National Park Service
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Natural Resource Stewardship and Science

Katahdin Woods and Waters National Monument

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/KAWW/NRR—2022/2472



ON THE COVER
Brachiopods from the Matagamon Sandstone; the smaller form with heavy ribbing may be a small spiriferid, and the larger form is attributed to *Leptostrophia magnifica* (NPS/VINCENT SANTUCCI).

Katahdin Woods and Waters National Monument

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Natural Resource Report NPS/KAWW/NRR—2022/2472

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Executive Summary

Katahdin Woods and Waters National Monument (KAWW) in northern Maine has a paleontological record documenting approximately half of the Paleozoic, from the Cambrian into the Early Devonian, a span of time from approximately 539 to 407 million years ago. Paleontological resources were recognized as a significant feature of the monument upon its establishment in 2016. Remoteness, complex geologic structures, and copious surficial cover have hindered the study of paleontology in northern Maine. Therefore, outcrops in KAWW and its surrounding area are scientifically important in this region.

The first report of fossils within what is now KAWW was made in 1838, by C. T. Jackson. Other brief reports were made in succeeding decades; the most detailed can be found in the papers published by Robert Neuman and Douglas Rankin from the 1960s to the 1980s. These two geologists incorporated fossils into their projects to provide information on topics such as the relative ages of rock units and paleogeography. The many brief reports over the decades have given a wide-ranging but fragmented picture of the paleontological resources of what is now KAWW.

The geological story told by the rocks of KAWW is of a series of collisions involving eastern North America and smaller crustal fragments, each contributing to what is now the eastern margin of the continent and to the formation of the Appalachians. The events were punctuated by volcanic eruptions and other igneous activity, including the supervolcano that produced the Katahdin Granite and Traveler Rhyolite. The bedrock geology of KAWW is incompletely understood because of extensive surficial cover, complex faulting, and other factors, but more than a dozen rock units have been recognized within the monument. Among these are sedimentary rocks, metamorphosed sedimentary rocks, extrusive igneous rocks, and intrusive igneous rocks. Many of the geologic units of KAWW are either unnamed or informally named units, so it is likely that future work will lead to revision of the geologic nomenclature. Fossils have been found in the great majority of the sedimentary rocks within KAWW, spanning the Cambrian, Ordovician, Silurian, and Early Devonian. The sedimentary formations and their fossils are marine in origin. Most of the described fossils are either corals or brachiopods (shelled animals that outwardly resemble clams and other bivalve mollusks). Crinoid columnals are common in some fossiliferous units.

At least four external repositories hold fossils collected from sites within KAWW before the monument was established: Eberhard Karls University of Tübingen, the National Museum of Natural History, the New York State Museum, and the Peabody Museum of Natural History. Among the fossils found at localities now within the monument are type specimens for four fossil species. Two other fossil species are based on specimens from localities potentially within the monument but with imprecise geographic information. The use of rivers as boundaries, particularly the East Branch of the Penobscot, complicates research of historical localities because past investigators frequently did not state on which side of the river a locality was found. However, rock units are usually exposed on both sides of the East Branch, so it is extremely likely that investigation would show that both sides have the same kinds of fossils.

In order to better understand, manage, and interpret the paleontological resources of KAWW, a paleontological resource inventory has been initiated. To gather information for the monument's paleontological resource information, a field excursion took place in October 2021. Several sites were visited and specimens collected. The 2021 field inventory produced the first collection of paleontological specimens from KAWW as a national monument. KAWW does not currently include paleontological resources in interpretation programs and material; in the future, paleontology could be incorporated as part of the geological story of the monument. Paleontological resource management at KAWW is complicated by the monument's relative newness, limited staff and funding, sparse infrastructure, and remote location.

Acknowledgments

Each park paleontological resource inventory requires an enormous amount of assistance to complete, and this report was no exception. We would first like to recognize the other members of the 2021 field survey party, without whose assistance we would not have had nearly as successful a field excursion: Eric Hendrickson, Robert Marvinney (Maine Geological Survey emeritus), and Chunzeng Wang (University of Maine at Presque Isle). Eric and his wife Elaine have also provided additional photos of fossils and localities in the monument. We would also like to recognize Dr. Wang's gracious permission to use information from his unpublished reconnaissance geologic mapping of the monument area.

Tim Hudson served as the first Superintendent of KAWW and helped to initiate this project. Mark Wimmer, current Superintendent, has reviewed this report. We acknowledge the support of the National Park Service's Geologic Resources Division, including Tim Connors, Stephanie Gaswirth, and Hal Pranger. Jim Comiskey (Regional Program Manager, Interior Region 1) served as peer review coordinator.

Many people have generously answered queries about fossil occurrences and specimens or provided other assistance. Lisa Amati (New York State Museum) untangled the renumbering of specimens placed in the museum early in the 20th century. Howard Feldman (American Museum of Natural History and Touro College) provided a brachiopod identification. Alicia Paresi and Jennifer McCann (Northeast Museum Services Center) assisted with the curation of the specimens collected during the field survey, and then tracked down the specimens after the delivery service sent them to the wrong location. Stephen Pollock (University of Southern Maine emeritus) provided advice on contacts and finding certain publications. Robert Marvinney and Stephen Pollock provided reviews. We thank Nancy Stamm and Dave Soller from the U.S. Geological Survey for providing access to the USGS's Examine & Report archives, and their assistance with using these files.

We would also like to thank the American Geosciences Institute for their assistance with Justin Tweet's position.

Dedication

Molly N. Ross retired in 2017 after 35 years with the National Park Service (NPS). She began her government career helping the Carter Administration establish, implement, and defend 56 million acres of national monuments in Alaska. She ended her career helping the Obama Administration establish 15 NPS national monuments that protect nationally significant resources and expand the telling of the American story. Molly served as Special Assistant to the NPS Director (2012–2017), Assistant Solicitor for National Parks (2000–2010), Senior Advisor to the Assistant Secretary for Fish and Wildlife and Parks (1993–2000), Assistant Chief of the NPS Air Quality Division (1984–1993), and Attorney-Advisor at the Department of the Interior (1978–1984). Molly received the Department of the Interior's Meritorious Service Award in 1995, the NPS Director's Award for Professional Excellence in Natural Resources in 2009, and the Coalition to Protect America's National Parks Hartzog Award in 2016.

One of the monuments Molly worked on was Katahdin Woods and Waters. She is excited about the development of a paleontological resources inventory for the park unit and is an advocate for the inventory and monitoring of more of its resources. Molly remains connected to this national monument through her continuing service on the founding board of the Friends of Katahdin Woods and Waters.

Molly has long appreciated the role played by the NPS in protecting and interpreting paleontological resources and celebrated the enactment of the Paleontological Resources Protection Act of 2009 (PRPA). Molly's interest intensified with her work establishing Waco Mammoth National Monument, which tells a fascinating story of a nursery herd of Pleistocene mammoths caught in the mud of flooding rivers. The NPS Paleontology Program plays an invaluable role in making the public aware of the nation's paleontological resource heritage.



Photo 1. Molly Ross thanks President Obama for establishing Waco Mammoth National Monument and other National Monuments (White House Photo).

Introduction

Katahdin Woods and Waters National Monument (KAWW) protects an area of northern Maine in Penobscot County known for its natural features, including woodlands, mountainous terrain, and rivers. KAWW was established August 24, 2016 and encompasses 35,435 ha (87,563 acres) distributed in five sections or units, one west of the East Branch of the Penobscot River and four east of it (Figure 1). The western section, the East Branch section, is the largest. Its boundaries roughly approximate an elongate right triangle on a squarish pedestal. It encompasses several peaks such as Deasey Mountain and Lunksoos Mountain, and streams and creeks including parts of Sandbank Stream and Wassataquoik Stream. Much of its eastern boundary is defined by the East Branch of the Penobscot River, commonly referred to as the East Branch. For this report, two areas of KAWW east of the East Branch are included with the East Branch section because they share a border, but it should be noted that they have different management policies (hunting is permitted east of the East Branch in KAWW). These are the TFG section, south of Bowlin Camps, and the Three Rivers section, which includes Lookout Mountain. The East Branch section of KAWW borders Baxter State Park on the west, which itself includes two points of interest for the National Park Service (NPS): the northern terminus of the Appalachian National Scenic Trail (APPA) is located within the state park at Mount Katahdin (or simply Katahdin), which is also a National Natural Landmark. The next largest section of KAWW, the Seboeis section, is east of the northern half of the East Branch section and includes Peaked Mountain and part of the Seboeis River. Finally, the smallest independent section of KAWW, the Hunt Farm section, is east of the southern half of the largest section, east of Hunt Mountain and below the mouth of Wassataquoik Stream. Millinocket is located about 18.5 km (11.5 mi) due south of KAWW, and Houlton is about 56 km (35 mi) east of KAWW.

This report provides detailed information on the paleontological resources of KAWW, including the history of paleontological work in the lands now within the monument, geologic units, taxonomic groups, localities, museum collections, research, interpretation, and management and protection. In addition to the main body of text, there are six appendices: Appendix A, tables of paleontological species arranged by stratigraphy; Appendix B, contact information for repositories; Appendix C, glossary; Appendix D, paleontological resource law and policy; Appendix E, an unpublished geologic reconnaissance map by Chunzeng Wang; and Appendix F, a geologic time scale.

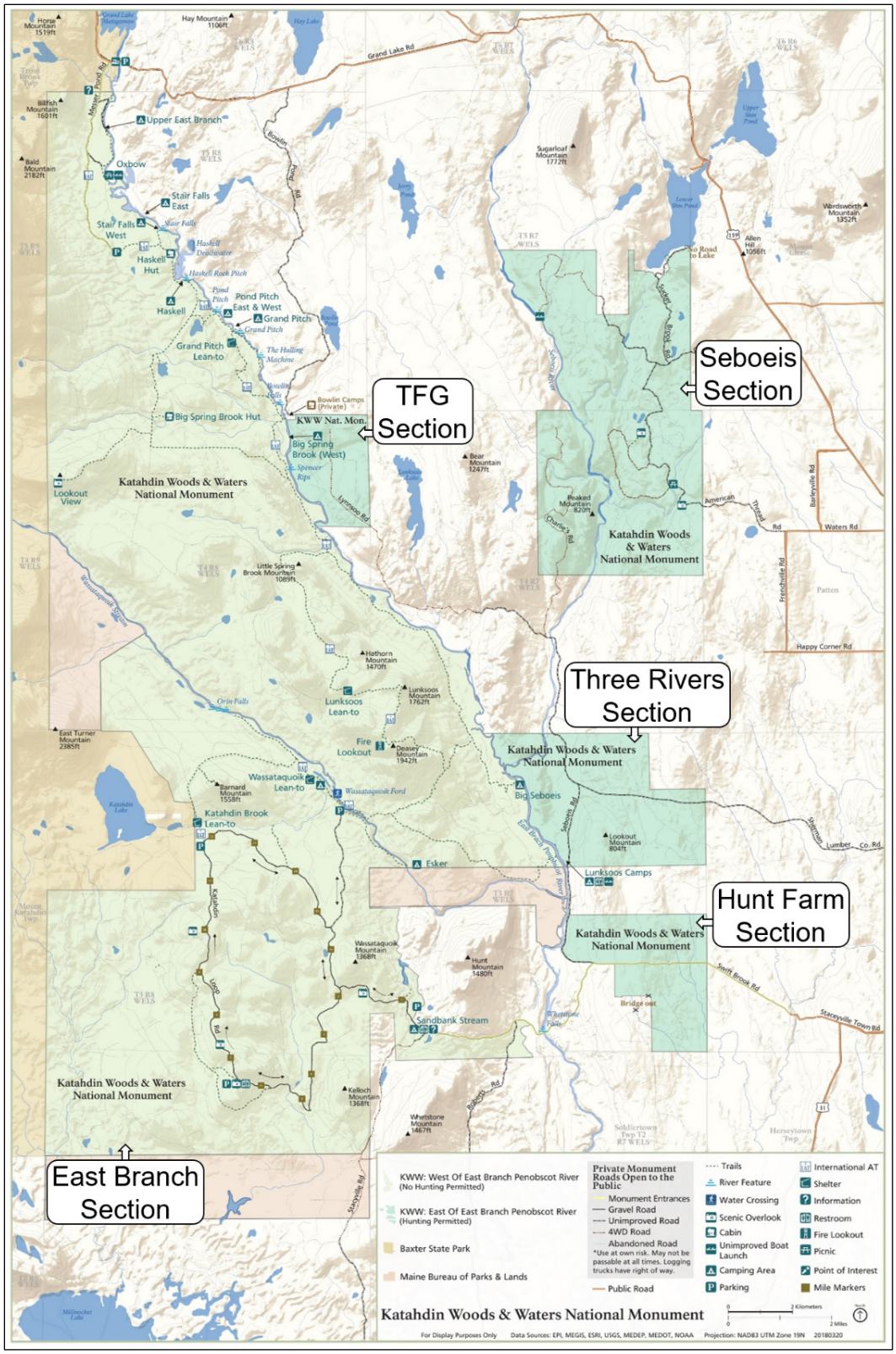


Figure 1. Park map of Katahdin Woods and Waters National Monument (NPS, with sections added as annotations). The light green section where no hunting is permitted and the two adjacent darker green sections are referred to collectively in this report as the East Branch section.

Significance of Paleontological Resources at Katahdin Woods and Waters National Monument

Paleontological resources, or fossils, are any evidence of past life preserved in geologic context. KAWW is one of 18 NPS units for which paleontological resources are specifically mentioned in the enabling legislation or establishing proclamation. The presidential proclamation establishing KAWW (Presidential Proclamation 9476, 81 FR 59121, 2016; https://www.federalregister.gov/documents/2016/08/29/2016-20786/establishment-of-the-katahdin-woods-and-waters-national-monument) describes the geology of the monument in some detail, including mention of paleontology in two paragraphs excerpted below (this material was not written as a scientific document; it is included for reference):

> *"Geologists were among the earliest scientists to visit the area. While surveys were done in the 1800s, in-depth geological research and mapping of the area did not begin until the 1950s. These mid-20th century geologists found bedrock spanning over 150 million years of the Paleozoic era, revealing a remarkably complete exposure of Paleozoic rock strata with well-preserved fossils. The lands west of the Penobscot East Branch are dominated by volcanic and granitic rock from the Devonian period, mostly Katahdin Granite but also Traveler Rhyolite, a light-colored volcanic rock that is similar in composition to granite. The oldest rock in Katahdin Woods and Waters, a light greenish-gray quartzite interlayered with slate from the early Cambrian period (over 500 million years ago), can be observed along the riverbank of the Penobscot East Branch for over 1,000 feet at the Grand Pitch (a river rapid). This rock is part of the Weeksboro-Lunksoos Lake anticline, a broad upward fold of rocks originally deposited horizontally, which is evidence of mountain-building tectonics. The fold continues north along the river and then turns northeast toward Shin Pond, exposing successive bands of younger Paleozoic rock of both volcanic and sedimentary origin on either side of the structure.*
>
> *Various formations in the area provide striking visual evidence of marine waters in Katahdin Woods and Waters during the geologic periods that immediately followed the Cambrian period. For example, Owen Brook limestone, an outcrop of calcareous bedrock west of the Penobscot East Branch containing fossil brachiopods, is of coral reef origin. Pillow lavas, such as those near the summit of Lunksoos Mountain, were produced by underwater eruptions. Haskell Rock, the 20-foot-tall pillar in the midst of a Penobscot East Branch rapid, is conglomerate bedrock that suggests a time of dynamic transition from volcanic islands to an ocean with underwater sedimentation. This conglomerate, deposited about 450 million years ago, contains volcanic and sedimentary stones of various sizes, and occurs in outcrops and boulders in several locations."*

The fossils of KAWW not only have intrinsic significance as evidence of past life, but are also significant in a regional context. The paleontology of northern Maine is relatively poorly known. Tectonism and igneous activity during the Paleozoic destroyed fossils. Hundreds of millions of years

later, the bedrock was scoured by advancing glaciers, then buried under glacially transported debris and further concealed by dense forests. The overall rarity of fossils and fossil-producing rocks in this region add additional importance to the fossils and rocks of KAWW, where fossils from the Cambrian to the Devonian have been found as part of a productive belt from west of Moosehead Lake northeast to Presque Isle (see Churchill-Dickson 2007 as a general reference on Paleozoic fossils of Maine). Aside from serving as evidence of ancient life and past environments, the fossils here have also been used to provide relative ages for their rock formations and show biogeographic connections. Both types of information are used to place rocks in time and space in the complex framework of terranes that make up Maine and the northern Appalachian Mountains. The demonstrated fossil productivity of most of the bedrock units of KAWW indicates the importance of the resource and the potential for significant further discoveries.

Purpose and Need

The NPS is required to manage its lands and resources in accordance with federal laws, regulations, management policies, guidelines, and scientific principles. Authorities and guidance directly applicable to paleontological resources are cited in Appendix D. Paleontological resource inventories have been developed by the NPS to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues, and thus to inform management decisions and actions that comply with these laws, directives, and policies. Options for paleontological resource management are locality-specific, and may include no action, surveys, site monitoring, cyclic prospecting, stabilization and reburial, shelter construction, excavation, closure, patrols, and alarm systems or electronic surveillance. See Appendix D for additional information on applicable laws and legislation.

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to KAWW staff for use in formulating management activities and procedures that would enable compliance with related laws, regulations, policy, and management guidelines. Additionally, this project will facilitate future research, proper curation of specimens, and resource management practices associated with the non-renewable paleontological resources at KAWW. The objectives of the paleontological resource inventory project include:

- Locating, identifying, and documenting paleontological resource localities through field reconnaissance and perusal of archives, using photography, GPS data, and standardized forms.
- Relocating and assessing the locations of historic fossil collecting sites when possible.
- Assessing collections of KAWW fossils maintained in external museum repositories.
- Documenting current information on faunal assemblages and paleoecological reconstructions.
- Conducting a thorough search for relevant publications, unpublished geologic notes, and external collections of fossils from KAWW, both predating and after its establishment.

History of Paleontological Work at Katahdin Woods and Waters National Monument

While paleontology has not been the singular focus of a publication concerning the lands now within KAWW boundaries, there is a rich history of geologic scholarship in the area. The geology of the area now included in KAWW was first scientifically described in the mid-19th century. The earliest observation that can be construed as a report of fossils within KAWW appears to be from Jackson (1838). During an investigation up the East Branch and the Seboeis River, Jackson observed that Peaked Mountain, now within the Seboeis section of KAWW, was made up of "Grau-wacke" (=graywacke) that included "large beds of limestone made up of madrepores" (used in the archaic sense of any "stony" coral) (Jackson 1838:23). Jackson also reported that "huge boulders of madrepore limestone abound" in the vicinity of the mountain. It is not clear which formation he was referring to. Based on the descriptions of the formations mapped at Peaked Mountain in Neuman (1967), the unnamed Silurian conglomerate (see below) seems to be the most likely source. It should be noted that Jackson was interested in emphasizing the economic potential of the area (Neuman 1967), and so may have described the limestone as more abundant than it is. His report of fossils was corroborated, but in a less extravagant fashion, by Hitchcock (1861a), who reported small beds of Silurian limestone with tabulate corals on Peaked Mountain.

More paleontological information was published in the 1860s, albeit still not in great detail. Charles Henry Hitchcock, the State Geologist of Maine in 1861–1862, led an expedition to the area in August 1861. The paleontology of areas now within KAWW was mentioned in passing in several resulting publications (Hitchcock 1861a, 1861b; Holmes 1861; Billings 1869; the publications often cited as 1861 may have actually been published in 1862, while the publication cited as Billings 1869 was delivered January 12, 1863, as noted in Williams 1900). Hitchcock not only reported fossils on Peaked Mountain, but also observed fossils at several other places in or near KAWW, including: crinoids and the tabulate coral *Favosites gothlandica* in boulders in the Whetstone Falls area (Hitchcock 1861a:393); Early Devonian fossils in boulders on the east side of the East Branch (Hitchcock 1861a:400); "very large boulders of fossiliferous limestone" in the vicinity of "Upper Falls" (now known as Haskell Rock Pitch) (Hitchcock 1861a:402); a new species of the trilobite *Dalmanites* from the Stair Falls area (Hitchcock 1861a:402); and a locality identified as "Johnston's Camp", in the "central part of No. 5, R. 8", where Hitchcock's expedition found "the finest locality of Devonian fossils we have yet seen in Maine, but the ledges do not appear—the specimens are entirely in loose fragments, whose source must be very near" (Hitchcock 1861a:402).

Holmes (1861) gave a few more details about some of the localities. The trilobites were collected from the east side of Stair Falls, indicating they were from outside of KAWW. "Johnston's Camp" ("Camp Johnston" of his usage) was a logging camp that had been constructed by party member William A. Johnston two years before. The geographic position of the camp was not rendered any more precisely than in Hitchcock's report. The camp was used as a base of operations for several days. Holmes (1861) also indicated that Hitchcock would later provide more details on the fossils, but unfortunately this was not fulfilled. Instead, the only fossil from this group to be described was

the Stair Falls trilobite, as new species *Dalmanites epicrates* (Billings 1869) (Figure 2). A fire at the Portland Society of Natural History in 1866 is thought to have destroyed Hitchcock's collection (Williams 1900; Clarke 1909).

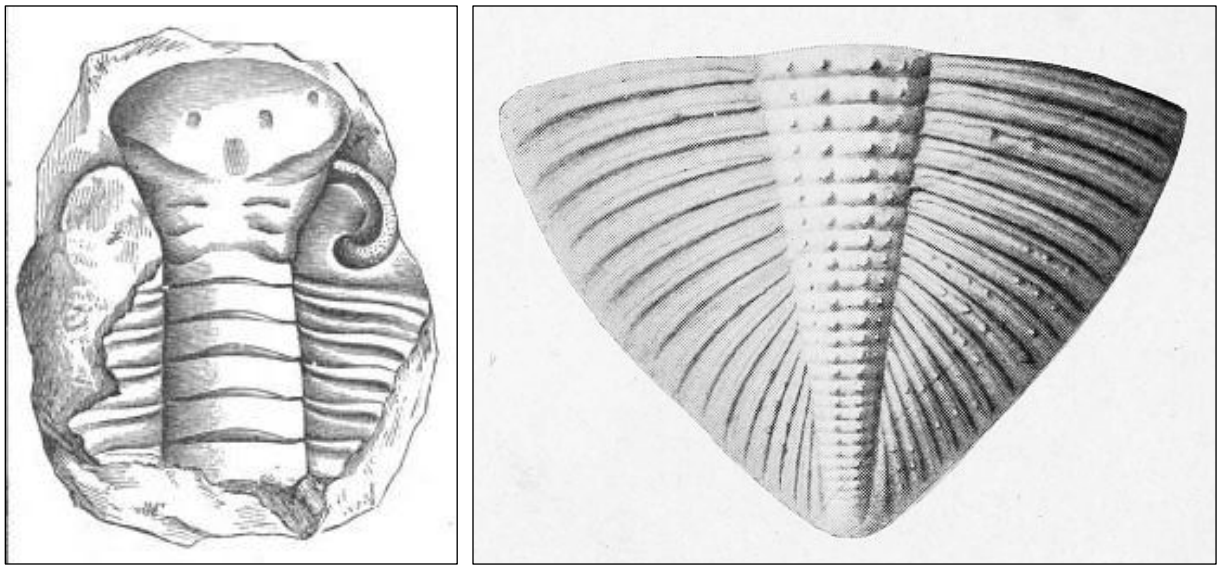


Figure 2. Trilobites named from Devonian rocks in or near Katahdin Woods and Waters National Monument. **Left.** *Dalmanites epicrates*, illustrated in Billings (1869) (Figure 21 in plate); **Right.** Pygidium (tail section) of *Dalmanites ploratus* (Clarke 1907).

Dodge (1881, 1890) reported on a small graptolite assemblage from a site on the north side of Wassataquoik Stream, west of its junction with the East Branch and a short distance outside of KAWW. This locality is now known to be in the Ordovician-aged Wassataquoik Chert (Neuman 1967).

John Mason Clarke and O. O. Nylander began a project in 1905 to restudy the Devonian of Maine; from Clarke's (1909) description, it appears that Nylander was the field geologist. The first fruit of this was another new trilobite species, *Dalmanites ploratus* (Clarke 1907; more recently *Odontochile ploratus* per Delo 1940) (Figure 2). In a later publication, Clarke provided locality descriptions and faunal lists for several localities in or near KAWW. The most productive was locality 3452 (New York State Museum?), encompassing loose blocks at "Cunningham's Camp" located southwest of Matagamon Lake and west of the East Branch of the Penobscot in No. 5, R. 8 (also written as T5 R8 WELS, which in full is Township 5 Range 8 West of the Easterly Line of the State). This site would be within KAWW. Per Clarke, this locality "appears to be practically the same place as that referred to by Hitchcock as 'Johnston's camp,' no longer known" (Clarke 1909:65). Clarke attributed this and other Devonian localities in the KAWW area to the Moose River Sandstone; this unit name is no longer used in the KAWW area, having been replaced by the Matagamon Sandstone.

The next report of fossils from the area is a mention of the Cambrian trace fossil *Oldhamia* from T5 R8 WELS by Smith (1928a). Rudolf Ruedemann described the Penobscot *Oldhamia* as new species *O. smithi* in Ruedemann (1942); the precise source locality is not given beyond the East Branch of

the Penobscot in No. 5, R. 8 (also written T5 R8 WELS), so it may or may not have been named from KAWW, but *Oldhamia* is definitely known from the monument. Ruedemann and Smith (1935) discussed the Dodge graptolite site and named the Grand Falls Formation, later renamed the Grand Pitch Formation (Neuman 1962) because the "Grand Falls Formation" name was already in use (Neuman 1960, 1962). Several decades after Smith and Ruedemann, in 1996, noted trace fossil paleontologist Adolf Seilacher collected specimens of *Oldhamia* within what is now KAWW, as shown by Peabody Museum of Natural History collections records. Some of these specimens were illustrated in his publications (e.g., Seilacher et al. 2005).

