The westward-dipping subduction caused the uplift of the hinterland, the formation of the forearc basin, and the onset of the terrigenous sediment supply system (e.g., Niida and Kito, 1986; Ueda, 2016). The depositional environment of the Yezo Group exhibits a deep-sea or continental slope setting in its lower part, transitioning to shallower marine and continental conditions toward its middle to upper part (Takashima et al., 2004; Ueda,

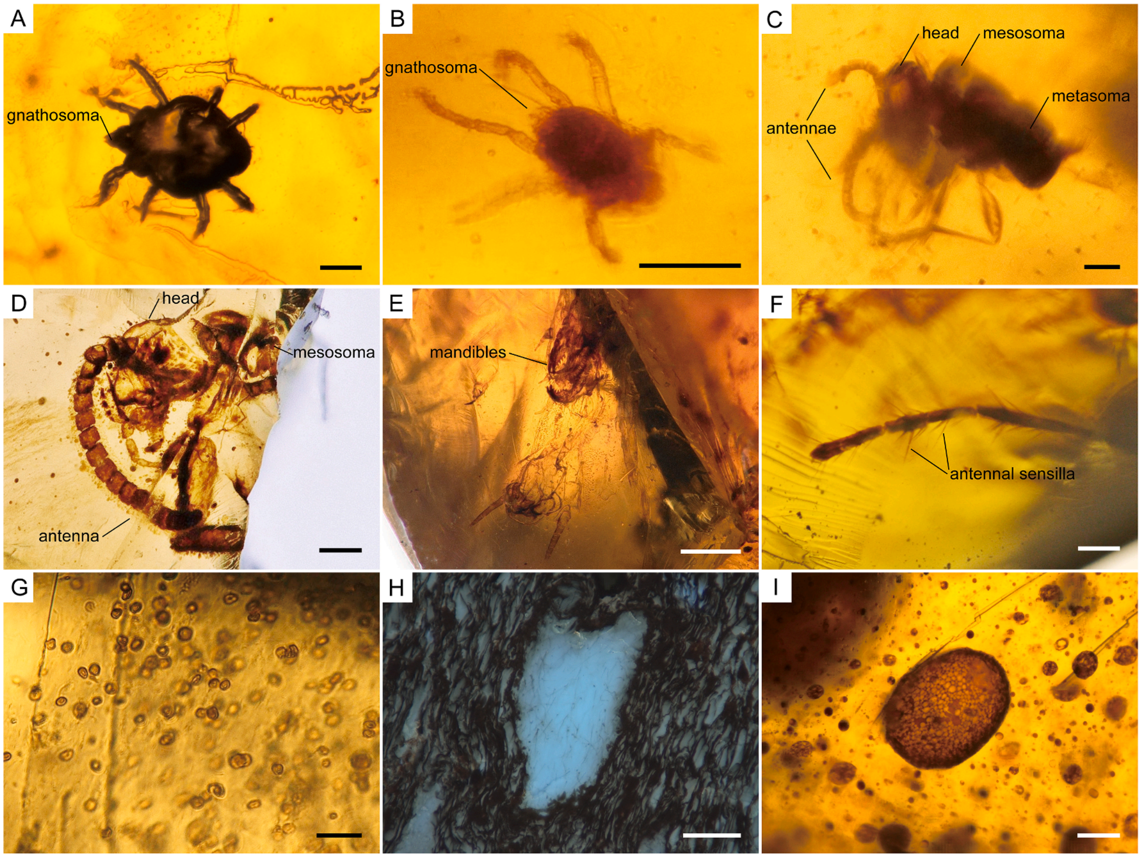

Fig. 3. Bio-inclusions in Nakagawa amber from the upper Aptian in northern Hokkaido, Japan. A–F. Arthropods. A. Mite. B. Juvenile individual of a mite. C, D. Hymenopterans. E. Mouthparts of an indeterminate arthropod. F. Antenna of an indeterminate arthropod. G. Pollen grains. H. Plant tissue and fungal hyphae. I. Phloem sap drops. Scale bars: 100 μm (A–D, F, H, and I), 250 μm (E), 25 μm (G).

