AN INVENTORY OF PALEONTOLOGICAL RESOURCES FROM KATMAI NATIONAL PARK AND PRESERVE, SOUTHWEST ALASKA

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Abstract—We present a preliminary framework of a paleontological inventory of Katmai National Park and Preserve (KATM), which is situated at the northeastern end of the Alaska Peninsula, southwest Alaska. The park was originally established as Katmai National Monument in 1918 to protect the region surrounding the stratovolcano Mount Katmai and the Valley of Ten Thousand Smokes, which was the site of the largest volcanic eruption experienced globally in the 20th century. In addition to the spectacular modern volcanic features, the park is also rich in paleontological resources consisting primarily of Mesozoic invertebrates and Cenozoic terrestrial plants. The principle fossil-producing units include the Talkeetna and Naknek formations (Jurassic), Staniukovich, Herendeen, Pedmar and Kaguyak formations (Cretaceous), non-marine units of Paleogene (Paleocene?, Eocene and Oligocene) age (Copper Lake Formation, Hemlock Conglomerate, and Ketavik Formation) and Quaternary lake sediments. One of the earliest reports of fossils from Alaska is associated with collections made near the abandoned Katmai Village (destroyed in the 1912 eruption) and described by Grewingk (1850). Our current locality compilation shows approximately 1000 locality records from within the boundaries of KATM. The park presents many opportunities for future paleontological research, including the study of the Upper Jurassic Naknek Formation, whose paleontological content and sedimentological features suggest evidence of a major episode of climatic cooling during an otherwise generally Mesozoic "greenhouse" world. The potential for vertebrate fossils in the Naknek Formation at KATM is suggested by the occurrence of pliosaur remains and a dinosaur trackway in this formation south of the park.

INTRODUCTION

Katmai National Park and Preserve (KATM), at the northeastern end of the Alaska Peninsula (Fig. 1), is best known for the 1912 historic eruption of Novarupta, the largest volcanic event of the 20th century, rivaled only by the 1991 eruption of Mt. Pinatubo in the Philippines. The park was proclaimed Katmai National Monument on September 24, 1918 to protect this volcanically devastated region surrounding Mount Katmai and the Valley of Ten Thousand Smokes. The monument was formally redesignated as a national park and national preserve on December 2, 1980.

Although most famous for its volcanic features, KATM is also host to an excellent record of Jurassic, Cretaceous, and Cenozoic sedimentary rocks with rich paleontological resources, and was one of the first places from which fossils were reported in Alaska, dating back to the publication of Grewingk (1850), when Alaska was still owned by Russia. This paper represents a preliminary assessment of the rich fossil record of the park, prepared with the intention of providing baseline paleontological resource data for future researchers and park resource management staff. To date, fossil observation and collecting in KATM has been done primarily in support of regional geological mapping, but even as a secondary component of study, fossils have proven to be abundant. At this time we recognize approximately 1000 distinct fossil localities containing a plethora of invertebrate and plant remains. Table 1 presents a list of fossil invertebrate and plant species that have been established on the basis of type specimens found in KATM. Vertebrate fossils are represented only by few fragmentary remains, but we are certain that future investigations will uncover many more, especially in the Late Jurassic age Naknek Formation, which has yielded dinosaur trackways and remains of marine reptiles near the park.

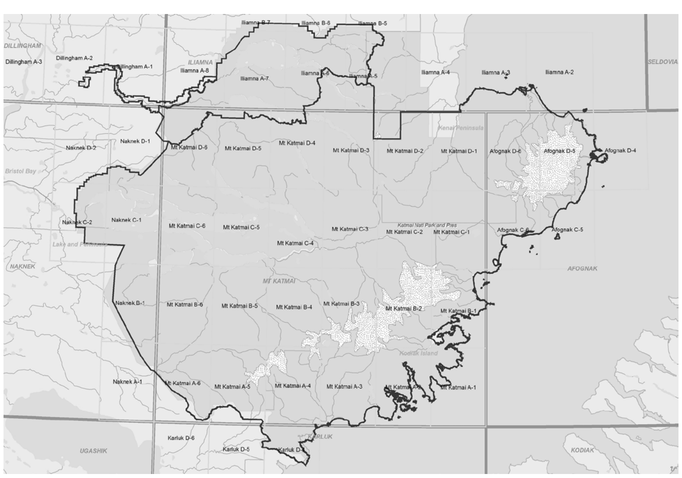

FIGURE 1.Map showing areal extent of the Katmai National Park and Preserve (KATM) with boundaries outlined for the component 1;63,300 scale quadrangles. (image courtesy of Tim Connors, National Park Service, Lakewood, Colorado).

Geologic maps covering all or major parts of the KATM include Mather (1925), Keller and Reiser (1959), Jones and Miller (1976), Magoon et al. (1976a), Detterman and Reed (1980), Riehle et al. (1987, 1993), Miller et al. (1995), and Wilson et al. (2012, 2015). Most of the formations found in KATM are excellently described by Riehle et al. (1993), Miller et al. (1995), and Detterman et al. (1996), and much of the following discussion was derived from those papers.

Our assessment is derived primarily from a compilation and examination of all available published paleontological literature on KATM, as well as assembling the vast array of unpublished internal USGS paleontological reports (known vernacularly as E&R reports) for the park. The term E&R refers to "Evaluation and Report," which contain important paleontological resource and locality data. An additional and valuable source of paleontological information on KATM is Bennison and Johnson (1967), a report prepared by Sinclair Oil & Gas Company on fossils collected by Sinclair within the park. In addition, this effort has benefited from three short field visits by the authors to KATM (Blodgett in 2004 and 2012, and Santucci in 2000). This paper is part of a series of recently funded NPS studies concerning the paleontological resources and the geological framework of National Park units in Alaska (Kenworthy and Santucci, 2003; Blodgett et al., 2012, 2013, 2015; Blodgett and Santucci, 2014; Elder et al., 2009; Rohr and Blodgett, 2013; Rohr et al., 2013; Santucci et al., 2011).

MESOZOIC UNITS

Talkeetna Formation (Lower Jurassic)

The oldest stratigraphic unit exposed in KATM is the Lower Jurassic Talkeetna Formation, which crops out only in the western part of the park, northwest of the Bruin Bay fault (Riehle et al., 1987, 1993; Riehle, 2002). The formation according to Riehle et al. (1993)

TABLE 1. List of established invertebrate and plant species with holotypes found in KATM.