Most of what is known about the paleontology of KAWW is due to mapping conducted in the 1950s and 1960s by Robert Neuman and Douglas Rankin and published in a series of papers (e.g., Neuman 1960, 1962, 1966, 1967, 1968, 1980; Rankin 1961, 1965; Neuman and Rankin 1966, 1980). Neuman mapped the Shin Pond and Stacyville 15′ Quadrangles for the U.S. Geological Survey over six years ending in 1963, while Rankin mapped the Traveler Mountain 15′ Quadrangle for his dissertation over five years ending in 1961 (Pollock and Anderson 2013). Among other achievements, they documented the Ordovician sequence from Pond Pitch to Haskell Rock Pitch, and the informally named "Owen Brook Limestone". Three fossil coral taxa discovered in the Ordovician sequence were later described as new species (Elias 1982). Little new paleontological information has been published since this time, but the documented resources were recognized in the presidential proclamation establishing KAWW, as discussed above.

Summary of 2021 Paleontological Survey

The KAWW paleontological inventory, under Technical Assistance Request 15445, was originally scheduled for 2020, with a field visit that fall. The SARS-CoV-2 pandemic necessitated a delay of the planned field work until fall 2021. In the meantime, the inventory report was taken as far as possible based on the literature; this lengthy gestation allowed for the collection of copies of practically every known publication of significance on the geology of the monument area.

From October 4 to October 7, 2021, Vincent Santucci and Justin Tweet of the National Park Service Paleontology Program conducted a field exploration of KAWW (permit KAWW-2021-SCI-0005). Also participating and sharing their expertise were Isabel Ashton, KAWW Integrated Resource Program Manager (also Acting Superintendent at the time of the visit); Eric Hendrickson, friend of the monument and deeply versed in local natural and human history; Robert Marvinney, Maine State Geologist emeritus; and Chunzeng Wang, professor of Earth and Environmental Studies at the University of Maine at Presque Isle.

Although fossils have been reported from numerous localities in and near the boundaries of KAWW, geographic and other documentation is limited for many of the sites. The 2021 field survey revisited several of the most significant of the previously reported localities for which good locality information existed. These included the “Owen Brook Limestone”, the Ordovician sequence exposed along the East Branch, and Lower Devonian Matagamon Sandstone rocks at Stair Falls. Three paleontological localities, the first for KAWW as a monument, were formally documented. Six pieces of fossiliferous Matagamon Sandstone were collected at one of these localities, also the first for KAWW as a monument. Fossils were observed at the two “Owen Brook” localities but were not collected. The field crew intended to visit the Peaked Mountain area but were prevented by high water; Hendrickson later made a visit to this area.



Photo 2. From left to right, Vincent Santucci, Eric Hendrickson, Robert Marvinney, and Chunzeng Wang at the Haskell campground. Field work in KAWW in early October proved to be a picturesque proposition (NPS/JUSTIN TWEET).

Geology

Geologic History

The following section is intended as a brief semitechnical summary of the geologic history of KAWW, to provide background for monument staff and references for technical information.

The bedrock of KAWW tells a complex story of sedimentation, volcanism, and structural deformation. Briefly, the bedrock geology of Maine is made up of crustal fragments (terranes) that collided with each other and the eastern margin of North America during the first half of the Paleozoic, approximately 540 to 400 Ma (million years ago; see Appendix F for a geologic time scale). North America, also known as Laurentia when discussing this time frame, rifted from a supercontinent just before the Cambrian. Some smaller continental fragments also separated from the supercontinent and eventually collided with Laurentia (van Staal et al. 2012). Many of the events that occurred during this process are incompletely understood, with multiple hypotheses vying in the literature, and it is beyond the scope of this document to describe the events in detail or evaluate the likelihood of the various hypotheses.

Much of Maine, including KAWW, is underlain by a terrane known as Ganderia or Gander (van Staal et al. 2009, 2012). Ganderia is thought to have rifted free from the supercontinent approximately 505 Ma (van Staal et al. 2012). The oldest rocks exposed in KAWW, belonging to the Cambrian-age Grand Pitch Formation, were deposited at Ganderia before it was part of North America. These marine rocks show evidence of an episode of geologic deformation not recorded in the more recent rocks of the area. This episode is known as the Penobscot Orogeny (mountain-building event; Penobscot disturbance of older reports) (Neuman and Max 1989; Zagorevski et al. 2007; van Staal et al. 2009). The Penobscot Orogeny took place in Ganderia during the Early Ordovician, approximately 480 Ma (Zagorevski et al. 2007). When it occurred, Ganderia had not yet docked with North America, as shown by the fossils of the Early Ordovician-age Shin Brook Formation, deposited above the Grand Pitch Formation. These are similar to those from other components of Ganderia (locations now in Newfoundland, New Brunswick, Ireland, Wales, and Norway), rather than North America (Neuman and Whittington 1964; Neuman 1984; Neuman and Max 1989).

Volcanism occurred as Ganderia moved north during the Ordovician. The rocks produced at this time include the unnamed Ordovician pillow basalts of the Lunksoos Mountain area (Neuman 1967). Marine sedimentary deposition followed for the rest of the Ordovician, punctuated by occasional volcanic eruptions; the resulting rocks include the Wassataquoik Chert and the unnamed sequence on the East Branch between Pond Pitch and Haskell Rock Pitch (Neuman 1967).

Ganderia accreted to Laurentia sometime during the Late Ordovician–Silurian time frame, approximately 450 to 423 Ma (van Staal et al. 2009). This event is historically known as the Taconic Orogeny (e.g., Neuman and Rankin 1980; Eldridge et al. 2012). More recently, the Taconic Orogeny name has been applied to a different collision, and the culmination of the Ganderia–Laurentia collision has become known as the Salinic Orogeny (e.g., Dorais et al. 2009; van Staal et al. 2009; Seaman et al. 2019). The reference to “culmination” is because of the possibility that Ganderia had

partially rifted by this time, with some parts colliding with North America before others (van Staal et al. 2009). The Rockabema Quartz Diorite may be associated with this Salinic event (Neuman 1967; Taconic of his usage). Additional marine deposition followed for much of the Silurian, again punctuated by volcanic eruptions. The rocks include the Allsbury Formation and several unnamed units, among them the "Owen Brook" reef limestone.

Another orogeny, the Acadian Orogeny, occurred in Maine during the late Silurian and Early Devonian, approximately 421 to 400 Ma (van Staal et al. 2009). This was the result of another terrane (Avalonia) colliding with Laurentia (van Staal et al. 2009). Although the final location of Avalonia is distant from the KAWW area (van Staal et al. 2009), the effects of its collision were widespread, moving northwest across Maine over tens of millions of years (Bradley et al. 2000). As the continental margin warped from the collision, a basin formed that accumulated the sediments that became the Seboomook Group and Matagamon Sandstone (Rankin 1965; Pollock 1987; Pollock et al. 1988; Bradley et al. 2000). Deposition transitioned from marine turbidites in the former to a delta system advancing to the northwest for the latter (Hall et al. 1976; Pollock et al. 1988).

The most obvious evidence of the Acadian Orogeny in the KAWW area is Katahdin itself (Rankin and Caldwell 2010), which is part of an enormous igneous intrusion (a batholith) that was emplaced during the mountain-building event (Seaman et al. 2019). The intrusion is approximately 40 km (25 mi) in diameter and 5 km (3 mi) thick (Rankin and Hon 1987) and crystallized 406.9 ± 0.4 Ma (Rankin and Tucker 1995). The volcanic phase of the igneous activity is preserved as the adjacent Traveler Rhyolite, erupted between 407.3 ± 0.5 and 406.7 ± 1.4 Ma (Rankin and Tucker 1995). Essentially, the magma chamber intruded its own volcanic pile (Rankin and Hon 1987). Together, the Katahdin Granite–Traveler Rhyolite rocks are the remains of a supervolcano that erupted approximately 407 Ma, the largest of several volcanic complexes of similar age in central Maine. Approximately 800 km^3 (190 mi^3) of the eruptive material is preserved today as the Traveler Rhyolite, out of an original volume of perhaps 5,000 km^3 (1,200 mi^3) (Seaman et al. 2019).

Excluding a few minor exceptions, the Katahdin–Traveler activity marks the last direct record of geologic events in the KAWW area until the Quaternary, which began 2.58 Ma. These exceptions include the Trout Valley Formation of Baxter State Park, which dates to about the Early–Middle Devonian boundary (Allen and Gastaldo 2006; approximately 393 Ma), and a few localized instances of igneous activity later in the Devonian (e.g., the Horserace pluton of 392 Ma; Bradley et al. 2000). The Trout Valley Formation is significant for its fossils, particularly early land plants and the unusual *Prototaxites*, currently interpreted as a giant, tree-like fungus (Allen and Gastaldo 2006; see section under "Paleontological Localities: Paleontological Localities Near KAWW" for a brief discussion). Any rocks deposited more recently have been lost to erosion.

The Quaternary record of the KAWW area is dominated by the activity of glaciers. Only the evidence of the most recent glaciation (the Wisconsinan) can be clearly discerned because evidence of older glaciations has been disrupted by succeeding glaciations. At the height of the Wisconsinan, the Last Glacial Maximum (LGM), glaciers were of sufficient thickness to cover Katahdin. It was once again exposed from beneath the ice between approximately 17,000 and 13,000 years ago (Davis et al. 2015). End-Wisconsinan glacial retreat from Maine began approximately 22,000 to 20,000

years ago; at this time, the glacial front was at what is now the continental shelf. The retreating glacial front reached southern KAWW between 15,100 and 14,000 years ago, passed the area marked by the junctions of the East Branch with Wassataquoik Stream and the Seboeis River about 14,000 years ago, and departed KAWW by about 13,900 years ago (Hooke and Hanson 2017). Postglacial adjustments permitted marine water to reach approximately as far north as the East Branch–Seboeis confluence in the Penobscot Valley at approximately 14,000 years ago, before retreating toward the modern coastline. The East Branch was also reformed approximately 14,000 years ago, near the confluence with the Seboeis, and grew north and south (Hooke and Hanson 2017). Humans may have arrived in the Penobscot Valley around 10,000 years ago and were definitely there before 8,500 years ago (Sanger et al. 2003).

At this time more than a dozen rock units have been distinguished in KAWW on published maps of the area (Neuman 1967; Neuman and Rankin 1980; Osberg et al. 1985; Eldridge et al. 2012), but the existing stratigraphic scheme is unsettled. For example, the maps include several unnamed and/or undivided units. Mapping can be challenging in this area due to extensive surface cover and faulting. All of the existing bedrock maps have limitations. None of the maps is at a scale of 1:24,000, which is preferred for resource management. Neuman (1967) does not document the Katahdin or Traveler Mountain 15′ Quadrangles and therefore does not include a significant part of KAWW. Rankin (1961) maps the Traveler Mountain 15′ Quadrangle, but the document is an unpublished dissertation. Osberg et al. (1985) is a statewide map based on a compilation of existing maps, so it does not have the same level of detail as the Neuman and Rankin maps and cannot reach the same level of stratigraphic nuance in this complex area. However, it is convenient because a digital version has been produced. Chunzeng Wang (University of Maine at Presque Isle) is undertaking reconnaissance mapping of the area based on the Neuman and Rankin maps (pers. comm., October 2021 and March 2022; see Appendix E). Wang's reconnaissance map is the most recent, but it is preliminary and unpublished. It also includes significant revisions of stratigraphic units, which are beyond the scope of this report to evaluate. The geologic map included below as Figure 3 is based on Osberg et al. (1985), while the descriptions in this report are primarily after Neuman and Rankin. It is hoped that precision and detail in the text will facilitate "translation" between existing publications and between older literature and any future stratigraphic revisions.

In approximately ascending order (oldest to youngest, using 2022 geochronologic divisions; the stratigraphic relationships of some of the unnamed units are not clear), the geologic units of KAWW include: the Grand Pitch Formation (early? Cambrian)[1]; altered andesitic and basaltic rocks (Middle? Ordovician); Wassataquoik Chert (Late Ordovician); an unnamed and undivided sequence of sedimentary rocks with Late Ordovician fossils; Rockabema Quartz Diorite (Ordovician–Silurian); Allsbury Formation (early?–middle Silurian); conglomerate (Silurian); tuff breccia (Silurian); "Owen Brook Limestone" (late Silurian); Seboomook Group (Early Devonian; including rocks attributed the Carrabassett Formation by Osberg et al. 1985); Matagamon Sandstone (Early Devonian); Traveler

[1] "Early" and "Late" (capitalized if formally defined, lowercase if not) refer to age; "Lower" and "Upper" are used when referring to stratigraphic position.

Rhyolite and Katahdin Granite (Early Devonian); and Quaternary cover (Pleistocene–Holocene) (Neuman 1967; Neuman and Rankin 1980; Osberg et al. 1985; Eldridge et al. 2012) (Figure 3; Table 1). In addition to the formations exposed in the monument, two additional formations with significant fossils are exposed within a few km (or miles) of KAWW: the Ordovician Shin Brook Formation (Neuman and Whittington 1964) and Devonian Trout Valley Formation (Dorf and Rankin 1962).

Most of the sedimentary formations of KAWW are known to be fossiliferous within the monument (Table 1), and those that are not known to be fossiliferous here at this time may eventually yield fossils. There is currently some complication about the fossils in some of the formations: in several cases fossils were reported from along the East Branch, but which side of the river was not specified. This is of interest for management purposes because the East Branch often marks a boundary of KAWW. It can be assumed that for a report of a general variety of fossil, such as "brachiopods" or "trace fossils", the side of the river is not important, because it is likely that examples of broad groups will be found on both sides of the river if the same rock unit is present. However, in cases of specific fossils, such as type or illustrated specimens, the same cannot be assumed.

Reconnaissance surficial geology maps of the four 15′ quadrangles in which KAWW is located (Newman 1981a, 1981b, 1981c; Newman and Genes 1986; William Newman should not be confused with Robert Neuman) depict no significant areas of bedrock or thin surficial deposits in KAWW in the Katahdin 15′ Quadrangle (Newman 1981a), a few local areas in the Shin Pond and Traveler Mountain 15′ Quadrangles (Newman 1981b, 1981c), and significant areas of thin surficial deposits in the KAWW portion of the Stacyville 15′ Quadrangle (Newman and Genes 1986).

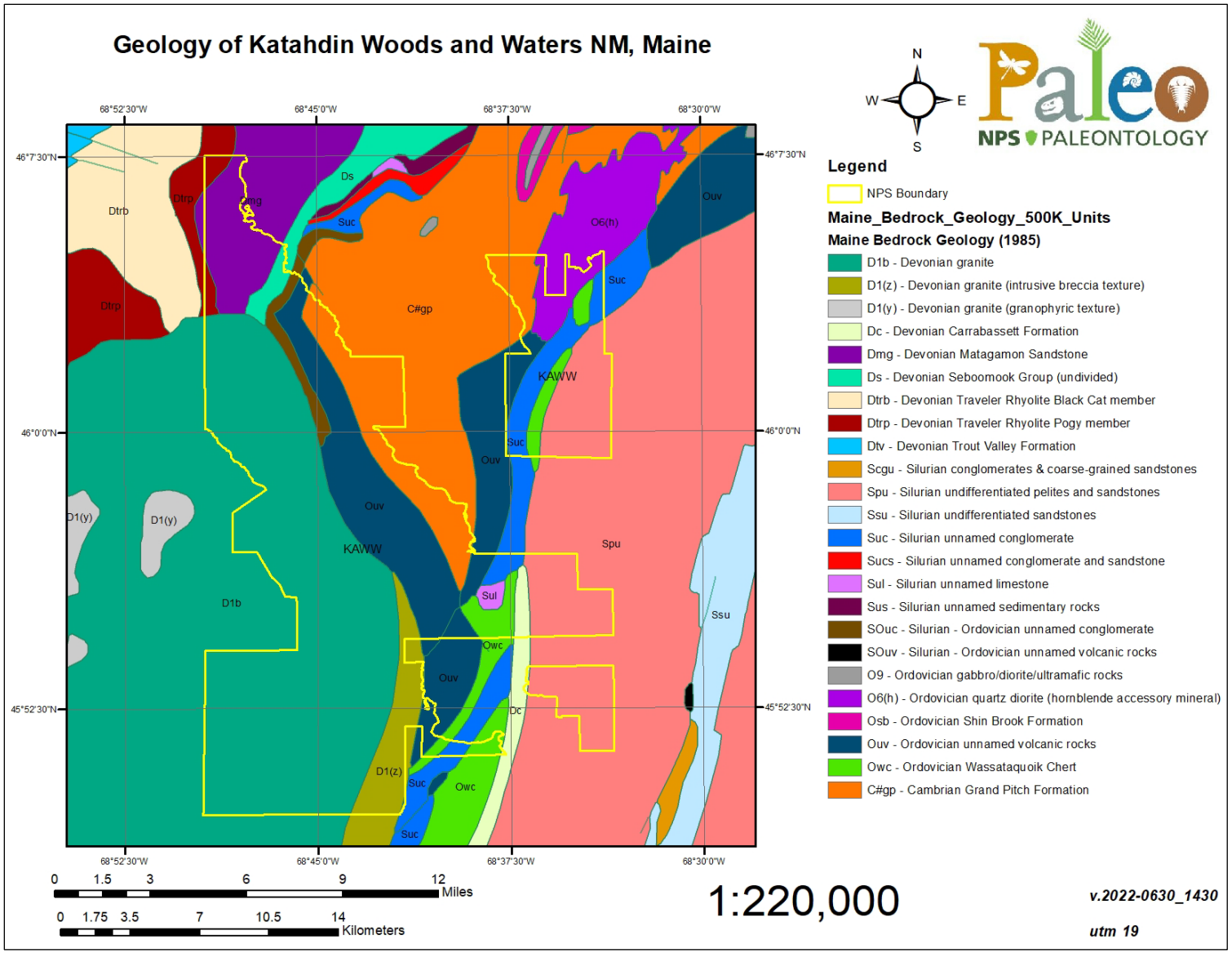


Figure 3. Geologic map of Katahdin Woods and Waters National Monument, based on Osberg et al. (1985). The Carrabassett Formation (Dc), if indeed present (see discussion below under "Seboomook Group undivided"), is today part of the Seboomook Group.

Table 1. Summary of Katahdin Woods and Waters National Monument stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within KAWW	Depositional Environment
Quaternary cover	Pleistocene–Holocene	Unspecified marine fossils; fossiliferous fragments of older rocks are found as float	Glacial drift, glacio-fluvial, fluvial, swamps
Katahdin Granite	Early Devonian	Unfossiliferous	Igneous rocks emplaced at depth
Traveler Rhyolite	Early Devonian	Unfossiliferous	Eruptive igneous rocks
Matagamon Sandstone	Early Devonian	Brachiopods, monoplacophorans, bivalves, gastropods, trilobites, crinoids, a cylindrical structure, and possibly tentaculitids	Delta front and delta plain
Seboomook Group	Early Devonian	None to date	Prodelta-marine basin
“Owen Brook Limestone”	late Silurian	Stromatoporoid sponges, tabulate and rugose corals, brachiopods, crinoids, and fossil debris	Reefal marine
Tuff breccia	Silurian	Tabulate corals, brachiopods, pelmatozoans, and fossil debris in limestone clasts	Marine and volcanic, presumably
Conglomerate	Silurian	Tabulate and rugose corals, brachiopods, and reworked Middle Ordovician graptolites; perhaps the source of the tabulate corals near Peaked Mountain as well	Marine
Allsbury Formation	early?–middle Silurian	Graptolites	Marine
Rockabema Quartz Diorite	Ordovician–Silurian	Unfossiliferous	Igneous rocks emplaced at depth
Undivided Ordovician sequence of East Branch	Late Ordovician	Tabulate and rugose corals, brachiopods, perhaps gastropods and trilobites	Marine with volcanic eruptions
Wassataquoik Chert	Late Ordovician	None to date; graptolites, conodonts, and apparently cephalopods and gastropods just outside	Marine
Altered volcanic rocks	Middle? Ordovician	Unfossiliferous	Eruptive igneous rocks
Grand Pitch Formation	early Cambrian?	Invertebrate trace fossil *Oldhamia antiqua*	Marine

Geologic Formations

Grand Pitch Formation (early? Cambrian age)

Description: Gray, green, and red slate and siltstone (Figure 4), vitreous quartzite, and more minor graywacke and tuff. It is well-exposed along the East Branch from Grand Pitch to Bowlin Falls. These outcrops are notable for supporting several waterfalls on the quartzite beds (Figure 5). Deformation of the formation is complex and has completely destroyed sedimentary features locally (especially in slate beds). Overall, it is probably at least 1,500 m (5,000 ft) thick (Neuman 1967). The upper contact with Ordovician and Silurian rocks is an angular unconformity (Neuman 1962). In older reports, this formation was known as the Grand Falls Formation (Ruedemann and Smith 1935), but that name was already in use, so it was renamed the Grand Pitch Formation in Neuman (1962). There is evidence suggesting that the area mapped as the Grand Pitch Formation includes another, undescribed unit of disrupted strata (Boone and Boudette 1989; Neuman and Max 1989; Neuman 1994).



Figure 4. Grand Pitch Formation slate at Grand Pitch (NPS/JUSTIN TWEET).



Figure 5. The Grand Pitch Formation at its type locality, looking west into Katahdin Woods and Waters National Monument across the East Branch (NPS/JUSTIN TWEET).

There is little evidence for the age of the Grand Pitch Formation. The only fossil yet reported from the formation, the invertebrate ichnofossil *Oldhamia*, is most abundant in lower Cambrian rocks (Seilacher et al. 2005). However, *Oldhamia* is not necessarily limited to this time frame, nor has it been established that the entire formation is only early Cambrian in age (Neuman 1960, 1962, 1967). The depositional environment has been interpreted as a continental slope–rise setting (Wellensiek et al. 1990). When *Oldhamia* is found as the only type of fossil in a formation, as in the Grand Pitch Formation, this is thought to be an indication of deep marine deposition (Seilacher et al. 2005).

Fossils found within KAWW: *Oldhamia* (Peabody Museum of Natural History records).

Fossils found elsewhere: *Oldhamia* is the only fossil yet reported from this formation.

Altered volcanic rocks (Middle? Ordovician)

Description: "Gray and greenish-gray fine-grained igneous rocks, probably largely of extrusive origin" (Neuman 1967:I8). Because of their greenish color and alteration, the rocks have been lumped collectively as "greenstone", but include a variety of igneous compositions, among them basalt, andesite, and probably dacite. Pillow lavas and flow breccias show that at least some were

formed extrusively. The rocks crop out as ledges on ridges, typically weathering dark brown (Neuman 1967). Neuman (1967) found these volcanic rocks (acronyms Ov and Ovr on the associated map) in six discrete areas that he interpreted as fault-bounded, originally making one area. The unnamed unit was depicted as a north-south belt that splits into northeast and northwest forks west of the East Branch–Seboeis junction.

The age of this unnamed unit is poorly known, but it must be older than the overlying Wassataquoik Chert, and it may be contemporaneous with the Shin Brook Formation of Middle Ordovician age, exposed just outside of KAWW (Neuman 1967). Some of the rocks have been complexly intruded by the Rockabema Quartz Diorite. Faulting makes it difficult to be sure of the exact thickness of this unit, but it thins dramatically from perhaps 2,700 m (9,000 ft) in the Hunt Mountain area to about 300 m (1,000 ft) at Pond Pitch (Neuman 1967). Wellensiek et al. (1990) introduced an informal name, the “Stacyville Volcanics”, for this unit; previously Rankin (1961) referred to these rocks as the “Pond Pitch Basalt” (Figure 6). Some areas of interest in KAWW include the pillow lavas in the vicinity of Lunksoos Mountain, and a small area of volcanic breccia in Little Spring Brook (Neuman 1967).



Figure 6. Basalt at Pond Pitch (NPS/JUSTIN TWEET).

Fossils found within KAWW: Fossils have not yet been reported from this unit within KAWW. Fossils are unlikely, but not entirely impossible (e.g., a fossiliferous sedimentary interval of local extent in the volcanics).

Fossils found elsewhere: Fossils have not yet been reported from this unit.

Wassataquoik Chert (Late Ordovician)

Description: "Thin-bedded chert, including medium- to dark-gray, greenish-gray and red varieties, with volcanic rocks interbedded in some places" (Neuman 1967:I11). Four areas of outcrops are mapped in a NNE–SSW belt from Millinocket Lake in the south to Lower Shin Pond in the north. The thickness of this unit is unclear. It may range from 90 m (300 ft) to 460 m (1,500 ft), to as much as 910 m (3,000 ft) where there is abundant interbedded tuff. Most beds have fine laminations, and beds have been tightly folded. The lower contact with the altered volcanic rocks discussed above appears to be conformable, while no upper contacts have been found; potential upper contacts are generally faults, although in some places there are conglomeratic beds of Wassataquoik Chert fragments (Neuman 1967). Wellensiek et al. (1990) reported interbedding with the underlying volcanics. Microfossils place the formation in the middle Caradocian of the Ordovician (Sweet and Bergström 1966), previously included in the Middle Ordovician but now considered early Late Ordovician. Conodont fossils indicate a "north Atlantic" biogeographic affiliation (Neuman 1984).

Fossils found within KAWW: Fossils have not yet been reported from this unit within KAWW, but localities yielding graptolites and conodonts have been found within 1 km (0.6 mi) of the monument.

Fossils found elsewhere: Brachiopods (Pollock and Anderson 2013), cephalopods, gastropods (Weddle 2005), graptolites (Ruedemann and Smith 1935), and conodonts (Sweet and Bergström 1966).