2016; Kubota et al., 2025). The upper part of the Yezo Group is known for its continuous occurrences of both marine macro- and micro-fossils (e.g., Matsumoto, 1942) and represents a standard stratigraphical section in the Cretaceous of the circum-Pacific. It has also yielded abundant mineralized plant fossils, enabling the reconstruction of a diverse flora (Nishida, 1991, 2005). In contrast, fossil occurrences from the lower part of the Yezo Group are scarce.

The new amber locality is at Shimonakagawa Quarry (44.827722, 142.112528; Fig. 1) in the Nakagawa area of northern Hokkaido. At the quarry, ca. 150-m-thick continuous outcrops of the uppermost part of the Sorachi Group and the lowermost part of the Yezo Group are exposed (Fig. 1C) (Kubota et al., 2025). In the lowermost part of the Yezo Group, a total of 30 amber-bearing beds occur intercalated within the alternating sandstone and siltstone beds, associated with abundant plant debris (Kubota et al., 2025). In several horizons, amber is extensively exposed across a ~10 m $\times$ 10 m bedding plane (Kubota et al., 2025). The depositional ages of the deposits are strictly determined by zircon SHRIMP U–Pb dating of two interbedded ash-fall tuff layers in the lowermost part of the Yezo Group, indicating 116.76 ± 0.68 Ma and 114.82 ± 0.89 Ma, respectively (Kubota et al., 2025). The associated ammonites (*Acanthohoplites* sp.) and belemnites (*Neohibolites* sp.) further support these ages. The depositional environment is interpreted as deep-sea, and the amber is considered to have been supplied along with large quantities of plant debris by a tsunami, as suggested by facies analysis (Kubota et al., 2025).

3. Results and discussions

Nakagawa amber pieces typically exhibit yellow, orange, and brown colors and high transparency (Fig. 2). They occur as angular fragments (<1 mm to several centimeters in diameter), spherical lumps (<1 mm to several centimeters in diameter), and planar forms (up to ~7 cm in thickness; Fig. 2F). The planar amber aligns horizontally on the depositional surfaces and shows distinctive internal and external structures comparable to soft-sediment deformation structures, such as flame-like structures (Fig. 2F). Some plant remains are attached or incorporated into the amber, and their tissues are completely infilled with amber (Fig. 3H). This suggests that these remains represent the resin source plants.

Approximately 30 kg of amber was collected from the studied quarry, which is only a small part of the total yield. Of this material, about 4 kg was preliminarily observed with microscopy, revealing the presence of numerous bio-inclusions (Fig. 3). These inclusions comprise arthropods (Figs. 3A–F), plant tissues (Figs. 3G, H), fungi-like forms (Fig. 3H), and protist-like forms (Fig. 3I), which Lozano et al. (2020) interpreted as phloem sap. A total of 19 arthropod specimens were discovered, including complete individuals, isolated heads, abdomens, tarsi, antennae, wings, and indeterminate fragments. Among these specimens, two are tentatively assigned to mites (Figs. 3A, B) and two to Hymenoptera (Figs. 3C, D), possibly representing new species. The fungi-like structures exhibit various morphologies (e.g., filamentous, reticulate, dendritic; Fig. 3H). Plant tissues include pollen grains, tracheids, and stellate hairs (Fig. 3G). Pollen grains often occur as tetrads, indicating minimal dispersal and suggesting entrapment close to the resin source plant. Phloem sap drops are abundant within the amber matrix and inside plant tissues adhering to the resin.

Although many of these bio-inclusions are fragmented with the amber matrix, each fragment is exceptionally well-preserved. Arthropods exhibit micron-to submicron-scale features, such as leg setae, serrated mandibles, and antennal sensilla (Figs. 3A–F). These anatomical details in Cretaceous amber have shed light on the mode of life and early evolution of extinct insects, particularly regarding their sensory systems and feeding adaptations (Taniguchi et al., 2021, 2024; Li and Huang, 2022; Azar et al., 2023).