TAXON	TIME	FORMATION	CITATION	NOTES
Phylloceras alaskanum	Jurassic	Naknek	Imlay 1981	Ammonite, based on USNM 256879 from USGS locality 25832, an island just off of mouth of Douglas River
Pachydiscus (Pachydiscus) hazzardi	Cretaceous	Kaguyak	Jones 1963	Ammonite, based on USNM 131185 from Union Oil Company locality JCH 1754
Pachydiscus (*Pachydiscus*) *kamishakensis*	Cretaceous	Kaguyak	Jones 1963	Ammonite, based on USNM 131193 from USGS locality 25856
Glycymerita aleuta	Cretaceous	Kaguyak	Squires 2010	Bivalve, based on UCMP 555899 from the Mount Douglas area
Crataegus alaskensis	Paleocene?/ Eocene	Copper Lake	Hollick 1936	Angiosperm, based on USNM 38945 from USGS collection 3547
Myrica banksiaefolia var. *curta*	Paleocene?/ Eocene	Copper Lake	Hollick 1936	Angiosperm, based on syntype USNM 38790 from USGS collection 5939
Osmunda dubiosa	Paleocene?/ Eocene	Copper Lake	Hollick 1936	Fern, based on USNM 38666 from USGS collection 3526
Acer douglasense	Eocene	Copper Lake	Wolfe and Tanai 1987	Angiosperm, based on USNM 396006A, a leaf from USGS locality 11361 (Cape Douglas)
Æsculus arctica	Oligocene	Hemlock	Knowlton 1904	Angiosperm, based on USNM 30087 (not 30085 per Hollick 1936) from Kukak Bay; genus now spelled *Aesculus*
Corylus harrimani	Oligocene	Hemlock	Knowlton 1904	Angiosperm, based on USNM 30072 from Kukak Bay
Corylus? *palachei*	Oligocene	Hemlock	Knowlton 1904	Angiosperm, based on USNM 30069 from Kukak Bay
Hicoria magnifica	Oligocene	Hemlock	Knowlton 1904	Angiosperm, based on USNM 30080, 30082, and 30085 from Kukak Bay
Phyllites saundersi	Oligocene	Hemlock	Knowlton 1904	Angiosperm, based on USNM 30078 and 30091 from Kukak Bay
Picea harrimani	Oligocene	Hemlock	Knowlton 1904	Conifer, based on USNM 30070 and 30071 from Kukak Bay
Pterospermites alaskana	Oligocene	Hemlock	Knowlton 1904	Angiosperm, based on USNM 30081 and 30089 from Kukak Bay
Pterospermites magnifolia	Oligocene	Hemlock	Knowlton 1904	Angiosperm, based on USNM 30088 from Kukak Bay
Vaccinium alaskana	Oligocene	Hemlock	Knowlton 1904	Angiosperm, based on USNM 30077 from Kukak Bay
Corylus evidens	Oligocene	Hemlock	Hollick 1936	Angiosperm, based on USNM 38844 from USGS collection 3517
Cupania comparabilis	Oligocene	Hemlock	Hollick 1936	Angiosperm, based on USNM 38955 from USGS collection 3517
Populus congerminalis	Oligocene	Hemlock	Hollick 1936	Angiosperm, based on USNM 39166 from USGS collection 3517

consists of: "Brown tuffaceous sandstone and dark-gray siltstone, interbedded in upper part(?) with red, green, or pink tuff and lahar deposits, volcaniclastic conglomerate, and dark-green, purplish-green, or grayish-brown lava flows and breccias mainly of basaltic andesite or andesitic composition. Unit represents deposits of volcanic arc (Reed and others, 1983) and interbedded marine sediments. Distinctive conglomerate contains highly rounded, spherical clasts solely of porphyoaphantic lava that may be pillows. … Crops out only northwest of Bruin Bay fault. Maximum exposed thickness in map area is about 1,200 m on south shore of Kulik Lake (T. 14 S., R. 34 W.)."

The Talkeetna Formation is a widespread unit throughout much of the Peninsular terrane, and is recognized both at its type locality in the southern Talkeetna Mountains northeast of Anchorage, as well as in exposures along the west side of Cook Inlet, as far south as Puale Bay. No fossils have as yet been reported from rocks of the Talkeetna Formation within KATM, though their relative abundance in the well-studied exposures of the southern Talkeetna Mountains (both as invertebrate and plant remains) suggest that they are likely to be found in the park.

Naknek Formation
(Upper Jurassic; Oxfordian–Tithonian)

The Late Jurassic Naknek Formation was established by Spurr (1900) under the name Naknek Series, and was subsequently renamed the Naknek Formation by Martin (1926). This is an extremely widespread formation that crops out along the entire length of the Peninsular terrane, from west of Port Moller on the central part of the Alaska Peninsula, northeastward up to the southeastern edge of the Talkeetna Mountains. Detterman et al. (1996) recognized the following members in ascending order on the Alaska Peninsula: Chisik Conglomerate Member, Northeast Creek Sandstone Member (defined therein), Snug Harbor Siltstone Member, Indecision Creek Sandstone Member (defined therein), and Katolinat Conglomerate Member (defined therein). This is the most areally widespread formation within KATM, and includes both marine and nonmarine strata.

Marine rocks of the Naknek Formation are characterized by the local abundance of the bivalve genus *Buchia*. Other genera of bivalves, belemnites, and ammonites are also present in lesser numbers, but are nowhere as abundant as the overwhelming mass of *Buchia* shells that can be considered a guide fossil for this formation (Miller and Detterman, 1985). The high abundance and low taxonomic diversity fauna associated with the Upper Jurassic Naknek Formation was noted by Imlay (1953, 1965), leading Blodgett (2012), Blodgett and Santucci (2014), and Blodgett et al. (2015) to speculate that the reduced faunal diversity (typified by the great abundance of *Buchia*, complete absence of inoceramid bivalves, and reduced ammonite generic diversity) in the Late Jurassic and earliest Cretaceous fauna of Alaska, Canadian Arctic Islands, and adjacent Northeast Russia represented a time interval of major global cooling within a generally Mesozoic greenhouse world. Sedimentological evidence indicating local intermontane glacial conditions during Oxfordian time in the lower Naknek Formation in Cook Inlet was recently presented by Wartes and Decker (2015).

The Naknek Formation within the boundaries of KATM was characterized by Riehle et al. (1993) as follows: "Most extensive sedimentary rock unit of the Alaska Peninsula, which in Katmai area consists of five members. Oldest conglomerate member contains granitic clasts derived by erosion of adjacent Alaska Aleutian Ranges batholiths. Fossils locally abundant in fine-grained rocks are chiefly several species of pelecypod *Buchia*, representing late Oxfordian through Tithonian time. Thickness throughout Alaska Peninsula is typically 1,700-2,000 m (Detterman and others, in press). … At most localities formation consists mainly of only one or two members. Crops out only southeast of Bruin Bay fault."

Naknek Formation outcrops near the former village of Katmai were the source of some of the earliest described fossils from Alaska (Grewingk, 1850; later redescribed in part by Pompeckj, 1900). However, some confusion exists as to the locality (or localities) represented by the collections described by Grewingk, as they appear to be mixed. Not only are Naknek Formation fossils present within Grewingk collections, but fossils apparently from the underlying Middle Jurassic Shelikof Formation (probably derived from just south of KATM) and the Upper Cretaceous Kaguyak Formation, based on the occurrence of the belemnite *Belemnitella* reported by Pompeckj (1900), may be present as well (Stanton and Martin, 1905, p. 409).

Publications with descriptions, discussion, and faunal lists of Naknek Formation collections from KATM include: Grewingk (1850), Pompeckj (1900), Spurr (1900), Smith (1925), Mather (1925), Martin (1926), Keller and Reiser (1959), Imlay (1959, 1981, 1984), Imlay and Detterman (1973), Jones and Miller (1976), Magoon et al. (1978), Miller and Jones (1981), Petering and Smith (1981), Miller and Detterman (1985), Detterman and Miller (1986), Detterman (1992), Elder and Miller (1993), Miller et al. (1995), and Detterman et al. (1996). The formation has over 460+ documented fossil localities within KATM (Elder and Miller, 1993; Miller et al., 1995; see especially the "Alaska Paleontological Database" available at www.alaskafossil.org).

Imlay (1959) illustrated a number of *Buchia* species (referred to the genus *Aucella*, a junior synonym to *Buchia*) from near Katmai Bay in KATM. These include *Aucella concentrica* (J. de Sowerby) (pl. 16, figs. 4-7) from USGS Mesozoic locality 10248 near Katmai Bay, *Aucella concentrica leguminosa* Stoliczka (pl. 16, figs. 8-10) from USGS Mesozoic locality 3124 near Katmai Bay, and *Aucella spitiensis* Holdhaus (pl. 16, figs.11-13) from USGS Mesozoic locality 3127. Subsequently, Miller and Jones (1981) provided photographic documentation of two species of the bivalve genus *Buchia* from within KATM. These are *Buchia rugosa* (Fischer) (illustrated on pl. 1, figs. 4-7) and *Buchia mosquensis* (von Buch) (shown on pl. 1, figs. 8-15) of the same paper. Figure 2 herein illustrates two right valves of the bivalve *Buchia mosquensis* (von Buch), one of the most common fossils found in Naknek Formation exposures in KATM.