Ordovician sequence of East Branch (Late Ordovician)

Description: Heterogeneous, including distinct intervals of siltstone, pebbly siltstone, massive sandstone, pebbly sandstone, conglomerate, and pillow basalt (Figures 7–9) (Neuman 1980). This interval was first recognized during the Neuman/Rankin work of the mid-20th century and was described in detail in Neuman (1967). The sequence on the East Branch is cut off by non-exposure, but further northeast along strike there are similar fossiliferous Silurian rocks above the thin belt of this undivided Ordovician sequence (Neuman 1967). The sequence is approximately 1,200 m (4,000 ft) thick on the East Branch between Pond Pitch and Haskell Rock Pitch, and several intervals have produced fossils, especially corals and brachiopods. The fossils permit the sequence to be dated to the Ashgillian Stage of the Late Ordovician (late Late Ordovician). They also show shifting depths and/or water temperature of the marine environment over time (Neuman 1980). Rankin (1961) identified these rocks as Silurian before the Ordovician age of the fossils was established and proposed to call them the "Kimball Brook Formation" along with other Silurian rocks nearby, with the "Haskell Rock Conglomerate" as its upper division. Rankin (1961) reported deriving the latter name from Smith (1928b), in which the conglomerate was incorrectly interpreted as lithified glacial till. These names were also in use briefly within the USGS, as shown by an internal communication between Boucot and Neuman (A. Boucot, USGS, written comm. to R. Neuman, 1963), but were not

used in Neuman (1967) or otherwise formally established. Work on the fossils has shown that although the putative narrow sliver of "Kimball Brook Formation" along the East Branch is lithologically similar to the rocks along Kimball Brook (Rankin 1961), they cannot be the same formation unless the definition is substantially changed. The East Branch rocks have fossils of Late Ordovician age, while the Kimball Brook rocks have yielded Silurian fossils except for one Late Ordovician collection near the base (Neuman 1967). The "Haskell Rock Conglomerate" would be stratigraphically between them, rather than forming the top of the interval. Rankin's "Kimball Brook Formation" grades upward into the "Haskell Rock Conglomerate" along the East Branch, the two differing in their relative proportion of conglomerate. Conglomerate is less abundant in the "Kimball Brook Formation", although it does include some, including a "double conglomerate" bed just above the volcanics at Pond Pitch so-called because it is a conglomerate made up of fragments from an older conglomerate (Rankin 1961).



Figure 7. Sedimentary rocks are present above the basalt at Pond Pitch (NPS/JUSTIN TWEET).



Figure 8. Haskell Rock and associated exposures are made up of conglomerate (NPS/JUSTIN TWEET).

Fossils found within KAWW: Tabulate corals (Neuman 1980), rugose corals (Neuman 1980; Elias 1982), brachiopods (Neuman 1980), possibly sponges or red algae (W. Oliver, USGS, written comm. to D. Rankin, 1960), possibly gastropods (Elias 1982), possibly trilobites (Neuman 1967; Elias 1982), and possibly graptolites (R. Neuman, USGS, written comm. to D. Rankin, 1963). Because the sequence is exposed on both sides of the East Branch, and authors have not always specified which side of the river a given fossil came from, it is not always possible to state whether or not a given report pertains to KAWW or the area just outside of it. However, it is unlikely that a given group would not be present on both sides. Additionally, authors to date have focused on biostratigraphically important fossils such as brachiopods and corals, so it would not be surprising if other taxonomic groups are also present but have not been reported.

Fossils found elsewhere: No other taxonomic groups have been reported outside of KAWW.



Figure 9. Conglomerate at Haskell Rock (NPS/JUSTIN TWEET).

Rockabema Quartz Diorite (Ordovician–Silurian)

Description: Altered quartz diorite, expressed in two phases (crystals of equal size or some crystals noticeably much larger) (Neuman 1967). This unit is mapped in the Seboeis section of KAWW (as the unit with acronym SOr; Neuman 1967), where it is associated with and intrudes older Ordovician greenstone (Ovr of Neuman 1967). Northeast of the Seboeis section, it underlies both Lower and Upper Shin Pond (Neuman 1967). The age of this unit is poorly constrained, being younger than the Middle Ordovician volcanics it intrudes but older than the late early Silurian sedimentary rocks that include pebbles eroded from it (Ekren and Frischknecht 1967; Neuman 1967). Neuman (1967) suggested that this unit intruded during the Taconic Orogeny (=Salinic Orogeny).

Fossils found within KAWW: Not applicable.

Fossils found elsewhere: Not applicable.

Allsbury Formation (early?–middle Silurian)

Description: Two members of the Allsbury Formation were mapped by Neuman (1967) in the KAWW area: a lower sandstone member composed of coarse-grained sandstone and conglomerate with interbedded gray and green slate; and an upper slate member composed of gray, greenish-gray,

and red slate, greenish-gray fine-grained sandstone, and some lime-rich siltstone. The sandstone member is mapped in the southeastern part of the Seboeis section of KAWW, the strip around Lookout Mountain, and in a small area of the northwestern part of the Hunt Farm section. It may be 1,500 to 2,100 m (5,000 to 7,000 ft) thick; the nature of its upper contact with the slate member is not known. The slate member makes up almost all of the bedrock of the Hunt Farm section and areas near Lookout Mountain (Neuman 1967). Neuman (1967) did not estimate its thickness or describe its upper contact. Graptolites in the slate member date from the late Llandovery to the early Ludlow (Neuman 1967). The formation is interpreted as a submarine fan complex (Roy et al. 1983). Based on the mapping of Neuman (1967), the Allsbury Formation is the unit newly exposed by construction at the future site of the KAWW visitor center (Figure 10), as well as the unit visible from Whetstone Bridge (Figure 11). The 2021 field inventory visited the newly created cuts but did not observe any fossils.



Figure 10. Freshly exposed Allsbury Formation slate at the future site of the Katahdin Woods and Waters National Monument visitor center (NPS/JUSTIN TWEET).



Figure 11. The view north from Whetstone Bridge shows rocks mapped by Neuman (1967) as the upper slaty part of the Allsbury Formation (NPS/VINCENT SANTUCCI).

Fossils found within KAWW: Graptolites (Neuman 1967).

Fossils found elsewhere: Tabulate corals (Ekren and Frischknecht 1967), rugose corals, pelmatozoan debris (Neuman 1967), and large crinoid columnals (Ekren and Frischknecht 1967).

Unnamed Silurian conglomerate (early Silurian, at least in part)

Description: Primarily pebble and boulder conglomerate (boulders up to 0.3 m or 1 ft in diameter). A variety of rock types are present as clasts, including quartzite and slate similar to the rocks of the Grand Pitch Formation, greenstone, quartz diorite similar to the Rockabema Quartz Diorite, chert, and felsite. Locally the conglomerate grades into a coarse sandstone. The conglomerate is mapped in the same faulted belt that includes the Wassataquoik Chert, with several areas found between Millinocket Ridge in the south and the Shin Ponds in the north (Neuman 1967). No estimation of its thickness or description of its contacts has been provided, presumably due to its sporadic, faulted outcrops.

The age of the conglomerate is not known precisely. Early Silurian (late Llandovery) brachiopods and tabulate corals were reported by Neuman (1967) from a lens of coarse lime-rich sandstone between sections of KAWW.

Fossils found within KAWW: Fossils reported from within KAWW include poorly preserved tabulate corals, rugose corals, and brachiopods (Neuman 1967), and graptolites of possible Middle Ordovician age (W. Berry, USGS, written comm. to R. Neuman, 1963). If the age assessment is

correct, either the fossils are in reworked fragments of older rocks (because graptolite fossils are too delicate to withstand weathering free from a rock), or the rock here is older than previously thought. The first possibility was documented by Neuman (1967) for a locality on Millinocket Ridge near KAWW in the same geologic unit.

Fossils found elsewhere: No other taxonomic groups have been reported outside of KAWW.

Unnamed tuff breccia (Silurian)

Description: Bedded tuff breccia, containing limestone fragments. This unit is limited to the 311-m (1,020-ft) hill just north of Wassataquoik Stream and is mapped almost entirely within KAWW. Most of the fragments in the breccia are angular pieces of felsitic volcanic rock, up to 15 cm (6 in) in diameter. Limestone fragments are concentrated in irregular intervals. The matrix of the breccia is medium gray tuff with abundant plagioclase crystals. Fossils indicate a Silurian age (Neuman 1967).

Fossils found within KAWW: Fossil debris (A. Boucot, USGS, written comm. to R. Neuman, 1963), and tabulate corals, brachiopods, and pelmatozoan fragments in limestone pebbles (Neuman 1967), indicating reworking. Because this unit is of limited extent and almost entirely within KAWW, all occurrences have been accepted as within the monument.

Fossils found elsewhere: None to date (see above).

"Owen Brook Limestone" (late Silurian)

Description: White and pink coarse-grained calcarenite and gray fine-grained limestone, often clay-rich (Figures 12 and 13). The unit is probably a small fault wedge, localized to an area around Owen Brook within KAWW (Neuman 1967). The purity of some of the limestone has been noted for its industrial potential, for use in agriculture, construction, paper-making, and other industries (Doyle 1966; Neuman 1966). The existence of this unit had been suspected before, based on the discovery of erratics from it as far south as Wassataquoik Stream, but the source rock was not discovered until geologic mapping in 1963 (Neuman 1966). Doyle (1966) mistakenly stated that this unit was first reported in Neuman (1960). The unit is interpreted as a reef, similar to the nearby reef rocks at Marble Pond outside of KAWW (Neuman 1967). Fossils indicate that it dates to the early late Silurian (early Ludlow) (Neuman 1966).

Fossils found within KAWW: Stromatoporoid sponges, tabulate corals, rugose corals, brachiopods (Neuman 1967), crinoids, and fossil debris (2021 field inventory); some have been found in float rocks transported elsewhere within KAWW (Neuman 1967). Doyle (1966) reported the presence of "many invertebrate phyla" but did not specify which, suggesting greater diversity may be present than what has been reported.

Fossils found elsewhere: This unit is only found within KAWW.



Figure 12. An outcrop of “Owen Brook Limestone”, partially overgrown and worn smooth by flowing water (NPS/VINCENT SANTUCCI).



Figure 13. Robert Marvinney inspects an outcrop of “Owen Brook Limestone” (CHUNZENG WANG).

Seboomook Group undivided (Early Devonian)

Description: "Graded beds of fine-grained gray sandstone and dark-gray siltstone and slate" (Neuman 1967). Beds are generally on the order of 10 cm (4 in) thick, grading from sandstone in the lower quarter up to siltstone and slate. There are also thicker beds of fine-grained sandstone that are very similar to the rocks of the Matagamon Sandstone (Neuman 1967). Beds of slate and sandstone assigned to the Seboomook Group transition both vertically and laterally into the Matagamon Sandstone in this area, and the contact is arbitrarily placed where the thicker beds of sandstone come to predominate (Neuman 1967; Pollock 1972). Slate and sandstone assigned to the Seboomook Group are mapped in a small area of northern KAWW, in a narrow southwest–northeast belt that crosses the East Branch between the Haskell Deadwater and Stair Falls (Rankin 1965; Osberg et al. 1985). The unit is about 1,500 m (5,000 ft) thick just outside of KAWW, thickening to perhaps as much as 3,000 m (10,000 ft) to the northeast where the Matagamon Sandstone is absent. Fossils indicate that this unit is of Early Devonian age (Neuman 1967). It was raised from a formation to a group in Pollock (1987), who also divided the unit into several formations, but left it undivided in the KAWW area because it was beyond the scope of the paper to assign names to all components of the Seboomook Group (S. Pollock, written comm., June 2022).

The Seboomook Group and Matagamon Sandstone are interpreted as parts of a deltaic system prograding to the northwest. Deposition of the Seboomook Group began with deep-marine turbidites, eventually transitioning to prodelta–marine settings before the onset of the delta front and delta plain rocks of the Matagamon Sandstone (Hall et al. 1976; Pollock et al. 1988). Deposition occurred during the regional deformation of the advancing Acadian Orogeny (Bradley et al. 2000).

The lowermost unit of the Seboomook Group is the Carrabassett Formation (Pollock 1987), interpreted as composed of turbidites deposited by north-flowing currents in an active marine trench slope setting just before the beginning of the Acadian Orogeny (Hanson et al. 1993). Osberg et al. (1985), writing before the Seboomook Formation was raised to a group, depicted a thin north-south sliver of fault-bounded Carrabassett Formation stretching as far north as just north of Lookout Mountain, in an area Neuman (1967) mapped as the Allsbury Formation. Osberg et al. (1985) is a compilation map of the entire state of Maine. Two sources are given for this area of the map: Neuman (1967) and "Ludman, A., unpublished reconnaissance and detailed mapping." Neuman (1967) does not include the Carrabassett Formation and could not have included it because it was not officially named until 1973 (Boone 1973); moreover, Neuman's maps do not include any indication of another unit where Osberg et al. (1985) have the Carrabassett Formation. Given that Neuman (1967) cannot be the source, the mapping of the Carrabassett Formation presumably reflects Ludman's work, which is not available to examine. The area in question is also mapped as the Allsbury Formation in Wang's reconnaissance map. With this information, it seems most likely that the mapping of the Carrabassett Formation by Osberg et al. (1985) is erroneous, although it is certainly not impossible that the formation is present elsewhere in the monument.

Fossils found within KAWW: Fossils have not yet been reported from this unit within KAWW.

Fossils found elsewhere: Plant debris (Hall et al. 1976), brachiopods (Rankin 1965; Neuman 1967), unspecified shelly fossils (Hall et al. 1976), bioturbation, and invertebrate tracks, trails, and burrows

(Hall and Stanley 1973; Hall et al. 1976); given changes in usage of the Seboomook name over the years (Pollock 1987), it is probably most prudent to only include reports from near KAWW. Fossils are generally rare in this and the overlying Matagamon Sandstone, and are typically death assemblages concentrated by environmental processes (e.g., storms, submarine currents and flows, etc.) (Pollock et al. 1988).

Matagamon Sandstone (Early Devonian)

Description: Fine- to medium-grained gray sandstone, often cropping out as 0.3–0.6 m (1–2 ft) thick beds, with thin-bedded and platy sandstone also common. Sedimentary structures such as lamination and crossbedding are present but subtle (Neuman 1967). The Matagamon Sandstone is mapped in the northern "tip" of KAWW (Rankin 1965; Osberg et al. 1985), where it is well-exposed at Stair Falls (Figure 14) (Rankin 1965). It is approximately 1,400 m (4,500 ft) thick in the vicinity of KAWW (Neuman 1967; Hall et al. 1976; Pollock et al. 1988). The contact with the overlying Traveler Rhyolite is conformable and transitional over a zone about 6 m (20 ft) thick, which includes some beds of volcanic tuff representing eruptions before the main phase of Traveler activity (Rankin 1965). As discussed in the Seboomook Group section, the Matagamon Sandstone is interpreted as the delta front and delta plain portion of a northwest-prograding deltaic system continued from the Seboomook Group (Hall et al. 1976; Pollock et al. 1988).



Figure 14. The Matagamon Sandstone at Stair Falls (NPS/VINCENT SANTUCCI).

Hitchcock (1861a) first recognized Devonian ("Oriskany") fossils in the rocks of the KAWW area, and Clarke (1909) described them as the "Moose River Sandstone", using a name first applied elsewhere in the state. Boucot (1961) rejected this, and the rocks were renamed the Matagamon Sandstone by Rankin (1965).

Fossils found within KAWW: Brachiopods (Hitchcock 1861a; Clarke 1909), monoplacophorans, bivalves, gastropods (Clarke 1909), trilobites (Clarke 1907, 1909), crinoids, an unidentified cylindrical structure (2021 field inventory), and possibly tentaculitids and unspecified fossils (Clarke 1909). The fossils reported by Hitchcock and Clarke were not found in situ, but from eroded blocks and fragments. Brachiopods, crinoids, and unidentified fossils observed during the 2021 field inventory were in situ. Hendrickson (written comm., May 2022) observed loose stones in northern KAWW with small brachiopods resembling some of those observed elsewhere in the formation.

Fossils found elsewhere: Plant debris (Rankin 1965; Hall et al. 1976), tabulate corals, nautiloids (Pollock et al. 1988), unspecified shelly fossils, and bioturbation (Hall et al. 1976). Different fossil assemblages are representative of different parts of the deltaic system (Pollock et al. 1988). Rankin (1961) described fossil fragments of plants and invertebrates as relatively common, while Neuman (1967) described fossils as rare in the Matagamon Sandstone. The distinction may be one of concentration, as Rankin reported that the invertebrate fossils were typically concentrated in "shell beds".

Traveler Rhyolite (Early Devonian)

Description: The Traveler Rhyolite is the eruptive phase of the igneous body that also produced the Katahdin Granite. Essentially, the Katahdin Granite is the magma chamber (which actually intrudes into the flows), and the preserved Traveler Rhyolite is the remnants of the volcanic carapace. The rhyolite is as much as 3,200 m (10,500 ft) thick, and is composed primarily of welded ash flows that erupted initially onto the Matagamon Sandstone. It has been divided into two members, the lower Pogy Member and the upper Black Cat Member (Rankin and Hon 1987). The Pogy Member is mapped in a small area of extreme northern KAWW (Neuman and Rankin 1980; Osberg et al. 1985; Rankin and Caldwell 2010). It is about 900 m (3,000 ft) thick and composed of moderately compacted welded ash, about 15% of which is visible crystals (phenocrysts) (approximately two-thirds plagioclase feldspar crystals and one-third quartz crystals), as well as some rock fragments. The overlying Black Cat Member, which has not been mapped in KAWW, is strongly compacted and has fewer phenocrysts (almost entirely feldspar) and fewer rock fragments. The differences are interpreted as the Pogy Member being sourced from the cooler upper part of the magma chamber (Rankin and Hon 1987). The eruption that produced the Pogy Member was followed, probably in short order, by the eruption that produced the Black Cat Member, drawing on the deeper region of the magma chamber (Rankin and Hon 1987). The base of the rhyolite is dated to 407.3 ± 0.5 Ma and the top is dated to 406.7 ± 1.4 Ma (Rankin and Tucker 1995).

Fossils found within KAWW: Fossils have not yet been reported from this unit within KAWW; fossils are unlikely, but not entirely impossible (e.g., a fossiliferous sedimentary interval of local extent in the volcanics).

Fossils found elsewhere: Fossils have not yet been reported from this unit.

Katahdin Granite (Early Devonian)

Description: Medium to light gray medium-grained massive granitic rock, more precisely classified as a quartz monzonite (Neuman 1967). This unit is mapped in the majority of the East Branch section of KAWW, in its western and southern areas (Osberg et al. 1985). The eastern part of the pluton is flanked by a zone of brecciated sedimentary rock partially assimilated into the granite. These rock fragments are cm-scale to m-scale in size (Neuman 1967). The source magma crystallized approximately 406.9 ± 0.4 Ma (Rankin and Tucker 1995), after the eruptions that produced the Traveler Rhyolite (Rankin and Hon 1987). The resulting batholith (Seaman et al. 2019) is approximately 40 km (25 mi) in diameter and 5 km (3 mi) thick, and was tilted after the Acadian Orogeny (Rankin and Hon 1987). It is exposed spectacularly on Katahdin, just west of KAWW in Baxter State Park.

Fossils found within KAWW: Not applicable.

Fossils found elsewhere: Not applicable.

Quaternary rocks and sediments (Pleistocene–Holocene)

Description: A combination of different types of deposits (Figure 15). Glacial till composed of heterogeneous clay, silt, sand, and larger material is most abundant. There are also areas of sand and gravel left by glacial streams and moraines, and postglacial deposits of stream alluvium (sand, gravel, and silt) and swamp deposits (peat, silt, clay, and sand). Quaternary deposits blanket most of KAWW (Newman 1981a, 1981b, 1981c; Newman and Genes 1986).

Fossils found within KAWW: Fossils of Quaternary age have not yet been published from KAWW. Late Quaternary marine fossils have been reported from near Big Seboeis within the monument, near the northern extreme of marine encroachment at the end of the last glacial episode (E. Hendrickson, pers. comm. from R. Hooke, 2006 and later). The 2021 field inventory stopped briefly in this area but did not observe fossils. Ponds and swamp deposits, as identified on the surficial geology maps, are the most likely sites to yield Quaternary fossils. Such fossils would be in the form of plant debris, pollen, spores, resistant parts of invertebrates, and so forth, and would date to the postglacial period.

Loose fossiliferous stones of Paleozoic age are known in the surficial deposits (Hitchcock 1861a; Neuman 1967), and are likely present throughout the monument, having either eroded in place or been transported by glacial or fluvial processes. Eric Hendrickson (written comm., May 2022) observed examples of transported fossiliferous stones containing small brachiopods in the bed of a brook in northern KAWW.

Fossils found elsewhere: Pond and bog sediments in the immediate vicinity of KAWW have yielded moss fossils, pollen of conifers and angiosperms, charcoal (Anderson et al. 1986), conifer wood (Anderson et al. 1988), microlepidopteran head capsules (Anderson et al. 1986), and diatoms (Davis and Davis 1980). These fossils are of particular interest for their utility in reconstructing past climates and ecosystems.



Figure 15. Quaternary deposits at Big Seboeis (NPS/JUSTIN TWEET).

The presence of fossiliferous glacial drift on the slopes of neighboring Katahdin has been reported since the first half of the 19th century (e.g., Bailey 1837), and many of the KAWW-area localities mentioned in Hitchcock (1861a) are described as displaced boulders. With these examples in mind, it would hardly be surprising for fossiliferous stones from a variety of sources to be found within KAWW. One intriguing possibility is the introduction of fossiliferous material from the Trout Valley Formation. Outcrops of this formation in Baxter State Park are directly "upstream" of KAWW under a regime of northwest-to-southeast glacial movement.

Taxonomy

See Appendix A for a full list of taxa.

Fossil Invertebrates

The vast majority of fossils reported from KAWW to date are corals or brachiopods (Appendix A). Several other groups are represented by a handful of taxa. It would not be surprising to discover that additional diversity is present but not previously reported because it occurs in groups that are not as historically useful for biostratigraphy as corals and brachiopods. For example, post-Cambrian marine assemblages often have bryozoans and crinoids, but bryozoans have not been reported from KAWW localities and the only published report of echinoderms to date is pelmatozoan debris from the Silurian tuff breccia (Neuman 1967), but the 2021 field inventory observed crinoid fragments in the "Owen Brook Limestone" and Matagamon Sandstone.

Phylum Cnidaria (jellyfish and corals)

Paleozoic corals can be divided into three groups, all of which are represented at KAWW: solitary rugose corals, colonial rugose corals, and tabulate corals. Solitary rugose corals are better known as horn corals for their shape, often resembling a cow's horn when weathered free from rock or in relief. If exposed in cross-section, they will often resemble a circular to elliptical sunburst, depending on the angle of the section (Figure 15). Colonial rugose corals may look similar to modern stony corals. Tabulate corals are colonial (Figure 17), but can usually be distinguished from colonial rugose corals by the sizes of the living chambers (less than a few millimeters in tabulates, substantially larger in rugose corals) and structures in the chambers (simple or no vertical walls in tabulates, generally more complex in rugose corals). They are sometimes called "honeycomb corals", which refers to *Favosites*-like tabulates; another common type are "chain corals" such as *Halysites*.



Figure 16. A horn coral in cross-section, "Owen Brook Limestone" (CHUNZENG WANG).



Figure 17. A tabulate coral in cross-section, “Owen Brook Limestone” (CHUNZENG WANG).

Rugose corals at KAWW are best known from the unnamed Upper Ordovician sequence, which has yielded several taxa of horn corals (Neuman 1980; Elias 1982). Among them are three species named from KAWW: *Bodophyllum neumani*, *Grewingkia penobscotensis*, and *Streptelasma rankini* (Elias 1982). A colonial rugose coral, *Entelophyllum*, has been reported from the “Owen Brook Limestone” in KAWW (Neuman 1967); this coral resembles a mass of small connected horn corals. Horn corals were observed in the “Owen Brook Limestone” during the 2021 field inventory. The unnamed Silurian conglomerate has also produced rugose corals in KAWW (Neuman 1967).

Tabulate corals have been reported from several formations in KAWW. Several taxa have been found in the unnamed Upper Ordovician sequence (Neuman 1980). The Silurian conglomerate, tuff breccia, and “Owen Brook Limestone” have yielded examples not identified to genus or species (Neuman 1967). The corals reported by Jackson (1838) and Hitchcock (1861a) may have come from the unnamed Silurian conglomerate, as discussed above.

Phylum Brachiopoda (lamp shells)

More genera and species of brachiopods have been reported from KAWW than any other type of fossil (Appendix A). Brachiopods are shelled bottom-dwelling invertebrates that resemble bivalve mollusks but have much different soft anatomies. Their shells can generally be distinguished from bivalve mollusks by symmetry. A single brachiopod valve usually has a line of symmetry, but the two valves are usually different shapes and sizes and thus are not symmetric to each other. A single bivalve valve is usually asymmetric, but the two valves are usually mirror images. Brachiopods are often informally separated into articulate and inarticulate forms based on how the shells hinge and shell composition; articulate brachiopod shells are usually made of calcium carbonate, whereas inarticulate brachiopod shells are usually phosphatic.