The late Early Cretaceous represents one of the most remarkable greenhouse periods throughout the Phanerozoic, with its onset occurring in the Late Aptian (Scotese et al., 2021). This interval marks the dawn of modern forest ecosystems, characterized by the rise of angiosperms and the decline of gymnosperms (e.g., Condamine et al., 2020). In response to these significant floristic changes, some orders of arthropods likely diversified in morphology, feeding habits, and nutrient acquisition strategies (e.g., Benton et al., 2022). The preservation of such small and soft-bodied terrestrial organisms requires unusual conditions; amber

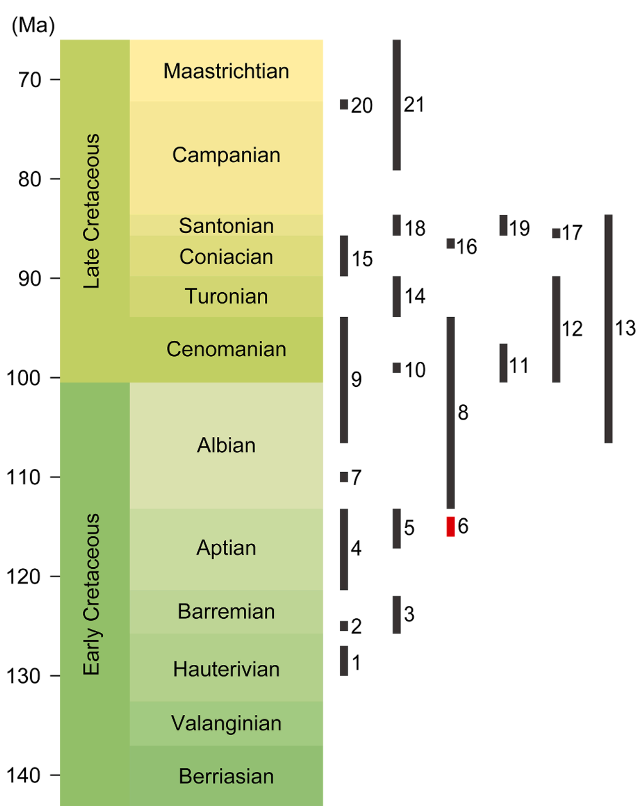

Fig. 4. Amber-rich localities with bio-inclusions in the Cretaceous. 1. Golling, Austria (Borkent, 1997); 2. Isle of Wight, UK (Tihelka et al., 2023); 3. Levantine area (Maksoud et al., 2017); 4. Choshi, central Japan (Obata and Matsukawa, 2009); 5. Doumanga, southern Congo (Perrichot et al., 2016); 6. Nakagawa, northern Japan (Kubota et al., 2025; this study); 7. Hkamti, northwestern Myanmar (Xing and Qiu, 2020); 8. Northern Spain (Álvarez-Parra et al., 2023); 9. Taimyr Peninsula, Russia (Rasnitsyn et al., 2016); 10. Hukawng Valley, Myanmar (Shi et al., 2012); 11. Agdzhakend, Azerbaijan (Kazantsev and Perkovsky, 2019); 12. Yakutia, Russia (Perkovsky et al., 2024); 13. France (Perrichot et al., 2007); 14. New Jersey, USA (Grimaldi et al., 1989); 15. Tavush, northeastern Armenia (Rasnitsyn et al., 2016); 16. Iwaki, northeastern Japan (Aiba et al., 2023; 2025; Aiba and Inose, 2024); 17. Kuji, northeastern Japan (Nakamine and Yamamoto, 2018); 18. Ajka, southern Hungary (Szabó et al., 2023); 19. Taimyr Peninsula, Russia (Rasnitsyn et al., 2016); 20. Tilin, Myanmar (Zheng et al., 2018); 21. western Canada (Loewen et al., 2024). Amber localities and their ages are based on Delclòs et al. (2023) and its Supplementary Information, Seyfullah et al. (2018), and primary references for each locality.