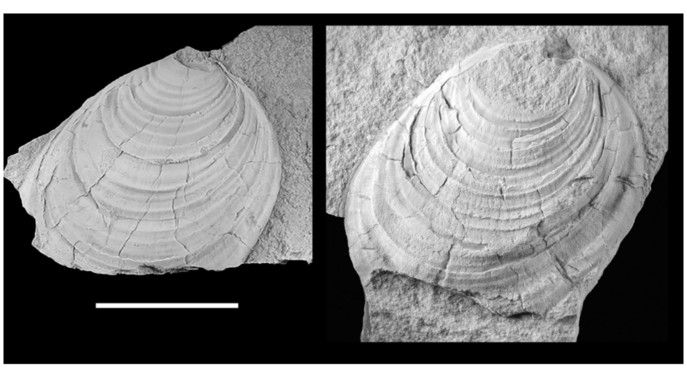

FIGURE 2. Two right valves of the bivalve *Buchia mosquensis* (von Buch) from the Upper Jurassic Naknek Formation, locality 04RB16 near the abandoned village site of Kaguyak. Scale bar is 2 cm.

Imlay (1981), in his study of Upper Jurassic ammonites of Alaska, illustrated the following taxa found within the boundaries of KATM: *Phylloceras alaskanum* Imlay, n. sp. (pl. 1, figs. 1-3; pl. 2, figs. 1, 5-6), *Partschiceras* sp. B (pl. 4, figs. 3-8), *Aulacosphinctoides* sp. (pl. 7, figs. 12-3), *Perisphinctes* (*Dichotomosphinctes*) cf. *P*. (*D*.) *muhlbachi* Hyatt (pl. 7, figs. 7, 12) and *Subplanites*? sp. (pl. 8, fig. 5). As noted by Imlay (1981, p. 18-19), "The Naknek Formation on the Alaska Peninsula is characterized faunally (table 6) by the ammonite *Phylloceras alaskanum* Imlay, n. sp., in association with the bivalve *Buchia concentrica* (Sowerby) or with *Buchia mosquensis* (von Buch) and *B*. *rugosa* (Fischer). *P*. *alaskanum* also occurs at one locality with the ammonite *Aulacophinctoides* and at two localities with the ammonite *Perisphinctes* (*Dichotosphinctes*)." A faunal list of ammonites and bivalves of the genus *Buchia* from select localities within KATM are presented in Imlay (1981, table 6).

Vertebrate fossils from the Naknek Formation within KATM are exceedingly rare, probably because no vertebrate paleontologist has yet undertaken an intense field study of the Naknek Formation within the park. Only one vertebrate fossil has been reported so far, consisting of a single bone fragment noted from USGS Mesozoic locality 12077 on the east side of Kejulik Pass (just below Gas Creek) in Smith (1925, p. 200) and Martin (1926, p. 215). The discovery of skeletal remains of the pliosaur *Megalneusaurus* (Blodgett et al., 1995; Weems and Blodgett, 1996) along the lower reaches of the Kejulik River in the Naknek Formation not far south of the southern boundary of KATM, as well as the occurrence of dinosaur footprints farther south in Naknek outcrops in the Chignik 1:250,000 scale quadrangle (Blodgett et al., 1995; Druckenmiller et al., 2011; Fowell et al., 2011) suggest that there is great potential for the discovery of both marine and nonmarine vertebrates within Naknek Formation outcrops of KATM.

Staniukovich Formation (Lower Cretaceous; Berriasian–Valanginian)

The Staniukovich Formation was first reported as exposed in KATM in the publications of Riehle et al. (1987, 1993), who noted it rests unconformably upon the Upper Jurassic Naknek Formation. This formation is limited in areal extent within KATM, and found only in the Mt. Katmai (B-2) and (B-3) 1:63,360 scale quadrangles. Riehle et al. (1993) described the formation as follows: "Staniukovich Formation (Early Cretaceous)—Three intervals of cross-bedded, fine-grained, feldspathic brown sandstone that probably represent offshore barrier bars, separated by thinly interbedded sandstone and siltstone. Abundant pelecypods (*Buchia*). Thickness is nearly 100 m 12 km north-northeast of Katmai (Tps. 20 and 21 S., Rs. 34 and 35 W.). Age is Berriasian and Valanginian at principal reference section near Herendeen Bay, 400 km southeast of map area" [far southwest of KATM on the central portion of the Alaska Peninsula].

The formation was subsequently described by Miller et al. (1995) as follows:

"Berriasian through Valanginian marine deposits of the Staniukovich Formation unconformably overlie fluvial rocks in the uppermost part of the Naknek Formation. Most of the Staniukovich has been erosionally removed in the map area, but nearly 350 m of the formation is preserved in the area about 12 km north of Mt. Katmai. Although the basal and uppermost parts of the formation are interpreted to represent inner shelf environments, the unit mainly consists of siltstone and shale deposited in lagoons developed behind barrier bars, the latter of which are represented by three thick sandstone units. The only macrofossils identified in this formation are Early Cretaceous *Buchia* bivalves (table 7). *Buchia crassicollis solida*, of Valanginian age, is found mostly in high-energy barrier bar environments, whereas the Berriasian species, *B*. *uncitoides*, is found mainly in finer grained rocks and is present in rocks indicative of bay environments in a least one locality (map no. 185, M8478, table 7)."

The Staniukovich Formation has 10 documented fossil localities within KATM (Elder and Miller, 1993; Miller et al., 1995; Alaska Paleontological Database). Only two species, both belonging to the bivalve genus *Buchia,* are recognized: *Buchia uncitoides* (Pavlow) of Berriasian age and the Valanginian age *Buchia crassicollis solida* (Lahusen). The bivalve genus *Buchia* is the most common megafossil found in both Upper Jurassic and earliest Cretaceous (Berriasian–Valanginian) age strata throughout the entire state of Alaska, and is considered to be indicative of cool-water Boreal Realm conditions (Imlay, 1965; Blodgett, 2012; Blodgett and Santucci, 2014; Blodgett et al., 2015). As noted earlier, the dominance by *Buchia* of marine shelfal communities in the Upper Jurassic and earliest Cretaceous of Alaska and the Canadian Arctic Islands (together with concomitant total disappearance of inoceramid bivalves at the same time) is thought to indicate a major global climatic cooling event. In contrast, both the Middle Jurassic and post-Valanginian Cretaceous marine biota contain abundant inoceramid bivalves, which were quite abundant during these warmer time intervals and apparently could not tolerate the very cool, high-latitudes waters of the Late Jurassic-Valanginian time interval.

Herendeen Formation
(Lower Cretaceous, Hauterivian–Barremian)

According to Detterman et al. (1996, p. 28-29): "Atwood (1911, p. 39) proposed the name "Herendeen Limestone" for about 800 ft of what he described as light-gray arenaceous limestone exposed along the east shore of Herendeen Bay, north of Coal Harbor (Mine Harbor) and near Marble Point in the Port Moller D-2 and D-3 1:63,360 quadrangles. However, these rocks are not limestone, but rather calcareous sandstone. We, therefore, here redefine this unit as the Herendeen "Formation" … "Prisms and shell fragments of *Inoceramus* form a major part of the rocks, but complete specimens have not been found in the Herendeen Bay-Port Moller area. The Herendeen Formation in the Mount Katmai area, near the northeast end of the Alaska Peninsula, has yielded numerous complete specimens of *Inoceramus ovatoides* as well as prisms and shell debris; it also contains the ammonites *Acrioceras* and *Hoplocrioceras* and the belemnite *Acroteuthis* (Jones and Detterman, 1966). These fossils permit an age determination of Hauterivian and Barremian (Early Cretaceous) for the Herendeen Formation.