The great majority of brachiopod taxa reported in the literature from KAWW come from the unnamed Upper Ordovician sequence (see Appendix A) (Neuman 1967, 1980). A few taxa have been found in the Silurian tuff breccia, "Owen Brook Limestone" (Neuman 1967), and Matagamon Sandstone (Clarke 1909). Brachiopods have also been found in the unnamed Silurian conglomerate in KAWW (Neuman 1967). The 2021 field inventory observed and collected several brachiopod morphotypes from the Matagamon Sandstone: a large thin shell with numerous fine radiating ribs, probably *Leptostrophia magnifica* (Figure 18); a smaller form with fewer, thicker ribs, perhaps a small spiriferid (Figure 18); a form with fine radiating ribs and prominent rugae, probably *Leptaena* or something similar (Figure 19); a smooth form resembling a productid brachiopod (Figure 19); a diminutive finely ribbed form (Figure 19); a bulbous ribbed form, possibly *Rensselaeria* (Figure 20); and a smooth D-shaped form (Figure 21).

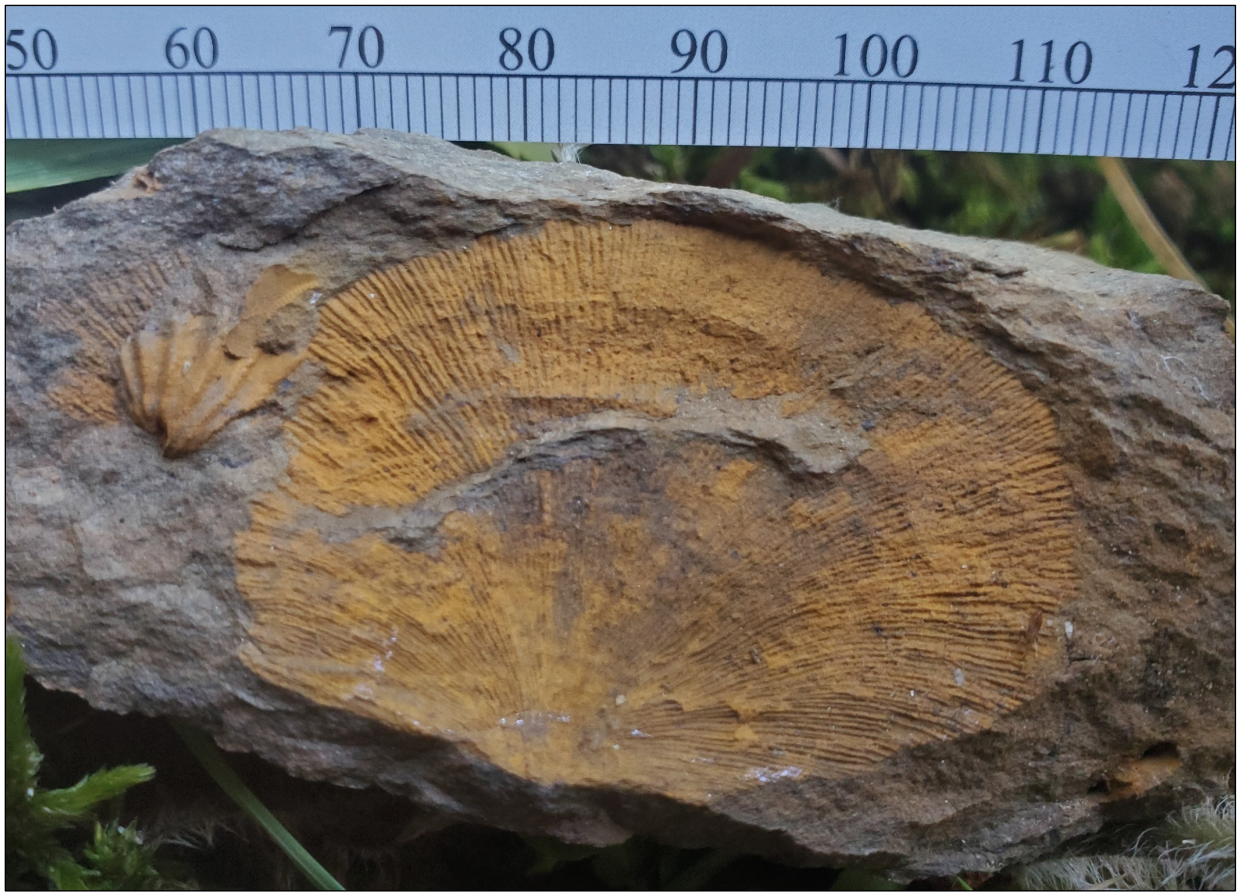


Figure 18. Two distinct brachiopod taxa are present on this piece of Matagamon Sandstone (KAWW 0374): a smaller form with heavy ribbing, perhaps a small spiriferid (upper left); and a larger form with numerous fine ribs (center) attributed to *Leptostrophia magnifica* (NPS/VINCENT SANTUCCI). Like many (but not all fossils) found at KAWW PAL 002, they have distinctive orange staining.

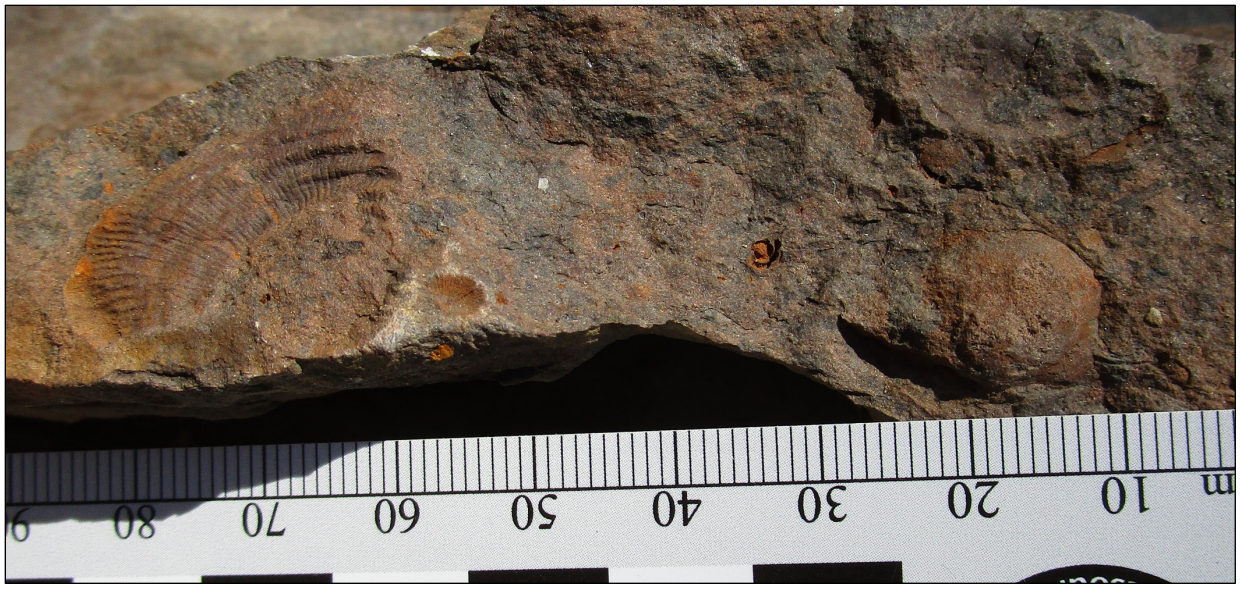


Figure 19. KAWW 0372 from the Matagamon Sandstone includes three brachiopod taxa: a large form with strong rugae and fine ribbing (left), probably *Leptaena* or something similar; a diminutive form with fine ribs (immediately right of the former); and a smooth-shelled form with “wing”-like lateral corners (right) (NPS/JUSTIN TWEET).



Figure 20. A bulbous shell with ribbing (note the prominent shadow showing the shape of the shell), perhaps the apex of a *Rensselaeria* or a similar form; KAWW 0370 (Matagamon Sandstone) (NPS/JUSTIN TWEET).



Figure 21. A small, smooth, D-shaped brachiopod shell on KAWW 0370 (Matagamon Sandstone) (NPS/JUSTIN TWEET).

Phylum Echinodermata (sea stars, sea urchins, sea lilies, etc.)

Echinoderms are a diverse group of animals known for five-fold symmetry and possession of a unique water vascular system. Sea stars (asteroids) and sea urchins (echinoids) are familiar modern echinoderms, but there are many other living and extinct echinoderm groups with a wide variety of body plans. Pieces of echinoderms are common fossils but complete specimens are not, because echinoderm skeletons usually disaggregate into constituent columnals, ossicles, plates, and other components. Paleozoic echinoderm fossils are dominated by "stem" segments (columnals) of stalked echinoderms, known as pelmatozoans. The majority of these belonged to crinoids (sea lilies), which still exist today, but there were several other groups of stalked echinoderms in the Paleozoic, so the pelmatozoan term is sometimes preferred. Pelmatozoan debris has been found in the unnamed tuff breccia within KAWW (Neuman 1967), and the 2021 field inventory observed crinoid columnals in the "Owen Brook Limestone" (Figure 22) and Matagamon Sandstone (Figure 23). Based on 2021 observations, it is somewhat surprising that they had not been reported before, although they may have been omitted or overlooked as of negligible scientific value (isolated columnals have little utility for taxonomy, age determination, or paleoenvironmental interpretation). Columnals in the Matagamon Sandstone were frequently preserved as hollow molds, leaving distinctive ring-like impressions in planar view and paired openings when seen in cross-section (Figure 23).



Figure 22. A well-defined crinoid columnal in the “Owen Brook Limestone” surrounded by other fossil fragments (NPS/JUSTIN TWEET).



Figure 23. A group of crinoid columnal molds in the Matagamon Sandstone with bright orange mineralization (NPS/VINCENT SANTUCCI).

Other Invertebrates

Several other phyla have been reported from KAWW's rocks, but none in nearly as great of diversity as corals and brachiopods.

Phylum Porifera (sponges)

Sponges have a relatively poor fossil record compared to their known abundance and diversity, which can be attributed to many groups either lacking hard parts or having only a spicular skeleton that disintegrates into microscopic structural elements upon death. The heavily mineralized stromatoporoids are one exception to this general rule. They were prominent reef-forming organisms in the Silurian and Devonian, and are represented in the reef rocks of the "Owen Brook Limestone" of KAWW (Neuman 1966, 1967). Their fossils often appear as layered structures. Additionally, the problematic genus *Solenopora* has been reported from a locality possibly within KAWW (W. Oliver, USGS, written comm. to D. Rankin, 1960). This genus was long thought to be a coralline red alga, but at least some of the fossils assigned to it are actually chaetetid sponges, another variety of heavily mineralized sponge. Without more information about the potential KAWW occurrence, it is not possible to determine whether the report pertains to red algae, sponges, or something else.

Phylum Mollusca

At least three classes of mollusks have been reported from KAWW. All reports are from the Matagamon Sandstone (Clarke 1909), with the potential exception of undetermined gastropods from an unspecified locality or localities in the boundary-crossing Upper Ordovician sequence (Elias 1982). They include monoplacophorans (*Cyrtolites expansus*), bivalves (*Pterinea radialis*), and gastropods (*Diaphorostoma desmatum*, *Diaphorostoma ventricosum*, *Plectonotus derbyi*, *Platyceras* cf. *calantica*, and *Platyceras* sp.) (Clarke 1909). What may be a coil of a gastropod shell is visible in one of the specimens collected from the Matagamon Sandstone (Figure 24).

Monoplacophorans are a group of mollusks that today are only represented by animals with limpet-like shells that live only at great depths on the seafloor, but which were formerly more abundant and diverse (taxonomically, ecologically, and anatomically). For example, *Cyrtolites*, the genus reported from KAWW (Clarke 1909), is known for a shell with a loose coil, resembling a coiled cephalopod much more than a limpet. Bivalves (clams, oysters, scallops, etc.) are familiar aquatic invertebrates today, but during the Paleozoic brachiopods filled many of the roles that would be taken by bivalves today. *Pterinea* resembles a scallop with a strongly skewed shell. Gastropods, more familiar as snails and slugs, are another group known from the Paleozoic that is very familiar today. Many Paleozoic snails had shells that resemble some modern form. The taxa reported from KAWW are members of groups that may or may not be true snails.



Figure 24. Several fossils are visible on this Matagamon Sandstone specimen (KAWW 0370), including circular crinoid columnals and, near the left center margin, a smooth possible coil of a gastropod shell (NPS/JUSTIN TWEET).

Phylum Arthropoda: Class Trilobita (trilobites)

Trilobites are one of the most familiar types of Paleozoic invertebrates. Because trilobites shed their exoskeletons to grow, most trilobite fossils are partial pieces of these shed exoskeletons, particularly the tail region (pygidium) and parts of the head region (the entire head shield is the cephalon; usually parts of the cheeks are missing, leaving what is called a cranidium). The central segments of the trilobite are rarely found intact, and the antennae and limbs are very rarely found at all.

Trilobites are known from the Matagamon Sandstone of KAWW, and are potentially known from the unnamed Upper Ordovician sequence. The Ordovician examples are another case where the reports come from an unspecified side of the East Branch, so it is extremely likely that trilobites are present on the rocks on both sides even if the specific examples in the literature came from the east. Reports of Ordovician trilobites can be found in Neuman (1967) and Elias (1982). Trilobites in the Matagamon Sandstone in the vicinity of KAWW were reported as far back as Hitchcock (1861a), Holmes (1861), and Billings (1869), which named the new species *Dalmanites epicrates* (Figure 2) In the case of these reports, it is likely that at least the bulk of the fossils came from the east bank. Clarke (1907, 1909) reported trilobites that definitely came from the Matagamon Sandstone within KAWW. Clarke also named a new species, *Dalmanites ploratus* (Figure 2; Clarke 1907), which was later transferred to the genus *Odontochile* (Delo 1940).

Phylum Hemichordata: Class Pterobranchia: Subclass Graptolithina (graptolites)

Graptolites are colonial hemichordates closely related to the modern pterobranch worms, colonial tube-dwelling worms found on the seafloor. The modern pterobranch *Rhabdopleura* may be a living representative of this otherwise extinct group (Mitchell et al. 2013). Graptolite colonies were either

attached to the seafloor or free-living in the water column. The attached colonies often resembled branching trees and are called dendritic, while the free-living colonies resembled long thin strips; reconstructions of these forms often show them with bulbous floats or attached to seaweeds, but there is no evidence for either adaptation (Maletz 2015). In either case close inspection of the long thin "arms" of the colony will show small cup-like structures that hosted the individual animals; the shapes of these structures give the arms a sawblade-like appearance. Graptolites (free-floating *Monograptus*) are definitely present in KAWW in the Allsbury Formation (Neuman 1967) and in an area mapped as the unnamed Silurian conglomerate (W. Berry, USGS, written comm. to R. Neuman, 1963; these are potentially reworked), and have been found at localities that may or may not be within KAWW in the unnamed Upper Ordovician sequence (R. Neuman, USGS, written comm. to D. Rankin, 1963).

Class Tentaculita

Tentaculita encompasses several extinct enigmatic groups known from fossils that can be described as "worm tubes". The namesake *Tentaculites* and its close relatives are known from mm- to cm-scale elongate conical fossils with distinct ribbing. One species, *Tentaculites leclercqia*, has been reported from a Matagamon Sandstone location potentially within KAWW (Clarke 1909). The designation of the species is confusing: in locality faunal lists, Clarke (1909) used *T. perceensis*, but in the description of taxa that follows in the document, *T. leclercqius* is used instead. *T. perceensis* is otherwise only used in faunal lists in Clarke (1905) and appears to be an uncorrected early name for *leclercqia*/*leclercqius*. Clarke (1907) named the species as *T. leclercqia*; he may have intended to amend the name to *leclercqius* or simply misspelled it in Clarke (1909). (The description of *T. leclercqia* in Clarke [1908] is also treated as that of a new species, but Clarke [1907] has precedence.) At any rate, the species does not appear to have been used in any later publications.

Ichnofossils

The only fossils reported from the Grand Pitch Formation, within KAWW or outside of it, are examples of the invertebrate burrow *Oldhamia*. This ichnofossil classically resembles a group of radiating straight to curved lines of equivalent length. The trace maker is interpreted as an animal that "mined" beneath microbial mats (Seilacher et al. 2005). The Grand Pitch *Oldhamia* was first reported by Smith (1928a) as *Oldhamia* (*Murchisonites*) cf. *occidens*. Ruedemann (1942) later renamed it *Oldhamia smithi*, with the type specimen being Smith's specimen from the East Branch of the Penobscot (Township 5, Range 8); this specimen potentially came from KAWW, but the locality information is equivocal. *Oldhamia smithi* has since been referred to *O. antiqua* (Seilacher et al. 2005). *Oldhamia antiqua*/*smithi* is recognized as groups of traces in arrays resembling palm leaves or firework bursts (Seilacher et al. 2005). Examples are found in the red slate of the Grand Pitch Formation (Neuman 1967).

Other Fossils

Fossil debris and unidentifiable fossils were observed in the "Owen Brook Limestone" and Matagamon Sandstone during the 2021 field inventory. KAWW PAL 001, in particular, featured heavily recrystallized bedrock with whitish streaks and spots in the gray limestone. Some of these likely represent invertebrate body and trace fossils, but cannot be readily interpreted (Figure 25). The

specimens collected from the Matagamon Sandstone included an unknown cylindrical fossil approximately 5 mm (0.2 in) in diameter, with a featureless or perhaps slightly wrinkled exterior (the potential wrinkling may be an artifact of preservation or mineralization) (Figure 26). It does not closely resemble any general category of Devonian invertebrate body fossil; perhaps it is a fragment of a plant stem, as plant debris has been reported from the formation in the area (Rankin 1961, 1965). Alternatively, it could be a fragment of a straight-shelled orthoceroid nautiloid (S. Pollock, written comm., June 2022).



Figure 25. Apart from a few crinoid columnals, the whitish objects in this photo of “Owen Brook Limestone” cannot be readily identified (NPS/VINCENT SANTUCCI).

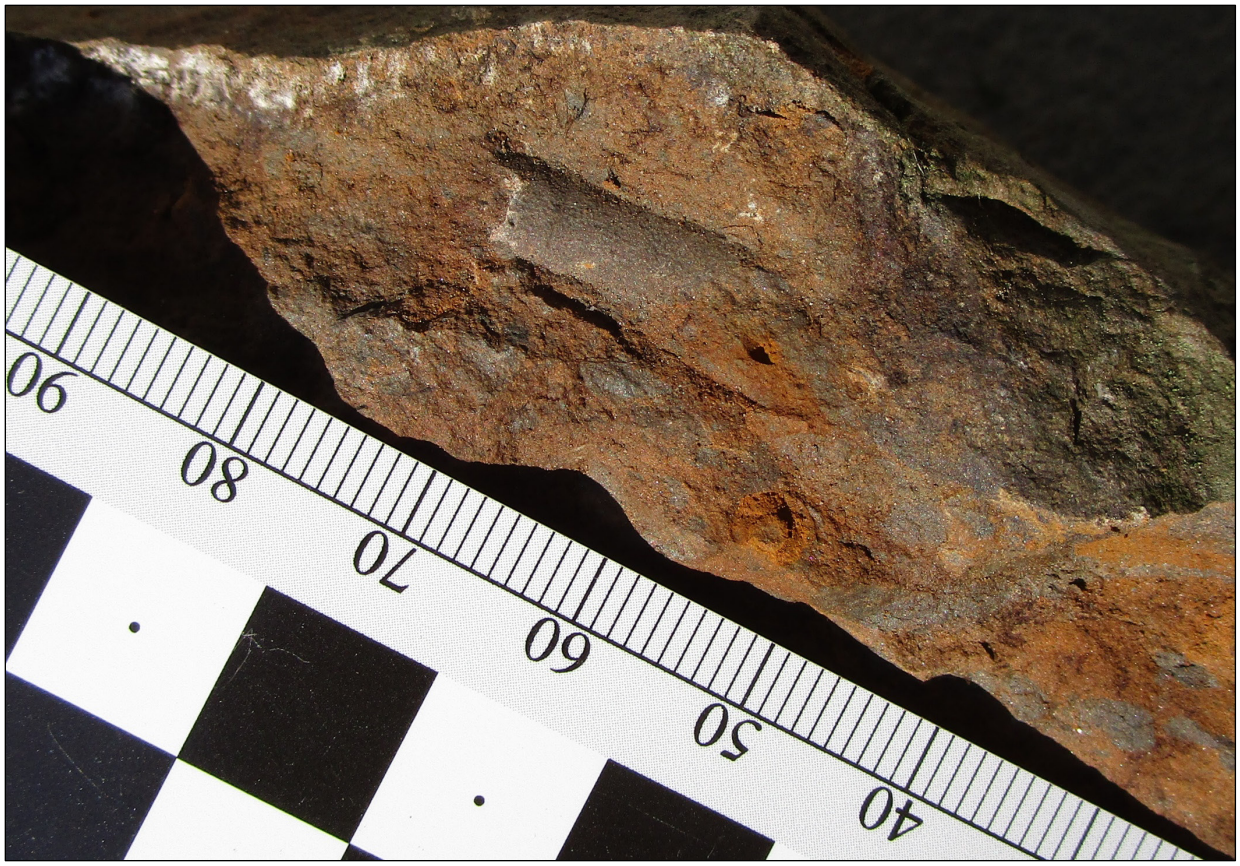


Figure 26. A cylindrical fossil of unknown origin from the Matagamon Sandstone (KAWW 0370) (NPS/JUSTIN TWEET).

Paleontological Localities

The following section provides information about fossil-producing localities, divided into two subsections for localities within KAWW and localities of interest in the immediate vicinity, and further subdivided by geologic formation. Locality data for fossil sites visited in 2021 is available to qualified researchers upon request.

Paleontological Localities Within Katahdin Woods and Waters National Monument

A small number of paleontological localities are known from KAWW, primarily from near the East Branch and other waterways or from elevated areas with outcrops of bare rock. They are divided by geologic unit in the following discussion. Only those localities visited in 2021 (KAWW PAL 001, 002, and 003) have precise and accurate coordinate data.

It should be noted that the minimal infrastructure of the monument and the prevalence of vegetative and surficial cover make accessing some localities challenging. For example, inland sites may require hiking on former logging roads that in some areas are heavily overgrown or partially blocked by blown-down trees. The challenges of access have bearing on resource management and protection.

Grand Pitch Formation

Although this is not stated in publications, at least some specimens of *Oldhamia antiqua* from the Grand Pitch Formation illustrated by Seilacher (e.g., Seilacher et al. 2005) came from an area now in KAWW, per collections information from the Peabody Museum of Natural History (Yale University, New Haven, Connecticut). Other examples of *Oldhamia* have been found in the vicinity of Grand Pitch and Bowlin Falls (Neuman 1960, 1962, 1967).

Ordovician sequence of East Branch

Neuman (1980:123) described the rock sequence exposed between Pond Pitch and Haskell Rock as "unique for its completeness, the apparent amount of time that it represents, the abundance and diversity of its fossils, the variety of rocks that it includes, and its relatively simple structure." Identifying the exact positions of the localities mentioned in Neuman (1967) (USGS 3889-CO, 4113-CO, 4412-CO) is difficult (they are not plotted on his maps because they are outside of the mapped quadrangles), but comparisons with USGS internal reports and Neuman (1980) indicate that USGS 3889-CO is outside of KAWW (fossiliferous horizon 2 of Neuman 1967) and USGS 4412-CO is also outside of KAWW, while USGS 4113-CO is more likely within KAWW. Neuman (1980) is more explicit, describing six fossiliferous intervals (reiterated in Neuman 1994 and Pollock and Anderson 2013):

1. The lowest fossiliferous interval is a dark gray siltstone. Fossils were collected from small roadside ledges on the west bank, in KAWW, and from a roche moutonnée east of the river, outside of KAWW. Neuman obtained a sample of 400 identifiable brachiopods from the ledges, which included about 160 specimens of *Catazyga*, 100 each of *Eostropheodonta* and *Sowerbyella*, a few *Fardenia*, and about 40 punctate or impunctate orthids, representing deep or cold water (Neuman 1980);

2. The next interval is in a massive sandstone in an isolated ledge on the east side (outside of KAWW), which produced more brachiopods, from a higher-energy, shallower-water setting than below (Neuman 1980);
3. A thick interval of pillow basalt separates the two lower horizons from the next, a pebbly siltstone found in KAWW (Neuman 1980). This interval has yielded tabulate corals, rugose corals, and brachiopods, including type specimens for rugose coral species *Bodophyllum neumani*, *Grewingkia penobscotensis*, and *Streptelasma rankini* (Elias 1982);
4. This interval is closely followed by ledges of pebbly sandstone in KAWW, with small brachiopods and fragments of horn corals at the bases of beds. They represent different forms than below, and are interpreted as coming from water of intermediate depth and temperature, but having been redeposited in deeper water (Neuman 1980);
5. The next interval is located in conglomerate in the Haskell Rock area, where brachiopods were found in pebbly siltstone on the east side, outside of KAWW, representing another deep-water community (Neuman 1980);
6. Finally, the uppermost interval identified in Neuman (1980) is conglomerate interbedded with siltstone and fine sandstone above Haskell Rock outside of KAWW, including more brachiopods.

The 2021 field inventory investigated several of these areas from Pond Pitch to above Haskell Rock but did not observe fossils.

Unnamed Silurian conglomerate

Neuman (1967) mentioned that scattered poor-quality fossils of tabulate corals, rugose corals, and brachiopods were present on Sandbank Stream. This occurrence may be related to or from the same place as the collection ST-62-41, which yielded a favositid tabulate coral and possible brachiopod (A. Boucot, USGS, written comm. to R. Neuman, 1963). Neuman also collected graptolite fragments from a locality in the same general area (collection ST-62-38), another collection that was omitted from Neuman (1967). These were tentatively identified as Middle Ordovician in age (W. Berry, USGS, written comm. to R. Neuman, 1963). Per Neuman's map, the locality should be in the unnamed Silurian conglomerate (Sg), suggesting that the graptolites were in reworked fragments of older rocks if the fossils are indeed of Middle Ordovician age. This situation was documented by Neuman (1967) for a locality on Millinocket Ridge near KAWW in the same geologic unit.