is a rare medium capable of such exceptional preservation. However, Lower Cretaceous amber-rich deposits with bio-inclusions are limited in terms of both geographic and stratigraphic distribution (Najarro et al., 2009; Delclòs et al., 2023) (Fig. 4): Austria (Vávra, 1993; Borkent, 1997; Fig. 4-1), UK (Tihelka et al., 2023; Fig. 4-2), the Levantine area (Lebanon, Syria, Jordan; Choufani et al., 2015; Maksoud et al., 2017; Sendi et al., 2023; Fig. 4-3), Japan (Fujiyama, 1994; Fig. 4-4), southern Congo (Bouju and Perrichot, 2020; Fig. 4-5), Spain (e.g., Álvarez-Parra et al., 2023; Fig. 4-8), Russia (Rasnitsyn et al., 2016; Fig. 4-9), Myanmar (Xing and Qiu, 2020; Fig. 4-7), and France (Perrichot et al., 2007; Fig. 4-13). Amber-rich localities with bio-inclusions in Aptian have been reported only from southern Congo (Bouju and Perrichot, 2020). In the Choshi area of central Japan, amber occurrences from the Barremian to the lower upper Aptian have been reported (Fujiyama, 1994). However, amber yields are low, and most bio-inclusions occur from reworked amber pieces whose ages have not been determined (Matsubara, 2009; Obata and Matsukawa, 2009). Only two arthropod specimens directly found from amber in Aptian deposits have been reported (Fujiyama, 1994; Perkovsky et al., 2020).

The fossiliferous amber-rich deposit in this paper represents the first report from the Aptian of the Asian region (Fig. 4). This locality is among the oldest amber-rich sites with bio-inclusions, and only five sites are older: those in Italy (Carnian, Upper Triassic; Schmidt et al., 2012), the Levantine area (Tithonian, Upper Jurassic and Barremian, e.g., Maksoud et al., 2017), Austria (Hauterivian; Borkent, 1997), the United Kingdom (lower Barremian; Tihelka et al., 2023), and southern Congo (upper Aptian; Bouju and Perrichot, 2020). The discovery of the new amber site not only fills regional and chronological gaps in the fossil record but also promotes a better understanding of the diversity of the terrestrial micro- and meso-organisms during the dawn of modern forest ecosystems.

In northeastern Asia, the Jehol Group (Valanginian–Albian) of northern China is known as a contemporaneous terrestrial Lagerstätte of compression fossils. The Jehol biota has provided crucial insights into the evolution of Early Cretaceous terrestrial ecosystems, including the origins of numerous insect lineages and the earliest fossil angiosperms (e.g., Cai et al., 2024). Nakagawa amber (upper Aptian) contains abundant bio-inclusions with exceptional three-dimensional anatomical detail. Palynological analysis of the uppermost part of the Sorachi Group to the middle part of the Yezo Group in the Nakagawa area indicates the appearance of angiosperms in the Barremian–early Aptian (Tanaka and Hirano, 2009). Bio-inclusions from Nakagawa amber have the potential to provide additional, high-resolution evidence for forest communities during the rise of angiosperms in East Asia.

In Nakagawa amber, in addition to spheroidal and fragmental forms, the distinct planar form is observed, which aligns horizontally on the depositional surface (Fig. 2F). This planar amber exhibits deformation structures on both its interior and exterior, similar to soft-sediment deformation structures, indicative of an unconsolidated condition at the deposition on the deep-sea floor (Kubota et al., 2025). These findings suggest that, after exuding from trees, the resin was rapidly transported underwater while still soft, without significant exposure to the atmosphere, in forested or coastal areas. Field experiments in modern swamp forests have shown that resin keeps unconsolidated and traps organisms underwater (Schmidt and Dilcher, 2007). Co-occurrence of terrestrial and marine organisms has been reported in a single piece of amber from Myanmar (Yu et al., 2019). Although the arthropods currently discovered from Nakagawa amber are terrestrial, it is plausible that aquatic or marine organisms could be trapped in the unconsolidated resin during its transport through water, warranting further detailed investigation.

CRediT authorship contribution statement

Aya Kubota: Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Conceptualization. **Ryo Taniguchi:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition. **Yoshinori Hikida:** Writing – review & editing, Investigation. **Yasuhiro Iba:** Writing – review & editing, Supervision, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

All data are included in the manuscript files.

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