The Herendeen Formation in the Mount Katmai area is composed of nearly 50 percent siltstone and shale that are interbedded with the calcareous sandstone. This composition suggests that these rocks were deposited in somewhat deeper water than the high-energy deposits in the Port Moller area. The occurrence of numerous complete *Inoceramus* shell, rather than only shell fragments, and the association with ammonites also suggest a deeper water deposition environment for the formation in the Mount Katmai area than in the Port Moller area.

The contact of the Herendeen with the underlying Staniukovich Formation is conformable in the type section and is placed at the base of the lowest resistant calcarenaceous sandstone bed. However, in the Mount Katmai area the Herendeen unconformably overlies both the Naknek Formation and the Staniukovich Formation. The upper contact of the Herendeen is a major unconformity throughout the Alaska Peninsula. The formation has been completely stripped away along most of the peninsula. Where it is still present, it is generally overlain by Upper Cretaceous (Campanian and Maestrichtian) rocks. Albian (Lower Cretaceous) rocks are present locally in the Mount Katmai area, where they disconformably overlie the Herendeen Formation."

The Herendeen Formation within KATM was described by Riehle et al. (1993) as follows: "Distinctive calcareous sandstone, thin-bedded, light-yellowish-gray or yellowish-brown to dark-olive-gray, which in the Katmai region is interbedded with an equal amount of siltstone or shale. Platy fracture and tabular crossbedding are common. Has belemnites (*Acroteuthis*) and *Inoceramus* prisms and, locally, complete *Inoceramus ovatoides*. Maximum thickness in map area is about 250 m, 23 km north-northeast of Mount Katmai (T. 21 S., R. 34 and 35 W.), but typical thickness is probably 25 m. Well exposed in northeastern part of map area and on west side of Barrier Range. Marine shelf deposit formerly present throughout the Alaska Peninsula; in Katmai region, probably an outer shelf deposit (Detterman and others, in press). Age is Hauterivian and Barremian. Unconformable on units Ks [Staniukovich Formation] and Jn [Naknek Formation]."

There are at least 36 documented fossil localities from the Herendeen Formation within KATM (Elder and Miller, 1993; Miller et al., 1995; Alaska Paleontological Database). Jones and Detterman (1966) illustrated a number of mollusks from unnamed Lower Cretaceous beds (now placed in the Herendeen Formation) in the Kamishak Hills area of eastern KATM. These include the ammonites *Acrioceras* cf. *A. starrkingi* Anderson (their figs. 3a-d) and *Hoplocrioceras* (?) sp., perhaps related to *H. remondi* (Gabb) (figs. 3e-f); the belemnites *Acroteuthis* sp. A (figs. 3g-i, 4c-d) and *Acroteuthis* sp. B (figs. 4a-b); and the inoceramid bivalve *Inoceramus ovatoides* Anderson (figs. 4e-f). Miller and Jones (1981) also illustrated fossils from the Herendeen Formation (identified as "Herendeen Limestone equivalent") including the belemnite *Acroteuthis* sp. (Miller and Jones, 1981, pl. 3, figs. 2-3; same specimen as *Acroteuthis* sp. B of Jones and Detterman, 1966, figs.4a-b) and the inoceramid bivalve *Inoceramus ovatoides* Anderson (Miller and Jones, 1981, pl. 1, fig. 8; same specimen illustrated as *Inoceramus ovatoides* Anderson in Jones and Detterman, 1966, fig. 4f). Figures 3 and 4 illustrate two specimens of *Inoceramus ovatoides* Anderson found in an exposure of the Herendeen Formation on a small offshore island south of the abandoned village site of Kaguyak in KATM.

Inoceramids abruptly reappear in great abundance in southern Alaska during the latter part of the Early Cretaceous in the Herendeen Formation (Hauterivian–Barremian) on the Alaska Peninsula and its lateral equivalent, the Nelchina Formation in the southern Talkeetna Mountains (representing the northeastern terminus of the Peninsular terrane). This interval also appears to coincide with a significant climatic global warming event when marine faunas of these regions become more diverse.

Pedmar Formation
(Lower Cretaceous; Albian)

The Pedmar Formation was formally named by Detterman et al. (1996) for a sequence of Albian age strata exposed at a sea cliff at the southern base of Mount Pedmar, near Katmai Bay. These strata

FIGURE 3. The bivalve *Inoceramus ovatoides* Anderson from the Lower Cretaceous Herendeen Formation exposed on small island offshore from the abandoned village site of Kaguyak. Island reachable from land at low tide and contains exposures of both uppermost Naknek Formation and overlying Herendeen Formation.

FIGURE 4. Another specimen of *Inoceramus ovatoides* Anderson from same locality in the Lower Cretaceous Herendeen Formation as specimen shown in Figure 3.

were first noted during field work in 1979 and represent the first documented occurrence of Albian strata on the Alaska Peninsula. Petering and Smith (1981) reported Albian age rocks at these exposures which contained the ammonites *Mesopuzosia* sp. and *Desmoceras* (*Pseudouhligella*) *dawsoni*. Miller and Jones (1981) illustrated three Albian age ammonites from these same beds (cited here as from an "unnamed Albian unit"): *Desmoceras* (*Pseudouhligella*) *dawsoni* (Whiteaves) (pl. 3, figs. 1, 7); *Marshallites cumshewaensis* (Whiteaves) (pl. 3, fig. 4); and *Calliphylloceras* cf. *C. aldersoni* (Anderson) (pl. 3, figs. 5-6). Miller et al. (1982) provided further documentation and a detailed measured section of the type Pedmar section (referred to in their paper as "unnamed rocks of Early Cretaceous (Albian) age"). In the same paper they illustrated four ammonite species from this unit: *Desmoceras* (*Pseudouhligella*) *dawsoni* (Whiteaves) (figs. 52a, b); *Marshallites cumshewaensis* (Whiteaves) (fig. 52c); *Turrilites*? sp. (fig. 52d) and *Calliphylloceras* cf. *C. aldersoni* (Anderson) (figs. 52 e, f). Albian-age rocks were earlier reported at Cape Kaguyak (Hazzard, 1950), but the existence of these beds could not be confirmed (Miller et al., 1995).

As noted by Miller et al. (1995): "At the type section at the base of Mt. Pedmar on Katmai Bay, the 82-m-thick Pedmar Formation is mostly composed of olive gray sandstone or siltstone. The formation is in fault contact with the Naknek Formation and is unconformably overlain by the Kaguyak Formation. The Pedmar was deposited in a shallow shelf environment and contains abundant plant debris, as well as a fairly diverse late Albian ammonite fauna in the upper part of the type section" … "A second area of sandstone and siltstone assigned to the Pedmar Formation crops out about 12 km south of Mt. Katmai. The section at this locality unconformably overlies the Herendeen Formation and unconformably underlies the Kaguyak Formation. In contrast to the late Albian age indicated for the type Pedmar section, the presence of the bivalve *Aucellina* cf. *dowlingi* at this second area …. suggests an early Albian age for that sequence." The first area mentioned is in the Mt. Katmai (A-3) 1:63,360 scale quadrangle, and the second area is located in the Mt. Katmai (B-3) 1:63,360 scale quadrangle.