Peaked Mountain

Because of the lack of clarity about the geological provenance of the fossils recorded from Peaked Mountain by Jackson (1838) and Hitchcock (1861a), the fossils are not attributed to a formation. From the geologic map in Neuman (1967), the unnamed Silurian conglomerate (Sg) seems to be the only good candidate for Silurian coral-bearing limestones, if both a Silurian age and an in situ origin are required. All of the other geologic units mapped by Neuman on the mountain are Ordovician, igneous, or both. It is possible that what Jackson and Hitchcock saw would now be considered Ordovician rather than Silurian, because the Ordovician was not in use when they were working. It is also possible that they observed an otherwise unrecorded small-scale occurrence of a Silurian unit similar to the "Owen Brook Limestone". Alternatively, Ekren and Frischknecht (1967) mentioned the

presence of coral-bearing limestone in the Allsbury Formation in the nearby Island Park Quadrangle, but although Neuman mapped the Allsbury Formation *near* Peaked Mountain (approximately 0.5 km or 0.3 mi to the east of the peak), he did not map it *at* the mountain. In passing, it is noteworthy that Neuman did not observe and comment upon fossiliferous rocks at Peaked Mountain, given he spent much more time in the area than either Jackson or Hitchcock and marked several outcrops on and near the mountain on his map (Neuman 1967). In November 2021, Eric Hendrickson (written comm.) reported observing crinoids and corals (Figure 27) in the area.



Figure 27. Potential tabulate coral corallites are visible as light spots against a darker matrix near center in this photo from Peaked Mountain (ERIC HENDRICKSON).

"Owen Brook Limestone"

The area where this unit crops out can be considered a single large locality, exposing some part of a late Silurian reef system. Neuman (1967) identified USGS 7445-SD as a specific locality with brachiopods of the genus *Conchidium*. Two sites were visited during the 2021 field inventory: a more heavily recrystallized western locality visited by the entire group (KAWW PAL 001; Figure 12); and

a more eastern locality (KAWW PAL 003; Figure 13), visited by Robert Marvinney and Chunzeng Wang. There were relatively few identifiable fossils at KAWW PAL 001, most of which were crinoid columnals (Figures 22 and 25). One exception was a poorly preserved horn coral in cross-section (Figure 28).

Fossil preservation and variety was superior at KAWW PAL 003, where fossils including horn corals (Figure 16), tabulate corals (Figure 17), crinoid columnals, and patches of fossil debris were observed.

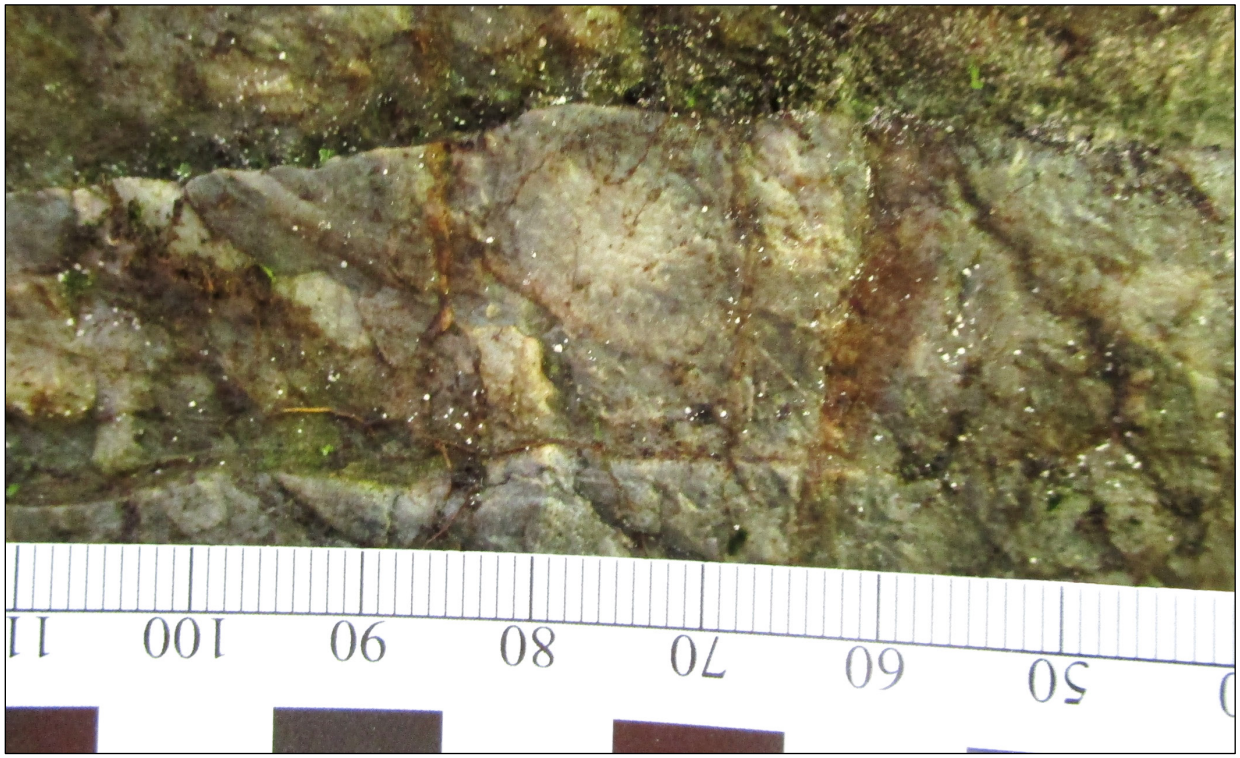


Figure 28. The central roughly circular object, with a bumpy surface texture, is a poorly preserved horn coral in cross-section; KAWW PAL 001 (“Owen Brook Limestone”) (NPS/JUSTIN TWEET).

Matagamon Sandstone

The Matagamon Sandstone is historically one of the most paleontologically productive formations in KAWW, but no localities that can be definitely placed within the monument have been reported in the literature since Clarke (1909). The early localities consisted of loose eroded material, not in situ rocks (Hitchcock 1861a; Clarke 1909). Additionally, Hitchcock (1861a) and Clarke (1909) both used now-vanished logging camps as geographical markers. These two factors make it difficult to pinpoint the productive localities.

Hitchcock’s party recovered fossils from two localities of particular interest, one apparently just outside of KAWW, the other apparently somewhere within KAWW. The first is Stair Falls, where Holmes (1861) reported that trilobites were collected from the east side, which is just outside of KAWW. Among these was the type specimen of *Dalmanites epicrates* (Billings 1869), now lost.

Rankin (1961, 1965) also reported fossils, in his case brachiopods, at Stair Falls. He did not specify whether or not the fossils were confined to one side of the falls.

Hitchcock's other locality is known as Johnston's Camp. Almost nothing is known about the location and geology of the site except that it was in the "central part of No. 5, R. 8" and that the fossils were "entirely in loose fragments", with the source not found (Hitchcock 1861a). (In hindsight, "central part" should be taken in general terms, because Devonian sedimentary rocks are largely confined to the northwestern part of Township 5, Range 8, and a strictly "central" location would be in Ordovician rocks east of the East Branch in the vicinity of the Haskell Deadwater.) Although the fossils here were reputedly of high quality, Hitchcock mentioned only one taxon by name, the brachiopod *Rensselaeria ovoides*, perhaps leaving further description for a publication that was never produced. Clarke (1907, 1909) referred to another camp, Cunningham's Camp, which was located southwest of Matagamon Lake and west of the East Branch in No. 5, R. 8, within KAWW (locality 3452). Again the fossils were found in loose blocks. Clarke was of the opinion that this site was essentially the same as Hitchcock's site. He listed the following taxa from this site: brachiopods *Hipparionyx proximus*, *Rensselaeria ovoides*, and *Spirifer arenosus*; monoplacophoran *Cyrtolites expansus*; bivalve *Pterinea radialis* var.; gastropods *Diaphorostoma desmatum*, *D. ventricosum*, *Platyceras* cf. *P. calantica*, *P*. sp., and *Plectonotus derbyi*; and trilobites *Dalmanites pleuroptyx*, *D. ploratus*, and *D*. sp. (Clarke 1909). It is not obvious from the original descriptions that Johnston's Camp and Cunningham's Camp are necessarily the same, although they were certainly in the same general area of what is now the monument. In both cases establishing the location is complicated by the nature of the finds: they were not in situ, so it is not possible to postulate that an existing outcrop or outcrops represents the location(s). Furthermore, in the absence of detailed collecting information, it is entirely possible that rather than collecting from a single point of limited areal extent, collection of fossiliferous stones may have occurred over a wider area centered on or accessed from the camps.

The 2021 field inventory observed and collected fossils from the west bank of the East Branch (KAWW PAL 002). Fossils were primarily brachiopods (Figures 18–21 and 29) and crinoid columnals (Figure 23). An unusual characteristic of fossils at this site is that they frequently have acquired a striking bright orange color (Figures 18, 23, and 29).



Figure 29. The orange color of these brachiopod shells (KAWW 0373; counterpart of the piece in Figure 18) was intense enough to affect the quality of photography (NPS/JUSTIN TWEET).

Paleontological Localities Near Katahdin Woods and Waters National Monument

Grand Pitch Formation

Locality USGS 3629-CO in Neuman (1967) is southeast of Grand Pitch and east of the East Branch, adjacent to KAWW. This locality was also mentioned in Neuman (1962), which included a photo of an *Oldhamia* specimen (USNM 139806) from the site. The 2021 field inventory searched for *Oldhamia* in this area (Figures 4 and 5) but did not find any.

Although not paleontological, excellent glacial striations, colorful banding, and minor faulting can be observed at Grand Pitch Formation outcrops at a locality north of Jerry Pond (Figures 30 and 31).

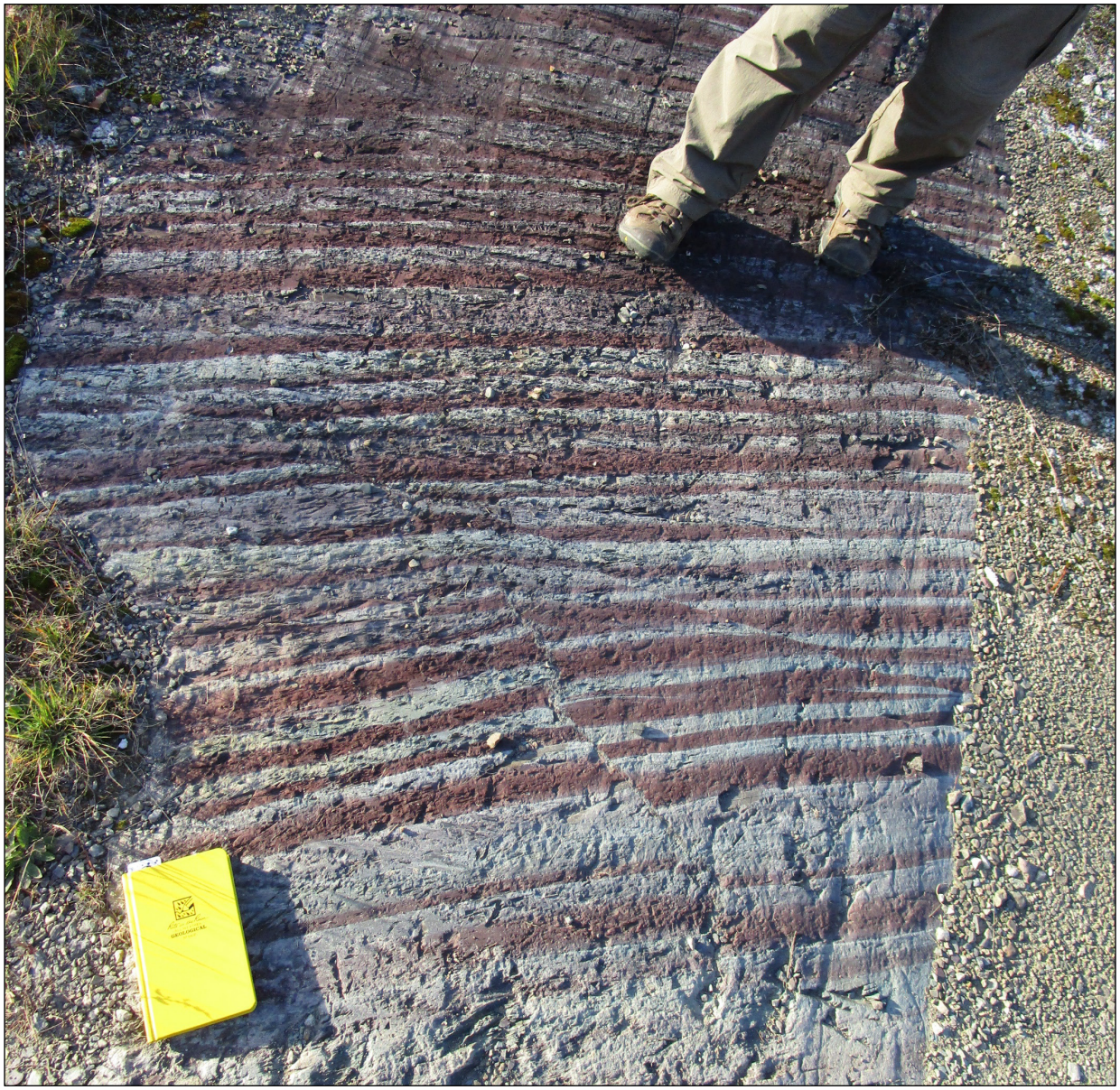


Figure 30. Bold red and gray banding makes minor faulting in the Grand Pitch Formation obvious (NPS/JUSTIN TWEET).

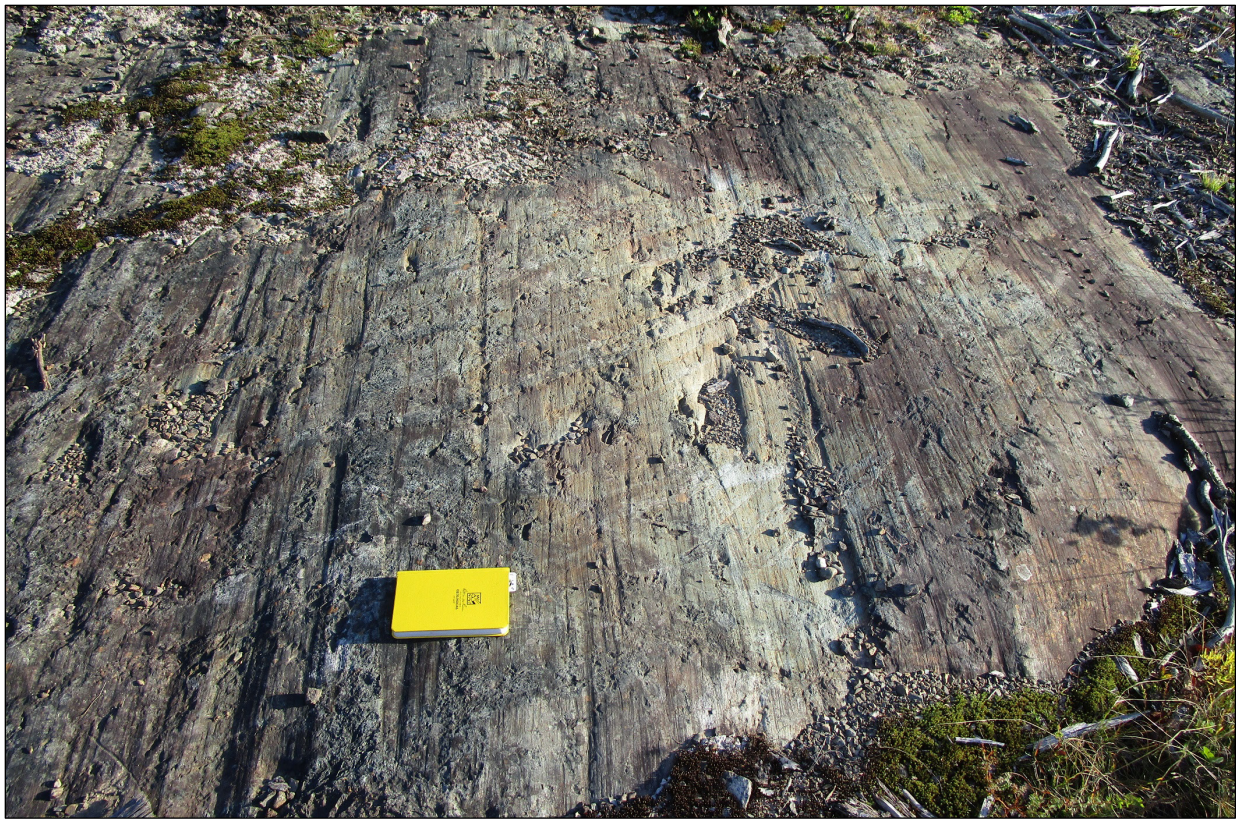


Figure 31. Glacial striations mark this exposure of the Grand Pitch Formation (NPS/JUSTIN TWEET).

Shin Brook Formation

The Early Ordovician Shin Brook Formation is not mapped within KAWW in any published works, being found as close to the monument as Sugarloaf Mountain, about 2.75 km (1.72 mi) north of the Seboeis section of KAWW (Neuman and Whittington 1964; Neuman 1967, 1980). It is possible that fossiliferous fragments of the Shin Brook Formation have been transported into KAWW, either by water or glaciers. Sponge spicules, bryozoans, brachiopods, trilobites, and cystoids have been found at USGS locality CO-3606 on the mountain; gastropods have been found at other locations in the formation (Neuman and Whittington 1964).

Wassataquoik Chert

Fossils have been reported from the Wassataquoik Chert just outside of KAWW, in an area along the Wassataquoik Stream. Fossils were first reported by Dodge (1881, 1890), who collected several taxa of graptolites from black shale. At the time, the Ordovician Period was not in wide use, and Dodge described the fossils as lower Silurian. Ruedemann and Smith (1935) obtained another collection from the same area and re-identified Dodge's taxa. Neuman (1967) identified the rocks and fossils as pertaining to the Wassataquoik Chert, named in the same article. Neuman made collections in the area in 1958 and 1961, including both graptolites and conodonts (Sweet and Bergström 1966). The conodonts have been identified to several genera and species consistent with an early Late Ordovician age (middle Caradocian *Diplograptus multidens* graptolite zone, then regarded as late Middle Ordovician) and an Anglo-Scandinavian affiliation (Sweet and Bergström 1966).

Silurian rocks of Kimball Brook/Bowlin Pond Road

Rankin (1961) and Neuman (1967) identified a series of fossiliferous Silurian localities in the area of Kimball Brook and Bowlin Pond Road, in a sequence akin to the undifferentiated Upper Ordovician rocks found on the East Branch; in fact, as mentioned above, Rankin (1961) included some of the East Branch rocks in his "Kimball Brook Formation". The fossils include stromatoporoid sponges, tabulate and rugose corals, brachiopods, trilobites, pelmatozoan debris, and graptolites. These rocks are also discussed in a field trip guide (Neuman 1980).

Neuman (1967) mapped a series of several relatively thin units in this area between the Grand Pitch Formation and Seboomook Formation (=Group), extending in a narrow belt northeast from the East Branch toward Jerry Pond. In ascending order, these are: the eastern extreme of the unnamed Ordovician conglomerates of East Branch, conglomerate, calcareous siltstone, limestone, and a second calcareous siltstone. Neuman mapped most of these as ending by Jerry Pond or a short distance east, but the unnamed upper calcareous siltstone has a much greater map extent. The 2021 field inventory visited a site on this outcrop belt northeast of Jerry Pond, preliminarily mapped by Wang as a conglomerate at the base of the Seboomook Group (a different interpretation than Neuman's, with significant implications for local geology). This small site is unusual for featuring numerous coral and shell fossils as part of a conglomerate (Figure 32), presumably incorporated into the conglomerate as clasts rather than living in an environment subject to the deposition of large clasts.

Late Silurian limestone of Marble Pond

Marble Pond, a horseshoe-shaped body of water northeast of the nearest part of KAWW, is noted for its fossils. It may have been mentioned as a fossil locality as far back as Holmes (1861), as "Horseshoe Lake" (also known as "Murch's Lake"). Limestone is exposed here along the southern and eastern shore of the pond; a small island about halfway along the shore may be a reef, and the shoreline outcrops may be reef debris. The reef framework appears to be stromatoporoid sponges, but tabulate corals, stemmed echinoderms, and brachiopods are also well represented. The fossils indicate an early late Silurian age (Wenlock or early Ludlow). Loose fragments of limestone along the East Branch near the Haskell Deadwater suggest that similar rock is buried under glacial drift in that area (Neuman 1967).

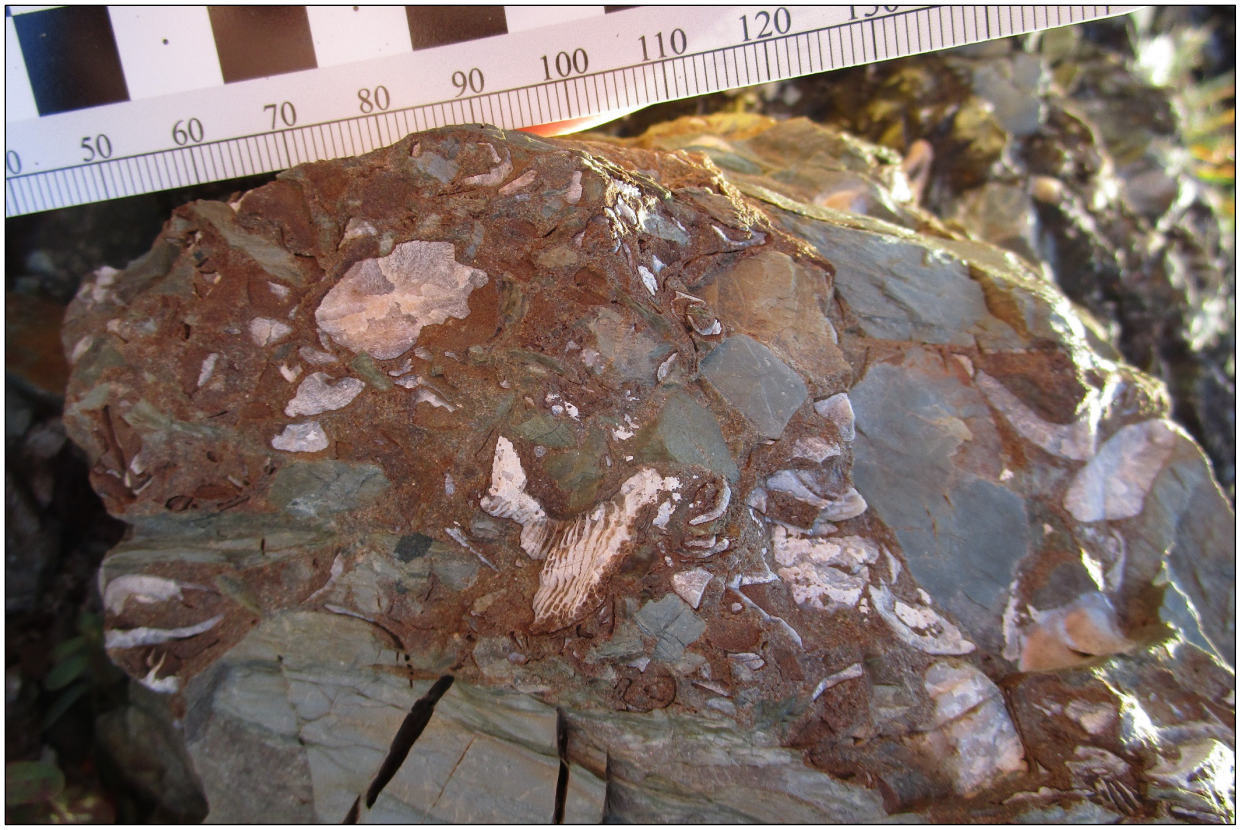


Figure 32. A horn coral and other fossils (whitish) are part of this poorly sorted conglomerate (NPS/JUSTIN TWEET).

Matagamon Sandstone

Rocks exposed east of the northeast corner of KAWW, adjacent to and continuing east of Grand Lake Road, trace the advance of the delta plain facies of the Matagamon Sandstone. Brachiopods, gastropods, trilobites, and invertebrate burrows have been observed here (Pollock and Anderson 2013).

The 2021 field inventory stopped at three sites west of Hay Lake, northeast of KAWW. The stratigraphically lowest site was on strike with Stair Falls and had brachiopods (Figure 33) and crinoid columnals. A short distance north was another small outcrop, with bits of plants, brachiopods, and bioturbation and trace fossils. This site also featured orange coloration of fossils, albeit not as bold as KAWW PAL 002 (Figure 34). Farther north, the most areally extensive and productive site had a thin shell bed horizon that preserved brachiopods, bivalves, and gastropods (Figure 35). Most were steinkerns (internal casts), but a few were external impressions.



Figure 33. Several brachiopods observed in one piece of Matagamon Sandstone (NPS/JUSTIN TWEET).

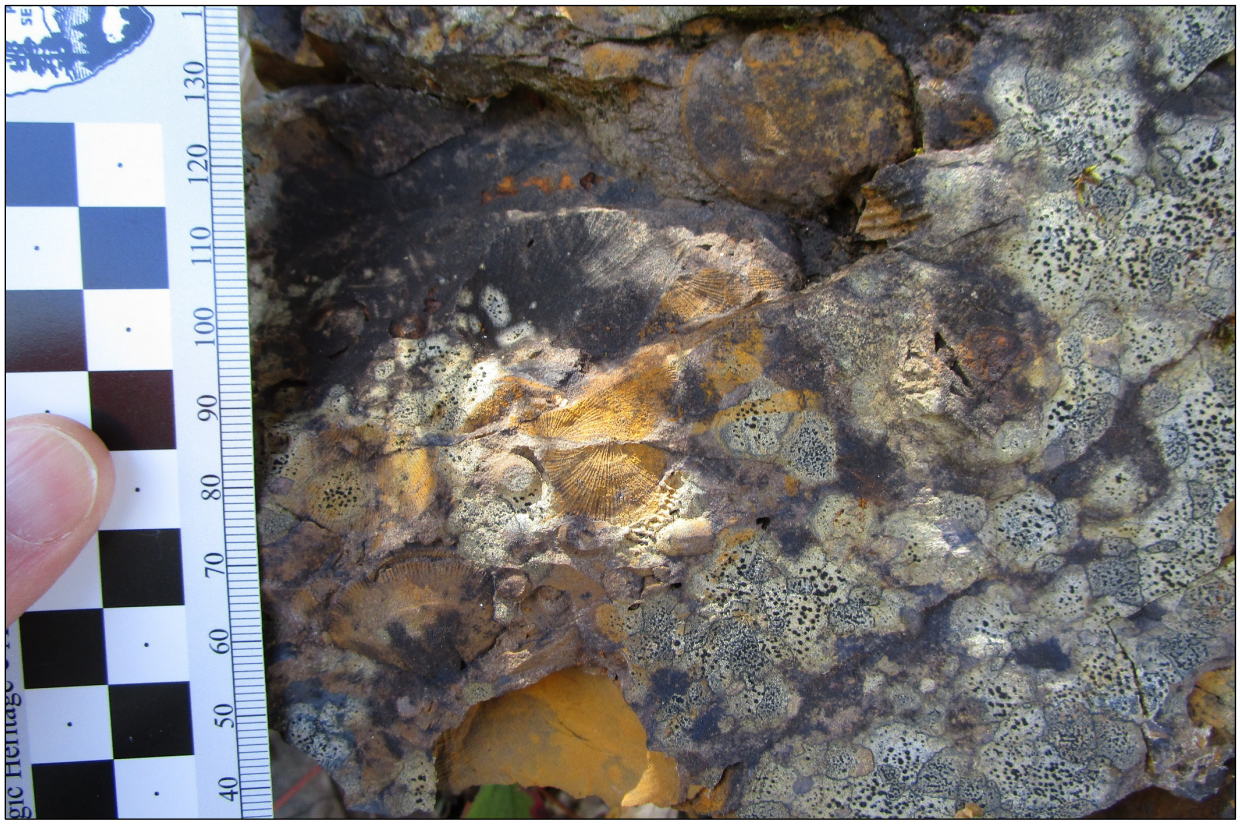


Figure 34. Orange shells in Matagamon Sandstone (NPS/JUSTIN TWEET).



Figure 35. A shell bed in Matagamon Sandstone (NPS/JUSTIN TWEET).

Trout Valley Formation

The Trout Valley Formation is a post-Acadian, late Early Devonian–early Middle Devonian formation with notable paleontological resources. As the name suggests, it is found in Trout Valley, which is in nearby Baxter State Park; productive outcrops are as near to KAWW as 6.3 km (3.9 mi) west of the north end of the monument (Allen and Gastaldo 2006). Plant fossils are abundant (Rankin 1961). It is not out of the question that glacially transported fossiliferous clasts from this formation will be found in KAWW.

The Trout Valley Formation is interpreted as fluvial and coastal, becoming more marine over time (Allen and Gastaldo 2006). It is particularly noted for its fossils of early land plants and the unusual *Prototaxites*, currently interpreted as a giant, tree-like fungus. Other fossils reported from this formation include palynomorphs, bivalves, gastropods, a eurypterid, ostracodes, invertebrate burrows and bioturbation, and fecal pellets, although not all of these are found in the same assemblages (Allen and Gastaldo 2006). Among the plant fossils found in this formation in Baxter State Park is Maine's state fossil, the early vascular plant *Pertica quadrifaria*, which could reach heights of approximately 2 m (6 ft) (Maine Geological Survey 2005).

Quaternary ponds

Pond and bog sediments in central Maine have been studied to provide information on deglaciation and post-glacial climate and environmental changes. Katahdin has been a focus of interest going back to 19th century arguments concerning whether or not it was glaciated and if it had glaciers that

postdated the general glacial retreat. Davis and Davis (1980) gave dates for several Katahdin ponds, and Davis et al. (2015) reviewed the Katahdin record and provided a table listing various ponds and bogs in the general vicinity that have provided radiocarbon dates. The most extensively described pond site in the area of KAWW is Upper South Branch Pond, approximately 5.5 km (3.4 mi) west of the north end of KAWW in northern Baxter State Park. Anderson et al. (1986) described the palynomorphs, macroscopic plant fossils, charcoal, and microlepidopteran larval head capsules of this site. The record here goes back approximately 12,000 years and shows changes in the local plant community as temperature and precipitation changed over time. The site also yielded a piece of conifer (?spruce) wood dating to 29,200 ± 500 radiocarbon years before present, which is thought to have either been reworked into the pond or transported by a glacier (Anderson et al. 1988).

Cultural Resource Connections

There are many ways for paleontological resources to have connections to cultural resources. Examples of paleontological resources in cultural contexts include, but are not limited to: fossils used by people for various purposes, such as petrified wood used for tools, spear points, and other artifacts, or fossil shells picked up as charms or simply because they looked interesting; associations of prehistoric humans with paleontological resources, such as kill sites of mammoths, prehistoric bison, and other extinct animals; incorporation of fossils into cultural records, such as fossils in American Indian lore, "tall tales" of mountain men, and emigrant journals; and fossils in building stone. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts. At this time, no fossils from a cultural context have been reported from KAWW.

Museum Collections and Paleontological Archives

Museum Collections and Curation

Park Collections

To date, only six fossil specimens have been collected from KAWW after it was established as a national monument. They are six hand samples of Matagamon Sandstone with representative examples of brachiopod shells, crinoid columnals, and other fossils, all collected from locality KAWW PAL 002 during the 2021 field inventory (Table 2). Currently, KAWW does not have museum facilities. The 2021 specimens are reposited at the NPS's Northeast Museum Services Center (NMSC) in Charlestown, Massachusetts (accession KAWW 00005, permit KAWW-2021-SCI-0005).

Table 2. Specimens collected from KAWW PAL 0002 (Devonian Matagamon Sandstone) and reposited at the Northeast Museum Services Center.

Specimen #	Field #	Identifiable Fossils	Other Comments
KAWW 0370	1	Bulbous ribbed shell (*Rensselaeria*?), large brachiopod with fine rays (*Leptostrophia magnifica*), brachiopod with rugae (*Leptaena*?), smooth D-shaped brachiopod, possible gastropod whorl, crinoid columnals, unknown cylindrical object	Counterpart of KAWW 0371
KAWW 0371	2	Bulbous ribbed shell (*Rensselaeria*?), crinoid columnals	Counterpart of KAWW 0370
KAWW 0372	3	Brachiopod with rugae (*Leptaena*?), smooth productid-like brachiopod, diminutive brachiopod with fine ribs	–
KAWW 0373	4	Large brachiopod with fine ribs (*Leptostrophia magnifica*), small brachiopod with heavy ribs (spiriferid?), crinoid columnals	Counterpart of KAWW 0374
KAWW 0374	5	Large brachiopod with fine ribs (*Leptostrophia magnifica*), small brachiopod with heavy ribs (spiriferid?), crinoid columnals	Counterpart of KAWW 0373
KAWW 0375	6	Large brachiopod with fine ribs (*Leptostrophia magnifica*)	–

Collections in Other Repositories

At least four repositories have or have had fossils collected from lands now within KAWW, although in all cases the specimens were collected many years before the monument was established. With the loss of Hitchcock's early collection to fire, the specimens reported by Clarke (1907, 1909) are the next oldest specimens that are still extant. Clarke (1907) did not provide a catalog number for the type specimen of *Dalmanites ploratus*, which was established by Delo (1940) as New York State Museum 13390e/1 (NYSM: Albany, New York). Any other specimens collected by Nylander for Clarke would likely be there as well, although it is possible that other material collected by Nylander from what is now KAWW is at the Nylander Museum of Natural History in Caribou, Maine. The NYSM also holds the holotype and paratype of *Oldhamia smithi* (Ruedemann 1942), potentially collected from KAWW. Per Lisa Amati (NYSM curator of invertebrate paleontology, written comm., August 2016 and June 2021), the holotype of *Oldhamia smithi* is NYSM 7830 and the paratype is NYSM 7831, and the holotype of *Dalmanites ploratus* is now NYSM 9802.

The Smithsonian's National Museum of Natural History (USNM; Washington, D.C.) reposits holotypes of three rugose corals named from KAWW in Elias (1982) (Table 2). Other specimens collected by Neuman and Rankin and submitted to the USGS for identification may also be in USNM collections, via the transfer of USGS collections.

Yale's Peabody Museum of Natural History (YPM; New Haven, Connecticut) reports 31 catalog numbers (YPM IP 204543–204573) of *Oldhamia antiqua* specimens collected by Adolf Seilacher in 1996 from near Grand Pitch in KAWW, as well as a cast of one specimen (YPM IP 204587) now at the University of Tübingen (Tübingen, Germany). Some of these specimens were illustrated in Seilacher's publications, such as Seilacher et al. (2005).

The fossils collected during Hitchcock's 1861 expedition are believed to have been lost in a fire at the Portland Society of Natural History in 1866 (Williams 1900; Clarke 1909), presumably including the missing holotype of *Dalmanites epicrates*. *D. epicrates* is included as potentially named from KAWW, but if specimens were only collected on the east side of Stair Falls, as implied by Holmes (1861), then the type would have been from outside of KAWW.

Type Specimens

Four fossil species are known to have been named from fossils collected within what is now KAWW (Table 3) and two others may have been named from fossils collected within the monument (Table 4), again many years before the monument was established.

Table 3. Fossil taxa named from specimens found within Katahdin Woods and Waters National Monument.

Taxon	Citation	Age, Formation	Type Specimen	Notes
Dalmanites ploratus	Clarke 1907	Devonian, Matagamon	NYSM 13390e/1 (now NYSM 9802)	Trilobite; transferred to *Odontochile* (Delo 1940)
Bodophyllum neumani	Elias 1982	Ordovician, unnamed	USNM 311760	Rugose coral
Grewingkia penobscotensis	Elias 1982	Ordovician, unnamed	USNM 311748	Rugose coral
Streptelasma rankini	Elias 1982	Ordovician, unnamed	USNM 311736	Rugose coral

Table 4. Fossil taxa named from specimens possibly found within Katahdin Woods and Waters National Monument.

Taxon	Citation	Age, Formation	Type Specimen	Notes
Dalmanites epicrates	Billings 1869	Devonian, Matagamon	Unknown (lost?)	Trilobite
Oldhamia smithi	Ruedemann 1942	Cambrian, Grand Pitch	NYSM 7830	Invertebrate trace fossil; synonym of *O. antiqua*

Archives

NPS Paleontology Archives

All data, references, images, maps, and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library. These records consist of both park-specific and service-wide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by NPS staff at KAWW, or additional questions arise regarding paleontological resources, contact the NPS Senior Paleontologist & Paleontology Program Coordinator Vincent Santucci, vincent_santucci@nps.gov. Park staff are also encouraged to communicate new discoveries to the NPS Paleontology Program, not only when support is desired, but in general, so that this information can be incorporated into the archives. A description of the Archives and Library can be found in Santucci et al. (2018).

E&R Files

E&R files (from "Examination and Report on Referred Fossils") are unpublished internal USGS documents. For more than a century, USGS paleontologists identified and prepared informal reports on fossils sent to the survey by other geologists, for example to establish the relative age of a formation or to help correlate beds. The system was eventually formalized as a two-part process including a form sent by the transmitting geologist and a reply by the survey geologist. Sometimes the fossil identifications were incorporated into publications, but in many cases this information is unpublished. These E&R files include documentation of numerous fossil localities within current NPS areas, usually predating the establishment of the NPS unit in question and frequently unpublished or previously unrecognized. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014). Several E&R files have been found for KAWW and its immediate vicinity (within 3 km [2 mi]), although there are implications in Rankin (1965), Neuman (1967), and the files themselves that other correspondence was made, whether or not it still exists.

Park Paleontological Research

Current and Recent Research

The first permit to be issued for paleontological or geological research at KAWW since the monument was established in 2016 is KAWW-2021-SCI-0005, study "Katahdin Woods and Water National Monument Paleontological Resource Inventory". This permit was issued to Justin Tweet for this project.

Paleontological Research Permits

See the National Park Service Natural Resource Management Reference Manual DO-77 section on Paleontological Resource Management, subsection on Scientific Research and Collection (https://irma.nps.gov/DataStore/Reference/Profile/572379). NPS Management Policies 2006, section 4.8.2.1 on Paleontological Resources, states that

> *The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit.*

Any collection of paleontological resources from an NPS area must be made under an approved research and collecting permit. The NPS maintains an online Research Permit and Reporting System (RPRS) database for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator's Annual Reports (IARs) are available on the RPRS website (https://irma.nps.gov/RPRS/). Additional information on NPS law and policy can be found in Appendix D.

Interpretation

KAWW does not currently interpret fossils and has very limited staff and resources for interpretation of any kind. At this early stage of the monument's existence, paleontological resources could be considered in conjunction with other earth history topics (glaciation, river processes, volcanism, etc.). KAWW and the vicinity are unusual in New England for preserving a relatively long geological and paleontological record amid tectonic, metamorphic, and structural complexities, as well as substantial surficial cover. The monument thus is well-situated to provide interpretation of geological topics in their natural setting.

Recommended Interpretive Themes

I. General Paleontological Information

All of the following interpretation topics include a section instructing visitors how to be paleontologically aware while in a park. A ranger may provide the visitor with advice on why fossils are important, how paleontologists look for fossils, what to do if fossils are found, and reminders to be aware that fossils exist and should be respected within park boundaries.

- Fossils are non-renewable resources that possess scientific and educational information and provide insight into what earth was like thousands and even hundreds of millions of years ago.
- When paleontologists survey for paleontological resources, the most important tool for planning is a geologic map. Paleontological resources are more common in certain geologic units, so knowing where those units are exposed is important for a successful search. Other tools that a paleontologist takes into the field include a field notebook for recording data and observations, small picks, brushes, consolidants to stabilize fossils, a GPS unit, a camera, topographic maps, and appropriate First Aid and other safety equipment. It might be helpful to provide examples of these items for visitors when giving an interpretive talk.
- If fossils are found in the park by a visitor, the visitor should photograph it and notify a ranger of where the resource was found, but most importantly, they should leave the fossil where they found it. It is extremely important for scientific and resource management purposes for locational information to be preserved. Visitors should be informed that park fossils are protected by law.

II. Fossils of Katahdin Woods and Waters National Monument

- A program could be developed to educate the public on what types of fossils are present in KAWW and what they tell scientists about Earth's dynamic history. The goal of this program is to increase visitors' understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of KAWW can be included. As the monument's infrastructure grows, kiosks, placards, or similar could be used at places of high visitation and geologic interest to interpret the geology and paleontology.

III. Further Interpretation Themes

Given that fossils are referenced in the KAWW enabling legislation, they would be considered significant and fundamental resources and values. Therefore, KAWW staff should consider

promoting their paleontological resources and provide additional opportunities or programs for visitors to learn about fossils on National Fossil Day, celebrated annually on Wednesday of the second full week in October (National Earth Science Week). For more information on this event visit: https://www.nps.gov/subjects/fossilday/index.htm. Conducting one or more paleontology-focused activities on this day would be a perfect opportunity to not only increase public awareness about paleontological resources in KAWW, but also to connect with other parks and museums that are also participating in this national event. The NPS Geologic Resources Division can assist with planning for National Fossil Day activities and provide supplies for the Junior Paleontologist Program including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Paleontological Resource Management and Protection

As mentioned in "Localities" above, the logistics of travel in Katahdin Woods and Waters National Monument have implications for paleontological resource management and protection. Unless an extensive system of roads and trails is developed, it is unlikely that inland fossiliferous areas (e.g., the "Owen Brook Limestone") will receive much visitation.

National Park Service Policy

Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 423 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official number. Of these, 283 are known to have some form of paleontological resources, and paleontological resources are mentioned in the enabling legislation of 18 units, including KAWW. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating these non-renewable paleontological specimens from federal lands. In March 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated Department of Interior (DOI) lands. More information on laws, policies, and authorities governing NPS management of paleontological resources is detailed in Appendix D. Paleontological resource protection training is available for NPS staff through the NPS Paleontology Program. The Paleontology Program is also available to provide support in investigations involving paleontological resource theft or vandalism.

Between 2009 and 2022 an interagency coordination team including representatives from the Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS) and U.S. Fish & Wildlife Service (FWS) developed the DOI final regulations for PRPA. The draft DOI regulations were published in the Federal Register in December 2016 and were available for 60 days to allow for public comment. The interagency team has reviewed public comments provided for the draft regulation and have incorporated these into the final regulation. The final regulation was surnamed by the DOI Solicitor's Office and each of the four bureau directors. On August 2, 2022 the DOI Paleontological Resources Preservation Act final regulation was published in the Federal Register. After 30 days the Office of Management and Budget approved the final DOI PRPA regulation, which is available at the following website: https://www.federalregister.gov/documents/2022/08/02/2022-16405/paleontological-resources-preservation. For more information regarding this act, visit https://www.nps.gov/subjects/fossils/fossil-protection.htm.

2006 National Park Service Management Policies (section 4.8.2.1) state

> *... Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage*

paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).

Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

Fossils have scientific, aesthetic, cultural, educational, and tourism value, and impacts to any of these values impairs their usefulness. Effective paleontological resource management protects fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Because fossils are representatives of adaptation, evolution, and diversity of life through deep time, they have intrinsic scientific values beyond just the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and a number of other conditions that together allow for a more complete interpretation of the physical and biological history of the earth. Therefore, paleontological resource management must act to protect not only the fossils themselves, but to collect and maintain other contextual data as well.

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. These processes or activities influence the stability and condition of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). The greatest loss of associated contextual data occurs when fossils are removed from their original geological context without appropriate documentation. Thus, when a fossil

weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil "float" can still be of scientific value. However, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. Similarly, inadvertent exhumation of fossils during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all of the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather it is sufficient to acknowledge that anything that disturbs native sediment or original bedrock has potential to result in the loss of the paleontological resources that occur there, or the loss of associated paleontological resource data.

Cave localities are in a distinct class for management due to the close connection with archeological resources and unique issues affecting cave resources. See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

Management strategies to address any of these conditions and factors could also incorporate the assistance of qualified specialists to collect and document resources rather than relying solely on staff to accomplish such a large task at KAWW. Active recruitment of paleontological research scientists should also be used as a management strategy.

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near KAWW, taxonomic groups that have been reported within KAWW boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management, and one that usually requires little to implement beyond time and equipment already on hand, such as cameras and GPS units. Monitoring enables the evaluation of the condition and stability of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). A monitoring program revolves around periodic site visits to assess conditions compared to a baseline for that site, with the periodicity depending on factors such as site productivity, accessibility, and significance of management issues. For example, a highly productive site that is strongly affected by erosion or unauthorized collection, and which can be easily visited by park staff, would be scheduled for more frequent visits than a less productive or less threatened site.

A monitoring program is generally implemented after an inventory has been prepared for a park and sites of concern have been identified, with additional sites added as necessary. Because each park is different, with different geology and paleontology among other factors, ideally each park that has in situ fossils or significant accumulations of reworked fossils would have its own monitoring protocol

to define its monitoring program. Data accumulated via monitoring is used to inform further management decisions, such as the following questions: Is the site suitable for interpretation and education? Does the site require stabilization from the elements? Is collection warranted? Is there a need for some form of law enforcement presence?

Collection is recommended to be reserved for fossils possessing exceptional value (e.g. rare or high scientific significance) or at immediate risk of major degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring is a more feasible potential management tool. The first step in establishment of a monitoring program is identification of localities to be monitored, as discussed previously. Locality condition forms are then used to evaluate factors that could cause loss of paleontological resources, with various conditions at each locality rated as good, fair, or poor. Risks and conditions are categorized as Disturbance, Fragility, Abundance, and Site Access. “Disturbance” evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities. “Fragility” evaluates natural conditions that may influence the degree to which fossil transportation is occurring. Sites with elevated fragility exhibit inherently soft rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. “Abundance” judges both the natural condition and number of specimens preserved at the locality as well as the probability of being recognized as a fossil-rich area by non-paleontologists, which could lead to unpermitted collecting. “Site Access” assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of fossils or fossil-bearing sediments. A locality with high access would be in close proximity to public use areas or other access (along trails, at road cuts, at beach or river access points, and so on).

Each of the factors noted above may be mitigated by management actions. Localities exhibiting a significant degree of disturbance may require either active intervention to slow accelerated erosion, periodic collection and documentation of fossil materials, or both. Localities developed on sediments of high fragility naturally erode at a relatively rapid rate and would require frequent visits to document and/or collect exposed fossils in order to prevent or reduce losses. Localities with abundant or rare fossils, or high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, in regard to both natural processes and human-related activities. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional visits by park staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and Santucci et al. (2009).

Foundation Documents and Resource Stewardship Strategies

Foundation Documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other importance resources and values, and interpretative themes. Mandates and commitments are also

identified, and the state of planning is assessed. Foundation documents may include paleontological information and are also useful as a preliminary assessment of what a park's staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document has been initiated for KAWW but has not been published.

A Resource Stewardship Strategy (RSS) is a strategic plan intended to help park managers achieve and maintain desired resource conditions over time. It offers specific information on the current state of resources and planning, management priorities, and management goals over various time frames. An RSS for KAWW has not yet been published.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age and lowercase letters indicating the formation's name. Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources. The ideal scale for resource management in the 48 contiguous states is 1:24,000 (maps for areas in Alaska tend to be coarser). The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) provides more information about geologic maps and their uses. The NPS Geologic Resources Inventory (GRI) has been digitizing existing maps of NPS units and making them available to parks for resource management. KAWW, as a recently established unit post-dating the establishment of the Inventory and Monitoring program, is not formally covered by the GRI. However, geologic maps exist for the monument, and if there is an opportunity to produce digital maps for KAWW, it should be pursued. Digital geologic maps will improve management of geological and paleontological resources, and are also important for infrastructure planning.

Paleontological Resource Potential Maps

A paleontological resource potential map is included in this report (Figure 36). The map shows the distribution of geologic units within a park that are known to have yielded fossils within the park (green on Figure 36), have not yielded fossils within the park but are fossiliferous elsewhere (yellow), or have not yielded fossils (red). This map gives a quick indication of areas where fossils may be discovered, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.).

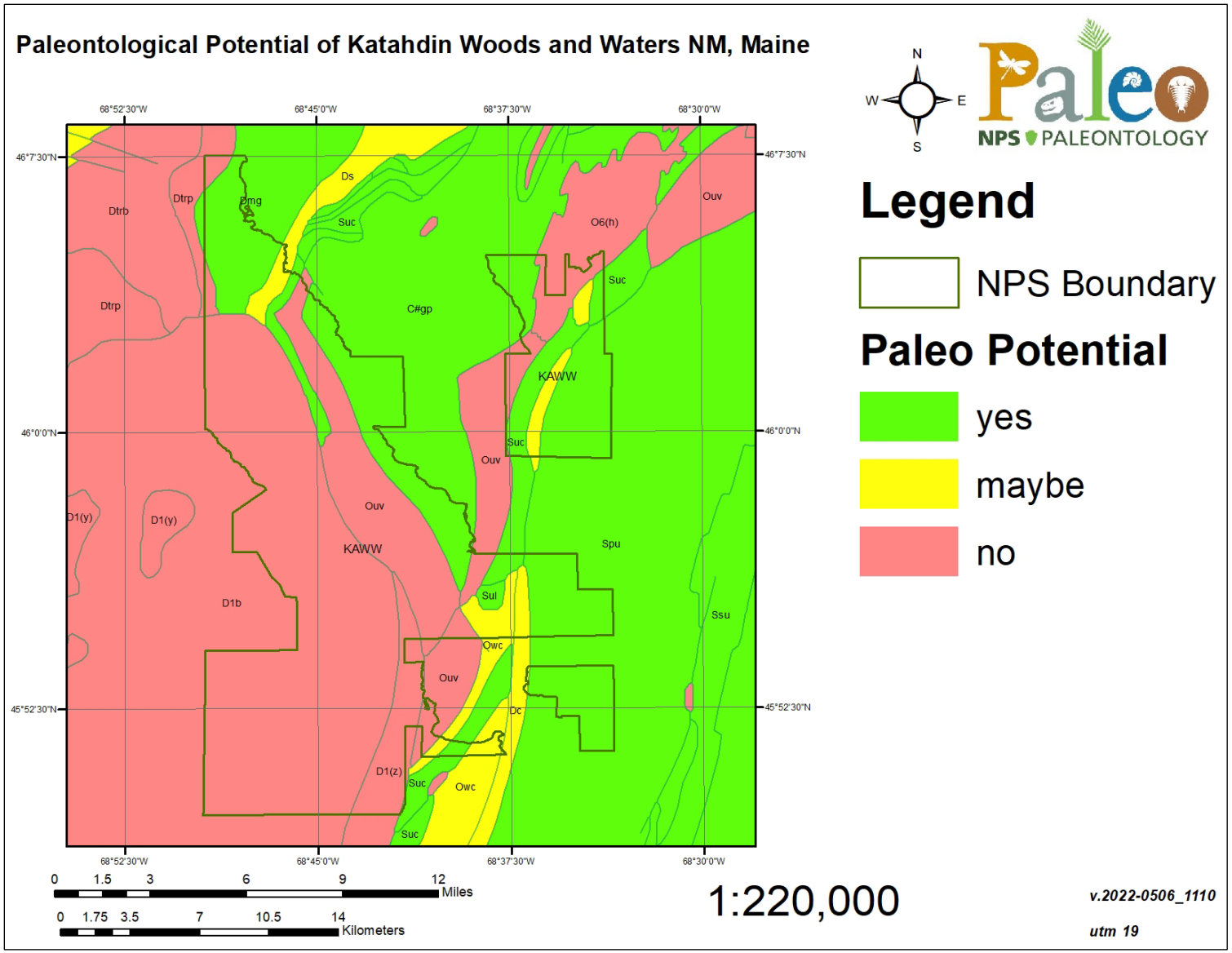


Figure 36. Map indicating paleontological potential of geologic map units in Katahdin Woods and Waters National Monument, using Osberg et al. (1985) as base map.