The name Pedmar Formation was used earlier by Riehle et al. (1993), Elder and Miller (1993) and Miller et al. (1995), but all noted that the formal description and naming of the formation would be appearing in the paper of Detterman and others, which was then in preparation. Seven fossil localities within KATM are currently recognized in the Pedmar Formation, including fauna of both early and late Albian age (Elder and Miller, 1993; Miller et al., 1995).

Kaguyak Formation
(Upper Cretaceous; Campanian–Maastrichtian)

The Upper Cretaceous Kaguyak Formation is especially well-developed in the eastern part of KATM. Riehle et al. (1993) described the unit as follows: "Kaguyak Formation (Late Cretaceous)—Lower part consists of thin-bedded, medium- to dark-gray siltstone and local thin limestone beds and abundant ammonites, pelecypods (*Inoceramus*), and limestone concretions. Upper part consists of medium- to dark-dark gray or pale-brown, graded greywacke sandstone interbedded with siltstone; flame structures occur in siltstone, and sandstone is thin bedded to massive and has rip-up clasts, and flute casts. Upper part represents upper and middle regimes of submarine fan, thus unit is inferred to be a marine fan prograding onto deep-water marine deposits (Detterman and others, in press [published in 1996]. Type locality is seacliff exposures between Swikshak and Big Rivers (Keller and Reiser, 1959; Detterman and Miller, 1985), where the measured thickness of 897 m is close to maximum in map area of about 1,050 m. Age is latest Campanian to early Maestrictian. Unit is disconformable on unit Kp [Pedmar Formation] and older rocks."

Detterman et al. (1996, p. 34-35) provided this description of the formation: "The Kaguyak Formation was named by Keller and Reiser (1959) for the sequence of rocks of Late Cretaceous age exposed in seacliffs along the shore of Kaguyak Bay between the Swikshak and Big Rivers (Afognak C-6 1:63,360 quadrangle (fig. 11.) These rocks had been described earlier by Martin (1926) and Hazzard and others (1950) but had not been named. This sequence of rocks was remeasured and described by Detterman and Miller (1985) as part of the Upper Cretaceous flysch sequence in southern Alaska. The formation is mapped only in the northeastern part of the Alaska Peninsula, from Katmai Bay northeastward to Kamishak Bay.

The type section in the seacliffs (section 16) begins at the mouth of the Swikshak River and continues westward along the cliffs for about 5 km in secs. 19 and 20, T. 18 S., R. 27 W., and secs. 13 and 14, T. 18 S., R. 28 W., Afognak C-6 1:63,360 quadrangle. Additionally, beds at the base of the formation on a narrow cape about 2 km southwest (sec. 24, T. 18 S., R. 28 W.) are projected into the section." Detterman et al. (1996, p. 35) indicated a thickness of 1116.8 m. for the type section.

Detterman et al. (1996, p. 36) provided the following discussion on megafossils from the Kaguyak Formation: "Megafossils are locally abundant in the lower part of the Kaguyak at the type section. Elsewhere they occur randomly throughout the formation. Most represent forms that were probably carried in by turbidity currents. Ammonites are common and include *Diplomoceras notabile*, *Neophylloceras ramosum*, *Pachydiscus kamishakensis*, *P. hazzardi*, and *Didymoceras* aff. *D. hornbeyense*. Some of the pachydiscids are 1 m or more across. *Inoceramus balticus* var. *kunmiensis*, *I. subundatus*, and *I. kusiroensis* also are common. These fossils have been to the *Pachydiscus kamishakensis* zone of late Campanian to early Maestrichtian age (Jones, 1963)." There are at least 120 documented fossil localities from the Kaguyak Formation within KATM (Elder and Miller, 1993; Miller et al., 1995; Alaska Paleontological Database).

Illustrations and/or descriptions of Kaguyak megafossils are found primarily in two publications: Jones (1963) and Miller and Jones (1981). Jones (1963) in his monographic treatment of Upper Cretaceous ammonites from KATM described and illustrated the following taxa: *Neophylloceras ramosum* (Meek) (described, but no Kaguyak forms illustrated); *Neophylloceras hetonaiense* Matsumoto (described, but no Kaguyak forms illustrated); *Pseudophyllites indra* (Forbes) (described, but no Kaguyak forms illustrated); *Didymoceras* aff. *D. hornbyense* (Whiteaves) (described, but no Kaguyak forms illustrated); *Diplomoceras notabile* Whiteaves (described, but not illustrated); *Pachydiscus* (*Pachydiscus*) *kamishakensis* Jones, n. sp. (pl. 18, figs. 1-2; pl. 19, figs. 1-2; pl. 20, figs. 1-2; pl. 21, figs. 2-3; pl. 22, figs. 1-2; pl. 23, fig. 2; pl. 24, fig. 1, pl. 25, figs. 1-2; pl. 35, figs. 1-3, 5, 6; text figure 17); *Pachydiscsus* (*Pachydiscus*) *hazzardi* Jones n. sp. (pl. 12, figs. 1-2; pl. 13, figs. 1-2; pl. 14, figs. 1-2; pl. 15, figs. 1-3; pl. 16, figs. 1-3, 7, 8, 13, 15, 16; text figure 18); *Pachydiscus* (*Pachydiscus*) *ootacodensis* (Stoliczka) (pl. 30, fig. 3; pl. 31, figs. 1-2); and *Pachydiscus* (*Neodesmoceras*) *obsoletiformis* Jones n. sp. (pl. 28, figs. 1-3). Miller and Jones (1981) illustrated the bivalve taxa *Inoceramus kusiroensis* Nagao and Matsumoto (pl. 4, fig. 2, *Inoceramus subundatus* Meek (pl. 4, fig. 3) and *Inoceramus balticus* var. *kuminiensis* (Nagao and Matsumoto) (pl. 4, fig. 7); and the following ammonites: *Pachydiscus* (*Pachydiscus*) *kamishakensis* Jones (pl. 5, fig. 4), *Nostoceras* sp. (pl. 5, fig. 1), and *Neophylloceras hetonaise* Matsumoto (pl. 5, fig. 2). Jones (1963, table 1 on p. 17) provides the following list of bivalves, gastropods, and ammonites from the Kaguyak Formation: *Inoceramus* ex. gr. *I. subundatus*, *Pseudophyllites indra*, *Pachydiscus* (*Pachydiscus*) *kamishakensis* n. sp., *Pachydiscus* (*Pachydiscus*) *ootacodensis*, *Pachydiscus* (*Pachydiscus*) *hazzardi* n. sp., *Pachydiscus* (*Neodesmoceras*) *obsoletiformis* n. sp., *Diplomoceras notabile*, *Neophylloceras ramosum*, *Neophylloceras hetonainse*, *Didymoceras* aff. *D. hornbyense*, and *Pachydiscus* sp. indet. Squires (2010) described a new species of bivalve, *Glycymerita aleuta*, from the Kaguyak Formation of KATM, which was illustrated on Figs. 10.1-10.7 of that publication. Imlay and Reeside (1954, p. 234) provide a short synoptic discussion of the ammonite and bivalve fauna in strata that were subsequently assigned to the Kaguyak Formation. Figure 5 illustrates the holotype specimens of the ammonites *Pachydiscus* (*Pachydiscus*) *hazzardi* Jones and *Pachydiscus* (*Pachydiscus*) *kamishekensis* Jones, both based on specimens from the Kamishak Formation in KATM. Figure 6 illustrates a float specimen of *Pachydiscus* (*Pachydiscus*) *kamishakensis* observed in float at the abandoned village site of Kaguyak. Figure 7 illustrates inoceramid bivalves observed along a single bedding plane exposed at Dakovak Bay in KATM. William Elder (National Park Service, San Francisco) examined the photograph and suggests that they "probably fall in the *Inoceramus* (*Endocostea*) group. Further, they are probably *I. shikotanensis* Nagao and Matsumoto which I don't think has been previously identified from the Kaguyak. They do bear a close resemblance to *I. (E.*) *kunimiensis* Nagao and Matsumoto to which I had assigned quite a number of specimens from the Kaguyak. The two are probably closely related or maybe even synonymous as *kunimiensis* is a quite plastic form. The undulation on the anterior margin of your specimens is the key in separating the species here as *kunimiensis* typically has a rounded margin there. *I. shikotanensis* is a key indicator species for the lower Maastrichtian in Japan."