Paleontological Resource Management Recommendations

The paleontological resource inventory at KAWW has documented rich and previously unrecognized paleontological resources from within monument boundaries. Although fossils have been reported from various localities and formations within KAWW and are notable enough that they were mentioned in the monument's establishing language, documentation has been scattered and sparse, usually made as an adjunct to another topic. This report captures the scope, significance, and distribution of fossils at KAWW as well as provides recommendations to support the management and protection of the park's non-renewable paleontological resources.

- KAWW staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff should receive guidance regarding how to recognize common local fossils. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff should take advantage of them, if funding and time permit.
- KAWW staff should photo-document and monitor any occurrences of paleontological resources that may be observed in situ. Fossils and their associated geologic context (surrounding rock) should be documented but left in place unless they are subject to imminent degradation. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.
    - Monitoring frequency is a function of many factors, e.g.: visitation or proximity to areas used by visitors; fragility, abundance, and rarity of the resource; and physical features of the site.
- Fossil theft is one of the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. When possible, incidents should be fully documented and the information submitted for inclusion in the annual law enforcement statistics. The areas most likely to be affected by resource theft are those nearest the East Branch, because inland areas are more challenging to reach and locate.
- Because geological projects in KAWW have generally focused on non-paleontological topics, there are opportunities for focused paleontological work within the monument, such as further investigations of the Ordovician sequence on the East Branch and the "Owen Brook Limestone". Staff should encourage outside research to thoroughly document these resources.
- To date, geologic mapping of KAWW has been at a scale of 1:62,500 at largest. Bedrock mapping at a scale of 1:24,000 would be useful for managing paleontological resources and other natural resources. Consideration should be given to opportunities to produce such maps, such as by partnering with the Maine Geological Survey and the USGS's STATEMAP program.

- Additional bedrock geologic exploration would also be useful for defining the geologic units that have been recognized as distinct but are unnamed or informally named, for example the "Owen Brook Limestone" and the Ordovician units exposed on the East Branch. A better understanding of these units will improve knowledge of KAWW's geologic history and paleontology.
- Fossils found in a cultural context should be documented like other fossils, but because of the cultural context will also require the input of an archeologist or a cultural resource specialist. Any fossil that has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.
- KAWW may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Scientists in Parks (SIP) Program is an established program for recruitment of geology and paleontology interns.
- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

If fossil specimens are found by KAWW staff, it is recommended they follow the steps outlined below to ensure proper paleontological resource management.

- Photo-document the specimen without moving it from its location if it is loose. Include a common item for scale, such as a coin, pen, or pencil, if a ruler or scale bar is not available.
- If a GPS unit is available, record the location of the specimen. If a GPS unit is not available, most smartphones can be used to record the location. If a smartphone is not available, either, record the general location and the height within the outcrop, if applicable. If possible, revisit the site when a GPS unit is available.
- Write down associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in KAWW, sketch of the fossil, position within the outcrop or if it or the rock it is in is loose, any associated fossils, and any other additional information.
- Do not remove the fossil unless it is loose in an area of heavy traffic, such as a public trail, and is at risk of being taken or destroyed. If the fossil is removed, be sure to wrap in soft material, such as tissue paper, and place in a labeled plastic bag with associated notes.

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Appendix A: Katahdin Woods and Waters National Monument Paleontological Species

The following table (Appendix Table A-1) documents the fossil species found at Katahdin Woods and Waters National Monument (KAWW) in stratigraphic context, as reported in the literature, in museum collections, and through personal observations. The rows are organized systematically, placing taxa of the same broad groups together. The columns are organized by formation, which are presented in ascending order (oldest to youngest) left to right. The columns also include the taxon (first column) and references (last column; included in "Literature Cited" above).

It is likely that some of the genera and species cited here are actually examples of different authors identifying the same forms using different names. Some of the taxa identified to the species level are now classified under different genera. It is beyond the scope of this document to locate and evaluate every potential taxonomic configuration of the taxa cited; instead, the most recent name used in KAWW-related literature is given. Some names may therefore be obsolete due to changes published in literature that is not directly related to geology in the KAWW area. A key listing updated identifications (as of 2021) is included after the table.

Cell symbology:
P = record from the east bank of the East Branch of the Penobscot adjacent to KAWW; such taxa are very likely also present in KAWW
R = reworked from an older formation (does not include modern float; the reworked fossil has to have been re-incorporated into another geologic unit)
U = taxon is present within KAWW, but the formation is uncertain
Y = taxon is present within KAWW in a given formation
? = unclear whether a taxon's locality is within KAWW
?? = stratigraphy and locality are both unclear
– = no record

Acronyms for stratigraphic units (adapted from Neuman 1967):
Dm = Matagamon Sandstone
Ssl = "Owen Brook Limestone"
Sx = tuff breccia
Sg = unnamed Silurian conglomerate
Sa = Allsbury Formation
Oc = unnamed Upper Ordovician conglomerate
Cgp = Grand Pitch Formation

Appendix Table A-1. Fossil taxa reported from Katahdin Woods and Waters National Monument in stratigraphic context.

Group	Taxon	Cgp	Oc	Sa	Sg	Sx	Ssl	Dm	References
Invertebrates	**Invertebrates overall**	**–**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**–**
Porifera (sponges) or Rhodophyta (red algae)	*Solenopora* sp.	–	?	–	–	–	–	–	Oliver 1960/9/29
Invertebrates: Porifera (sponges)	Stromatoporoidea undetermined	–	–	–	–	–	Y	–	Neuman 1966, 1967
Invertebrates: Cnidaria: Anthozoa (corals)	"Madrepores"	–	–	–	U	–	–	–	Jackson 1838
	Undetermined colonial corals	–	–	–	–	–	Y	–	Neuman 1966
	Anthozoa undetermined	–	Y	–	–	–	Y	–	Neuman 1980; Eldridge et al. 2012
Invertebrates: Cnidaria: Anthozoa: Tabulata (tabulate corals)	*Acidolites* sp.	–	?	–	–	–	–	–	Oliver 1961/8/23
	Catenipora sp. *C. piirsaluensis*	–	Y	–	–	–	–	–	Oliver 1977/7/15
	Catenipora sp.	–	Y	–	–	–	–	–	Neuman 1980
	"*Favosites gothlandica*"	–	–	–	U	–	–	–	Hitchcock 1861a
	Plasmoporella sp.	–	P	–	–	–	–	–	Oliver 1963/2/7
	Propora sp. (cf. *Proporella*)	–	Y	–	–	–	–	–	Oliver 1977/7/15
	Propora sp.	–	Y	–	–	–	–	–	Neuman 1980
	Reuschia sp.	–	Y	–	–	–	–	–	Neuman 1980
	"Billingsariinid" corals	–	P	–	–	–	–	–	Oliver 1963/2/7
	Favositida undetermined	–	–	–	Y	–	Y	–	Boucot 1963/4/17; Neuman 1967
	Heliolitida undetermined	–	–	–	Y	Y	–	–	Neuman 1967
	Tabulata undetermined	–	Y	–	–	–	Y	–	Neuman 1980; 2021 field inventory
Invertebrates: Cnidaria: Anthozoa: Rugosa (rugose corals)	*Bodophyllum neumani*	–	Y	–	–	–	–	–	Elias 1982
	Bodophyllum sp.	–	Y	–	–	–	–	–	Neuman 1980
	Entelophyllum sp.	–	–	–	–	–	Y	–	Neuman 1967
	Grewingkia penobscotensis	–	Y	–	–	–	–	–	Elias 1982
	Grewingkia sp.	–	Y	–	–	–	–	–	Neuman 1980
	Grewingkia sp. 1	–	Y	–	–	–	–	–	Oliver 1977/7/15
	Grewingkia? sp. 2	–	Y	–	–	–	–	–	Oliver 1977/7/15

Appendix Table A-1 (continued). Fossil taxa reported from Katahdin Woods and Waters National Monument in stratigraphic context.

Group	Taxon	Cgp	Oc	Sa	Sg	Sx	Ssl	Dm	References
Invertebrates: Cnidaria: Anthozoa: Rugosa (rugose corals) (continued)	*Grewingkia*? sp. cf. *G. bilateralis*	–	Y	–	–	–	–	–	Oliver 1977/7/15
	Kenophyllum? sp.	–	P	–	–	–	–	–	Neuman 1980
	Pycnactis? sp.	–	?	–	–	–	–	–	Oliver 1960/9/29
	Streptelasma rankini	–	Y	–	–	–	–	–	Elias 1982
	Streptelasma sp.	–	Y	–	–	–	–	–	Neuman 1980
	"Petraiid corals"	–	?	–	–	–	–	–	Oliver 1961/8/23
	Streptelasmatina undetermined	–	P	–	–	–	–	–	Oliver 1963/2/7
	Unspecified horn corals	–	P	–	–	–	Y	–	Neuman 1963/3/22; 2021 field inventory
	Rugosa undetermined	–	Y	–	Y	–	Y	–	Neuman 1966, 1967, 1980
Invertebrates: Brachiopoda (lamp shells)	**Brachiopoda overall**	**–**	**Y**	**–**	**Y**	**Y**	**Y**	**Y**	**–**
	Boreadorthis sp.	–	Y	–	–	–	–	–	Neuman 1980
	Catazyga cf. *C. anticostiensis*	–	P	–	–	–	–	–	Neuman 1967
	Catazyga sp.	–	Y	–	–	–	–	–	Neuman 1980
	Christiania sp.	–	Y	–	–	–	–	–	Neuman 1980
	Cliftonia sp.	–	P	–	–	–	–	–	Neuman 1980
	Conchidium sp.	–	–	–	–	–	Y	–	Neuman 1966, 1967
	Cryptothyrella sp.	–	Y	–	–	–	–	–	Neuman 1980
	Cyrtonotella sp.	–	Y	–	–	–	–	–	Neuman 1980
	Dalmanella sp.	–	P	–	–	–	–	–	Neuman 1963/3/22
	Dicoelosia sp.	–	P	–	–	–	–	–	Neuman 1980
	Dolerorthis sp.	–	P	–	–	–	–	–	Neuman 1980
	Eoplectodonta sp.	–	P	–	–	–	–	–	Neuman 1980
	Eostropheodonta sp.	–	Y	–	–	–	–	–	Neuman 1980
	Fardenia sp.	–	Y	–	–	–	–	–	Neuman 1980
	Fardenia? sp.	–	P	–	–	–	–	–	Neuman 1963/3/22

Appendix Table A-1 (continued). Fossil taxa reported from Katahdin Woods and Waters National Monument in stratigraphic context.

Group	Taxon	Cgp	Oc	Sa	Sg	Sx	Ssl	Dm	References
Invertebrates: Brachiopoda (lamp shells) (continued)	*Glyptorthis* sp.	–	P	–	–	–	–	–	Neuman 1967
	Gunnarella sp.	–	Y	–	–	–	–	–	Neuman 1980
	Hesperorthis sp.	–	P	–	–	–	–	–	Neuman 1967, 1980
	Hipparionyx proximus	–	–	–	–	–	–	Y	Clarke 1909
	Hirnantia sp.	–	Y	–	–	–	–	–	Neuman 1980
	Kinnella sp.	–	P	–	–	–	–	–	Neuman 1980
	Leangella sp.	–	Y	–	–	–	–	–	Neuman 1980
	Leptaena sp.	–	?	–	–	–	–	–	Neuman 1963/3/22
	cf. *Leptaena* (2021 form with rugae)	–	–	–	–	–	–	Y	2021 field inventory
	Leptellina sp.	–	?	–	–	–	–	–	Neuman 1963/3/22
	Leptocoelia cf. *L. flabellites*	–	–	–	–	–	–	?	Rankin 1965
	Leptostrophia magnifica (2021 large with fine ribs)	–	–	–	–	–	–	Y	2021 field inventory
	Leptostrophia? sp.	–	–	–	–	–	–	?	Rankin 1965
	Meristella sp.	–	–	–	–	–	–	?	Rankin 1965
	Nicolella sp.	–	Y	–	–	–	–	–	Neuman 1980
	Omniella sp.	–	P	–	–	–	–	–	Neuman 1963/3/22
	Oxoplecia sp.	–	?	–	–	–	–	–	Neuman 1963/3/22
	Platystrophia sp.	–	P	–	–	–	–	–	Neuman 1967, 1980
	Ptychopleurella sp.	–	P	–	–	–	–	–	Neuman 1967
	Rensselaeria ovoides	–	–	–	–	–	–	Y	Hitchcock 1861a; Clarke 1909
	cf. *Rensselaeria*? (2021 bulbous and ribbed)	–	–	–	–	–	–	Y	2021 field inventory
	Retrorsirostra sp.	–	Y	–	–	–	–	–	Neuman 1980
	Rhynchotrema sp.	–	P	–	–	–	–	–	Neuman 1967
	Sampo sp.	–	P	–	–	–	–	–	Neuman 1980

Appendix Table A-1 (continued). Fossil taxa reported from Katahdin Woods and Waters National Monument in stratigraphic context.

Group	Taxon	Cgp	Oc	Sa	Sg	Sx	Ssl	Dm	References
Invertebrates: Brachiopoda (lamp shells) (continued)	*Schizophorella* sp.	–	P	–	–	–	–	–	Neuman 1967
	Sowerbyella sp.	–	Y	–	–	–	–	–	Neuman 1967
	Spirifer arenosus	–	–	–	–	–	–	Y	Clarke 1909
	Triplecia sp.	–	Y	–	–	–	–	–	Neuman 1980
	Vellamo sp.	–	P	–	–	–	–	–	Neuman 1967, 1980
	2021: diminutive with fine ribs	–	–	–	–	–	–	Y	2021 field inventory
	2021: smooth, D-shaped	–	–	–	–	–	–	Y	2021 field inventory
	2021: smooth, productid-like	–	–	–	–	–	–	Y	2021 field inventory
	Dalmanellidae undetermined	–	Y	–	Y	–	–	–	Neuman 1967, 1980
	Leptellidae undetermined	–	Y	–	–	–	–	–	Boucot 1963/4/17
	Impunctate orthids	–	Y	–	–	–	–	–	Neuman 1980
	Punctate orthids	–	Y	–	–	–	–	–	Neuman 1980
	Orthoidea undetermined	–	Y	–	–	–	–	–	Boucot 1963/4/17
	Orthotetacea undetermined	–	Y	–	–	–	–	–	Boucot 1963/4/17
	Pentamerid? brachiopod	–	–	–	–	Y	–	–	Neuman 1967
	Plectambonitidae undetermined	–	Y	–	–	–	–	–	Boucot 1963/4/17
	Rhynchonellida undetermined	–	P	–	–	–	–	–	Neuman 1980
	Rhynchonelliformea undetermined	–	Y	–	–	–	–	–	Neuman 1980
	Rostrospiracea undetermined	–	Y	–	–	–	–	–	Boucot 1963/4/17
	Spiriferida? undetermined (2021 small with heavy ribs)	–	–	–	–	–	–	Y	2021 field inventory
	Strophomenida undetermined	–	Y	–	–	–	–	–	Boucot 1963/4/17
	Brachiopod?	–	–	–	Y	–	–	–	Boucot 1963/4/17
	Brachiopoda undetermined	–	Y	–	–	–	Y	–	Neuman 1967, 1980; Eldridge et al. 2012

Appendix Table A-1 (continued). Fossil taxa reported from Katahdin Woods and Waters National Monument in stratigraphic context.

Group	Taxon	Cgp	Oc	Sa	Sg	Sx	Ssl	Dm	References
Invertebrates: Mollusca: Monoplacophora	*Cyrtolites expansus*	–	–	–	–	–	–	Y	Clarke 1909
Invertebrates: Mollusca: Bivalvia (clams, oysters, etc.)	*Pterinea radialis*	–	–	–	–	–	–	?	Clarke 1909
	Pterinea radialis var.	–	–	–	–	–	–	Y	Clarke 1909
Invertebrates: Mollusca: Gastropoda (snails)	*Diaphorostoma desmatum*	–	–	–	–	–	–	Y	Clarke 1909
	Diaphorostoma ventricosum	–	–	–	–	–	–	Y	Clarke 1909
	Plectonotus derbyi	–	–	–	–	–	–	Y	Clarke 1909
	Platyceras cf. *calantica*	–	–	–	–	–	–	Y	Clarke 1909
	Platyceras sp.	–	–	–	–	–	–	Y	Clarke 1909
	Gastropoda unspecified	–	?	–	–	–	–	–	Elias 1982
Invertebrates: Arthropoda: Trilobita	**Trilobita overall**	**–**	**?**	**–**	**–**	**–**	**–**	**Y**	**–**
	Dalmanites epicrates	–	–	–	–	–	–	?	Billings 1869
	Dalmanites pleuroptyx	–	–	–	–	–	–	Y	Clarke 1909
	Dalmanites sp.	–	–	–	–	–	–	Y	Clarke 1909
	Diacalymene sp.	–	?	–	–	–	–	–	Neuman 1967
	Homalonotus vanuxemi	–	–	–	–	–	–	?	Clarke 1909
	Odontochile ploratus	–	–	–	–	–	–	Y	Clarke 1907, 1909; Delo 1940
	Sphaerocoryphe cf. *S. thompsoni*	–	?	–	–	–	–	–	Neuman 1967
	Trilobita undetermined	–	?	–	–	–	–	–	Elias 1982
Invertebrates: Echinodermata (sea stars, sea urchins, crinoids, etc.)	Crinoidea undetermined	–	–	–	–	–	Y	Y	2021 field inventory
	Pelmatozoan debris	–	–	–	–	Y	–	–	Neuman 1967
Invertebrates: Graptolithina	*Monograptus* sp. (slender hooked thecae)	–	–	Y	–	–	–	–	Neuman 1967
	Monograptus sp. (slender thecae, apparently square)	–	–	Y	–	–	–	–	Neuman 1967
	Biserial scandent graptolite?	–	–	–	R?	–	–	–	Berry 1963/1/24
	Dichograptid graptolite?	–	–	–	R?	–	–	–	Berry 1963/1/24

Appendix Table A-1 (continued). Fossil taxa reported from Katahdin Woods and Waters National Monument in stratigraphic context.

Group	Taxon	Cgp	Oc	Sa	Sg	Sx	Ssl	Dm	References
Invertebrates: Graptolithina (continued)	Indeterminate biserial graptolite	–	?	–	–	–	–	–	Neuman 1963/3/22
Invertebrates: Tentaculita	*Tentaculites leclercqia*	–	–	–	–	–	–	?	Clarke 1909
Invertebrates: Other	Undetermined invertebrates	–	–	–	–	–	–	Y	2021 field inventory
Ichnofossils: Invertebrate Trace Fossils	*Oldhamia antiqua*	Y	–	–	–	–	–	–	Seilacher et al. 2005; YPM records
	Oldhamia isp.	P	–	–	–	–	–	–	Neuman 1960
Other Fossils	Fossil debris	–	–	–	–	Y	Y	–	Boucot 1963/4/17; 2021 field inventory
	Cylindrical structure	–	–	–	–	–	–	Y	2021 field inventory
	Unspecified fossils	–	–	–	–	–	–	?	Clarke 1909

Additional information:

E&Rs were intended as preliminary identifications, and so are only used here when a taxon is not mentioned in other sources. They can be distinguished by the use of full dates in the reference.

The trilobites at TR-62-2/USGS 4113-CO are variously identified in pre-publication USGS communications as *Diacalymene*, *Treptaspis*, and a proetid (Whittington 1963/3/21) and *Flexicalymene* sp. and *Sphaerocoryphe* like *S. thompsoni* (Neuman 1963/3/22); the identifications published in Neuman (1967) are preferred here.

Two identifications have been supplied for the large, finely ribbed brachiopod morphotype: *Costistrophonella punctulifera* (H. Feldman, written comm., October 2021) and *Leptostrophia* (C. Wang, written comm., October 2021). The exterior view of the shell resembles both; however, the internal view (Figure 29), which was not available to Feldman, shows anatomy corresponding to *Leptostrophia magnifica*.

In Neuman (1980), Figure 3 shows six fossiliferous horizons along the East Branch of the Penobscot between Haskell Rock and Pond Pitch; for the following discussion, they are numbered 1 to 6, left to right (this is strictly based on the orientation of the figure, not stratigraphic position; this is actually opposite stratigraphic order, and opposite the order used above in "Paleontological Localities"). By comparison with the taxa identified in the text, horizons 1, 2, and 5 are regarded as located on the east bank, opposite KAWW, and horizons 3, 4, and 6 are regarded as within KAWW.

Reassigned species:

- *Dalmanites ploratus* = *Odontochile ploratus*
- *Oldhamia* (*Murchisonites*) cf. *occidens* = *Oldhamia smithi* = *Oldhamia antiqua*
- *Tentaculites perceensis* (Clarke 1909) accepted as slip for *T. leclercqia* (also spelled *leclercqius*); see discussion in text

Appendix B: Repositories of Katahdin Woods and Waters National Monument Fossils

The institutions known to have collections from Katahdin Woods and Waters National Monument are included below. Addresses, phone numbers, links, and email addresses to departments are included as available. This information is subject to change, particularly hyperlinks.

EBERHARD KARLS UNIVERSITY OF TÜBINGEN
Department of Geosciences
Hölderlinstr. 12
72074 Tübingen, Germany
+49-(0)7071-29-76862
https://uni-tuebingen.de/en/faculties/faculty-of-science/departments/geosciences/department/

Per Seilacher et al. (2005) and Yale Peabody records, there is at least one *Oldhamia* slab from KAWW in the collections of this institution.

NEW YORK STATE MUSEUM
Cultural Education Center
222 Madison Avenue
Albany, NY 12230
(518) 474-5816 (Research and Collections)
http://www.nysm.nysed.gov/
http://www.nysm.nysed.gov/research-collections/paleontology
nysmresearchcollections@nysed.govhttp://www.nysm.nysed.gov/

This museum reposits the holotype of *Dalmanites ploratus* (New York State Museum 9802), as well as the holotype and paratype of *Oldhamia smithi*, potentially collected from KAWW (NYSM 7830 and NYSM 7831).

NORTHEAST MUSEUM SERVICES CENTER
Charlestown Navy Yard
Building I, 4th floor
Charlestown, MA 02129
(617) 242-5613

The Northeast Museum Services Center is the repository for the specimens collected during the 2021 field inventory.

PEABODY MUSEUM OF NATURAL HISTORY AT YALE UNIVERSITY
P.O. Box 208118
170 Whitney Ave
New Haven, CT 06520
(203) 432-5050
https://peabody.yale.edu/
peabody.collections@yale.edu

The Peabody Museum of Natural History reposits 31 catalog numbers (YPM IP 204543–204573) for slabs bearing *Oldhamia antiqua* from KAWW.

SMITHSONIAN INSTITUTION, NATIONAL MUSEUM OF NATURAL HISTORY
Department of Paleobiology
P.O. Box 37012
NHB MRC 121
Washington, D.C. 20013
https://naturalhistory.si.edu/research/paleobiology
paleodept@si.edu

The National Museum of Natural History reposits the type specimens of *Bodophyllum neumani* (USNM 311760), *Grewingkia penobscotensis* (USNM 311748), and *Streptelasma rankini* (USNM 311736) (Elias 1982).

Appendix C: Glossary

Alluvial (adjective), **alluvium** (noun): a general term for unconsolidated terrestrial sediment moved by water and not attributed to a more specific process (i.e., not fluvial, glacial, or lacustrine).

Angiosperm: any of the flowering plants.

Angular unconformity: a type of unconformity in which horizontally layered strata are deposited on layered strata that have been tilted, so that the two sets of layers are not parallel.

Anticline: a geologic fold that is arched, or convex-up.

Arthropod: any of a diverse group of invertebrates with exoskeletons, segmented bodies, and jointed appendages. Insects, arachnids, and crustaceans are modern examples.

Batholith: an intrusive igneous body larger than 100 km^2 (40 mi^2) in area.

Biostratigraphy: using fossils to identify the relative positions and relative ages of rocks.

Bioturbation: disturbance of sediment by organisms to the extent that sedimentary features such as bedding and stratification are destroyed.

Bivalve: a mollusk with two shells. Examples include clams, oysters, mussels, and scallops.

Brachial valve: the upper shell of a brachiopod.

Brachiopod: a marine filter-feeding animal with two shells, resembling bivalve mollusks but more closely related to bryozoans. Brachiopods are sometimes known as “lamp shells” because some of them resemble ancient oil lamps.

Breccia: a conglomerate of angular rock fragments.

Bryozoan: a filter-feeding aquatic colonial animal. Bryozoans are sometimes called “moss animals” because they often encrust objects.

Calcarenite: a limestone made up of sand-sized calcareous fragments, a “limestone sandstone”.

Calcareous: mostly or partly composed of calcium carbonate; lime-rich.

Calcite: a mineral made of calcium carbonate; found in limestone and some fossils.

Calcium carbonate: $CaCO_3$, a mineral-forming compound. Calcite is a common form.

Cambrian: the first geologic period of the Paleozoic, noted for the abrupt diversification of life (“Cambrian explosion”); approximately 539 to 487 Ma.