Additional Kaguyak invertebrate taxa listed in Miller et al. (1995) include the following: the bivalves *Acila* (*Truncacila*) sp., *Anisomya sp.,* arcid, *Calva* sp., *Clisocolus*? sp., *Goniomya* sp., *Gycimeris*

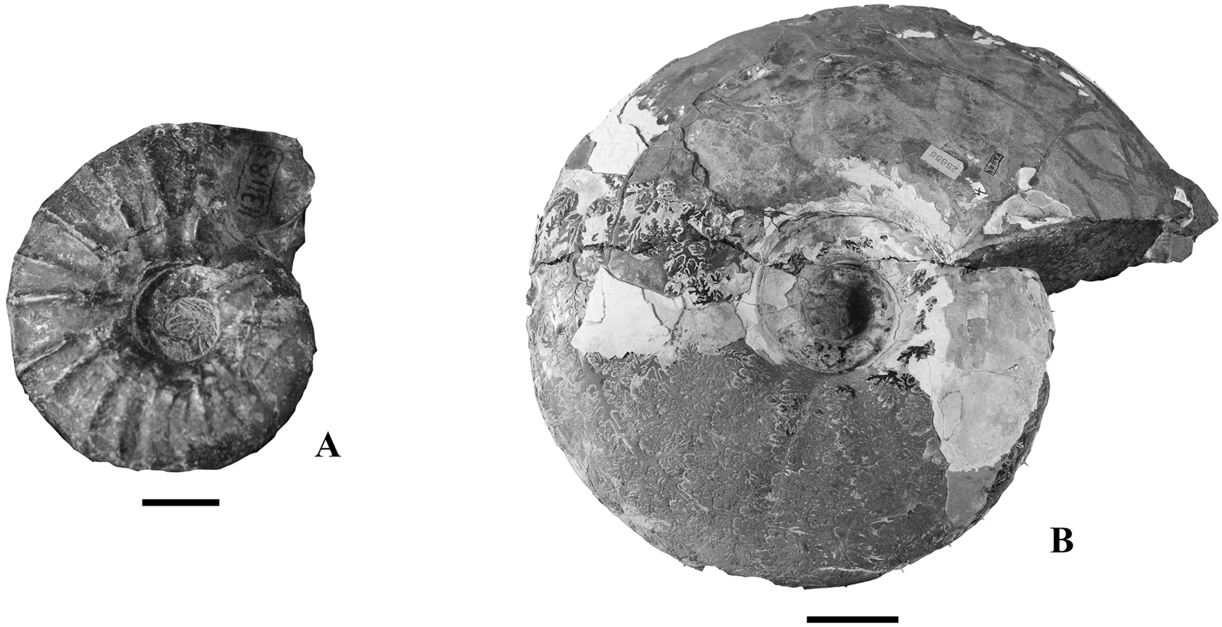

FIGURE 5. Ammonite holotypes from the Upper Cretaceous (Campanian-Maastrichtian) Kaguyak Formation. A. *Pachydiscus* (*Pachydiscus*) *hazzardi* Jones, 1963, USNM 131185, side view. Scale bar is 1 cm. B. *Pachydiscus* (*Pachydiscus*) *kamishakensis* Jones, 1963, USNM 131193, side view. Scale bar is 5 cm.

sp., *Indogrammatodon*? *whiteavesi* (Reinhart), *Indogrammatodon*? sp., *Inoceramus* cf. *peculiaris* Pergament, *Inoceramus yuasai* Noda, *Inoceramus* (*Endocostea*) *balticus marki* Giers, *Inoceramus* (*Platyceramus*) n. sp. A & n. sp. B, *Lima* sp., *Nucula* sp., *Nuculana* sp., ostreid, pectenid, *Pholadomya* sp., *Pleuromya* sp., *Protocardia* sp., *Sphenoceramus* sp. aff. *hetonaisense* Matsumoto, *Teredo* sp., trigoniid, *Yaadia* sp., *Yoldia* sp.; gastropods: acteonid, *Biplica miniplicata* Poponoe, *Biplica* sp., cerithiid, *Forsia* sp., fusid, *Gyrodes* sp., *Polinices* sp., *Remnita*? sp., *Tessarolax* sp., *Trochus* sp., *Zinitsys kingii* (Gabb); ammonites: *Anapachydiscus* sp., *Baculites anceps pacificus* Matsumoto and Obata, *Baculites lomaensis* Anderson, *Baculites occidentalis* Meek, *Baculites teres* Forbes, *Canadoceras yokoyamai* (Jimbo), *Exiteloceras* sp.; *Gaudryceras denmanense* Whiteaves, *Gaudryceras tenuiliratum* Yabe, *Glyptoxoceras* sp., and *Patagoisites alaskensis* Jones; scaphopods: *Dentalium* sp.; the crinoid *Isocrinus* sp.; and a rhynchonellid brachiopod. As indicated by the above faunal lists, the Kaguyak Formation is by far the most taxonomically diverse Mesozoic lithostratigraphic unit found within KATM.

CENOZOIC UNITS

Two Cenozoic-age nonmarine formations have been recognized within the boundaries of the KATM, both of which have yielded plant fossils: (1) the Copper Lake Formation (Paleocene(?)–early Eocene) and the overlying (2) Hemlock Conglomerate (Oligocene). A third unit, the Ketavik Formation of Parrish et al. (2010), has been considered synonymous with the Copper Lake Formation (Wilson et al., 2015). Unlithified Quaternary sediments occur within KATM and are fossiliferous in Idavain Lake.

FIGURE 6. Float specimen of the ammonite *Pachydiscus* (*Pachydiscus*) *kamishakensis* Jones found in the abandoned village site of Kaguyak.

Copper Lake Formation (Paleocene?–early Eocene)

Exposures of the Copper Lake Formation are limited essentially to the easternmost part of Katmai National Park, occurring typically near the coastline facing Shelikof Strait. However, the Ketavak Formation of Parrish et al. (2010), considered here and by Wilson et al. (2015) to

FIGURE 7. Bedding plane exposure with numerous specimens of inoceramid bivalves from exposures of the Upper Cretaceous Kaguyak Formation at Dakovak Bay in KATM. Scale bar marked in cm.

be equivalent in age and probably representing the same formation is found in the western part of KATM along the southern shore of Naknek Lake, near Brooks Camp.

Riehle et al. (1993) described the Copper Lake Formation as follows: "Two sequences of well-induated, massive fluvial conglomerate, separated by an interval of interbedded, medium- to dark-gray sandstone and siltstone. Clasts are chiefly subequal volcanic and metamorphic rocks, including chert and quartz, and lesser plutonic rocks. Carbonaceous detritus is locally abundant in sandstones and siltstones. Locally metamorphosed where adjacent to plutons and sills of the unit Ti. Named for exposures in the Iliamna quadrangle immediately north of the Katmai region (Detterman and Reed, 1980). Measured thickness of 1,025 m along east side of Spotted Glacier northwest of Cape Douglas (Detterman and others, in press), first measured by Magoon and others (1976a), is probably maximum in map area."

The Copper Lake Formation rests disconformably upon the Upper Cretaceous Kaguyak Formation and disconformably below the overlying Oligocene age Hemlock Conglomerate. Detterman and others (1996) who recognized its age here to be Paleocene(?) to early Eocene), provided the following account (see p. 42) of some of the earlier history of study of Tertiary rocks in KATM area:

> "Keller and Reiser (1959, p. 278-281) described Tertiary sedimentary rocks in the Mount Katmai area as probably of Eocene age. Recent investigations at the northeast end of the Alaska Peninsula, first by Magoon and others (1976a, 1976b) and more recently by us, have shown that the Tertiary sedimentary sequence there consists of two separate rock units of different age. The rocks are dissimilar in composition and are herein mapped as two formations, the Copper Lake Formation and Hemlock Conglomerate.
>
> Continental lower Tertiary strata in the Cape Douglas area were mapped as part of the West Foreland Foreland Formation by Magoon and others (1976a, 1976b). However, the lower Tertiary strata in the Cape Douglas area are very different from the type West Foreland (Calderwood and Fackler, 1972; Adkison, 1975; Adkison and others, 1975) in the upper Cook Inlet area. Consequently, we here reassign these strata to the Copper Lake Formation (see Detterman and Reed, 1980)."

Hollick (1936) listed and described fossil plants from four localities in what is now recognized to be the Copper Lake Formation at Cape Douglas. These localities which were collected by R.W. Stone in 1904 are: USGS Paleobotanical locality 3526 with *Osmunda dubiosa* Hollick, n. sp. (pl. 5, fig. 2) and *Ulnus braunii* Heer? (pl. 58, figs. 6-12); USGS Paleobotanical locality 3527 with *Dennstaedtia blomstrandi* (Heer) Hollick, n. comb. (pl. 2, fig. 5); USGS Paleobotanical locality 3547 with *Equisetum arcticum* Heer (pl. 8, figs. 8-10), *Sequoia langsdorfii* (Brongniart) Heer (pl. 15, figs. 2, 3) and *Crataegus alaskensis* Hollick, n. sp. (pl. 71, fig. 5); and USGS Paleobotanical locality 5939 with *Sequoia langsdorfii* (Brongniart) Heer (pl. 32, fig. 1b), *Myrica banksiaefolia curta* Hollick, n. var. (pl. 32, figs. 2, 3), *Myrica speciosa* Unger (pl. 32, fig. 1a; pl. 33, fig. 3), and *Myrica* (*Dryandroides*) *lignitum* (Unger) Saporta (pl. 32, fig. 4).

Five plant fossil localities were referenced by Magoon et al. (1976a) as the West Foreland Formation (now relegated to the Copper Lake Formation) at Cape Douglas. These are USGS Paleobotanical localities 9761, 11321, 11342, 11362, and 11363.

Wolfe and Tanai (1987) in their monograph on the genus *Acer* (maples) of the Cenozoic of western North America described and illustrated a single species of this genus from the Copper Lake Formation, *Acer douglasense* Wolfe and Tanai sp. nov. (pl. 1, figs. 1 and 3; also text-fig. 12A). This was collected at Cape Douglas (USGS Paleobotanical locality 11361) from beds they regarded as early Eocene in age and suggested as belonging to the West Foreland Formation (reassigned here in the Copper Lake Formation). Wolfe and Tanai (1987, p. 38) noted: "*Acer douglasense*, one of the two early Oligocene occurrences of *Acer*, occurs in beds assignable to the West Foreland Formation, a unit that, on other paleobotanical evidences includes beds of both latest Paleocene and early Eocene age (Magoon and others, 1976). The assemblage that contains *A. douglasense* is thought to be of early Eocene age."

Detterman et al. (1996, p. 43) made the following comment regarding the fossil flora of the unit: "The fossil megaflora from seacliff exposures of the Copper Lake Formation, especially from Sukoi Bay at Cape Douglas, indicates correlation with the Franklinian Stage (Ypresian) of the early Eocene (Magoon and others, 1976a; J.A. Wolfe, written commun., 1984)."

Data on palynomorphs from this formation are given in Houston (1994).

Ketavik Formation (Paleocene–early Eocene)

The Ketavik Formation was established by Parrish et al. (2010) as a new Paleogene age, non-marine formation in the western part of KATM. The type and reference sections are situated along the southern shore of Naknek Lake, near Brooks Camp. It is described by them (p. 351) as follows: "… quartz feldspathic and quartz lithic sandstone and conglomerate with rare, very thin interbeds of silty sandstone or mudstone. Several diorite dikes penetrate the formation at the type section. The section is in inferred disconformable contact with the Jurassic Talkeetna Formation and with Quaternary surficial sediments." Although the formation was recognized by its authors as being coeval with the Copper Lake Formation, it was separated by them due to its exposures being situated much farther west (west of the Alaska Peninsula volcanic arc) and deposited in a "different river system."

Both fossil leaves and fossil wood were described and illustrated from the Ketavik Formation by Parrish et al. (2010). Fossil leaves were illustrated in Figure 7 and include the following taxa: 7A, *Glyptostrobus europaeus*; 7B, *Zizyphoides flabella*; 7C, *Corylites* sp.; 7D, *Cercidiphyllum genetrix*; 7E, "*Carya*" *antiquorum*; and 7F, *Platimeliphyllum* sp. In addition, in Appendix A, the following leaves were listed and described: *Glyptostrobus europaeus* (Brongniart) Heer, *Platanus raynoldsi* Newberry, *Platimeliphyllum* sp. Maslova, *Zizyphoides flabella* (Heer) Crane, Manchester & Dilcher; *Chaetoptelea microphylla* (Newberry) Hickey; "*Parashorea*" *pseudogoldiana* (Hollick) Wolfe; *Cercidiphyllum genetrix* (Newberry) Hickey; "*Carya*" *antiquorum* Newberry; *Corylites* sp. Gardner ex Seward Holttum; Family Menispermaceae, Genus and species indeterminate; Family Lauraceae, Genus and species indeterminate; Family indeterminate, Indeterminate Genus and Species 1 and Indeterminate Genus and Species 2. Fossil wood was illustrated in both Figures 8 and 9. Fossil wood illustrated includes: *Cupressinoxylon* sp. A (figs. 8A-C), *Metasquoia* sp. D (figs. 8D-F); *Cedrus pennhallowi* (figs. 8G-J); *Pinus* sp. Section *Parrya* (figs. 9A-H); and *Platanoxylon* sp. I (figs. I-L). The same identical floral list of fossil wood taxa was described in Appendix B. The authors considered the fossil flora to indicate a warm temperate climate.

The authors suggested a late Paleocene to early Eocene age for the Ketavik Formation. The Ketavik Formation of Parrish et al. (2010), based on lithology and age assignment, was considered by Wilson et al. (2015, p. 15) to "more properly belong to the Copper Lake Formation," a decision with which we are in total agreement.

Hemlock Conglomerate (Oligocene)

The Hemlock Conglomerate in KATM is exposed only along the eastern coastal fringe of the park, facing Shelikof Strait. Riehle et al. (1993) described the Hemlock Conglomerate outcrops within KATM (unit Th on their map) as follows: "Poorly indurated fluvial sandstone and conglomerate and subordinate siltstone, shale, coal, and tuff. Yellowish brown to olive gray. Conglomerate has mainly chert, quartz, and plutonic-rock clasts and lesser abundant clasts of metamorphic rocks and silicified volcanic rocks. Rare tree stumps in growth position; abundant plant fossils in fine-grained strata. Locally metamorphosed where adjacent to plutons and sills of units Tab and Ti. Measured thickness of 558 m on north shore of Kukak Bay at Cape Nukshak is probably maximum in the map area. Unit at Cape Nukshak is probably late Oligocene and may be as young as early Miocene in age on the basis of plant fossils (J.A. Wolfe, written commun., 1988)." The formation was recognized by Riehle et al. (1993) as being disconformable upon the Copper Lake Formation, and unconformable upon either the Kaguyak or Naknek formations.