Carbonate: a general term for minerals containing carbonate ions (CO_3^{-2}), such as calcite, and rocks containing these minerals, such as dolomite and limestone.

Cephalon: the head shield of a trilobite.

Cephalopod: a mollusk with a prominent head fringed by tentacles. Examples include squids, octopuses, *Nautilus*, and many extinct forms, especially ammonoids.

Chert: a rock made of silica lacking obvious macroscopic crystals. Flint is a variety of chert found in chalk and marly limestone.

Clast: a rock fragment of any size. A rock made up of clasts, such as sandstone or shale, is called clastic.

Columnal: individual segments of an echinoderm's stalk, particularly crinoids. They often resemble doughnuts, sprockets, or gears.

Conifer: a general term for non-flowering plants that produce seeds and pollen from cones.

Conodont: an extinct eel-like chordate, known primarily from jaw elements.

Contact: in geology, the horizon or plane where two formations meet.

Coralline algae: "red algae" (rhodophytes) that secrete calcareous structures. Modern forms contribute to reefs.

Crinoid: an echinoderm, also known as a sea lily, featuring a cup-like body with feathery tentacular arms, and usually but not always attached to a surface with a stalk.

Devonian: the fourth geologic period of Paleozoic; approximately 419 to 359 Ma.

Diatoms: algae that secrete cell walls of silica. Diatoms are common microfossils.

Disconformity: an unconformity where the strata above and below the geologic contact are parallel, but the contact itself shows evidence of erosion or non-deposition.

Drift: in geology, a general term for any deposit of glacial origin.

Echinoderm: any of a group of invertebrates noted for their five-fold symmetry. Sea stars and sea urchins are familiar echinoderms.

Eurypterid: a type of extinct arthropod often known informally as a "sea scorpion" for its large scorpion-like appendages and general body shape.

Facies: a body of rock that is distinct from the surrounding rock, due to specific aspects of deposition and setting; facies are generally invoked when there are differences within a formation or member that are not suitable for mapping (e.g., not laterally persistent).

Fluvial: a river as depositional environment or mode of transport.

Flysch: an alternating sequence of sandstones and siltstones representing a marine tectonic basin in the process of being filled.

Formation: a group of rocks that share some characteristics and can be depicted on a geological map; the basic unit of stratigraphy.

Fossiliferous: a rock or deposit that yields fossils.

Graptolite: a colonial invertebrate that lived in bottom-attached or free-floating colonies; pterobranch "worms" may be modern graptolites.

Graywacke (also spelled **greywacke**): dark poorly sorted sandstone with larger grains in a clay matrix.

GRD: Geologic Resources Division of the National Park Service.

GRI: Geologic Resources Inventory.

Hardground: naturally cemented seafloor; hardening occurred before the seafloor was buried. Hardgrounds were inhabited by assemblages specialized to live on or in the hard surface.

Holocene: the second and most recent epoch of the Quaternary, following the Pleistocene and the last glacial maximum; approximately 11,700 years ago to the present.

Holotype: a name-bearing specimen for an organism. Some species are based on multiple specimens, which are called cotypes (outdated) or syntypes.

Horn coral: a solitary rugose coral. The name refers to the animal-horn-like hard structure.

Ichnofossil (also **trace fossil**): fossilized remains of biological activity of an organism, including root traces, footprints, tracks, burrows, trails, and other biogenically produced features.

In situ: when describing fossils, this means found in place at an outcrop.

KAWW: Katahdin Woods and Waters National Monument

Lacustrine: a lake as depositional environment.

Laurentia: the ancient core of the North American continent.

Lithology: the type(s) of rock in a formation, member, bed, or other division.

Ma: an acronym for "mega-annum," but more easily understood as "million years ago."

Macrofossil: a fossil that can be studied with the naked eye or a hand lens.

Marl: calcium carbonate mud or mudstone that commonly forms in lakes.

Member: a subdivision of a formation.

Microfossil: a fossil, typically a millimeter or less in size, that must be studied with a microscope.

Microlepidopteran: a general term for small moths (wingspan less than 20 mm [0.8 in]).

Mollusk: any of a diverse group of invertebrates noted for their combination of a muscular foot, a shell, and a mantle that covers the innards and secretes the shell. Examples include bivalves, cephalopods, and snails.

Monoplacophoran: a type of marine mollusk; most monoplacophorans have a cap-like or limpet-like shell, but some extinct forms had shells coiled in a flat plane.

Monzonite: a feldspar-rich intrusive igneous rock.

NPS: National Park Service.

Ordovician: the second geologic period of the Paleozoic, following the Cambrian; approximately 487 to 443 Ma.

Organic: made of organic compounds (i.e., molecules of carbon, hydrogen, nitrogen, and oxygen); pollen, spores, and cysts, all of which can be fossilized, have walls of organic composition.

Orogeny: a mountain-building event.

Ostracode (also spelled **ostracod**): a shelled crustacean, generally microscopic; known informally as "seed shrimp."

Paleozoic: a geologic era, dated approximately 539 to 252 Ma, noted for the diversification of invertebrates and the appearance of vertebrates and land plants.

Paratype: a specimen of an organism that helps define it, but which is not a name-bearing specimen.

Peat: partially decayed vegetation.

Pedicle valve: the lower shell of a brachiopod; it supports the pedicle.

Pedicle: in brachiopod anatomy, a stalk used to attach them to objects.

Pelite: a fine-grained sedimentary rock such as siltstone and mudstone.

Pelmatozoan: a general term for any echinoderm with a "stalk" or "stem" made up of columnals; the majority are crinoids, but several other groups of pelmatozoans existed during the Paleozoic.

Phenocryst: a crystal visible to the naked eye in an igneous rock otherwise composed mostly of crystals that are too small to distinguish.

Phosphate: in geology, a general term for minerals containing phosphate (PO_4^{-3}), such as apatite, found in bones and some shells (the phosphatic shells of some inarticulate brachiopods, for example).

Planktonic: an organism that floats freely but cannot swim against a current.

Pleistocene: the older of two epochs in the Quaternary, noted for ice ages; approximately 2.58 Ma to 11,700 years ago.

Pluton: a general term for an igneous intrusion; sometimes reserved for large intrusions.

PRPA: Paleontological Resources Preservation Act (2009).

Pygidium: the "tail" section of a trilobite. This section detached readily when the exoskeleton was shed, so pygidia are common fossils.

Quartzite: moderately metamorphosed quartz sandstone in which the quartz sand grains have recrystallized into an interlocking mosaic; sometimes also used for unmetamorphosed quartz-rich sandstone.

Quaternary: the most recent geologic period, noted for ices ages; approximately 2.58 Ma to the present.

Radiocarbon years: uncalibrated radiocarbon dates are presented as radiocarbon years before present (1950).

Reworked: a fossil that has been eroded from an older rock unit and redeposited in a younger unit.

Rhodophyte: "red algae," from their characteristic color; reef-dwelling coralline algae and many seaweeds are rhodophytes.

Roche moutonnée: a glacial feature consisting of an asymmetric bedrock ridge or bump; ice traveled up the low-angle side and plucked and eroded the steeper down-ice side.

Ruga: concentric corrugation on brachiopod shells; plural rugae.

Rugose coral: an extinct type of coral, with the name referring to the wrinkled surfaces of their fossils. Rugose corals included both colonial and solitary forms, with the solitary forms known as horn corals.

Schist: moderately metamorphosed mudstone, with original minerals recrystallized into small sheet-like mica crystals and other metamorphic minerals (schistosity).

Silica: the compound SiO_2, the building block of the common mineral quartz.

Silurian: the third geologic period of the Paleozoic, following the Ordovician; approximately 443 to 419 Ma.

Slate: slightly metamorphosed mudstone (such as shale), known for thin flat ("slaty") cleavage.

Spicule: a structural element of many types of organisms. Many sponges have a skeleton of spicules; the spicules can be simple and toothpick-like or have multiple points, and the form of the tips also varies.

Steinkern: a cast of the interior of a hollow organic structure, such as a snail shell, formed when sediments entered the structure and became rock, followed by dissolution of the outer structure.

Stratigraphy: the study of rock layers.

Stromatoporoid: a coral-like sponge; seemingly extinct although some modern sponges are very similar.

Strophomenid: a type of articulate brachiopod known from wide D-shaped shells. They lacked pedicles and lived directly on the sea floor.

Structure: in geology, structures are various three-dimensional features such as folds and faults.

Syncline: a geologic fold that is bowed down, or concave-up

Tabulate coral: a type of extinct colonial coral, commonly encrusting other fossils; fossils may resemble honeycombs.

Tectonics: the movements and interactions of Earth's plates.

Tentaculites: a type of extinct "tube worm" of uncertain affinities, known for mm- to cm-scale ribbed shells.

Terrane: a fragment of crustal material that has broken off of one plate and become attached to another.

Trace fossil (also **ichnofossil**): fossilized remains of biological activity of an organism, including root traces, footprints, tracks, burrows, trails, and other biogenically produced features.

Trilobite: an extinct marine arthropod with a roughly oval body featuring an axial lobe and two lateral lobes (the three lobes of the name), also divided into three sections (cephalon for the head, thorax, and pygidium for the tail); trilobites vaguely resembled woodlice (roly-poly bug or pillbug).

Tuff: a type of rock made of lithified volcanic ash.

Turbidite: sedimentary rock deposited by turbidity currents (submarine gravity flows).

Unconformity: a general term for any erosional or non-depositional surface between two rock units.

Valve: a shell; the term is usually applied to mollusks but sometimes to brachiopods as well. Snails and monoplacophorans are univalved (one shell) and bivalves and brachiopods are bivalved (two shells).

Vitreous: glassy, resembling glass.

Appendix D: National Park Service Paleontological Resource Law and Policy

The following material is reproduced in large part from Henkel et al. (2015); see also Kottkamp et al. (2020).

In March 2009, the Paleontological Resources Preservation Act (PRPA) (16 USC 460aaa) was signed into law (Public Law 111–11). This act defines paleontological resources as

> *...any fossilized remains, traces, or imprints of organisms, preserved in or on the [E]arth's crust, that are of paleontological interest and that provide information about the history of life on [E]arth.*

The law stipulates that the Secretary of the Interior should manage and protect paleontological resources using scientific principles. The Secretary should also develop plans for

> *...inventory, monitoring, and deriving the scientific and educational use of paleontological resources.*

Paleontological resources are considered park resources and values that are subject to the "no impairment" standard in the National Park Service Organic Act (1916). In addition to the Organic Act, PRPA will serve as a primary authority for the management, protection and interpretation of paleontological resources. The proper management and preservation of these non-renewable resources should be considered by park resource managers whether or not fossil resources are specifically identified in the park's enabling legislation.

The Paleontological Resources Management section of NPS Reference Manual 77 provides guidance on the implementation and continuation of paleontological resource management programs. Administrative options include those listed below and a park management program will probably incorporate multiple options depending on specific circumstances:

- **No action**—no action would be taken to collect the fossils as they erode from the strata. The fossils would be left to erode naturally and over time crumble away, or possibly be vandalized by visitors, either intentionally or unintentionally. This is the least preferable plan of action of those listed here.
- **Surveys**—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary fossil list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. A NPS Paleontological Locality Database Form will also be completed for each locality. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request and can be modified to account for local conditions and needs.

- **Monitoring**—fossil-rich areas would be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. Photographic records should be kept so that changes can be more easily ascertained.
- **Cyclic prospecting**—areas of high erosion which also have a high potential for producing significant specimens would be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas.
- **Stabilization and reburial**—significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants and reburied. Reburial slows down but does not stop the destruction of a fossil by erosion. Therefore, this method would be used only as an interim and temporary stop-gap measure. In some situations, stabilization of a locality may require the consideration of vegetation. For example, roots can destroy in situ fossils, but can also protect against slope erosion, while plant growth can effectively obscure localities, which can be positive or negative depending on how park staff want to manage a locality.
- **Shelter construction**—it may be appropriate to exhibit certain fossil sites or specimens in situ, which would require the construction of protective shelters to protect them from the natural forces of weathering and erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.
- **Excavation**—partial or complete removal of any or all fossils present on the surface and potentially the removal of specimens still beneath the surface that have not been exposed by erosion.
- **Closure**—the area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Fossil-rich areas may be closed to the public unless accompanied by an interpretive ranger on a guided hike.
- **Patrols**—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. In some situations a volunteer site stewardship program may be appropriate (for example the "Paleo Protectors" at Chesapeake & Ohio Canal National Historical Park).
- **Alarm systems/electronic surveillance**—seismic monitoring systems can be installed to alert rangers of disturbances to sensitive paleontological sites. Once the alarm is engaged, a ranger can be dispatched to investigate. Motion-activated cameras may also be mounted to visually document human activity in areas of vulnerable paleontological sites.

National Park Service Management Policies (2006; Section 4.8.2.1) also require that paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. In 2010, the National Park Service established National Fossil Day as a celebration and partnership organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value (https://www.nps.gov/subjects/fossilday/index.htm). National

Fossil Day occurs annually on Wednesday of the second full week in each October in conjunction with Earth Science Week.

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units

> *...to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner as will leave them unimpaired for the enjoyment of future generations.* (16 U.S.C. § 1).

Congress reiterated this mandate in the Redwood National Park Expansion Act of 1978 by stating that the NPS must conduct its actions in a manner that will ensure no

> *...derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress.* (16 U.S.C. § 1 a-1).

The Organic Act prohibits actions that permanently impair park resources unless a law directly and specifically allows for the acts. An action constitutes an impairment when its impacts

> *...harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources and values.* (Management Policies 2006 1.4.3).

Paleontological Resources Protection Act (P.L. 111-011, Omnibus Public Land Management Act of 2009, Subtitle D)

Section 6302 states

> *The Secretary (of the Interior) shall manage and protect paleontological resources on Federal land using scientific principles and expertise. The Secretary shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources, in accordance with applicable agency laws, regulations, and policies. These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public.*

Federal Cave Resources Protection Act of 1988 (16 USC 4301)

This law provides a legal authority for the protection of all cave resources on NPS and other federal lands. The definition for "Cave Resource" in Section 4302 states

> *Cave resources include any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems.*

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (National Park Service 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the management policies. The following is taken from section 4.8.2.1 of the NPS Management Policies 2006, "Paleontological Resources and their contexts":

> *Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).*
>
> *Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.*
>
> *The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.*
>
> *Parks will exchange fossil specimens only with other museums and public institutions that are dedicated to the preservation and interpretation of natural heritage and qualified to manage museum collections. Fossils to be deaccessioned in an exchange must fall outside the park's scope of collection statement. Systematically collected fossils in an NPS museum collection in compliance with 36 CFR 2.5 cannot be outside the scope of the collection statement. Exchanges must follow deaccession procedures in the Museum Handbook, Part II, chapter 6.*
>
> *The sale of original paleontological specimens is prohibited in parks.*
>
> *The Service generally will avoid purchasing fossil specimens. Casts or replicas should be acquired instead. A park may purchase fossil specimens for the park museum collection only after making a written determination that*

- *The specimens are scientifically significant and accompanied by detailed locality data and pertinent contextual data;*
- *The specimens were legally removed from their site of origin, and all transfers of ownership have been legal;*
- *The preparation of the specimens meets professional standards;*
- *The alternatives for making these specimens available to science and the public are unlikely;*
- *Acquisition is consistent with the park's enabling legislation and scope of collection statement, and acquisition will ensure the specimens' availability in perpetuity for public education and scientific research.*

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

(See Natural Resource Information 4.1.2; Studies and Collections 4.2; Independent Research 5.1.2; Artifacts and Specimens 10.2.4.6. Also see 36 CFR 2.5.)

NPS Director's Order-77, Paleontological Resources Management

DO-77 describes fossils as non-renewable resources and identifies the two major types: body fossils and trace fossils. It describes the need for managers to identify potential paleontological resources using literature and collection surveys, identify areas with potential for significant paleontological resources, and conduct paleontological surveys (inventory). It also describes appropriate actions for managing paleontological resources including: no action, monitoring, cyclic prospecting, stabilization and reburial, construction of protective structures, excavation, area closures, patrols, and the need to maintain confidentiality of sensitive location information.

Excerpt from Clites and Santucci (2012):

Monitoring

An important aspect of paleontological resource management is establishing a long-term paleontological resource monitoring program. National Park Service paleontological resource monitoring strategies were developed by Santucci et al. (2009). The park's monitoring program should incorporate the measurement and evaluation of the factors stated below.

Climatological Data Assessments

These assessments include measurements of factors such as annual and storm precipitation, freeze/thaw index (number of 24-hour periods per year where temperature fluctuates above and below 32 degrees Fahrenheit), relative humidity, and peak hourly wind speeds.

Rates of Erosion Studies

These studies require evaluation of lithology, slope degree, percent vegetation cover, and rates of denudation around established benchmarks. If a park does not have this information, there may be opportunities to set up joint projects, because erosion affects more than just paleontological resources.

Assessment of Human Activities, Behaviors, and Other Variables

These assessments involve determining access/proximity of paleontological resources to visitor use areas, annual visitor use, documented cases of theft/vandalism, commercial market value of the fossils, and amount of published material on the fossils.

Condition Assessment and Cyclic Prospecting

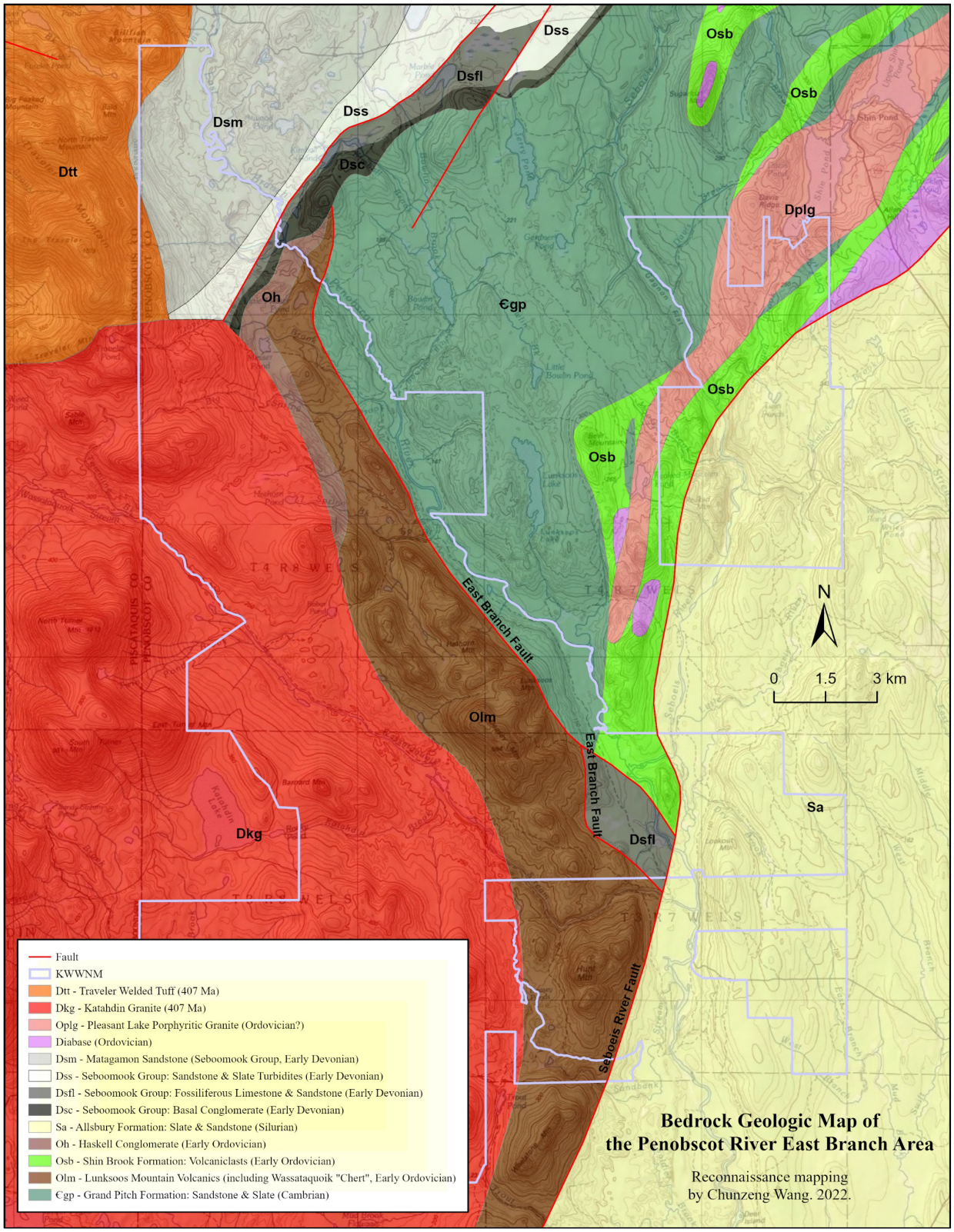
These monitoring methods entail visits to the locality to observe physical changes in the rocks and fossils, including the number of specimens lost and gained at the surface exposure. Paleontological prospecting would be especially beneficial during construction projects or road repair.

Periodic Photographic Monitoring

Maintaining photographic archives and continuing to photo-document fossil localities from established photo-points enables visual comparison of long-term changes in site variables.

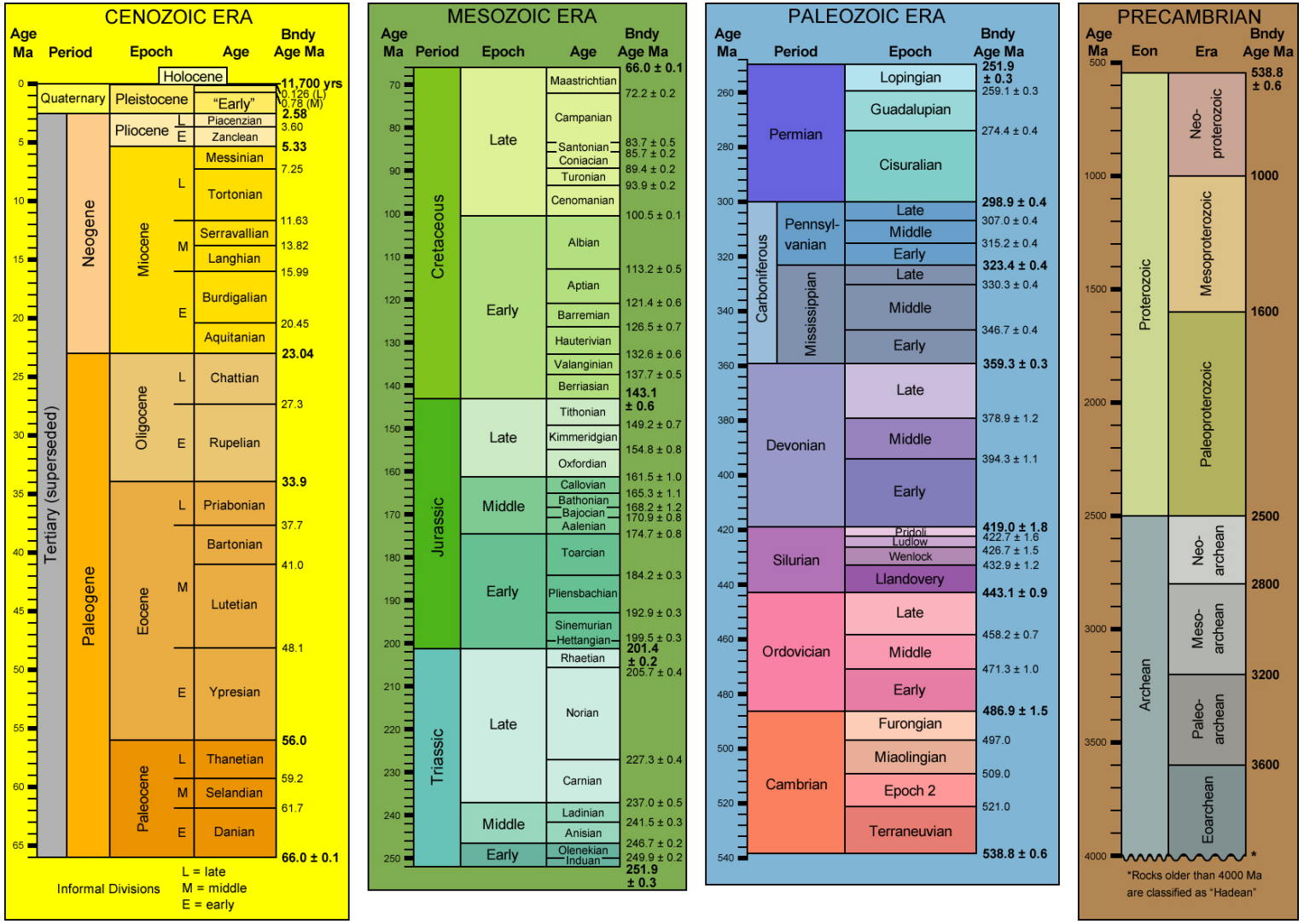
Appendix E: Reconnaissance Geologic Map of Katahdin Woods and Waters National Monument

Chunzeng Wang (University of Maine at Presque Isle) has undertaken reconnaissance mapping of the area based on the Neuman and Rankin maps (pers. comm., October 2021 and March 2022). He has permitted a copy of the map (as of March 2022) to be included in this document (Appendix Figure E-1) for reference purposes for this work in progress. There are some differences from existing stratigraphic nomenclature and assignments; these have not yet been published.



Appendix Figure E-1. Reconnaissance mapping of Katahdin Woods and Waters National Monument and vicinity, courtesy Chunzeng Wang.

Appendix F: Geologic Time Scale



Ma=Millions of years old. Bndy Age=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

The Department of the Interior protects and manages the nation’s natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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