The Hemlock Conglomerate in KATM is depicted as the Tkth unit (the Oligocene age Tyonek Formation and Hemlock Conglomerate, undivided) on the map of Magoon et al. (1976a). Their map shows three generalized localities (containing a total of four USGS Paleobotanical collections 9968, 11365, 11366, and 11380) in KATM, all belonging to the Angoonian (late Oligocene) Floral Stage.

Detterman et al. (1996, p. 49-50) provided numerous details on the formation as it crops out in KATM: "Magoon and other (1976a, b) applied the name "Hemlock Conglomerate" to these rocks and correlated them with the type Hemlock Conglomerate noted at Capps

Glacier in the Cook Inlet area by Calderwood and Fackler (1972) … The rocks at both localities are very similar in composition, but the rocks in the Mount Katmai area are considerably thicker than those measured at the type section in the Cook Inlet area. The Hemlock Conglomerate in the Mount Katmai area consists mainly of fluvial sandstone and conglomerate; there are also minor interbeds of siltstone, shale, and coal. … Tertiary fluvial sedimentary rocks that are here considered to be part of the Hemlock Conglomerate are exposed in the mountains bordering Shelikof Strait from Katmai Bay northeastward to Cape Douglas. In most exposures the Hemlock unconformably overlies the Kaguyak Formation (Upper Cretaceous). In a few localites, such as near Hallo Bay, the Hemlock lies unconformably on the Naknek Formation (Upper Jurassic). In the Cape Douglas area, the Hemlock Conglomerate disconformably overlies the Copper Lake Formation of early Tertiary age."

Detterman et al. (1996, p. 50-51) made the following summary statement regarding the fossil flora and age of the Hemlock Conglomerate in KATM: "Megaflora fossils found in most outcrops of the Hemlock are mainly broadleaf deciduous plants; evergreen needles are also present. These fossils suggest a late Oligocene age (J.A. Wolfe, written commun., 1988) though an earliest Miocene(?) age can not be ruled out (J.A. Wolfe, 1988). On the basis of Wolfe's interpretations, we consider the age of the Hemlock Conglomerate as late Oligocene."

A distinctive well-preserved flora has been described and illustrated from this formation at Kukak Bay (Knowlton, 1904). The material he studied was collected by De Alton Saunders of the famous Harriman Alaska Expedition in 1899. Floral taxa recognized by Knowlton (1904) from Kukak Bay include: *Equisetum globosum* Lesq., *Picea harrimani* sp. nov. Knowlton, *Picea* (branches), *Picea*? (seed), *Pinus*? (leaves), *Pinus*? (scales), *Sequoia heeri* Lesq., *Sequoia* (cone), *Taxodium distichum miocenum* Heer, *Taxodium tinajorum* Heer, *Juglans acuminata* Al. Br., *Hicoria magnifica* sp. nov. Knowlton, *Betula* (branch), *Corylus macquarri* (Forbes) Heer, *Corylus harrimani* sp. nov. Knowlton, *Corylus*? *palachei* sp. nov., *Alnus corylifolia* Lesq., *Alnus* sp., *Ulmus braunii* Heer, *Acer trilobatum* var., *Aesculus arctica* sp. nov. Knowlton, *Pterospermites magnifolia* sp. nov. Knowlton, *Pterospermites alaskana* sp. nov. Knowlton, *Andromeda grayana* Heer, *Vaccinium alaskanum* sp. nov. Knowlton, and *Phyllites saundersi* sp. nov. Many of the foregoing taxa were illustrated in his paper. Knowlton (1904) regarded the Kukak Bay material to be late Eocene in age, however, Wolfe and Tanai (1987) have more recently indicated the source beds to be late Oligocene in age.

Hollick (1936) listed and described some fossil plants collected by T.W. Stanton and R.W. Stone (USGS Paleobotanical locality 3517) from beds also at Kukak Bay in Hemlock Conglomerate. These include: *Populus congerminalis* Hollick n. sp. (pl. 116, fig. 2); *Corylus evidens* Hollick n. sp. (pl. 49, fig. 3); *Corylus* sp. ?, staminate aments (pl. 49, fig. 4); *Cupania comparabilis* Hollick, n. sp. (pl. 74, fig. 5), and *Ilex insignis* Heer (pl. 73).

Wolfe and Tanai (1987) listed the following species of maples (genus *Acer*) from USGS Paleobotanical locality 11812 (seemingly the same as where Knowlton's material was collected) in the Hemlock Conglomerate: *Acer tigilense* Chelebaeva, *Acer chaneyi* Knowlton; *Acer smileyi* Wolfe and Tanai sp. nov.; and *Acer megasamarum* Tanai & Suzuki. In the same paper they illustrated these species as follows: *Acer tigilense* (pl. 27, fig. 1), *Acer chaneyi* (pl. 32, fig. 4), *Acer smileyi* (pl. 22, fig. 3, and pl. 23, fig. 6), *Acer megasamarum* Tanai & Suzuki (pl. 52, fig. 5). Wolfe and Tanai (1987, p. 47) made the following comment regarding this locality:

"In Alaska, only the Kukak Bay assemblage (Knowlton, 1902 (sic, should be 1904); recollected by J.A. Wolfe in 1984) is assigned to the late Oligocene. Absent from the Kukak Bay assemblage are typical Alaskan Miocene taxa such as *Quercus furuhjelmi* and *Alangium mikii*; present, however, are *Salix* (*Vetrix*) and *Fagus*, which are unknown in assemblages such as the Redoubt Point but are common in the Alaskan early and middle Miocene."

Data on palynomorphs from this formation are given in Houston (1994).

Quaternary Rocks and Sediments (Pleistocene–Holocene)

Quaternary fossils of KATM are not well-known at this time. An exception is the microfossils of Idavain Lake in the western part of the park. Idavain Lake sediments and microfossils were described in detail by Brubaker et al. (2001) as part of a larger study of Late Quaternary vegetation change. Brubaker et al. worked from a 1245-cm sediment core. A series of 11 radiocarbon dates from the core establish that the oldest sediments are slightly older than 14,100 ± 0.06 radiocarbon years before present, in the latest Pleistocene. They recovered an assortment of pollen and spores from mosses, clubmosses, ferns, horsetails, conifers, and angiosperms, representing a variety of ecosystems over three time-successive zones. The oldest zone, from the base of the core to about 12,000 radiocarbon years before present, is dominated by palynomorphs of grasses, herbs, *Salix* shrubs, and true mosses. The second zone, from about 12,000 to 8000 radiocarbon years before present, is characterized by the dominance of birch pollen, and spikes of fern, sphagnum moss, and poacean grass palynomorphs. The most recent zone, from about 8000 radiocarbon years ago to the present, is characterized by the dominance of alder pollen. Birch, fern, sphagnum moss, and poacean grass palynomorphs remain common in this zone, but are not as common as in the previous zone (Brubaker et al., 2001). More recently, Wang (2008) discussed head capsules of larval chironomid midges from another core taken from the lake, in this case about 16 m long and going back to about 16,000 years ago. In addition to the chironomid remains, leaf and wood fragments were also found in the core.

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